Attention, Mindwandering and Mood: relating personal experiences in daily life and in the classroom to laboratory measures

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I, Michael Hobbiss, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

The studies presented in Chapter 2 of this thesis have been published with my supervisor, Nilli Lavie, as a co-author. The full citation for this published paper is:

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Abstract

This thesis examines whether laboratory measures of attention focus in the face of task-irrelevant distraction can predict or reduce real-world experiences of distraction henceforth ‘attention lapses’ (covering both external, and internal sources such as mindwandering), with a specific consideration of educational environments, the adolescence period, and relationships to mood. To establish a novel measure of attention focus in a variety of real-world environments, I conducted real-time sampling of distractibility, mindwandering and mood across a wide range of everyday environments and activities, e.g. reading in the park (Chapter 2). The results established a replicable single construct underlying everyday attention lapses, and also highlighted a negative correlation between attention lapses and mood, with greater levels of mindwandering and distraction from some external sources associated with reduced levels of mood. To assess whether daily-life attention lapses can be predicted from a laboratory attention-task measure, Chapters 3-4 employed a modified attention distractibility task and examined its relationship to distractibility reports in the real-world, specifically educational settings (at secondary school and university) in both adults and adolescents (aged 13-18). The results established that attention lapses in these settings can be predicted from distractor interference effects on task performance (across adults and adolescents) and that while distractibility levels did not differ between adolescents and adults, response variability was significantly higher in adolescence. In addition, perceptual load reduced distractibility in adults but not in adolescents. Chapter 5 subsequently examined whether an interpolated testing intervention was effective in reducing both mindwandering and external distraction during a university lesson. The results demonstrated that interpolated testing reduced mindwandering and increased recall but did not affect distractibility. This thesis thus extends our understanding of the relationship between mindwandering, external

distraction and mood in everyday settings, and of methods which might be used both to predict and mitigate such experiences.

Impact statement

A number of aspects of this thesis have the potential to create beneficial impact, both within and beyond academia. Within academia, the results provide new evidence that mindwandering can be considered as a specific form of a more general propensity towards task-irrelevant distraction, providing new evidence in an ongoing debate within the field of cognition as to the relationship between mindwandering and distraction. A second contribution to theoretical understanding is the demonstration that the propensity to lose attention focus is associated with lower mood across the full healthy mood spectrum and during everyday activities, extending a relationship previously only addressed in the context of clinical conditions (such as depression or anxiety). A negative correlation was found between mindwandering (in a range of everyday environments) and mood, with some relationships also reported between specific exterbal distractions and reduced mood, especially in the case of adolescent participants. Such a finding may also be of importance outside of academia, for example when considering the design of offices or educational spaces, as it illustrates that highly distracting environments may have emotional implications, as well as known effects on task performance.

Performance measures from the focused attention task performance provide further theoretical advances which are likely to be of benefit to the field. Adolescent and adult response characteristics were found to be significantly different to one another across a number of task performance measures (notably, response variability, error rates and perceptual load modulation of response time). Such findings are important for future uses of attention tasks across age groups, as they demonstrate that the outcome measures employed may need to be adapted to fit the response characteristics of the participant group. Furthermore, the finding that response variability may be predictive of adolescent experiences of attention lapse is consistent with intra-individual variability models of attention deficits (Kelly et al., 2008 in *NeuroImage*; Sonuga-Barke & Castellanos, 2007 in *Neuroscience & Biobehavioral Reviews*), but provides a novel extension of such accounts into non-clinical adolescent populations. Data from this thesis therefore raises the possibility that the emotional dysregulation associated with the period of adolescence may also have attentional correlates, in a similar manner to arousal dysregulation theories of ADHD. A final contribution of this thesis to theoretical understanding is the clarification provided about the mechanisms underlying the effects of interpolated testing. Through the use of novel design and analysis methods, this demonstrates that attention effects may not be the root cause of learning gains after interpolated testing, but also that interpolated testing may be activating a number of mechanisms which combine to explain the effects seen on both learning and attention.

The thesis may also have applied impacts, especially in the field of education. The finding that performance measures can be predictive of levels of inattention in educational settings raises the possibility that task measures of a general propensity towards task-irrelevant distraction could be used by teachers to personalize instructional methods. Finally, the thesis demonstrates that interpolated testing, previously only shown to reduce mindwandering in the context of video lectures, can be used successfully in a real-life educational setting. This provides a clear rationale for both educators and researchers to begin adopting the technique more widely in instructional design.

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Acknowledgements

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Chapter 1

General Introduction

1.1 Preface

Attention is an important cognitive function which is essential for information processing and serves as a gateway for information to move on to further cognitive processes such as perception, understanding, learning and memory. Attention failures can therefore have severe psychological consequences. For example, individuals who are more efficient at actively suppressing salient distractors display increased visual and working memory capacity (Gazzaley, 2011; Zanto & Gazzaley, 2009). Learning (i.e. memory for stimuli) is enhanced when competing locations are actively suppressed through attentional mechanisms (Markant, Worden, & Amso, 2015). The ability to suppress irrelevant visual information has also been found to correlate strongly to fluid intelligence (de Jong & Das-Smaal, 1995; Ren, Goldhammer, Moosbrugger, & Schweizer, 2012; Ren, Schweizer, & Xu, 2013) and overall IQ (Melnick, Harrison, Park, Bennetto, & Tadin, 2013; Polderman et al., 2006; Sigman, Cohen, & Beckwith, 1997). In contrast, the inability to filter out such competing stimuli predicts low working memory capacity (Gaspar, Christie, Prime, Jolicœur, & McDonald, 2016). Given this, it is unsurprising that attention skills are a strong predictor of academic achievement (J. Breslau et al., 2009; Duncan et al., 2007; Merrell, Sayal, Tymms, & Kasim, 2017) and subsequent job performance (Mannuzza & Klein, 1999) as well as other social and affective difficulties (Barriga et al., 2002).

Although we naturally all suffer from lapses in attention at one time or another, attention control skills appear to vary widely between individuals, both during laboratory tasks (Heitz & Engle, 2007; Heitz, Unsworth, & Engle, 2005; Rosenberg et al., 2016) and in applied settings (Jones & Martin, 2003; G. E. Larson, Alderton, Neideffer, & Underhill, 1997; Wallace & Vodanovich, 2003). This can take the form of distractibility from external sources in the world around us, but can also be in the form of mindwandering, where we may engage in task-unrelated thoughts, feelings and musings. While both mindwandering and irrelevant distraction are known to produce interference with task performance (Kane, Gross, Chun, & Smeekens, 2017; Lavie, 2005, 2010; Mcvay & Kane, 2009; Smallwood et al., 2004) it remains less clear how these two kinds of attention lapses relate to one another. Previous research suggests that they may share a close relationship, for example they may be modulated by similar factors such as perceptual load (Forster & Lavie, 2014) and working memory capacity (Kane, Kwapil, Mcvay, & Myin-Germeys, 2007; Mcvay & Kane, 2009), and may rely on shared executive control mechanisms (Forster & Lavie, 2014; McVay & Kane, 2010). However, whether these two forms of attention lapses reflect the same mechanism of reduced attention focus, and are thus best described as arising from a single underlying construct, or whether they may be governed by different cognitive and affective states, are current questions that deserve further investigation. The relationship of attention lapses as studied in laboratory tasks to those experienced in daily life, as well as their relationship to mood in the healthy mood range, are also currently unclear.

Accordingly, this thesis initially examines the link between external distractibility and mindwandering during everyday experiences. In order to do so, it was first necessary to establish a measure of attention lapses in a variety of real-world environments, especially given that an individual's experiences of attention lapses in the form of mindwandering and distractibility by task- or activity-irrelevant external distractions may be different within rather austere laboratory situations compared to the outside world (Hines & Shaw, 1993; Kane, Gross, et al., 2017; Shaw & Giambra, 1993). Most previous studies which have investigated mindwandering in everyday life have done so using probe questions which measure the frequency of responses over multiple questions (e.g. Franklin et al., 2014, 2013;

Kane et al., 2017; Kane, Kwapil, Mcvay, & Myin-Germeys, 2007; Killingsworth & Gilbert, 2010; McVay, Kane, & Kwapil, 2009; Ottaviani & Couyoumdjian, 2013; Poerio, Totterdell, & Miles, 2013; Song & Wang, 2012). However, the overall amount of an individual's experience of mindwandering (and external distraction) is likely to depend not only on the frequency but also on the duration of episodes (Smallwood, 2013a). Despite this, a relative paucity of studies have examined the duration of such experiences (cf. Bastian & Sackur, 2013; Krawietz, Tamplin, & Radvansky, 2012; in laboratory assessments of response time variability and reading comprehension respectively).

Duration of attention lapse is a factor likely to be especially relevant for research questions regarding some of the real-world implications of lapsed attention (previously noted using measures of frequency of attention lapses), such as impaired educational performance (Unsworth, Brewer, & Spillers, 2012; Unsworth, McMillan, Brewer, & Spillers, 2012), or negative associations with mood (Franklin, Mrazek, et al., 2013; Killingsworth & Gilbert, 2010), both of which would appear likely to be impacted by more extended durations of lapsed attention. Despite this, it remains unclear how external distractibility and mindwandering relate to mood in the non-clinical range. There is clear evidence of attention-related dysfunction (including both external distractibility and mindwandering) in clinical mood disorders (e.g. Gohier et al., 2009; Nolen-Hoeksema, 2000; Nolen-Hoeksema & Morrow, 1993), however less work has addressed such relationships in typical populations, especially in the case of external distractibility. Therefore, the present thesis also investigated how external distractibility and mindwandering relate to mood, in non-clinical samples in everyday settings.

Our interest in how laboratory measures of attention relate to daily life settings extends further to a particularly important setting of education. Given the clear importance of attention to learning this thesis investigated whether laboratory measures of attention can predict the duration of attention lapses in educational settings. The most prevalent educational setting is schooling, and the present thesis accordingly investigates these hypotheses within the context of a secondary school. However, as secondary school students are of adolescent age, and because less is known about selective attention abilities in this age group, compared to adults and children, a further aim of the thesis was to address any developmental changes in selective attention through adolescence, and in comparison to adults. Therefore, focused attention in the face of irrelevant distraction was compared between secondary school students (aged 13-18) and adults using a modified task of irrelevant distraction (Forster & Lavie, 2008a, 2008b). Although there has been previous work on attention in adolescence, the results of such investigations have been mixed and it is not clear whether the measures used would extend to allowing us to predict real-world susceptibility to interference from task-irrelevant distractions. Equally, while some previous research has used attention-related measures to predict instances of inattention in educational settings (Ko, Komarov, Hairston, Jung, & Lin, 2017; Unsworth, McMillan, et al., 2012) none have previously examined task-irrelevant distraction specifically. Therefore, the thesis assesses whether individual differences in performance on this paradigm (specifically a measure of the interference caused by a task-irrelevant distractor to reaction time (RT), and measures of response variability) can be related to experience of distractibility from task-irrelevant sources (including mindwandering) in educational settings.

An example of a theory with extensive experimental support which could provide applied benefits in such settings is perceptual load theory (Lavie, 1995, 2005). Perceptual load theory predicts that in conditions of high perceptual load, perceptual capacity will be fully exhausted by the focus of attention, resulting in reduced perceptual processing of extraneous stimuli. In contrast, in conditions of low perceptual load in the task, spare capacity will "spill over" to the perception of unattended stimuli, leading to distraction and impaired performance. Perceptual load theory has been supported by numerous studies which have demonstrated the effects of high (vs. low) perceptual load in laboratory studies of visual perception, using a variety of behavioural and neuroimaging methods. However, such findings cannot inform our understanding of attentional processes in the complex, rich and multisensory environments of everyday life without studies which translate laboratory findings into effects on everyday functioning. Reciprocally, naturalistic measurements of everyday experiences may provide theoretical insights into common mechanisms or structures underlying attention focus (and conversely, distractibility), as well as the link between attention and mood in non-clinical populations.

Finally, the thesis assesses whether attention focus in an educational setting can be improved. Interpolated testing, the process of providing recall opportunities at various points throughout learning sessions, has been associated with reductions in self-reports of mindwandering during learning (Jing, Szpunar, & Schacter, 2016; Szpunar, Jing, & Schacter, 2014; Szpunar, Khan, & Schacter, 2013), as well as improved recall (see Pastötter & Bäuml, 2014; Yang, Potts, & Shanks, 2018 for reviews). However, the effects on external distractibility, and the structure of the link between attention lapses and effects on learning, is not yet clear. Using a novel counterbalanced interpolated testing design within a series of university lessons, I therefore examine the within-subject effects of the manipulation on reports of mindwandering and external distraction, as well as on learning and mood.

In the following sections of this chapter I review some of the relevant empirical findings, from which the questions examined in this thesis have been drawn. First, the principles of load theory will be outlined, followed by a summary of the existing evidence in support of the theory. Next the review focuses on the relationship between mindwandering and external distraction, examining evidence both from laboratory and naturalistic settings, and from various measurement techniques. The relationship between these constructs and mood is also reviewed. Following this, I review findings from developmental attention and executive function research with adolescents, focusing in particular on response characteristics which might be different to adult groups. Finally, the review examines inattention in educational environments, covering both school and university settings. Findings pertaining to the prevalence and consequences of inattention are reviewed, along with studies which have tested interventions designed to reduce levels of inattention.

1.2 Load theory of attention

Selective attention, the ability to focus attention on a particular aspect of our environment whilst excluding other competing stimuli, is an essential component of healthy cognitive functioning. As the information processing capacity of the brain is limited, the role of a selective attention mechanism in governing the focus of attention, and the process by which it achieves this, is of great theoretical and practical importance. Perceptual load theory of attention (Lavie, 1995, 2005, 2010; Lavie & Tsal, 1994) has been influential in the study of selective attention, offering a resolution to the traditional 'early-' vs 'late-selection' debate in attention. Load theory has been able to reconcile seemingly conflicting experimental findings by positing the existence of a fixed capacity attentional 'filter' which, crucially, always proceeds automatically until its capacity is reached. 'Perceptual load' therefore refers to the extent to which the focal task places a demand on processing capacity, with information excluded only when the perceptual system becomes overloaded. By so doing, the locus of selection therefore depends on the level of perceptual load in the task. Where perceptual load is high, capacity can be fully engaged purely by target of attention, and irrelevant distractors will not be perceived (as proposed by early-selection theories). Where perceptual load is low and capacity is not fully utilised by the main focus of attention, additional information from the environment will be processed until capacity 'runs out' automatically and involuntarily (as suggested by late-selection theories).

1.2.1 Previous empirical evidence

1.2.1.1 Traditional measures of selective attention

Perceptual load theory predicts that if task-relevant load is low and a distractor is presented on any given trial, its interference with task-relevant processing can be inferred from either delayed responses to the target or an increase in the number of errors, relative to distractor-absent conditions. In contrast, if task-relevant load is high, we would expect the effect of the distractor to be reduced, by virtue of the fact that perceptual capacity has already been fully occupied in processing task-relevant information.

These predictions have generally been upheld. For example, one common test of selective attention, negative priming (Tipper, 1985) describes the slowing of responses to a target stimulus if that same stimulus has been used as a distractor in previous trials. The finding that ignoring an object can subsequently affect visual processing was taken as evidence of the selective inhibition of that object in visual processing (Fox, 1995; Kane, May, Hasher, Rahhal, & Stoltzfus, 1997; May, Kane, & Hasher, 1995; Tipper, 2001). However, the negative priming effect has been shown to be modulated by the perceptual load of the task.

Lavie and Fox (2000) found that negative priming effects were found from distractors presented in low perceptual load (when only a single letter target was presented as a prime), but were eliminated by high perceptual load (when five additional neutral non-target letters were presented in the prime). This suggests that in high-load conditions distractor perception is reduced, rather than distractor inhibition being increased.

A second common test of attentional control is the flanker task (Eriksen & Eriksen, 1974), sometimes also called the response-competition task, in which a target stimulus (e.g. an 'X' or a 'Z') is presented flanked by non-target stimuli, traditionally in a horizontal orientation. The non-target stimuli can be either congruent to the target (e.g. distractor X for target X) incongruent to it (e.g. distractor Z for target X), or neutral (having no relationship to it). The flanker task is a measure of sustained attention and interference control, as evidenced by the degree of performance deterioration due to incongruent flanking stimuli, and has been widely used across a variety of experimental designs and population groups (e.g. Bishop, 2009; Cosman & Vecera, 2009; Dye, Green, & Bavelier, 2009), particularly in recent years in developmental studies of attention (Diamond & Barnett, 2007; Dwyer et al., 2014; Posner, Rothbart, & Rueda, 2014; Wetzel et al., 2016). Again, distractor effects from flankers have been found to be reduced under conditions of high perceptual load (Lavie, 1995; Lavie & Cox, 1997; Lavie & de Fockert, 2003). For example, Lavie and Cox (1997) presented six letters in a circular array and asked participants to search for one of two possible targets (an 'X' or a 'Z'). In the 'low load' condition, the five non-target positions were occupied by lower-case 'o's. In the 'high load' condition, non-target positions were occupied by five different angular letters. In addition to the central letter search task, a single congruent or incongruent distractor letter appeared in the periphery (See Figure 1.1).

Figure 1.1. Display stimuli from Lavie and Cox (1997)

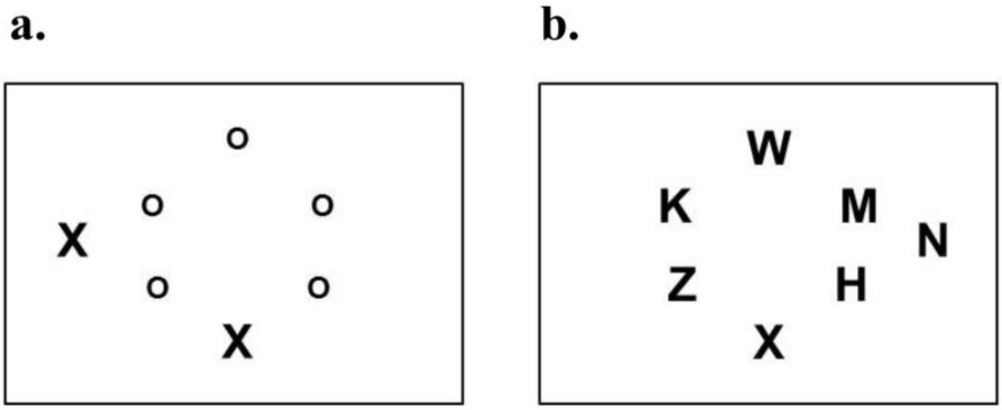

Figure 1.1. Display stimuli from Lavie and Cox (1997), depicting low load display (panel a) and high load display (panel b).

In the low load condition, there was a larger interference effect from incompatible distractors (reaction times were slower for incompatible, compared to compatible, distractor trials). In the high load condition, however, this difference was eliminated, with no difference between RTs for compatible and incompatible trials. Such findings have been replicated with various modifications, including using distractors at fixation (Beck & Lavie, 2005), with stimuli appear abruptly (Cosman & Vecera, 2009) or which move or loom (Cosman & Vecera, 2010b, 2010a), and when distractors are presented in a separate sensory modality (Molloy, Griffiths, Chait, & Lavie, 2015; Raveh & Lavie, 2015).

Neural evidence suggests that the modulation of processing by perceptual load is mediated by changes in visual cortex responses. Schwartz et al. (2005) asked subjects to perform a rapid stream visual detection task of either low load (e.g. detecting any red cross) or high load (detecting specific conjunctions of colour and shape, such as yellow upright or green inverted crosses). Concurrently, they used fMRI to assess V1 activity in relation to peripheral task-irrelevant checkerboard patterns. They found that visual cortex activity related to the task-irrelevant distractor was decreased by higher load in the central task (the effects of load were also present, and in fact became larger, for successive extrastriate areas through to V4). O'Connor, Fukui, Pinsk, & Kastner (2002) reported similar findings, but also reported load-related modulation of activity related to the checkerboard distractors in the Lateral Geniculate Nucleus (LGN). The modulation of activity in the LGN, the gateway for entry of sensory information into visual cortex, suggests that perceptual load modulates activity from the very earliest stages of the processing stream at which cortical top-down signals could affect visual processing.

Further support for the modulation of neural activity by perceptual load comes from ERP studies of the visual cortex. Handy, Soltani and Mangun (2001) found that the amplitude of the occipital (P1) potential (at 80–130 ms after distractor presentation) was significantly reduced by high perceptual load (a challenging letter discrimination task), compared to low perceptual load (a simple feature detection task). More recent studies have shown that the modulation of processing by perceptual load can be used to remove the differences between clinical and non-clinical groups. For example, highly anxious individuals show larger amygdala responses than controls in response to emotional stimuli when under low perceptual load, however this difference is abolished under high perceptual load (Bishop, Jenkins, & Lawrence, 2007).

However, boundary conditions have also been suggested, in which perceptual load predictions may not be upheld in all circumstances. For example, some clinical conditions, such as autism spectrum disorder (ASD) appear to display enhanced attentional capacity limits, compared to the typical population (Mottron, Burack, Dawson, Soulières, & Hubert, 2001; Mottron, Dawson, Soulières, Hubert, & Burack, 2006), and so display differences in the level of perceptual load at which the predictions of load theory appear to be upheld. For example, Remington, Swettenham, & Lavie (2012) used an inattentional blindness paradigm to measure the awareness of an irrelevant extraneous stimulus during a letter search task, in both typical adults and an ASD group. They found that high perceptual load modulated distractor detection rates and detection sensitivity in normal adults but not in people with ASD. Other studies have suggested that perceptual load does modulate distractor processing in ASD, but only at very high levels of perceptual load, above that required for typical adults (Hessels, Hooge, Snijders, & Kemner, 2014; Remington, Swettenham, Campbell, & Coleman, 2009). A failure of perceptual load to modulate distraction has also been documented in cases where the target and distractor are significantly spatially distinct (Parks, Beck, & Kramer, 2013), such as in different hemifields (Torralbo & Beck, 2008; Wei, Kang, & Zhou, 2013). In an interesting recent extension of such spatial irregularities in distractor processing, Thomas & Nicholls (2018) reported that while no spatial effects were present when responding to a letter search array in low load conditions, in high load conditions irrelevant distractors presented on the left side of the array were responded to significantly more quickly than those on the right. Thus, distractor filtering may not operate in a uniform manner across the whole visual field.

1.2.1.2 Distraction by task-irrelevant stimuli

The paradigms described above have been highly influential in shaping our understanding of attention, but one cannot extrapolate directly from these results to everyday life. For example, although in both response-competition tasks and attentional capture tasks the distractors are said to be ‘irrelevant’ (in that they may be spatially distinct from the target, and participants are asked to ignore them), these distractors are in fact relevant. In flanker tasks, for example, distractors appear in consistent locations in relation to the target and will often be the same as the target (e.g. letters in the classic Eriksen & Eriksen task). The distractor therefore, although nominally ‘irrelevant’ to the goals of the task, has a clear response-relevance, due to its relationship to the target (Forster & Lavie, 2008b). In addition to response relevance, distractors may also possess location relevance in relation to the main task. Indeed, the expected locations of distractors in these paradigms seem to receive advance attentional allocation. Tsal and Makovski (2006) found that distractor locations received more attention than empty locations (resulting in speeded perception of other stimuli appearing in these locations), even when these distractor locations were specifically given as ‘to-be-avoided’. Thus, at least in the case of response-competition paradigms where distractor stimuli are presented on every trial, participants appear to allocate attention to any location where an item is expected, regardless of its task relevance. Distraction from a response-relevant object in an anticipated location does not seem to model our standard experience of distraction in the real world, where the source and position of the distraction may be unanticipated and the form of the distraction may be completely unassociated with our current focus (for example a siren or a passer-by distracting us as we are trying to read).

Similarly, although the ‘singleton’ feature of distractors in attention capture paradigms are nominally unrelated to the task, it has been shown that even attention capture does depend on whether distractors share particular properties with the task set, so that their interference with the task still relies on their relevance to it (Becker, Folk, & Remington, 2010; Folk, Remington, & Johnston, 1992). For example, if the target is a singleton (e.g. a certain letter) and the distractor is also a singleton (e.g. a different colour), the distractor may attract attention due to a goal-driven control setting to search for singletons, rather than due to the stimulus properties of the distractor itself (Vecera, Cosman, Vatterott, & Roper, 2014). Visual search tasks which do not require participants to search for singleton targets do not show the same level of attention capture from irrelevant singleton distractors (Bacon & Egeth, 1994; Leber & Egeth, 2006; Leber, Kawahara, & Gabari, 2009).

Thus while the experience of attentional capture by a stimulus that is irrelevant to our main focus (in terms of visual features, meaning, and location) is one that is immediately familiar (for example as a mobile phone notification disrupting one's train of thought), attention capture research has not reached a clear understanding on the mechanisms underlying this occurrence. In order for research on distraction to cast more light on distraction in everyday life, it is therefore important that paradigms are designed in which the distractor is 'entirely irrelevant' to the task, in that they appear in a different position, are semantically irrelevant, and which include singleton search controls. Forster & Lavie (2008a) introduced such a design, using a visual search task in which famous cartoon characters were used as a distractor stimulus, whilst the task was a letter search (see Figure 1.2). The cartoons used by Forster and Lavie were brightly coloured, appeared infrequently and were meaningful, and were therefore likely to capture attention (Theeuwes, 1991, 1992), but also appeared in different peripheral locations outside of the search array (to avoid any expectancy effects on attentional allocation) and were visually and semantically unrelated to the letter search task. Entirely irrelevant distractors captured attention, as measured through increased search RTs, although the cost was greater for infrequent and meaningful distractors. Distraction was modulated by perceptual load even when the low load condition consisted of search set size of three target letters, ruling out the use of a singleton-detection strategy (Forster & Lavie, 2008b, Experiment 4). Irrelevant distractor interference has also been found in other tasks, such as a sequential forced-choice response task (Forster & Lavie, 2011), also ruling out attention capture by relevance (due to common onset of the stimuli), and using distractors of varying semantic and affective salience (Biggs, Kreager, Gibson, Villano, & Crowell, 2012).

Figure 1.2. Perceptual load effects on distraction comparing traditional congruent/incongruent distractors with distraction from 'entirely irrelevant' distractors from Forster and Lavie (2008)

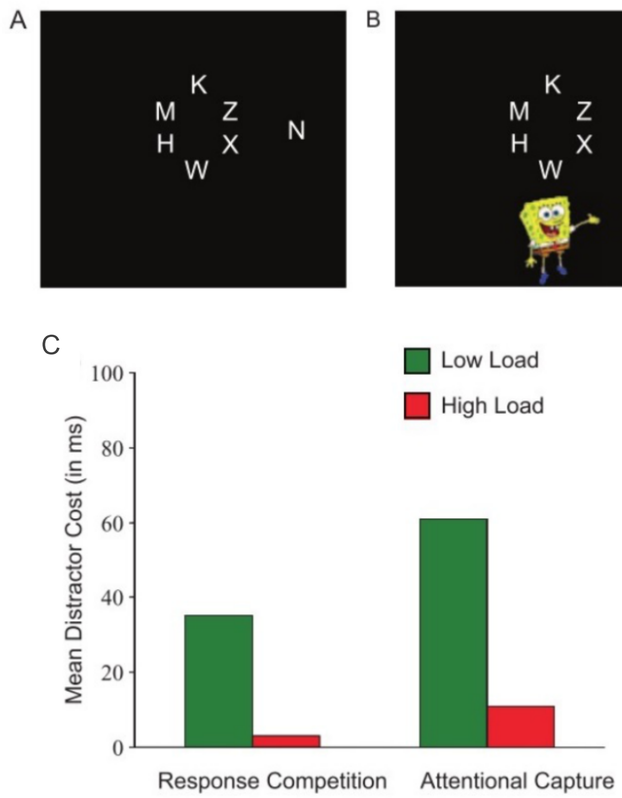

Figure 1.2: Perceptual load effects on distraction comparing traditional congruent/incongruent distractors with distraction from 'entirely irrelevant' distractors. Example high load stimuli and results from Forster & Lavie (2007) measuring interference from response competition distractors (Stimulus - panel A. Results – panel C) and Forster & Lavie (2008) measuring attention capture by task-irrelevant distractors (Stimulus - panel B. Results – panel C). Taken from Lavie (2010)

Perceptual load thus appears to be an effective method for reducing distractor related processing. This raises the question of how such findings might be best applied to focused attention in applied, real-world situations. For example, it might be possible to reduce or abolish impairments in attention focus, such as those experienced by sufferers of attention deficit hyperactivity disorder (ADHD) or other groups, under conditions of high perceptual load. Forster, Robertson, Jennings, Asherson and Lavie (2014) used the irrelevant distractor paradigm to investigate the impact of perceptual load on irrelevant distraction, comparing a group of adults with ADHD with age- and IQ-matched controls. Adults with ADHD experienced increased distraction in low load conditions, but increasing perceptual load was equally effective at reducing distractor interference for both groups, reducing the load distractor costs of the ADHD group to a similar level to those experienced by the control group under low load. In a further example, Forster and Lavie (2016) compared reports of childhood ADHD symptoms with the magnitude of a distractor cost to reaction times in both the irrelevant distractor paradigm, and a paradigm where *the same distractor stimuli* functioned as task-relevant, response-competition distractors. Crucially, they found that childhood ADHD symptoms positively correlated with response-irrelevant distractor interference, but not with the interference caused by response-competition distractors. Forster and Lavie concluded that their findings suggested the existence of a relatively stable attention-distractibility trait, which specifically conveys vulnerability to irrelevant distraction. However, it is not currently known whether this paradigm might also be able to predict distraction in other real-life situations, for example whether task-irrelevant distractor interference in the experiment is correlated with distraction in school students during lessons.

1.3 Mindwandering and external distraction

Lapses in attention focus do not only occur in response to external stimuli. Indeed, feeling one's mind drifting away from our desired focus of attention towards other (internal) deliberations or reveries would appear to be a ubiquitous human experience. It is only in recent years, however, that the academic study of such a phenomenon (usually called mindwandering, or task-unrelated thoughts; TUTs) has attracted the attention befitting its regularity (see e.g. Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2006, 2015, for reviews). Although the topics of mindwandering and attention focus (or conversely distractibility), have been typically studied separately, a growing body of studies has begun to directly investigate the relationship between them. Indeed, some researchers argue that both reflect a common failure of attention focus, as long as the external distractors are entirely irrelevant to the task at hand (e.g. Forster & Lavie, 2014; McVay & Kane, 2010). Much research has demonstrated the interfering effects of both external distractions and mindwandering on task performance. For example, the addition of distractor stimuli during visual search tasks leads to slower response times compared with distractor-absent trials (Forster & Lavie, 2008a; Lavie, 1995; Lavie & Cox, 1997; Lavie, Hirst, de Fockert, & Viding, 2004; see Lavie, 2005; 2010 for reviews) even when the distractors are entirely irrelevant to the task at hand (e.g. Forster & Lavie, 2008a; b). In a similar vein, mindwandering research has demonstrated that a higher frequency of task-unrelated thought (TUT) reports is associated with increased errors in go/no-go tasks and in antisaccade tasks (Kane, Gross, et al., 2017; Mcvay & Kane, 2009; Smallwood et al., 2004). A higher number of reports of both mindwandering and irrelevant distractions was also found to be associated with slower reaction times and increased variability in reaction times on the Sustained Attention to Response Task (SART; e.g. Stawarczyk, Majerus, Catale, & D'Argembeau, 2014; Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011), though in some cases mindwandering was associated with a greater effect on the RT than the distraction reports (see Stawarczyk et al., 2014).

Distractor interference effects have been directly related to mindwandering in a series of studies that assessed both distractor interference effects and the occurrence of task-unrelated thoughts. Forster and Lavie (2009) incorporated TUT probes into the irrelevant distractor paradigm (originated by Forster & Lavie, 2008a; b), a letter search task in which a brightly coloured task-irrelevant distractor stimulus (an image of a famous cartoon character) appeared at a peripheral location during a minority of trials. During blocks of either low or high perceptual load in the search task (varied by the target and non-target letter similarity), participants were intermittently probed as to whether their current thought was task-related or task-unrelated. Increased perceptual load did not only reduce irrelevant distractor interference effects but also reduced mindwandering reports, thus demonstrating that both external distraction and "internal distraction" in the form of TUTs are modulated by a common attentional mechanism.

Forster and Lavie (2014) subsequently established a direct relationship between mindwandering and external distraction and suggested these can both be classed as manifestations of reduced attention focus, leading to greater distractibility towards both external sources (task-irrelevant stimuli) or internal sources (task-irrelevant thoughts, i.e. mindwandering). They tested this hypothesis in an individual differences study and found that the rate of everyday mindwandering reports (on the Daydreaming Frequency sub scale of the Imaginal Processes Inventory; DDFS; Singer & Antrobus, 1970) was positively correlated with the magnitude of distractor interference from task-irrelevant stimuli (cartoon images presented in the periphery during a letter search task). The positive correlation with the rate of mindwandering was only found for these entirely irrelevant distractors. Response competition effects from the same cartoon images when these were made task-relevant (either congruent or incongruent with response to target names, producing response competition effects) were not associated with mindwandering. Forster and Lavie therefore concluded that task-irrelevance is an important consideration in the relationship between mindwandering and external distraction, in support of their proposal that a common attentional mechanism (i.e. reduced ability to focus on task-relevant material) underlies distraction from task-irrelevant sources, both external and internal. Subsequently, Forster and Lavie (2016) argued that these findings suggested that common attentional mechanisms might underly distraction from task-irrelevant sources, both external and internal, and that individual variation in the efficiency of this mechanism creates an 'attention-distractibility trait', which governs a general vulnerability to distraction from irrelevant sources.

The relationship of mindwandering and irrelevant distraction was further examined in a series of studies by Stawarczyk and colleagues (Stawarczyk & D'Argembeau, 2016; Stawarczyk et al., 2014; Stawarczyk, Majerus, Van der Linden, & D'Argembeau, 2012; Stawarczyk, Majerus, Maj, et al., 2011; Stawarczyk, Majerus, Maquet, & D'Argembeau, 2011). These studies investigated the relationship between the frequency of TUT reports and reports about thoughts concerning task-irrelevant distractions, with both assessed by probe questions during performance of the SART. The probes allowed for a clear distinction between task-relevant and irrelevant experiences, allowing 'stimulus-independent task-unrelated thoughts' (mindwandering) and 'stimulus-dependent task-unrelated thoughts' (external distractions) to be differentiated from task-related thoughts (as well as from each other). Using this design, Stawarczyk et al. (2014) and Stawarczyk & D'Argembeau (2016) reported that the frequencies of mindwandering and external distraction reports were not significantly correlated. In addition, while mindwandering TUT reports were found to correlate significantly with the DDFS, irrelevant distraction reports were not (see Stawarczyk et al., 2012; 2014; Stawarczyk & D'Argembeau, 2016). Although these results may appear incompatible with the conclusions of Forster and Lavie (2014), I note that the response options for participants did not allow participants to report both mindwandering and external distraction in response to the same probe (e.g. Stawarczyk et al., 2014; Stawarczyk, Majerus, Maj, et al., 2011; Stawarczyk, Majerus, Maquet, et al., 2011), whereas both reports might be expected during a period of reduced attention focus on the task. This restriction is likely to limit the strength of any relationship between the two variables, and is therefore not ideally suited to demonstrating how mindwandering and external distraction relate to one another over time. Moreover, the nature of irrelevant external distractions measured in the rather quiet and distraction-impoverished settings of lab testing could potentially restrict any relationship to mindwandering in daily life as measured by the DDFS (further compounded by the inclusion of components in the 'external distraction' measure which could have been classified by many participants as mindwandering, e.g. thoughts about lighting, temperature or hunger etc.).

Unsworth and McMillan (2014) also assessed the relationship of mindwandering reports and external distraction reports using thought probes during experimental tasks. They used probe questions (repeated across five attention control tasks) that involved a distinct probe for reports of mindwandering ("I am zoning out/my mind is wandering") versus reports of external distraction ("I am distracted by information present in the room (sights and sounds)"). As in the studies of Stawarczyk et al., participants were only able to select one response from the probe options, so both options of mindwandering and external distraction could not be reported about their current experience in response to the same probe. When probe responses were modelled using a latent variable analysis, a model where external distractions and mindwandering loaded onto distinct latent variables was superior to one where they both loaded on a single variable. These factors were however strongly correlated with one another, and moreover, in a model that assessed common variance between all probe reports and performance on the attention control tasks, a single 'general attention' latent factor was formed, albeit with residual mindwandering and external distraction factors. Whilst these results clearly illustrate that mindwandering and external distraction appear to share a good deal of variance in common, the findings that a model in which external distractions and mindwandering loaded onto distinct latent variables was superior to one where they both loaded on a single variable (as well as the findings of residual, separate mindwandering and external distraction factors apart from the 'general attention' factor) might at first sight appear inconsistent with Forster and Lavie's suggestion that both are driven by the same 'reduced attention focus' mechanism. A few aspects of the study preclude a clear conclusion on this matter, however. Firstly, the fact that each of the mindwandering and external distraction measures consisted of repetition of the very same probe response across five tasks should have led to a greater correlation within a measure than between two different measures (with different probe questions), resulting in separate latent variables. Secondly, it is important to note that the attention control tasks used by Unsworth and McMillan did not explicitly measure task-irrelevant distraction (which Forster and Lavie showed to relate to mindwandering), but instead measured task-relevant response competition effects. Thirdly, as I mention earlier, the response measures precluded the reporting of mindwandering and external distraction on the same probe. Taken together, these factors raise the possibility that the study measures lacked the sensitivity to demonstrate the sort of relationship between mindwandering and external distraction that might be expected on a shared mechanism of reduced attention focus account.

It is likely, however, that any measure of external distraction taken in a laboratory setting will limited, given the reduced levels of external distracting stimuli present. Similarities between mindwandering and external distraction are perhaps unsurprising in this context, but this raises the question of whether such similarities would persist in the real world. There is in fact evidence that these constructs may display different patterns outside of the laboratory. For example, Kane, Gross, et al. (2017) found that performance on laboratory tasks of inhibition (antisaccade and go/nogo tasks) and response competition (flanker tasks) correlated with laboratory mindwandering rates (as measured by probe questions during the tasks), but *not* with daily-life mindwandering (as subsequently measured over a week of experience sampling). Even the laboratory mindwandering rate was not significantly correlated to reports of mindwandering in daily life (although see McVay et al., 2009, for a contrasting finding with a much smaller sample). In a further example, Shaw and Giambra (1993) asked participants to perform a vigilance task (monitoring a stream of letters for an infrequently presented target) and probed whether they were mindwandering at regular intervals. Participants diagnosed as having ADHD reported significantly more spontaneous mindwandering during the task, compared to non-clinical controls (a result replicated by Hines & Shaw, 1993). In addition, participants completed the mindwandering and the distractibility sub-scales from the Imaginal Process Inventory (Singer & Antrobus, 1970). ADHD participants reported more mindwandering in daily life than controls, and, within the non-clinical controls, high scorers on the Conners Abbreviated Rating Scale (Conners, 1973) for ADHD symptoms also reported more daily life mindwandering. However, neither daily-life distractibility or mindwandering rates were significantly correlated with frequency of mindwandering in the laboratory task. Both studies suggest that the complex relationship between mindwandering and external distractions may be different within the laboratory compared to outside.

Some studies have therefore investigated the relationship between reports of mindwandering and external distraction outside of the laboratory. Unsworth et al. (2012) asked college students to keep a diary of their cognitive failures over the course of one week, which did allow for the reporting of both mindwandering and external distraction within the same diary entry. Participants' records included those in which their attention was distracted from a task by an irrelevant stimulus in the external environment ("e.g. a flat-mate's phone ringing"), as well as incidents of mindwandering ("e.g. during a class lesson"), among other types of cognitive failures (such as "memory failures"). Unsworth et al. found a significant positive correlation between the total number of diarised mindwandering and irrelevant distractions, demonstrating their potential association in college student life (see also Unsworth, Brewer, & Spillers, 2012; Unsworth & McMillan, 2017, for similar findings). Unsworth and colleagues' results have broken new ground, especially by relating the everyday experience of both mindwandering and external distractions (as well as other cognitive failures) to academic success. However, a diary study relies on participants intentionally choosing when to record attention states. As the act of engaging in the diary recording is in itself irrelevant to any of their daily tasks, it may be inherently biased to being used during states of overall reduced attention focus which involved intentional mindwandering as well as other external diversions towards irrelevant distractions. For example, a student present in a lecture that they find boring may enter a state of reduced attention focus in which they may engage in mindwandering, listen intently to other people talking, check their mobile phone notifications etc., and in which they may *also* be more likely to record their experiences in the diary as a form of task-avoidance. While consistent with our hypothesis that a state of reduced attention focus should involve both mindwandering and irrelevant distraction, it remains plausible that there are cases of irrelevant distraction without mindwandering and vice versa, and that these were not recorded simply because these cases lacked the intention to disengage attention from current task or activity to make a diary recording. In other words, a diary method may not be best suited to reveal whether unintentional disengagement of attention focus (e.g. in the form of unintentional mindwandering) is also associated with increased external distraction and vice versa. In addition, it is not known whether the association of mindwandering and external distraction findings will persist across a wider variety of everyday activities, across the richer forms of distraction prevalent in daily life (rather than simply the college environment), and across a more diverse sample of the whole population. Finally, since the diary reports did not include the source of external distraction (e.g. mobile phone, noise, people etc.), it remains unclear whether mindwandering is only associated with some types of external distraction but not others.

1.4 Mindwandering, external distraction and mood

In addition to questions regarding the relationship between mindwandering and external distraction, previous research has also indicated links between these constructs and mood. Previous research has, for example, reported a relationship between depression or dysphoria and the frequency of mindwandering and, in a separate body of studies, a link between depression and the level of distractor interference effects. Smallwood, O’Connor, Sudbery and Obonsawin (2007) found that dysphoric students (i.e. those scoring highly on a depression inventory without meeting the criteria for clinical depression) reported more frequent mindwandering whilst performing a cognitive test and their mindwandering negatively affected performance on a main task more than in the non-depressed group. Participants scoring highly on the Beck Depression Inventory also report more frequent mindwandering whilst completing a SART, as well as reduced dispositional mindfulness (Deng, Li, & Tang, 2014). Self-reported mindwandering frequency in everyday life has also been linked to negative affect and increased self-report of depressive symptoms (Mrazek, Phillips, Franklin, Broadway, & Schooler, 2013; Stawarczyk et al., 2012). Elevated levels of distraction from external stimuli have also been noted for people reporting low levels of mood. Students with higher scores on the Beck Depression Inventory have been found more distractible on the ‘emotional Stroop’ test compared to those with lower scores, exhibiting greater delayed identification of the colour of words with negative (vs. neutral) emotional connotations (Gotlib & McCann, 1984). While this effect might be partially explained by higher sensitivity to negative stimuli in depression, clinically depressed people also display performance deficits on attentional tests with emotionally-neutral stimuli, suggesting there may be a relationship between attention focus and mood. In a version of the Continuous Performance Test, for example, Cornblatt, Lenzenweger and Erlenmeyer-Kimling (1989) found that depressed individuals were more adversely affected by an auditory or visual distractor when detecting two identical stimuli (such as numbers or shapes) presented in a sequence. Similarly, Gohier et al. (2009) found a larger distractor-related impairment of reading comprehension in depressed patients compared to non-depressed controls. Importantly, these effects were found not just for emotional but also for emotionally-neutral or semantically-related distractor words.

The finding of elevated levels of distraction and mindwandering in cases of existing low-mood, even by emotionally-neutral material, does not inform about the relationship between attention focus and level of mood in the mentally-healthy population. Evidence exists, however, to suggest that in the case of mindwandering the connection persists in everyday life and among participants reporting normal ranges of moods. Killingsworth & Gilbert (2010) examined both the rate of mindwandering and ratings of mood during everyday activities in a large sample of 2250 participants. Participants responded to a phone application reporting their activities, ongoing emotions and mindwandering episodes (upon randomly timed probes). The results demonstrated that lower levels of mood were reported during periods of mindwandering compared to when people reported being "on task" (see Figure 1.3). As might be expected, this effect was larger for mindwandering with negative content, but even neutral unrelated thoughts were associated with negative mood (and largely replicated by Franklin et al., 2013, though see Poerio et al., 2013 for replicating the correlation of mindwandering and negative mood only for unrelated thoughts of negative content). In another study in which students responded to experience sampling questionnaires at regular intervals over the course of one week, Kane, Gross, et al. (2017) found that reports of mindwandering were more likely to coincide with reports of experiencing more negative affect (feeling anxious, sad, irritable or confused).

Figure 1.3 Mean happiness reported during each activity and while mindwandering from Killingsworth and Gilbert (2010)

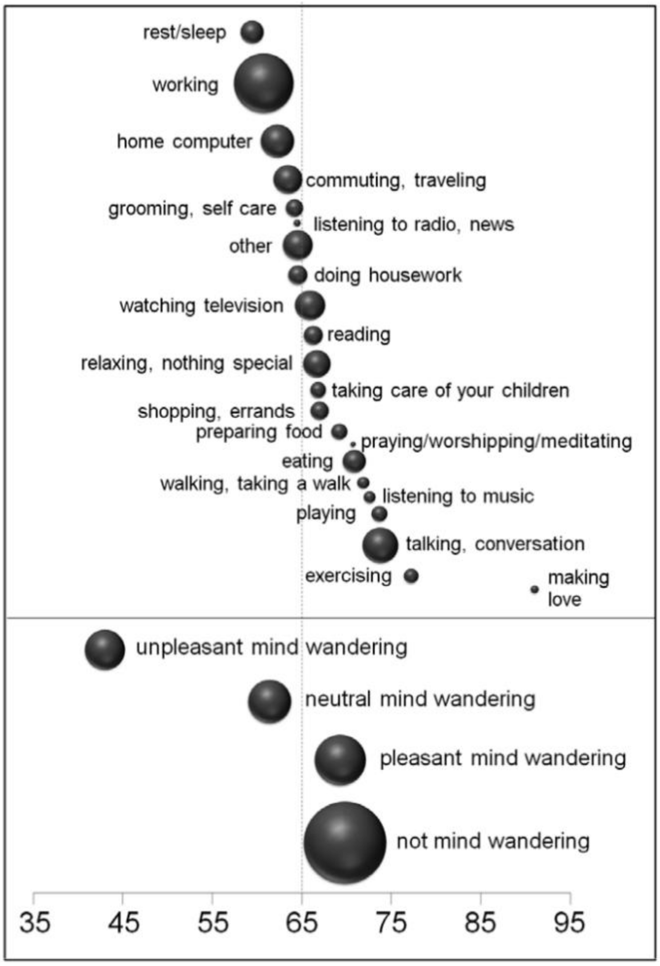

Figure 1.3. Mean happiness reported during each activity (top) and while mindwandering to unpleasant topics, neutral topics, pleasant topics or not mind wandering (bottom), taken from Killingsworth and Gilbert (2010). Dashed line indicates mean of happiness across all samples. Bubble area indicates the frequency of occurrence. The largest bubble ("not mind wandering") corresponds to

53.1% of the samples, and the smallest bubble ("praying/worshipping/meditating") corresponds to 0.1% of the samples.

Killingsworth and Gilbert and other mindwandering studies thus far have not assessed distraction by irrelevant external stimuli and thus their results are restricted to the relationship of mindwandering and mood. However, as mentioned above, Forster & Lavie (2009, 2014) have advanced the hypothesis that mindwandering is a manifestation of a more general susceptibility to irrelevant distractions, whether from internal TUT or external distractions. This raises the question as to whether the same relationships that have been noted between mindwandering and the wide range of healthy mood levels (including happiness) would be present for external distractions.

1.5 Measuring distraction, mindwandering and mood in everyday environments

The relationships between distraction, mindwandering and mood are arguably best investigated in the context of daily life experiences, which are likely to present more sources of external distraction and a greater range of mood variation than in the laboratory (answering recent calls in the literature for more 'ecologically valid' psychology and neuroscience; Matusz et al., 2019; Peelen & Kastner, 2014; van Atteveldt et al., 2019). However, the move towards naturalistic measurements of cognitive constructs requires careful adjustment of tools and methodologies. For example, when it comes to assessing external distraction in everyday environments it is necessary to avoid using a sampling method that might bias the distraction report (e.g. by either being itself a source of distraction, or by being directly related to a potential source of distraction). Many studies which have previously investigated mindwandering and/or mood in everyday life have done so using experience sampling (Franklin et al., 2014; Franklin, Mrazek, et al., 2013; Kane, Gross, et al., 2017; Kane et al., 2007; Killingsworth & Gilbert, 2010; McVay et al., 2009; Ottaviani & Couyoumdjian, 2013; Poerio et al., 2013; Song & Wang, 2012). Experience sampling methods involve probing the content of participants' ongoing experiences at repeated intervals throughout the test period. Questions are generally delivered through an electronic device, for example through palm pilots/handheld personal assistants (Franklin et al., 2013; 2014; Kane et al., 2007; Kane, Gross, et al., 2017), or to the participant's mobile phone through an application (Killingsworth and Gilbert, 2010; Ottaviani & Couyoumdjian, 2013; Poerio, Totterdell & Miles, 2013) or text messaging (Song & Wang, 2012). While the use of these devices allows researchers to randomly sample multiple daily life experiences per person, the measure of external distraction with technological devices such as mobile phones and tablets precludes an unbiased assessment of irrelevant distraction. Mobile phones and other devices such as tablets are known to be a prevalent source of distraction (Glass & Kang, 2018; Kuznekoff & Titsworth, 2013; Oulasvirta, Rattenbury, Ma, & Raita, 2012) which can produce enhanced attentional responses, comparable in magnitude to stimuli of personal significance (such as hearing one's own name; Roye, Jacobsen, & Schröger, 2007). Studies which attempt to assess external distractions in everyday life will naturally need to include mobile phones or other mobile devices such as tablets as a potential source of distraction. Therefore, to achieve an unbiased measure of mobile device distraction it may be necessary that measurement techniques are used which avoid using these kinds of devices in the measurement. This thesis therefore examines reports of external distraction experiences (as well as mindwandering) using methods designed not to contribute to such experiences directly.

Another open question in the measurement of everyday experiences is use of the measurement of the duration, as opposed to the prevalent technique of measuring the frequency, of the experience. Whilst a valuable research tool, probe questions, which collect frequency of responses in response to multiple questions, are limited in two ways. Firstly, the framing of most probe questions does not allow for any information to be gathered regarding the inter-probe interval, which can often be as long as a few hours (see Weinstein, 2017 for a review). Two consecutive probe reports of mindwandering or distraction may therefore represent either two separate short-lived events or one prolonged task-disengaged episode (a state which might be especially relevant for research questions regarding associations with mood). Secondly, it is unlikely that mindwandering and external distraction will be reported together in any one probe question. This may either be because immediate reporting of concurrent mindwandering and external distraction is less likely due to 'perceptual decoupling' during the very instant of mindwandering (see e.g. Smallwood, 2013; Smallwood & Schooler, 2015), or because response options explicitly preclude this (Stawarczyk et al., 2014; Stawarczyk, Majerus, Maj, et al., 2011; Stawarczyk, Majerus, Maquet, et al., 2011; Unsworth & McMillan, 2014; Unsworth & Robison, 2016). When using standard probe questions, therefore, this makes it unclear how mindwandering and external distraction relate to one another over time, for example whether within a particular period of time increased duration spent mindwandering might be associated with more or less time also being distracted by external stimuli. It was therefore important for this thesis to examine the duration of everyday cognitive experiences and their links to mood, as well the existing complementary research on their frequency.

1.6 Attention and executive functioning in adolescents

It has been established that executive control functions differ between adolescents and adults in some RT tasks, whilst on other paradigms even younger adolescents achieve adult levels of performance. Although there has been research on some executive functions which are known to be related to distraction (such as inhibitory control; Alahyane, Brien, Coe, Stroman, & Munoz, 2014; Dwyer et al., 2014; Liston et al., 2006; Taylor, Barker, Heavey, & Mchale, 2015), the work so far has not as yet assessed whether selective attention is fully developed in adolescence when the distractors are entirely irrelevant. Instead, previous research has tended to report contrasting results when comparing adolescents to adults, depending on the form of the tasks, for example whether they create response-related distraction (using the classic flanker task, for example), compared to task using affective or motivationally relevant distractors.

In the case of response related distraction, variants of the common Eriksen Flanker test (Eriksen & Eriksen, 1974) have failed to find a significant difference in response competition effects, at least beyond the very early stages of adolescence. For example, (Grose-Fifer, Rodrigues, Hoover, & Zottoli, 2013) used a letter version of the flanker task, in which participants were asked to press a key corresponding to the central letter (either an S or an H) in an array of five letters, to compare congruency effects on RTs between adults and an adolescent group. They found no main effect of age on congruency effects (or on overall RTs) when comparing the adolescent group and the adult groups. Similar results have been reported using an arrow version of the flanker task; as a part of a large investigation into developmental trends in executive function development, Huizinga, Dolan and van der Molen (2006) gave a battery of executive function tasks, including an arrow flanker, to participants in four age groups: children (mean age 7), young adolescents (mean age 11), mid-adolescents (mean age 15), and young adults (mean age 21). Huizinga et al. found that the RT difference between congruent and incongruent trials were no different between mid-adolescents and adults. The young adolescent group (with participants between ages 10 and 12) displayed a significantly larger congruency effect than the older age groups (both mid-adolescents and adults). Using the same arrow flanker paradigm in an ERP study, Ladouceur, Dahl and Carter (2007) found no RT difference in congruency effects between late adolescents (age 16) and adults, with both groups responding more quickly (and more accurately) than a 'young adolescent' group of age 12. This suggests that mid and older adolescents do not show the greater congruency effects on the flanker task that are observed in children (Huang-Pollock, Carr, & Nigg, 2002; Konrad et al., 2005; Rueda, Posner, Rothbart, & Davis-Stober, 2004).

In contrast, when affective or motivational components are introduced into tasks, adolescents have tended to display greater distractibility than adults. Grose-Fifer et al. (2013) also used an 'affective' version of the flanker task. In this version, three faces displaying a particular emotional expression (either happy or fearful) are presented to the participant, who has to decide on the emotion displayed on the target (central) face, whilst ignoring the irrelevant (distractor) faces either side. 'Congruent' flankers consist of faces displaying the same emotional expression (e.g. happy flankers to a central happy face), while 'incongruent' flanker faces display different emotions (see Figure 1.4). Grose-Fifer et al. investigated differences between adolescents and adults in the effects of the irrelevant distractor faces. They found a greater cost to RT and accuracy from incongruent emotional flanker faces in both young (11-14) and older adolescents (15-17) compared to adults. A valence effect was specifically present for RT effects in the presence of happy face targets. Congruency effects were significantly greater for both groups of adolescents than adults when the target face was happy (the two adolescent groups did not differ from one another). This suggests that the ability to successfully ignore specific emotional stimuli, such as fearful faces, may not yet have reached adult-like levels by 15-17 years of age.

Figure 1.4. Display stimuli from the emotional flanker task from Grose-Fifer et al. (2013).

Figure 1.4. Display stimuli from the emotional flanker task from Grose-Fifer et al. (2013). Fearful incongruent stimulus is shown.

'Affective' versions of the standard go/no-go task have also been used to contrast adolescents and adults. Cohen-Gilbert and Thomas (2013) presented letters against a background of affective pictures from the International Affective Picture System (IAPS: Lang, Bradley, & Cuthbert, 2008) and found that adolescents (up to age 19) displayed a greater failure to suppress responses to a 'nogo' stimulus (an 'X') in the presence of a negative background image (such as threatening animals), in comparison to adults (age 20-25). Similarly, Cohen et al. (2016) used a go/no-go task which asked participants to respond to faces (e.g. responding only to 'neutral' faces and inhibiting responses to other emotional expressions such as 'happy' or 'fearful'), but with the addition of an emotional manipulation that saw trials presented within blocks of sustained negative emotion (anticipation of an unpredictable aversive noise), positive emotion (anticipation of an unpredictable monetary reward), and neutral emotion (no event anticipated). Performance accuracy in response to calm cues (neutral faces) whilst under negative emotion was significantly impaired even up to the age of 21, in comparison to a group of adults aged between 22 and 25. In a further example using a visual search task, Roper, Vecera and Vaidya (2014) found that 'value driven attentional capture' (RT interference effects caused by attentional capture from previously rewarded stimuli which were no longer relevant to the task) persisted for longer in adolescents between ages 13 and 16 than in adults. In adults the association was extinguished by a quarter of the way through the subsequent testing phase, whereas in adolescents the interference persisted throughout the entire testing phase of 240 trials.

To summarise, adolescents have generally not been found to differ from adults in response related distraction (using the classic flanker task, for example), whereas they have been shown to display impairments in the face of affective or motivationally relevant distractors. It is therefore unclear whether these effects are due to motivation/emotion control, or simply because these stimuli are highly salient. They may therefore represent a more general deficit in the ability to control attention in the face of task-irrelevant distraction. Thus it is important for this thesis to clarify this alternative hypothesis regarding the mechanisms of adolescent distraction.

Secondly, whilst in adults perceptual load is a well-established determinant of selective attention (e.g. Lavie, 2005; 2010; Lavie et al., 2015 for reviews), including in children (Huang-Pollock, Carr & Nigg, 2002; Remington, Cartwright-Finch & Lavie, 2014), the reduction of distractor interference by high perceptual load is not yet as widely demonstrated in adolescents. Only one study to date has examined the effect of perceptual load on adolescent distraction. Couperus (2011) investigated the impact of increases in perceptual load in children, adolescents and adults using an event related potentials (ERP) study. The impact of perceptual load on neural markers of unattended perception (peak amplitude of the

P100 waveform) was compared in five groups of children between 7 and 18 years old and a group of young adults (mean age 24 years). Subjects were asked to identify whether a character appearing in the middle of a screen was a letter or number. Load was manipulated through stimulus duration, with the character presented for 100ms in a low-load block, and between 30 and 90ms in a high-load block (depending on performance, a correct answer speeded the next presentation by 10ms, an incorrect answer slowed it by 10ms). In 20% of trials, an irrelevant character (a % sign, presented 200ms following the central task) was presented alone in the periphery (at the top of the display) without the target stimulus, allowing for a target-free measurement of neural activity in response to the irrelevant character, as a function of the perceptual load of the ongoing block (see Figure 1.5). Eye movements were controlled so that these could not account for any of the effects. Across all age groups the amplitude of the P100 to distractor stimuli was lower under high load conditions than under low load conditions, with no interaction between load and age. Therefore the reduction of distractor processing under high load conditions did not appear to vary as a function of age. However, as the distractor stimulus was not particularly salient it remains unclear whether perceptual load can modulate distractor from irrelevant but salient stimuli in adolescents.

Figure 1.5. Stimulus display from Couperus (2011)

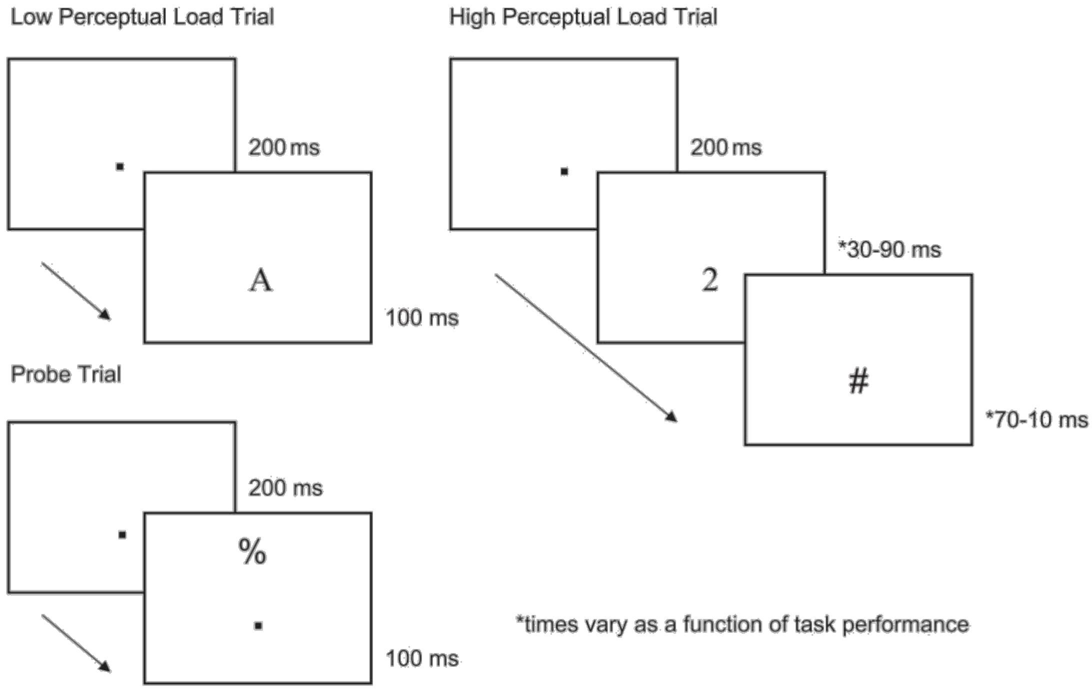

Figure 1.5. Stimulus display from Couperus (2011)

1.6.1 Response variability and distraction in developmental and adult populations

One way that deficits in focused attention have previously been found to be expressed is through an increase in intra-individual RT variability (e.g. Kofler et al., 2013 for a meta-analysis on increased response variability in ADHD). Within the ADHD literature, adolescents have been found to show greater variability than adults (Kofler et al., 2013; Valko et al., 2009). However, less is known about the comparison of intra-individual variability between typically developing adult and adolescent groups, and the development of this ability through the adolescent period. In one notable example examining the development of sustained attention abilities over the lifespan, Fortenbaugh et al. (2015) reported data from a large online study with over 10,000 participants from the age of 10 as they performed a ‘gradual-onset continuous performance task’ (gradCPT), a test of sustained attention based on the go/nogo paradigm. In the gradCPT (Esterman, Noonan, Rosenberg, & Degutis, 2013; Rosenberg, Noonan, DeGutis, & Esterman, 2013), a central stimulus gradually transitions between different images (for example between images of male and female faces, or between city and mountain scenes) at a constant rate, with participants instructed to respond to one of the stimuli but not the other (e.g. only male faces, or only city scenes). The target stimuli are presented on 90% of trials, with non-target stimuli on the remaining 10% of trials. In a ‘distractor’ version of the task, the central stimuli are presented over background distractor images (Rosenberg et al., 2013). Fortenbaugh et al. found that reaction time variability (measured as the coefficient of variation – CV – the ratio of the RT standard deviation to the mean) decreased significantly year on year between age 10 and 16, then stabilizing and remaining constant into adulthood.

Reaction time variability can also be examined in greater detail by fitting trial-by-trial RT data to the ex-Gaussian distribution (Leth-Steensen, King Elbaz, & Douglas, 2000) which separates each individual’s RT distribution into exponential (“ex-”) and normal (Gaussian) components. Within the normal component of the RT distribution, this approach provides estimates of mu (μ), the mean reaction time of the normal distribution, and sigma (σ), the standard deviation of the normal component. Tau (τ) reflects the exponential component of the RT distribution, and is a measure of the degree to which the mean RT is skewed by a subset of extremely slow responses that occur outside of the normal component of the RT distribution. Although therefore similar to a measure of a distribution's skewness, tau is considered a more reliable metric (Schmiedek, Oberauer, Wilhelm, Süß, & Wittmann, 2007). If a participant’s RTs are normally distributed, then mu and sigma will equal the mean RT and SDRT respectively, and tau (τ) will equal zero. Thus, ex-Gaussian methods allow for the identification of variability which may be missed when the parameters of the normal distribution, such as mean and standard deviation, are considered alone (Williams, Strauss, Hultsch, Hunter, & Tannock, 2007). Increased intra-individual RT variability is known in some conditions (for example ADHD) to result at least partially from a larger number of responses in the very slow end of RT distribution (Kofler et al., 2013; Leth-Steensen et al., 2000; Williams et al., 2007), producing a distribution of RTs which is more heavily positively skewed. This is reflected in RT distributions which are not necessarily different in terms of mu or sigma, but which are significantly larger in terms of tau. Thus, ex-Gaussian methods provide a means of understanding the source of differences in response variability between groups. Whilst ex-Gaussian methods have been successfully applied to the analysis of other populations displaying elevated RT variability (such as ADHD sufferers), a comparison between typically developing adults and adolescents using this method has not thus far been reported. In light of the results of Fortenbaugh et al. (2015), investigating whether increased adolescent response variability also results from increases in tau, or whether it occurs in the normal portion of the RT distribution, appears an important next step for research.

1.7 Faces as distractor stimuli

Experimental demonstrations of irrelevant distraction have to date used a relatively limited set of distractor images, primarily cartoon images (Forster & Lavie, 2008b, 2008a, 2011). Semantically meaningful distractors have been shown to produce stronger attentional capture effects in the paradigm (Forster & Lavie, 2008a), however there is no reason to suppose that any suitably salient and meaningful stimulus would produce similar attentional capture effects. Diversifying the range of distractor stimuli which can be shown to produce such effects will both demonstrate the robustness of the original findings, but will also allow for the modification of the paradigm for comparing groups which may have varying levels of familiarity with the distractor stimuli (given that familiarity can affect visual search performance and distractor interference effects; Malinowski & Hübner, 2001; Mruczek & Sheinberg, 2005; Wang, Cavanagh, & Green, 1994; He & Chen, 2010; Lin & Yeh, 2014).

One potential candidate for such an alternative distractor stimulus is faces. Faces are salient stimuli (Jenkins, Lavie, & Driver, 2003; Lavie, Ro, & Russell, 2003), due to their high level of sociobiological importance (De Renzi, 2000). However, it has been suggested that faces may be a 'special' class of distractor in that their processing might not be subject to modulation by perceptual load. For example, Lavie, Ro and Russell (2003) investigated the role of task load in the processing of distractor faces. Participants searched for a name among one, two, four, or six letter strings in the centre of a display (representing varying levels of perceptual load) and indicated by a speeded key press whether it was a politician's or a pop star's name, while ignoring a distractor face (also of either a politician or pop star) in the periphery. Distractor effects were not significantly modulated by high load conditions, in contrast to the predictions of perceptual load theory, suggesting that the face distractors were perceived and recognised, regardless of search load. In contrast, congruency effects were significantly reduced by high perceptual load when the experiment was repeated using meaningful names and images of objects (fruits and musical instruments). This suggests that face processing may be mandatory, in that faces are perceived preferentially and quickly, no matter the processing demands of the attended task. Thoma and Lavie (2013) subsequently replicated these findings, but showed that when the names of the famous people in the main task were replaced with their faces, distractor faces were *not* perceived in the high load condition (see Figure 1.6). Thus, under some circumstances, such as when the task itself involves faces, it appears that face processing may indeed be modulated by the perceptual load in the task. Thoma and Lavie (2013) concluded that face perception may have its own specific capacity limits.

Figure 1.6. Example of a display from Thoma and Lavie (2013)

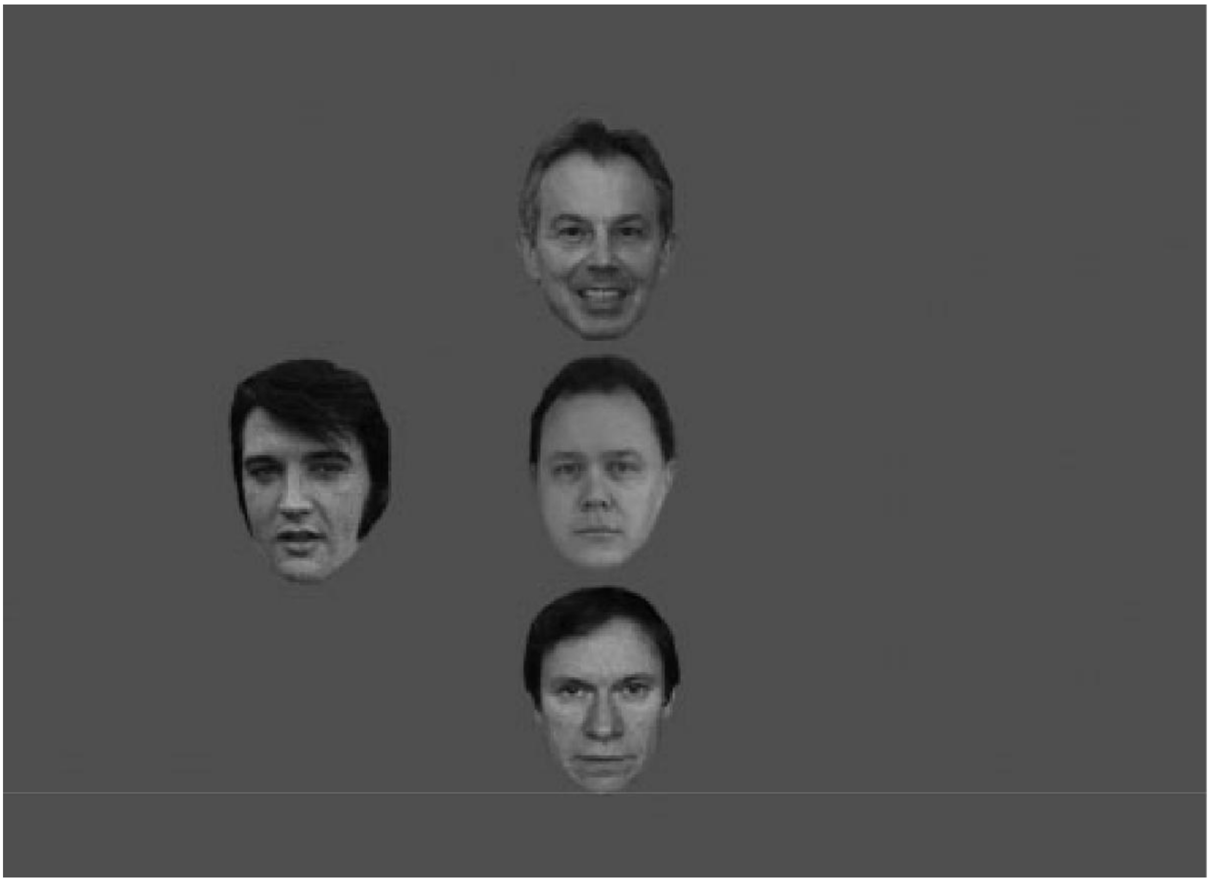

Figure 1.6. Example of a display in the incongruent condition with a relevant set size three from Thoma and Lavie (2013; Experiment 1).

One important factor which appears to affect the processing of facial stimuli is the task context in which faces are encountered (Brebner & Macrae, 2008). Lavie, Ro and Russell (2003) and Thoma and Lavie (2013) presented their distractor faces as response-competition distractors within a task that also employed faces. Using a paradigm which presented a letter search task superimposed over a task-irrelevant famous face, Jenkins, Burton and Ellis (2002) found that recognition memory for facial distractors was modulated by perceptual load (a result replicated for unfamiliar faces by Jenkins, Lavie, & Driver, 2005). Thus, it may be that when faces are operating as a response-competition distractor, as in these paradigms, their processing is not subject to perceptual load modulations in the same way as other distractor stimuli. In addition, participants performing recognition memory studies with unfamiliar faces do not seem to show universal face expertise, suggesting that special features of face processing may be limited to faces with which we are familiar (Young & Burton, 2018).

As has been previously noted, however, response-competition paradigms may not provide a valid model of experiences of distraction in the real world (see Section 1.2.1.2). This raises the question of whether face-distractors would be modulated by perceptual load when presented in a manner that is entirely task-irrelevant. One previous study has investigated the load modulation of task-irrelevant distraction by faces. Sato & Kawahara (2014) used a letter search task modelled on that of Forster and Lavie (2008a; b). Distractor faces were presented irregularly for 100ms in the periphery of the screen, outside the letter search array. Sato and Kawahara reported that a load effect on distraction was not obtained for their adult participants, and concluded that the interference from distractor faces occurred independently of perceptual load. The faces were presented for 100ms, too short a time to allow visual saccades to the periphery (Braun & Breitmeyer, 1988), therefore ensuring that the faces were not processed in the fovea. However, previous studies have shown that the visual acuity of faces drops sharply when perceived in the periphery, with an increase in contrast and size of the images being shown to be necessary for peripheral identification of faces to equate with foveal (Mäkelä, Näsänen, Rovamo, & Melmoth, 2001). The extent to which the distractor stimuli were perceived with sufficient acuity as being faces is therefore unclear. Reduced perception or awareness of the distractor could result in a decreased distractor effect in the low load condition, which in turn would make any perceptual load modulation difficult to detect. In light of the modulation of the processing of face distractors in paradigms in which the full processing of the distractor stimulus could be assured (Jenkins et al., 2003, 2005; Thoma & Lavie, 2013), this thesis tests the prediction that task-irrelevant, anonymous faces would be significantly modulated by perceptual load, in line with the predictions of perceptual load theory.

1.8 Inattention and educational settings

There are growing calls in the psychological and neuroscientific literature on attention for more ecologically valid research, which links cognitive processes traditionally studied in the laboratory, with the 'real-world' (e.g. Matusz, Dikker, Huth, & Perrodin, 2019; Peelen & Kastner, 2014; van Atteveldt, van Kesteren, Braams, & Krabbendam, 2019). Such studies allow for the external validity of well-established laboratory models to be tested, ideally in a manner which maintains the integrity of the original question (Ansari & Coch, 2006; Matusz et al., 2019). More naturalistic research can, for example, be achieved through the use of real-life stimuli, such as natural scene images during visual search rather than simplified or schematic images (Çukur, Nishimoto, Huth, & Gallant, 2013; Guo, Preston, Das, Giesbrecht, & Eckstein, 2012; Peelen & Kastner, 2011; Preston, Guo, Das, Giesbrecht, & Eckstein, 2013). Alternatively, ecological validity can be achieved by quite literally taking research into real-world environments, for example by conducting experimental paradigms in natural settings, thereby accessing participants in the midst of ongoing everyday activities and states (Bevilacqua et al., 2019; Dikker et al., 2017; Ko et al., 2017; Müller, Sänger, & Lindenberger, 2018).

One example of a real-world environment where the application of cognitive psychology and neuroscience techniques has often been argued to hold great promise is educational settings such as lecture theatres and the classroom (Ansari & Coch, 2006; Goswami, 2006; Howard-Jones, 2014; Samuels, 2009). In addition to the obvious societal importance of education, such settings offer real-world environments which remain at least partially controlled, and in which behavioural and cognitive outcome measures (such as academic performance or student engagement; Scholkmann, Holper, Wolf, & Wolf, 2013; Watanabe, 2013) can be collected with greater validity than in some other settings. For example, a classroom environment has been found to be able to reproduce findings from similar studies in controlled laboratory settings, such as in measuring attentional engagement (Poulsen, Kamronn, Dmochowski, Parra, & Hansen, 2017), further demonstrating the potential of classrooms to act as productive locations for the translation of laboratory findings into real-world studies. In the context of such translational work linking neuroscience and educational settings, it is not surprising that studies have often identified attention as a key mechanism of interest. Focused attention is known to play a critical role in most forms of learning (Amer, Campbell, & Hasher, 2016; C. Stevens & Bavelier, 2012), and attention skills (and, conversely, attention lapses) have been widely linked to academic outcomes in both school and university settings, as will be discussed in the sections below.

1.8.1 Inattention in school environments

A number of different measures have demonstrated a link between attention skills and academic outcomes. For example, performance on focused attention tasks has been linked to general academic success at school (Checa, Rodríguez-Bailón, & Rueda, 2008; Checa & Rueda, 2011; Steinmayr, Ziegler, & Träuble, 2010). More commonly, many studies have employed teacher ratings of student attention skills. Sayal, Washbrook, & Propper (2015) found a linear association between teacher ratings of inattention at age 7 and GCSE scores, with each one point increase in inattention symptoms associated with lower GCSE scores, even after controlling for confounding variables. These findings suggest that attention-distractibility will occur on a continuum within schools, and that the potentially harmful effects of inattention on academic achievement are likely to be felt well beyond the clinical end of the attention-distractibility spectrum. As such, there is clearly a pressing case to understand and measure inattention and distractibility in school classrooms. It is therefore important to investigate attention task measures that can predict focused attention during classroom learning at school.

As indicated above, however, the most frequently used measure of student attention problems in the academic literature to date has been teacher ratings. Such measures have undoubtedly proven useful in the prediction of subsequent inattention and academic success. For example, increases in teacher-rated attention problems from age 6 to age 11 (measured using the attention sub scale of the Teacher Report Form; Achenbach, 1991) have been found to precede declines in academic achievement from age 11 to age 17 (N. Breslau et al., 2010). Using the same scale, teacher ratings of attention problems at age 6 also predict mathematics and reading attainment age 17 (J. Breslau et al., 2009). This correlation was found after controlling for IQ at age 6 (as well as maternal education), and so does not seem to simply reflect the influence of confounding variables such as IQ or parental education. Teacher ratings have also proven useful in helping to specifically identify the importance of inattention in these outcomes. For example, using adapted versions of the diagnostic criteria for ADHD in edition 4 of the Diagnostic and Statistical Manual of Mental Disorders

(DMS), teacher ratings of inattention, but not hyperactivity, predict English and mathematics performance at age 11 (Merrell et al., 2017; see Figure 1.7). In another study, again using DSM criteria, only teacher ratings of inattentive classroom behaviour, and not ratings of other behaviour problems such as oppositional behaviour, hyperactivity or anxiety, were independently associated with diminished academic achievement (Rabiner, Murray, Schmid, & Malone, 2004). Interestingly, the negative effects of attention problems appear to be cumulative (or to be felt more severely the longer an individual remains in education). Merrell & Tymms (2001) found that the negative association between teacher-ratings of attention problems and academic performance persisted even when controlling for academic performance at the time of the first measurement (the start of reception year).

Figure 1.7. Box and whisker plot from Merrell et al. (2017) showing attainment at age 11 by number of criteria met relating to inattention at age 5

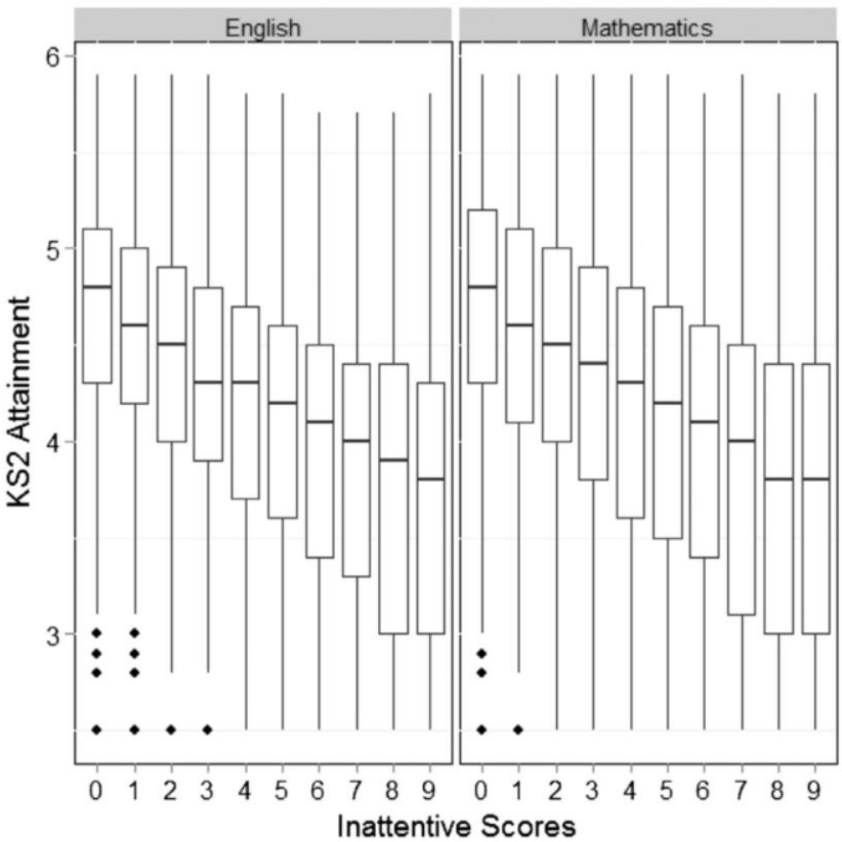

Figure 1.7. Box and whisker plot from Merrell et al. (2017) showing attainment in English and Mathematics at age 11 by number of criteria met relating to inattention at age 5.

However, teacher ratings possess both practical and methodological limitations. Teacher ratings of inattention can vary in their reliability both within and between schools (Merrell & Tymms, 2001) and between countries (Merrell, Jones, Tymms, & Wildy, 2013). For example, Merrell et al. (2013) found that teachers in Scotland rated inattentive, hyperactive and impulsive behaviour (from DSM-IV criteria) to be more severe than teachers in Australia or England for children of the same age. This creates difficulties for the assessment of the scale, and effects, of inattention internationally, given that criteria such as those used by the DSM are considered to be an international standard. In addition, teacher ratings of attention problems can be unstable over time. Rabiner et al. (2010) found that fewer than half of students who received clinically elevated ratings of attention problems from their teachers in a given year also maintained this level of rating in the following year. This may be because inattentive behaviour (and the subsequent teacher ratings of it) can be influenced by contextual factors in the classroom which are altered when the student moves classes. Indeed, teachers report witnessing items related to inattention more frequently than those related to hyperactivity or impulsivity (Merrell et al., 2013; Merrell & Tymms, 2005), so the impact of contextual factors on inattention reports may be magnified. This is a concern as clinical measures of inattention (at least in ADHD samples) have suggested it to be a relatively stable characteristic over time (Biederman et al., 2004). Teacher ratings are also likely to be less sensitive to some forms of inattention, such as mindwandering, even though students diagnosed with attention problems during childhood also report experiencing a higher frequency of mindwandering (Hines & Shaw, 1993; Shaw & Giambra, 1993).

1.8.1.1 Objective and task-based measures of inattention in school settings

In one line of research in schools, some task measures of attention have been previously related to teachers' ratings of attention deficit hyperactivity disorder (ADHD) symptoms manifested at the school (Hoerger & Mace, 2006). However, this work has focused on the childhood period (due to the developmental nature of the disorder) and has typically used behavioural task measures of impulsivity and self-control rather than attention specifically (for example, Hoerger & Mace, 2006 used a computerised test of gratification postponement). In addition, some previous research has shown that other objective tests (such as the Stroop test, and visual and auditory response competition tasks where participants respond to target stimuli whilst inhibiting responses to other similar stimuli) can be used to validate teacher ratings of students' attention control skills (at least in terms of differentiating between the top and bottom quartiles; Das, Snyder, & Mishra, 1992; Papadopoulos, Das, Nelly Kodero, & Solomon, 2002). However, Stroop-like tasks do not provide a valid measure of selective attention abilities, as participants are not required to ignore any features of stimuli, rather, they must simply inhibit competing responses towards the same stimulus (see Lavie & de Fockert, 2005; Lleras, Buetti, & Mordkoff, 2014 for criticisms of the Stroop task as a measure of selective attention and distraction). It therefore remains unknown whether well-established task measures of focused attention in the face of irrelevant distraction can be used to predict the level of distractibility during school classroom lessons in secondary school aged adolescents, thus addressing the issue of attention at school beyond ADHD symptoms and early developmental effects.

Another line of research, in keeping with a desire to bring laboratory measures of attention to bear on our understanding of educational processes, has seen a number of recent studies employ neuroscientific methods, such as EEG, to investigate attention and learning naturalistically in high-school classrooms (Bevilacqua et al., 2019; Dikker et al., 2017). For example, Dikker et al. (2017) found that the brain-to-brain synchrony (the level of coherence in EEG signals between group members – a measure of group shared attention) of high school students (age 17-18) in a senior biology class was correlated both with the teaching style used (lecture vs. video) and individual differences (such as the student's reports of their focus and the teacher's likeability). Bevilacqua et al. (2019) used the same design, and found that brain-to-brain synchrony could be related to learning; test scores were found to increase as the level of brain-to-brain synchrony increased, both among the group of students (again age 17-18) and also between students and their teacher. However, EEG and other real-time measurement methods offer only limited practical applications for teachers at present (see section 1.8.2.2 for a more extended discussion of these limitations).

1.8.2 Inattention in higher education

One difference between school classrooms and higher education environments, such as lectures and seminars, is the prevalence and scale of use of potentially highly distracting tools such as laptops and mobile phones in HE settings. A recent strand of research into inattention in higher education has assessed the prevalence and impact of distraction by non-academic technology use during lectures. For example, Kraushaar and Novak (2010) asked participating students to install activity-monitoring software onto their laptops and monitored the programs that were running during lectures, dividing them into 'productive' programs (which could be considered course-related, such as viewing the lecture slides) and ‘distractive’ programs not relevant to the course (such as web browsing, email, instant messaging etc) Their study found that 62% of the programs that students had open on their laptops were considered distracting and that technology use such as instant messaging was negatively correlated with quiz averages, project grades, and final exam grades.

In another study, Wood et al. (2012) examined the impact of different kinds of technology use on lecture retention. They randomly allocated students to a variety of technology use conditions (Facebook use, instant messaging, emailing or texting), for comparison to a control condition of pencil and paper note-taking. Wood et al., found that technology use overall was associated with reduced recall of the lecture material. Interestingly, some types of technology use were found to be more harmful for subsequent retention of lecture material than others; students in the Facebook and instant messaging conditions performed significantly worse than controls on subsequent tests, while the texting and email conditions did not. A further study, from Wei, Wang and Klausner (2012), suggested one mechanism by which the relationship between the individual, technology use and academic outcomes might be sustained. Wei et al. reported a structural equation model that suggested technology use (in this case self-reported texting rates in class) significantly mediated the relationship between students’ self-regulation abilities (the extent to which they reported being able to cognitively engage with learning and block extraneous distractors), and their most recent assessment scores. Specifically, students with higher self-regulation abilities send fewer text messages, which allowed them to sustain their attention on classroom learning more effectively.

Similar prevalence and effects of non-academic technology use have been reported for video lectures. Risko, Buchanan, Medimorec and Kingstone (2013) found that 75% of laptop-using students performed a task other than note-taking on their devices (over half reported checking emails, 45% surfing the internet, and nearly a third reported using instant messaging or playing games). Risko et al. then asked their participants to watch an hour-long video lecture on Ancient Greek History. Half of the participants viewed the lecture without computer access, whereas the other half were given a concurrent task responding to ten email tasks across the course of the lecture, to simulate typical email use. Probe questions embedded at intervals throughout the lecture recorded whether participants focused on the lecture content. Students in the email task group reported spending significantly less time attending to the lecture, compared to the control group. In addition, the email group performed significantly worse in a subsequent test of the lecture material, with levels of attention during the lecture fully mediating the association between computer use and retention of the lecture material. In a similar study, Kuznekoff and Titsworth (2013) focused on the effect of messaging on mobile phones. Students in a ‘high texting’ condition responded to questions in an online survey, delivered every 30 seconds to simulate the receipt of regular text messages. Compared to a control group, the high texting group took fewer notes and recalled significantly less information from a 12-minute video lecture.

Indeed, the potentially harmful effects of distraction by technology may not be restricted to the user themselves, but to others for whom the device is in their view as well. The extensive literature on attention capture demonstrates that moving stimuli, or stimuli which onset and offset such as flashing lights, are effective at capturing attention involuntarily (e.g. Franconeri & Simons, 2003; Jonides & Yantis, 1988). Therefore, the regular changes in the configurations of screen-based displays during even relatively mundane tasks are likely to capture the attention of students in the vicinity. To test such a hypothesis, Sana, Weston and Cepeda (2013) performed a laboratory simulation of a lecture setting in which half of the participants were also given 12 concurrent online tasks to complete during the lecture, Not only did subjects who were given the additional tasks perform worse than control participants on a subsequent test of the lecture material, but control participants who were in direct view of a multitasking participant performed worse than those who were not. Similar findings have since been reported for actual classroom learning by Glass and Kang (2018), who used a counterbalanced design where two groups of students studying the same course were permitted to bring electronic devices to alternating lectures (with the order switched between groups). Glass and Kang found that when electronic devices were permitted in class, even students who did not use them performed more poorly, compared to their performance on questions taken from lectures in which the devices had not been permitted (students who did use devices also performed more poorly on exam questions from 'device permitted' lectures than from 'device banned' ones, as expected).

A number of the studies above might also be described as illustrating the harmful effects of multitasking, rather than distraction per se. Multitasking involves the intentional allocation of attention towards a secondary task (or the division of attention between two tasks simultaneously), whereas distraction involves the misallocation of attention towards a task-irrelevant stimulus. However, these are clearly complementary and overlapping fields. Many technological devices will produce distracting stimuli which attract attention (e.g. vibrations or flashing lights on the receipt of a message), in order to encourage users to engage with a secondary task (e.g. reading or replying to the message). The evidence from Sana et al., (2013) and Glass and Kang (2018) also demonstrates that multitasking behaviour with technological devices from one individual may produce highly distracting stimuli for others, with consequent impaired recall of lecture material. What is clear is the potential for technology to be harmful to learning in academic settings.

Compared to the recent interest in distraction from technology, other forms of external distraction have been relatively little researched, both in terms of their sources and the impact that they might have on academic performance. Indeed, visual distractions from non-technology sources have seemingly not been explicitly investigated in lecture settings as yet. Auditory distractions have, however, received some research attention. Across three experiments Zeamer and Fox Tree (2013) found that task-irrelevant auditory stimuli (including concurrent speech but also non-linguistic noises) impaired recall of a short video lecture. Most notably, whilst recall was impaired for a test of verbatim recall of lecture content, even gist processing of the lecture material was also found to be impaired compared to a no-noise control condition. Distraction occurred whenever it was difficult for a listener to process sounds and assemble coherent, differentiable streams of input.

1.8.2.1 Mindwandering in higher education settings

Potentially the most potent source of distraction in lectures and similar educational settings may, however, not come from external stimuli at all. The past decade has seen an expansion of research into the topic of mindwandering, including assessing the prevalence of such lapses in attention, and their relationship to academic outcomes. Two notable studies have examined these questions in the context of genuine, live educational settings. Lindquist and McLean (2011) asked students attending an introductory Psychology lecture to respond to five thought probes spaced at specific intervals, recording whether or not they were experiencing task-unrelated thoughts at the moment of the probe. They found that students reported mindwandering in response to 33% of the probes on average. Mindwandering rates increased with time in the lecture, in line with experimental findings that mindwandering rates increase with time on task (Mcvay & Kane, 2009; Smallwood, Obonsawin, & Reid, 2005; Smallwood, Riby, Heim, & Davies, 2006; Teasdale et al., 1995). Increased mindwandering rates were associated with reduced note-taking, and with poorer performance on a subsequent end of term exam of the lecture material.

In another study using live lectures, Wammes et al. (Wammes, Seli, Cheyne, Boucher, & Smilek, 2016, see also Wammes, Boucher, Seli, Cheyne, & Smilek, 2016) used up to three probe questions in each session of a 12 week lecture course, and tested students' recall through both end of lecture quizzes and a final exam. Overall rates of mindwandering were 34%. Wammes et al.'s probe responses also allowed participants to distinguish between intentional and unintentional mindwandering; rates of unintentional mind wandering were relatively low, and did not increase over the course of a lecture, whereas intentional mindwandering did. Interestingly, different forms of mindwandering were associated with different aspects of test performance. Intentional mindwandering rates correlated negatively with daily quiz scores ($r = -.21$), whereas unintentional mindwandering was significantly negatively associated with exam scores ($r = -.20$). Neither form of mindwandering was significantly associated with a pre-term self-report measure of motivation to learn, suggesting that mindwandering rates (and their harmful effect on learning) cannot simply be reduced to motivation or interest in the lecture. However, a pre-term measure may not be sensitive to reveal interest once lessons have started. It seems unlikely, for example, that intentional mindwandering would be uncorrelated to interest during the lecture itself.

A number of other studies have examined complementary hypotheses in the context of video lectures. Risko, Anderson, Sarwal, Engelhardt and Kingstone (2012) used four probe questions at specific intervals throughout hour-long video lectures (although these probes were subsequently collapsed into two measures, of 'first half' and 'second half' of the lecture respectively). Across two studies, students indicated that they were mindwandering in response to around 40% of probes, a rate that again increased with time in the lecture. In contrast to the delayed recall test of Lindquist and McLean (2011), Risko et al. tested retention of the material immediately after the end of the lecture, however they found similar results, with a significant negative correlation between mindwandering rates and test performance. Kane, Smeekens, et al. (2017) performed a combined experimental-correlational study which examined whether the frequency of students' probe-caught mindwandering during a video lecture on statistics could predict learning (and interest) during the lecture, whilst also measuring a number of individual differences variables. Off-task mindwandering was reported on an average of 45% of probes. Kane et al. found that mindwandering uniquely predicted both learning (post-test performance) and self-reported interest in the lecture above and beyond all other individual-differences variables.

It should also be noted that the harmful associations between mindwandering and learning do not seem to be reducible to time on task, for example in the context of hour-long lectures. Whilst mindwandering rates do seem to rise with time on task, Szpunar et al. (2013) also found around 40% rates of mindwandering even during a 21 minute long video lecture. In another study, Hollis and Was (2016) showed their participants two videos from an online course in public relations, both of which were only 13 minutes long, and probed their mindwandering states at four intervals. They found that off-task thinking was reported on 43% of probes and that higher levels of mindwandering predicted poorer performance on post-test quizzes, when examined using structural equation modelling. Notably, Hollis and Was allowed participants to specify the content of their mindwandering into 5 categories. Of these, the most common ('thinking about or using another technology') accounted for 29% of all off-task thinking. In addition, Hollis and Was found that mindwandering rates were negatively predicted by topic interest (using a simple self-report questionnaire), and by working memory capacity (from a set of complex span tasks; and in contrast to some other studies, such as Kane, Smeekens, et al., 2017, which found a non-significant relationship between working memory capacity and mindwandering rate during a video lecture).

I note here that the common findings that experiences of attention lapses (whether from external or internal sources) are associated with reduced test or exam scores are in line with the interpretation as an internal source of distraction, as described in Section 1.3.

1.8.2.2 Predicting inattention in higher education settings using objective and task-based measures

In a similar manner to the research described above in school classrooms (section 1.7.1), researchers have investigated measures to allow the prediction of inattention states in higher education settings. Ko et al. (2017) used real-time EEG signals to assess changes in neural signals in individual college students within a lecture setting. A visual attention task paradigm was incorporated into the lecture and randomly appeared within the lecture presentations. Participants responded to one of four stimuli (triangle, square, circle and star) by pressing the corresponding picture on a smartphone application as quickly as possible after display. Response time to the attention task thus provided a task-based measure of attention focus at various points in the lecture. The results of this study revealed significant tonic spectral changes (in alpha, theta, beta, and gamma bands) preceded trials with long response times or missed target detections. Thus, Ko et al. concluded that EEG signals might be able to detect drops in an individual student's levels of attention focus, with obvious potential benefits for teaching efficacy. However, if laboratory measures are to be of genuine use to educators, it is important that they are able to provide information that is of direct relevance to their practice and planning. EEG, and other measures which aim to detect attention lapses as they occur, must therefore be able to relay useful information to teachers about changes in attention states in real time. At present, however, the measurement and processing of EEG signals is not sensitive or fast enough to provide such information. EEG systems are also prohibitively expensive for regular classroom use. The same difficulties apply to a number of other real-time physiological and performance-based correlates of attention focus which have been identified, for example eye tracking data such as blinking, gaze direction and pupil dilation (Faber, Bixler, & D'Mello, 2018; Franklin, Broadway, Mrazek, Smallwood, & Schooler, 2013; Smilek, Carriere, & Cheyne, 2010), RT variability (Adam, Mance, Fukuda, & Vogel, 2015) and heart rate (Pham & Wang, 2015). In addition to ongoing improvements in such reactive measures of inattention, therefore, it is potentially more valuable at present to look at methods which might be able to predict inattention states, or inattentive students, in advance. One such method is performance on some attention task measures, which may be able to predict focused attention during learning.

This approach was taken by Unsworth, McMillan, et al. (2012). Unsworth and colleagues created an 'attention control' latent variable from college students' performance on three attention control tasks (flanker, anti-saccade and psychomotor vigilance task). They also asked the same students to keep a diary of their cognitive failures over the course of one week, including distraction from a task by an irrelevant stimulus in the external environment ("e.g. a flat-mate's phone ringing"), as well as incidents of mindwandering ("e.g. during a class lesson”). Using a structural equation model, Unsworth, McMillan, et al. found significant relationships between attention failure (total reported attention failures in the diary), attention control (a latent variable of attention task performance) and academic success (self-reported scores on the SAT - a standardised test widely used for university admission in the USA). Individual susceptibility to everyday attention failures mediated the relationship between attention task performance and SAT scores (see also Unsworth, Brewer, et al., 2012). Thus, a common factor derived from three attention control tasks was able to predict the frequency of distraction and mindwandering in college students’ daily life, and to link this to academic success. However, the daily life incidences of inattention comprised of a variety of settings (not just in lectures, but also for instance also while cooking, studying, driving or having a conversation). It is therefore unclear how the results were specifically related to inattention during the students’ classes. In addition, as none of the tasks used measured the interference from a task-irrelevant distractor specifically, it is not clear whether performance on such tasks offers the best model for predicting task-irrelevant distraction in daily life.

A promising task-based measure of the type of inattention that may harm learning is the irrelevant distraction task, which measures the interference caused by visual distractors that are entirely irrelevant to the task (Forster & Lavie, 2008a). It has been shown that the individual magnitude of irrelevant distractor interference effects (on reaction times) in this task can predict childhood inattentive symptoms in a non-clinical sample of adults (Forster & Lavie, 2016). In addition, individual differences in performance on the task predict individual differences in everyday mindwandering reports in adults (Forster & Lavie, 2014). Given the well-established connection between inattention (from both internal and external sources) and impaired academic performance, measures that may be able to predict differences in student experiences of inattention hold great potential.

1.9 Reducing inattention in educational environments

The clear tendency for higher levels of inattention to be associated with adverse academic outcomes has unsurprisingly led a number of researchers to investigate potential means for mitigating these effects, through interventions designed to reduce students' rates of task-irrelevant distractibility. Szpunar (2017) distinguishes between approaches which are reactive (detecting and refocusing lapses of attention in real time as they occur during learning) and proactive (developing educational techniques, materials or environments that encourage on-task processing). Reactive approaches (such as those using EEG and other physiological markers described above in Sections 1.8.1.1 and 1.8.2.2) undoubtedly hold promise for detecting lapses in attention during task performance by providing real-time information to educators regarding students' attention states, as yet they lack the sensitivity and cost-effectiveness to be widely adopted (see Section 1.8.2.2). As a result, the majority of studies in this area have thus far investigated proactive methods.

Proactive methods can take a variety of forms. For example, some can involve making environmental changes during the lecture, to minimise sources of distraction or otherwise create conditions conducive to concentration. Lindquist and McLean (2011) found that lower rates of mindwandering were found among students who chose to sit in the front third of the lecture theatre. This suggests that seating arrangements could potentially be used to improve attention focus, however such a hypothesis has not been specifically tested as yet, and the finding is likely to be mediated by other variables such as the level of interest in the subject.

In addition, the fact that students in Lindquist and McLean's study were free to choose their seating position may have meant that seating choice interacted with other variables such as motivation or interest.

Another recent study also examined the effect of changes in the environment on learning. Robison and Unsworth (2015) investigated another very common form of learning activity undertaken by students: reading. They examined whether individual differences in working memory capacity (taken in this study as an index for vulnerability to distraction) would affect reading comprehension when participants read a text in either noisy or silent environments. WMC was negatively associated with reading comprehension in both conditions, with participants in the noise condition reporting higher rates of attention lapse overall (although mindwandering rates did not vary between conditions). However, the specific source of distraction mediating the relationship varied by background condition: in the silent condition the effect was mediated by mindwandering, whereas in the noisy condition it was mediated by external distraction. Whilst these results suggest that a reduction in background noise can help to reduce overall levels of attention lapse, they also show that the removal of external distractions is unlikely to be an entirely effective strategy for limiting attention lapses, as this may merely lead to an increase in the effect of mindwandering on performance instead.

Other proactive methods have focused on the learner specifically, and examined the effectiveness of interventions designed to increase their engagement with the target information. For example, Kane, Smeekens, et al. (2017) performed a note-taking manipulation, with half their participants asked to take notes during their video lecture, whilst the other half were asked merely to listen carefully to the lecture without taking notes. Encouraging long-hand notetaking in this way was not found to affect mindwandering rates across participants (although some positive effects were found for particular groups of individuals such as those with less prior knowledge of the topic or those who were coded as having taken notes of particularly high quality). Another manipulation during a reading and memory task was described by Halin, Marsh, Hellman, Hellström and Sörqvist (2014) who asked participants to read texts, with either quiet or speech background noise. In addition, they manipulated the font of the extract, with one easy-to-read font and one more difficult font. Background speech impaired recall of the text on subsequent tests, but only when the text was displayed in the easy-to-read font. When the text was in the more difficult to read font, recall in the background speech condition was significantly better than for the easy-to-read font (although in the silent condition the opposite pattern was present, with impaired recall for the hard-to-read font). The magnitude of the disruption caused by the background speech was mediated by working memory capacity, but only in the easy-to-read condition. Therefore, in environments where background noise can be reliably predicted (such as open offices or other noisy work environments), increasing the difficulty of the text for the reader may be an aid to selective attention, especially for people with lower working memory capacity. However, such an intervention seems unlikely to be easily adaptable to more intermittent background noise or speech disturbances such as might be experienced in a lecture or seminar.

1.9.1 Interpolated testing

The most commonly researched proactive method for reducing attention lapses in educational settings, however, has been the use of quizzing and testing. Specifically, one recently researched technique has been to use 'interpolated testing', providing recall opportunities (often in the form of quiz questions) at various points throughout learning sessions. The benefits of testing, or other forms of memory retrieval activities, for the memory of the retrieved information are well established (see e.g. Roediger & Butler, 2011; Roediger & Karpicke, 2006 for reviews; Rowland, 2014 for a meta-analysis). For example, retrieval practice has been shown to produce large gains in long-term retention relative to repeated studying, and has also been associated with an increased ability to flexibly retrieve and transferred knowledge to different contexts. In addition to this, however, interpolated testing has been shown to produce 'forward effects' on learning, promoting improved learning of new material presented after the recall opportunity, although usually within the same learning session (Pastötter & Bäuml, 2014; Yang et al., 2018 for reviews). This observation has been well-replicated in laboratory studies, but has also been demonstrated in applied contexts in both educational and clinical settings, enhancing learning in students and reducing memory deficits in clinical populations (Pastötter & Bäuml, 2014). Crucially for the present thesis, however, in addition to improved learning, interpolated testing has also been associated with reductions in self-reports of mindwandering during learning from video lectures (Szpunar et al., 2014, 2013). Importantly, these effects appear to be primarily restricted to task-irrelevant mindwandering, rather than thoughts related to the lecture content (Jing et al., 2016). Thus, the forward effects of testing appear to extent to attentional effects as well as to memory. The following section therefore focuses on studies which have examined the attentional effects of interpolated testing.

The potential of testing to positively impact attention was initially noted by Bunce, Flens and Neiles (2010), who conducted a study in a live lecture setting in which students used clickers to measure the duration of students' self-reported attention lapses during a lecture (they did not differentiate between attention lapses from different sources, such as internal or external). The students clicked one button to indicate an attention lapse lasting 1 minute or less, another button to indicate a lapse of 2 to 3 minutes, and a third button to indicate a lapse of 5 minutes or more. In addition, one of the researchers attended the lecture and noted the pedagogical style (e.g. lecture, demonstration, quizzes etc) being used at each point of the lecture. Inattention reports were then mapped against the teaching methods being used at the time of the lapse. They found that students reported significantly fewer attention lapses during period when they were responding to questions, than during lecture segments of comparable length. There were also fewer reported lapses in attention during lecture segments in the period immediately following either a demonstration or a question, when compared to lecture segments that preceded the active learning methods. Therefore, in addition to influencing attention during the period of responding to quiz questions, the results suggested that quizzing might have beneficial forward effects, in the form of reduced attention lapses during subsequent lecture periods. However, Bunce et al. (2010) did not differentiate between sources of attention lapse, or set out to test interpolated testing specifically (rather they simply compared pedagogical approaches being used at different points of the lecture). Subsequently a number of researchers have specifically investigated the effect of interpolating quizzes throughout a video lecture (though corresponding studies in live lecture settings have not yet been reported), and measured the effect of this intervention on both attention lapses (usually mindwandering) and on subsequent academic performance.

In an influential study which pioneered the research design for studies of the effect of interpolated testing on attention, Szpunar et al. (2013) asked participants to watch a 21-minute long introductory video lecture in statistics, split into four sections. At the end of the first three segments, the experimental 'test' group completed a 2-minute test on the content of the segment, whereas control groups spent the same amount of time completing another activity (either maths puzzles or restudying their notes from the lecture independently). At the end of the fourth and final segment, all groups completed a final test on the content of the lecture. Szpunar et al. reported two studies, the first in which the number of mindwandering bouts were estimated after the final test, and a second in which four mindwandering probes (one in each segment of the lecture) were inserted. Results for both studies were very similar. In both studies, mindwandering rates were reduced by the inclusion of interpolated testing (in Study 4 the rate was cut in half, from 40% of probes to 20%). Students in the testing condition took significantly more notes during the lecture and, importantly, also performed significantly better on the final test than control students.

In a follow up study which used the same design (and same lectures), but with high school age participants, Szpunar et al. (2014) again found that, compared to an untested control group, students who completed interpolated testing reported significantly fewer mindwandering episodes, and took significantly more notes. Szpunar et al. also included a confidence judgement asking participants to predict, on a 0–100% scale, how well they would perform on the final test. Both the interpolated test group and an untested group displayed similarly high levels of confidence (77% and 78% respectively), but only the testing group performed close to their prediction on the final test (75%, compared to 48% in the untested group). Thus it seems that another forward effect of interpolated testing may be to reduce the gap between students' predictions of their own learning and reality (a valuable feature given students' tendency to overestimate their own learning efficiency; Hacker, Bol, & Keener, 2008).

Interpolated testing has not always been found to reduce mindwandering rates, however. Jing et al. (2016) showed participants an extract of a video lecture on public health, divided into eight 5-minute segments. Rather than answer quiz questions, the 'tested group' engaged in free recall, whereas the 'restudy' control group restudied the lecture slides. Both groups then took a final cumulative test on the lecture content. In their first experiment, Jing et al., found that although the testing group performed better on the final cumulative test, there were no differences between groups in the level of mindwandering reported in response to the probe questions (one of which occurred during each lecture segment). Notably, however, despite using a longer (40-minute) public health lecture they reported mindwandering rates of between 20-25%, which was considerably lower than what had been found by Szpunar et al. using statistics lectures (Szpunar et al., 2014, 2013). This raises the possibility that positive effects of interpolated testing on mindwandering may only apply to situations where baseline rates of mindwandering are relatively high (Schacter & Szpunar, 2015), or it may simply be due to a reduced mindwandering measure sensitivity at lower frequencies. Alternative experimental designs, such as repeated measures, within-subject designs, have not yet been reported in the interpolated testing literature, but may provide more sensitive measures which are able to answer such questions.

1.9.1.1 Mechanisms underlying the effects of interpolated testing

The mechanism (or mechanisms) underlying the reported relationships between interpolated testing and both learning and attention remain unclear, for example whether the attentional effects arise from the same source as the learning effects. Some of the effects of interpolated testing can be accounted for by theories of the general role of testing on learning. For example, the transfer appropriate processing (TAP) theory (Blaxton, 1989; Graf & Ryan, 1990; Morris, Bransford, & Franks, 1977) states that initial testing conditions will be more similar to final test conditions than will restudy (or no test) conditions. Therefore, an initial test induces a greater similarity with the type of processing that occurs at the final test, resulting in improved recall during the final test. Such theories make predictions that do not appear to invoke attentional mechanisms specifically. Of particular relevance to the role of attention, in contrast, are theories put forward to account for the forward benefits of testing on learning (some of which are more explicitly linked with attentional effects). Yang et al. (2018) list eight theories proposed to account for the forward testing effect on learning (see Figure 1.8).

Table 1. Theories proposed to account for the forward testing effect

Theories	References	Descriptions	Motivational?	Active phases
Release from PI	Szpunar et al.[13]	Interim testing induces context changes between blocks, which reduce the build-up of PI and facilitate recall of target (new) items	No	Retrieval
Encoding reset	Pastötter et al.[15]	Interim testing induces context changes between blocks, which "reset" subsequent encoding of new information and make it as effective as the encoding of prior information	No	Encoding
Activation facilitation	Wissman et al.[29]	Interim testing induces greater retention of tested information and makes the tested information more active while encoding new information, which helps encoding and comprehension of new information	No	Encoding
Encoding strategy	Cho et al.[24]	Interim testing induces more effective encoding strategies than no interim testing	No	Encoding
Retrieval strategy	Cho et al.[24]	More effective retrieval strategies are developed during prior interim tests, which facilitate recall of target (new) items in the subsequent interim test	No	Retrieval
Test expectancy	Weinstein et al.[14]	Interim testing induces a greater expectancy of an immediate interim test, which motivates more effort toward encoding new information	Yes	Encoding
Failure-encoding-effort	Cho et al.[24]	Retrieval failures in prior interim tests induce dissatisfaction and motivate more effort toward encoding new information	Yes	Encoding
Retrieval effort	Cho et al.[24]	Retrieval failures in prior interim tests motivate more effort to retrieve the target (new) items in the subsequent interim test	Yes	Retrieval

Figure 1.8. Theories proposed to account for the forward testing effect (reproduced from Yang et al., 2018)

Three of the theories described by Yang et al. involve a motivational component which is also likely to facilitate attentive processing (for example increased post-test effort devoted to encoding and retrieval, Cho, Neely, Crocco, & Vitrano, 2017; Neely & Cho, 2015; or increased expectancy of future tests, Weinstein, Gilmore, Szpunar, & McDermott, 2014), whereas the remaining five involve changes to either encoding or retrieval processes (e.g. Soderstrom & Bjork, 2014; Szpunar, McDermott, & Roediger, 2008; Tullis, Finley, & Benjamin, 2013; Wissman, Rawson, & Pyc, 2011), which are likely to be more independent of attentional allocations to future information.

Szpunar (2017) suggests that the shared positive effects of interpolated testing on both learning and attention may both result, at least in part, from enhanced attentive processing of new (post-test) material. However, direct evidence for this interpretation is missing, as no research has yet examined of the relationship between testing, learning and attention lapses in more specific detail. Currently, it is unclear how broadly the attentional effects of interpolated testing may be observed, given that previous research has concentrated almost entirely on mindwandering, rather than other measures of focused attention such as reduced irrelevant distraction from external stimuli. However, if a 'general facilitation of attentive processing' account (Szpunar, 2017) is accurate, then it might also be expected that interpolated testing would be associated with benefits for measures of focused attention beyond simply mindwandering reports. Testing this question was therefore the primary purpose of Chapter 5 in the present thesis.

In addition, some previous research has suggested that the effects on learning and those on attention may be separable. Jing et al. (2016) reported that an interpolated testing intervention which failed to lead to a reduction in mindwandering was still associated with improved performance on a final test. However, Jing et al. did not specifically test the relationship between testing, attention and learning. If interpolated testing supports new learning by facilitating attentive processing, then we might expect that the degree of facilitation in attention (indexed for example in the scale of reduction in mindwandering reports) would mediate the improvements seen in learning. The absence of this relationship would be suggestive of more independent mechanisms separately contributing to the effects on learning and those on attention.

1.10 **General methodology**

The primary aim of the present thesis was to examine in detail the relationships underlying experiences of distraction, mindwandering and mood in everyday environments (focusing in particular on adults and adolescents in educational settings), and the extent to which such experiences can be both predicted, and mitigated, using tools developed from laboratory research into cognition

1.10.1 Task-based measure of task-irrelevant distraction

The experimental tasks used were all modified versions of the irrelevant distractor paradigm, a visual search task first described by Forster & Lavie (2008a; b). Perceptual load was manipulated using a letter search task that required participants to search for an X or N in a circle of letters under either low (no target-similar items), or high load conditions (five target-similar items; Lavie & Cox, 1997). On 10% of trials, a visual distractor (an adult face with a neutral-expression) was also presented at fixation (see Figure 1.9). Individual differences in performance on the irrelevant distractor task were used to predict reports of distractibility in everyday educational settings, in both adolescents and adult samples (in experiments reported in Chapter 3).

Figure 1.9. Stimulus display for the modified irrelevant distractor task

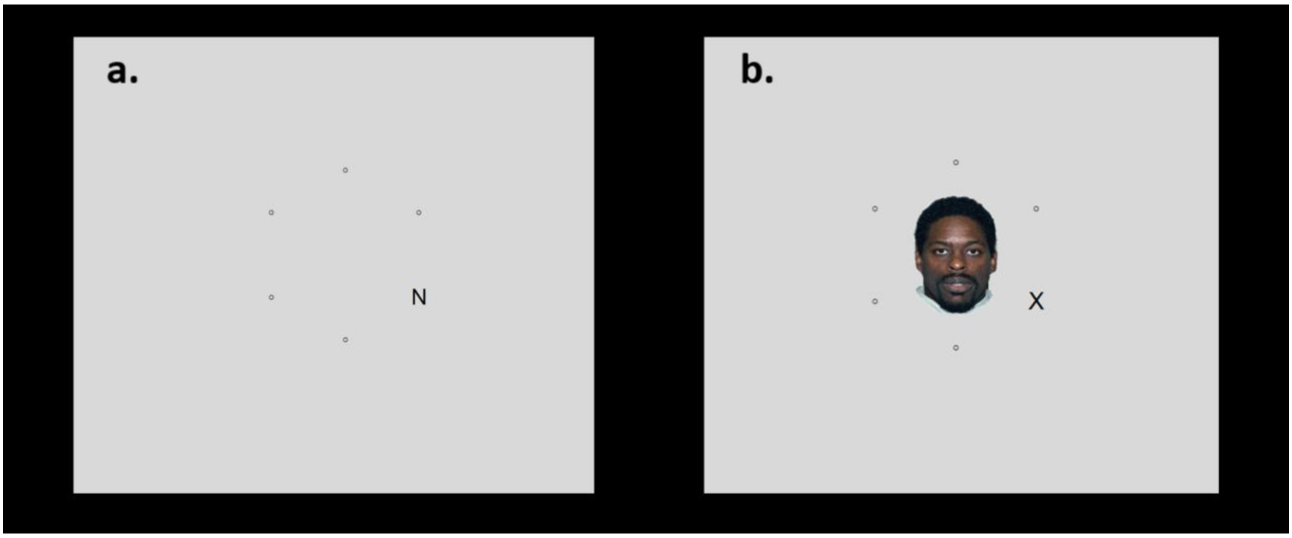

Figure 1.9. Stimulus display for the modified irrelevant distractor task illustrating distractor absent (a) and distractor present (b) conditions. Facial stimulus shown is reproduced in accordance with NimStim guidelines (Tottenham et al., 2009).

1.10.2 Establishing a measure of attention focus, and mood, in everyday environments

Initially, however, it was necessary to establish a novel measure of attention focus, which was able to investigate the relationship between task-irrelevant external distraction, mindwandering and mood in everyday environments. A number of recent studies have investigated the relationship between mindwandering and external distractions, both in laboratory conditions (Stawarczyk & D'Argembeau, 2016; Stawarczyk et al., 2014, 2012; Stawarczyk, Majerus, Maj, et al., 2011; Stawarczyk, Majerus, Maquet, et al., 2011; Unsworth & McMillan, 2014), in everyday life (Unsworth, Brewer, et al., 2012; Unsworth & McMillan, 2017; Unsworth, McMillan, et al., 2012) and in mixed settings (Forster & Lavie, 2014; Kane, Gross, et al., 2017; Kane, Smeekens, et al., 2017; McVay et al., 2009). Whilst reports from everyday settings have tended to suggest a close relationship between mindwandering and external distractions, studies have not examined the source of external distractions, so it remains unclear whether mindwandering is only associated with some types of external distraction but not others. In addition, while a good deal of previous research has associated rates of mindwandering with lowered mood (Franklin, Mrazek, et al., 2013; Kane, Gross, et al., 2017; Killingsworth & Gilbert, 2010), such a relationship has not been investigated in the case of attention lapses from external distractor stimuli. Therefore, I conducted real-time sampling of people's experience of the duration of mindwandering and irrelevant distractions (e.g. music, phone, etc.), and their happiness levels, in two studies with 524 people undertaking common daily-life activities (Chapter 2). The results help to clarify the underlying relationship between mindwandering and external distraction (from a range of sources), as well as the link to mood and developmental trends within these associations.

1.10.3 Adult and adolescent performance on task measures of irrelevant distraction

While the effects of perceptual load on visual attention in adult samples (e.g. Lavie, 2005; 2010; Lavie et al., 2015 for reviews) and to a lesser extent also in children (Huang-Pollock, Carr & Nigg, 2002; Remington, Cartwright-Finch & Lavie, 2014) are well-established, the effects on adolescent samples remain less widely researched (see section 1.6). Accordingly, adult (Study 3) and adolescent (Study 4) groups performed a modified version of the irrelevant distractor task (Forster & Lavie, 2008; see section 1.10 above). Performance was compared both in terms of well-established metrics of distractibility and load processing (the interference caused by the distractor presentation to response time and accuracy), but also in terms of the groups' response distributions and variability. On the basis of developmental differences in experimental performance between the groups, an additional study (Study 5) was conducted to rule out an alternative explanation for the effects found (an own-age bias for the facial stimuli biasing the attention capture effects).

1.10.4 Predicting experiences of distraction in educational settings

Chapter 4 assessed whether performance on a modified irrelevant distractor task could predict the duration of an individual's experiences of distraction in an educational setting. As reviewed earlier, while some previous research has used attention-related measures to predict instances of inattention in educational settings (Ko et al., 2017; Unsworth, McMillan, Brewer & Spillers, 2012), none have measured the interference from a task-irrelevant distractor specifically. Consequently, adults (Studies 6 and 8) and adolescents (Study 7) completed the irrelevant distractor task, and reported on the duration of their experiences of distraction from a variety of sources, during a recent educational experience: private study (Study 6), a classroom lesson (Study 7) and a lecture (Study 8).

1.10.5 Reducing distraction in educational environments

Finally, Chapter 5 considers the issue of the improvement, rather than prediction, of attention focus. I investigate the effect of interpolated testing on reports of mindwandering and external distraction. As described in section 1.8.1, interpolated testing has been associated with reductions in self-reports of mindwandering during learning (Szpunar, Khan & Schachter, 2013; Szpunar, Jing & Schacter, 2014; Jing, Szpunar & Schacter, 2016), however the effects on external distraction, and the structure of the link between attention lapses and effects on learning, is not yet clear. Using a novel counterbalanced interpolated testing design across two taught university seminars with 122 students, I therefore examine the within-subject effects of the manipulation on reports of mindwandering and external distraction. Participants completed two taught seminars, one featuring interpolated testing and one containing restudy periods, before a taking quiz on the seminar content and completing a distraction checklist at the end of each session.

Chapter 2

Attention, mindwandering and mood in everyday life

Introduction

As described in more detail in the General introduction (Section 1.3), the relationship between mindwandering and mood has been a topic of an expanding body of recent research. Within this, some have argued for a very close relationship between the two, for example that both reflect a common failure of attention focus, as long as the external distractors are entirely irrelevant to the task at hand (e.g. Forster & Lavie 2014). It has been previously reported, however, that measurements of the relationship between mindwandering and external distractions may be different in daily-life settings outside of the laboratory, compared to those taken in controlled environments (Kane, Gross et al., 2017; Hines & Shaw, 1993; Shaw & Giambra, 1993). Such environments are likely to present more sources of external distraction (and more potential triggers for mindwandering episodes) than those in the laboratory. It is therefore important to establish a measure of attention focus in a variety of real-world environments.

In the present Chapter, I therefore report two studies examining the relationship between irrelevant distraction and mindwandering through people's reports about daily life experience, predicting that they should be positively correlated, as would be expected if they both reflect a state of reduced attention focus. In addition, as a large study of mindwandering in daily life reported that mindwandering was linked to lower levels of happiness (Killingsworth & Gilbert, 2010) here I examine also whether this relationship replicates in a different setup, and whether it may also apply to external distraction. I predicted that if the relationship of mindwandering and happiness is driven by a state of reduced ability to maintain attention focus then irrelevant distractions should also be associated with reduced levels of happiness.

Study 1

Materials and method

Participants

Using opportunity sampling, I aimed to obtain data from a minimum of 390 participants (and no less than 50 in each city or town) in order to achieve sufficient power to detect small effect sizes at the level of single predictors, given the 13 study predictors in our planned regression analyses (see Harris, 2014). This resulted in a final sample of 459 unpaid participants (188 males) aged between 13-79 years (mean age = 31.7 years, *SD* = 15.53) that agreed to participate. No regression analysis was run prior to the end of data collection. The research was approved by the University College London research-ethics committee. Seventeen participants were discarded due to incomplete information.

Procedure

Participants were recruited from a variety of public locations in the UK cities and towns of London (central) (population size 1,525,000, average income £45,250), Birmingham (1,124,600, £23,344), Leicester (348,300, £20,956), Brighton (289,200, £21,788), Walsall (278,700, £19,500) and St Albans (146,300, £18,928) (Office for National Statistics, 2015; 2017). Population size and regional average income were considered because these have been shown to relate to levels of happiness (e.g. Diener, Sandvik, Seidlitz, & Diener, 1993;

Nguyen et al., 2016). In each location, sampling took place during daylight hours. Sampling occurred across all days of the week (including weekends). Participants were approached individually by an experimenter when engaging in a variety of everyday activities and contexts (including both outdoor and indoor), such as cafés, pubs, parks and gardens, shopping centers, streets, and transport hubs (e.g. train stations), and asked if they would consent to complete a survey on their current experiences. If they consented to participate in the study, they were then asked to complete a paper-based 'distraction checklist' designed to measure their recent experiences of distraction (see Appendix 1). In the case of participants who were seen to be engaging in a social activity with other people prior to the completion of the checklist, the experimenter ensured that peers could not view responses from the participant. Participants first reported how long they had been in the location in response to the question: '*How long have you been here (in minutes)?*' They then rated how often and for how long over this time period their attention was diverted away from their main focus to different task-irrelevant distractions, in response to the question '*Over this time, how often and for how long (in minutes) did you divert your attention from your main focus by attending to [distraction source]*'. The distraction sources were: 'your mobile phone (or tablet)', 'advertising', 'vehicles', 'construction noise', 'strangers', 'background music', 'animals', and 'unrelated thoughts (mindwandering)'. Following this, participants rated their current level of happiness on a scale of 1 (extremely unhappy) to 100 (extremely happy). Finally, respondents reported their age, gender, and current state of wellness (by responding '*yes*' or '*no*' to the question '*Are you currently well (health wise)?*').

To ensure that only attention diversions from the main focus of activity (as phrased in the checklist) were considered, I only analysed reports of distractions up to a maximum of 50% of their 'time here'. It was assumed, however, that distractions could be experienced in parallel (i.e. that more than one source of distraction could be experienced at the same time). As a result, values of the 'total distraction duration' experienced by a participant could exceed their 'time here' figure. Whilst participants provided reports on both the frequency and duration of distractions they were experiencing, 'duration' provided a more continuous measure and was also found to be much more internally consistent than 'frequency' (Cronbach's alpha = .735 vs .248), so duration measures alone were taken forward for subsequent analysis.

Results

Participants reported an average time of 36.2 minutes (SD = 47.6, mode = 30) of being engaged in their current activity at the sampling location. 23 participants (5% of the sample) reported feeling currently unwell. 315 (71% of the sample) reported being engaged in a social activity, together with friends, family or colleagues. The remainder of the sample reported being alone, whilst reading, shopping or walking, amongst other activities. Table 2.1 displays descriptive statistics for all variables of interest in the study. The most frequently reported distractions (strangers, mindwandering, mobile phones and background music) were all approximately normally distributed with values of skewness and kurtosis below widely accepted values (i.e. skewness < 3, kurtosis < 10; see e.g. Kline, 2014). Some of the more infrequently reported distraction sources showed a strongly positively skewed distribution, as might perhaps be expected from distraction sources which are rarer in general, but which might still cause significant disruption on occasions when they are present. Mean happiness (out of 100) was 75.1 (SD = 20.2, Range = 0-100), meaning that the sample reported slightly higher mean happiness than the UK average (UK mean in the World Happiness Report 2017 = 68.2, SD = 16.3; Helliwell, Layard, & Sachs, 2017).

Table 2.1. Descriptive statistics for all measures of interest: Study 1

	% reporting	Mean	St Dev	Skewness	Kurtosis
Age		31.82	15.37	0.96	-0.15
Happiness		74.97	20.31	-1.35	2.23
Mobile device	78	17.03	18.14	0.85	-0.76
Adverts	56	7.85	13.24	2.09	3.50
Vehicles	43	4.97	10.85	2.92	8.26
Strangers	86	15.60	17.27	1.04	-0.36
Background Music	55	10.85	16.33	1.51	0.93
Animals	22	2.87	8.56	4.10	17.71
Construction noise	31	3.67	9.74	3.37	11.47
Mindwandering	87	18.45	17.33	0.75	-0.82

Table 2.1. Happiness was measured on a scale of 0-100. All mean distraction figures are expressed as percentage duration of the total activity duration. '% reporting' represents the percentage of the sample who reported any level of distraction from the source.

The three most prevalent categories of reported distraction were mindwandering, mobile phones and strangers (I note however that the modal duration reported for each of the external distraction categories was 0% while for mindwandering it was 10% of the duration). In order to ensure that the experimenter did not introduce bias in the reporting of the 'stranger' category (since the experimenter could potentially be classified as a distraction from a stranger – indeed 4/442 of the sample noted this to the experimenters), all analyses reported below for Study 3 were repeated omitting the category of 'Strangers'. All significant relationships reported below remained significant when this category was omitted. Reports of mindwandering duration (18%) are broadly comparable, if in the lower regions, to estimates of mindwandering rates in previous studies from both the laboratory and everyday life (which have ranged between 10% and 50%; e.g. Kane et al., 2007; Killingsworth & Gilbert, 2010; Smallwood, McSpadden, & Schooler, 2008; Song & Wang, 2012; Szpunar et al., 2013).

Zero-order correlations

A correlation matrix for all variables of interest can be seen in Table 2.2. Significant negative correlations with age were found for all the distractor sources. This is consistent with previous research which has suggested that experiences of both distraction and mindwandering may be affected by age (e.g. Cohen et al., 2016; Maillet et al., 2018; Olesen et al., 2007; Stawarczyk et al., 2014). Age was therefore included as a control variable in all the follow-up regression analyses.

Table 2.2. Correlation matrix for all variables of interest: Study 1

	1	2	3	4	5	6	7	8	9	10	11	12
1. Age												
2. Wellness	.03											
3. Happiness	.02	**-.21****										
4. City size	**-.12***	-.08	.01									
5 City income	**-.20****	**-.10***	.03	**.24****								
6. Mobile phones	**-.23****	-.01	**-.14****	**.12****	.04							
7. Adverts	**-.14****	.04	-.08	.03	.04	**.24****						
8. Vehicles	**-.18****	.05	.03	-.04	-.01	**.22****	**.31****					
9. Strangers	**-.16****	.01	-.07	**.11***	**.20****	**.23****	**.34****	**.26****				
10. B'ground Music	**-.21****	.03	-.01	-.07	**.09***	**.27****	**.43****	**.34****	**.44****			
11. Animals	**-.12***	-.07	.08	.05	**.18****	**.16****	**.25****	**.27****	**.21****	**.29****		
12. Construction noise	**-.14****	.07	-.04	-.06	.02	**.24****	**.27****	**.49****	**.28****	**.37****	**.30****	
13. Mindwandering	**-.21****	-.02	**-.13****	.06	.09	**.29****	**.37****	**.27****	**.42****	**.30****	**.22****	**.22****

Table 2.2. Pearson Correlation Coefficients are shown. * p < .05, ** p < .01

In addition, the duration of distraction reported for the different sources were all significantly correlated. Notably, mindwandering duration was significantly positively correlated with each of our measured external distractions.

Underlying structure of mindwandering and external distraction

To further investigate the structure and relationship between our distraction measures, an exploratory factor analysis (EFA) was conducted. EFA using a principal-axis factor extraction was used to analyse the factor structure of the distraction sources. For interpretation of the factors (and given that we had already demonstrated that the factors were correlated with one another) an oblique (direct oblimin) rotation was used. The Keyser-Meyer-Olkin measure of sampling adequacy indicated that the sample was adequate (KMO = .831). Bartlett's test for sphericity was significant ($X^2(28) = 683.48$, $p < .001$) suggesting that there were sufficient inter-item correlations for EFA. Only one factor showed an Eigenvalue of greater than 1 and inspection of the scree plot (see Figure 2.1) revealed a clear inflexion after one factor. This factor accounted for 38.69% of the overall variance.

All sources of distraction, including mindwandering loaded significantly onto the first factor (see Table 2.3) and were not only above the critical significance value for a sample size of n = ~400 (0.26) but also above the 0.4 practical significance loading value (e.g. Stevens, 2012). The results of the factor analysis thus suggest that participant reports of both mindwandering and distraction from external sources are best explained by a single underlying construct as predicted from our 'state of reduced attention focus' hypothesis.

Table 2.3. Component loadings onto single factor	
Distraction source	**Loading**
Background Music	0.66
Adverts	0.58
Strangers	0.58
Construction noise	0.57
Vehicles	0.57
Mindwandering	0.54
Animals	0.44
Mobile device	0.42

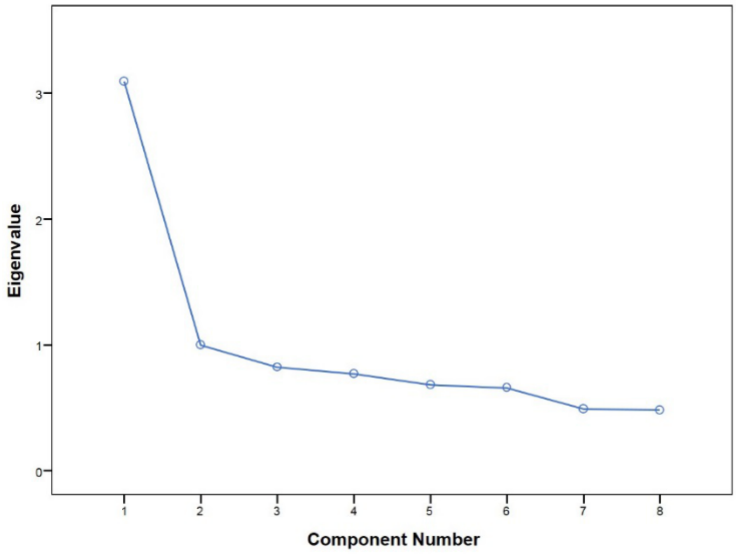

Table 2.3. EFA component loadings onto single factor: Study 1

Figure 2.1. Scree plot for EFA of distraction sources for Study 1 showing a single factor with an Eigenvalue of greater than 1 and a clear inflexion after one factor.

As I had only a single measure of mindwandering, compared to multiple measures of external distraction, it is possible that mindwandering was included in the distraction factor simply because there were no other mindwandering measures to pull it into a separate factor. In other words, rather than mindwandering and distraction genuinely reflecting one underlying factor (of attention failure) one could perhaps argue that this is just a result due to the structure of our data. On this alternative account a similar effect would be expected to occur in the case of any other single measure which correlated with all distractors. I therefore created a second EFA in which I also included age (another single measure variable which correlated with all distractors but was not expected to be part of the same latent factor as distraction). In this second EFA model age was not incorporated into a single factor. Instead, a two-factor solution was produced with age loading only weakly onto both factors (Factor 1: -.306; Factor 2: -.231), below the value for practical significance. Thus, the data was sensitive to reveal more than one factor even in the absence of multiple measures of the mindwandering variable, suggesting the alternative account is an unlikely explanation of these findings

Predicting mindwandering from external distraction

In addition, to assess whether mindwandering can be directly predicted from levels of external distraction when background variables are controlled, we conducted a hierarchical multiple regression (Table 2.4). Model 1 explained a significant portion of variance in mindwandering. Of the background variables in model 1 only age was a significant predictor of mindwandering: older respondents showed reduced rates of mindwandering, consistent with previous reports (e.g. Frank, Nara, Zavagnin, Touron, & Kane, 2015; Jackson & Balota, 2012; Krawietz, Tamplin, & Radvansky, 2012; McVay, Meier, Touron, & Kane, 2013). Happiness was included as a control variable in model 2, with external distractions in model 3.

Table 2.4 - Summary of the hierarchical regression analysis for variables predicting mindwandering: Study 1

	Model 1 - Background variables		Model 2 - Happiness		Model 3 - Irrelevant distractor variables	
	β	t	β	t	β	t
Wellness	0.01	0.21	-0.02	-0.34	-0.03	-0.67
Gender	0.02	0.36	0.02	0.31	-0.03	-0.64
Age	-0.20	-4.05***	-0.19	-3.99***	-0.09	-1.98*
City size	0.01	0.21	0.01	0.20	-0.01	-0.30
City income	0.04	0.88	0.05	0.95	-0.00	-0.06
Happiness			-0.12	-2.57*	-0.08	-1.92

	Model 1 - Background variables		Model 2 - Happiness		Model 3 - Irrelevant distractor variables	
	β	t	β	t	β	t
Mobile device					0.13	2.82**
Adverts					0.17	3.53***
Vehicles					0.09	1.84
Strangers					0.28	5.77***
Background music					0.01	0.18
Animals					0.06	1.34
Construction noise					0.01	0.14
	Adjusted R^2	F	Adjusted R^2	F	Adjusted R^2	F
Model Statistics	0.04	4.14**	0.05	6.58*	0.27	18.98**

Table 2.4. β = Beta, the standardised regression coefficient; Adjusted R^2 significance levels are for R^2 change F-tests. * $p < .05$ ** $p < .01$ *** $p < .001$

Model 3 explained a significant portion of variance in mindwandering and three distraction types significantly explained a unique source of variance in mindwandering: strangers, adverts and mobile phone use. Thus, mindwandering can be uniquely predicted from the level of external distractions, and this is not driven by any mediating background variables or level of happiness.

Given that our measure involved the retrospective reporting of attention lapses, it was important to establish that the results were not confined to any memory recall strategies or biases, which would be more likely to occur for participants reporting longer periods of time on their current activity. I therefore analysed correlations between mindwandering and external distraction in participants who reported having been in the sampling location and engaged in their current activity for 5 minutes or less (n = 45). These were all of comparable size or slightly lower than the full dataset (mobile devices r_s = .22; adverts r_s = .21; vehicles r_s = .27; strangers r_s = .24; background music r_s = .21; animals r_s = .14; construction r_s = .18). This suggests that the findings regarding the relationship between distraction and mindwandering apply to short durations (which should suffer less from any recall strategies and biases) as well as longer ones.

Age differences in distraction and mindwandering reports

Age was significantly negatively correlated with all distraction sources (see Table 2.2). Previous research into the effect of age on daily-life attention lapses has tended to compare younger and older adults (e.g. Frank et al., 2015; Jackson & Balota, 2012; Krawietz et al., 2012; Maillet et al., 2018; McVay et al., 2013). This raises the question as to whether age effects are applicable to younger people in general, or whether age effects are still present within younger age groups (e.g. when comparing distraction reports between adolescents and young adults). A further analysis was conducted to ascertain whether distraction reports differed between equal sub-samples of 'adolescents' (n = 105, age 13-19, mean age = 17.0) and 'young adults' (n = 105, age 22-29, mean age 25.2). Adolescents reported a greater mean distraction duration for every source of distraction (Table 2.5). This pattern is notable as it suggests that the correlations with age are unlikely to simply be driven by environmental differences or behaviour patterns in relation to certain distraction sources (such as increased usage of mobile phones by adolescents). A series of independent groups t-tests were conducted to compare mean distraction duration reports from each source, revealing that the adolescent group reported increased distraction levels which reached Bonferroni corrected significance in the case of mobile devices and background music. Mindwandering rates were not significantly higher among adolescents. This is consistent with previous laboratory findings that adolescents report more frequent external distractions, but not more mind-wandering, than young adults (Stawarczyk et al., 2014).

Table 2.5 Age differences in mean distraction reports from different sources between adolescent and young adult groups: Study 1

	Adolescents	Young Adults	t(208) =
Mobile device	23.4	16.2	**2.81****
Adverts	10.2	8.1	1.13
Vehicles	8.2	4.3	2.34*
Strangers	28.7	20.0	1.85
Background Music	18.3	9.8	**3.59*****
Animals	4.9	3.0	1.31
Construction noise	6.2	2.9	2.18*
Mindwandering	22.9	19.2	1.54

Table 2.5. Mean distraction figures are expressed as percentage duration of the total activity duration. t values represent independent t-test results * p < .05 ** p < .01 *** p < .001. Bold text = Bonferroni significance reached (8 comparisons, α = 0.006).

Distraction, mindwandering and mood

The zero order correlations showed that mindwandering was significantly negatively correlated with happiness (r_s = -.126, p = .008; see Table 2.2) in replication of Killingsworth and Gilbert's (2010) results. A novel finding was that distraction from mobile phones was also significantly negatively correlated with levels of happiness (r_s = -.138, p = .004; Table 2.2). No other individual distractors displayed significant correlations with happiness.

A hierarchical regression examined whether distraction levels could predict happiness when controlling for background variables known to be associated with happiness levels (age, gender, wellness, city size/population density, and regional average income) which were entered into model 1 of the regression model (see Table 2.6). Model 2 consisted of the proportional time distracted by the various environmental distractions listed in the checklist. Model 3 included the interaction terms between age, sampling location and wellness and the individual distractor sources. No interaction terms were significant, so they were omitted from Table 2.6, as well as subsequent analyses.

Table 2.6 - Summary of hierarchical regression analysis for variables predicting happiness: Study 1

	Model 1 - Background variables		**Model 2 - Distractor variables**	
	β	t	β	t
Wellness	-0.21	-4.47***	-0.20	-4.31***
Gender	-0.02	-0.45	-0.02	-0.37
Age	0.03	0.63	0.000	0.00
City size	-0.00	-0.06	0.02	0.42
City income	0.03	0.55	0.01	0.24

	Model 1 - Background variables		Model 2 - Distractor variables	
	β	t	β	t
Mobile device			-0.13	-2.50*
Adverts			-0.06	-1.00
Vehicles			0.09	1.55
Strangers			-0.01	-0.27
Background music			0.06	0.98
Animals			0.10	2.00*
Construction noise			-0.06	-1.11
Mindwandering			-0.11	-2.02*
	Adjusted R^2	**F**	**Adjusted R^2**	**F**
Model Statistics	0.04	4.24**	0.07	2.67**

Table 2.6. β = Beta, the standardised regression coefficient; Adjusted R^2 significance levels are for R^2 change F-tests. *p < .05 ** p < .01 *** p < .001

Model 1 explained a significant portion of variance in happiness ratings. Of the background variables, wellness was a significant predictor of happiness. No other background variable was found to be significantly associated with happiness. Model 2 explained a significant portion of variance in happiness ratings, demonstrating that distraction overall is correlated with happiness, after controlling for background variables. In Model 2, three distractions also explained a significant amount of unique variance in happiness: distraction from mobile devices, animals and mindwandering. As expected, mobile phone distraction and mindwandering both negatively predicted happiness ratings. In contrast, distraction by animals was unexpectedly correlated with higher happiness levels.

An analysis of participants engaged in their current activity for 5 minutes or less (n = 45) showed that zero order correlations between happiness and significant distraction and mindwandering sources were of comparable magnitude to the full dataset (mobile devices r_s = -.204; mindwandering r_s = -.117). This suggests that our findings regarding relationships to happiness apply to short durations (which should suffer less from any reduced time estimation ability) as well as longer ones.

2.2.6 Social engagement

Relatively few studies investigating attention states and mood in everyday life have investigated the effect of social engagement. In an experience sampling study, Kane, Gross, et al. (2017) found that mindwandering rates were unaffected by whether participants reported being alone or with others. However, it is not clear what such a finding might mean for the relationship to external distractions and to happiness. Killingsworth and Gilbert (2010), who assessed both mindwandering and happiness, did not report an analysis of the relationship as a function of social engagement. In our sample, 315 participants reported being engaged in a social activity, whereas the remainder (127) reported being alone. In both groups, mindwandering reports positively correlated with all external distractions (Table 2.7), however the magnitude of the correlations varied between groups, with lone participants reporting slightly weaker relationships between mindwandering and some external distractions (such as adverts, background music and construction noise) than those who reported engaging with others.

Table 2.7. Correlations for mindwandering with external distractors, split by social engagement

	Mobile device	Adverts	Vehicles	Strangers	B'ground Music	Animals	Construction
Alone	.28**	.26**	.30**	.45**	.16	.15	.07
Social engagement	.27**	.42**	.26**	.42**	.38**	.26**	.30**

Table 2.7. The Pearson Correlation Coefficient is shown. * $p < 0.05$ ** $p < 0.01$

I next compared distraction, mindwandering and happiness reports between participants who were alone when sampled and those who reported being engaged in a social activity. Lone participants reported being less happy (alone M = 70.67, social engagement M = 76.85, t(440) = -2.933, p = .002) and also more distracted by both mindwandering (alone M = 22.09, social engagement M = 16.56, t(440) = 3.076, p = .004; in contrast to Kane, Gross et al., 2017) and mobile phones (alone M = 22.52, social engagement M = 14.89, t(440) = 4.053, p < .001). No other distractions reached Bonferroni corrected significance (a =.006; all t < 1.3, all p > 0.15).

I performed the same hierarchical regression model to predict happiness as reported in Table 2.6, but with the addition in Model 2 of a 'social engagement' variable, which coded whether the participant was alone or engaged in a social activity. Distractor reports were moved to Model 3. The results can be seen in Table 2.8.

Table 2.8 - Summary of hierarchical regression analysis for variables predicting happiness including social engagement: Study 1

	Model 1 - Background variables		**Model 2 - Social engagement**		**Model 3 - Distractor variables**	
	B	t	β	t	β	t
Wellness	-0.21	-4.47***	-0.21	-4.40***	-0.20	-4.25***
Gender	-0.02	-0.45	-0.03	-0.69	-0.03	-0.54
Age	0.03	0.63	0.04	0.8	0.01	0.24
City size	-0.00	-0.06	0.00	0.04	0.02	0.41
City income	0.03	0.55	0.02	0.29	0.01	0.09
Social engagement			0.14	2.89**	0.09	1.92*
Mobile device					-0.11	-2.07*
Adverts					-0.05	-0.93
Vehicles					0.09	1.56
Strangers					-0.02	-0.27

Background music					0.05	0.89
Animals					0.10	1.90
Construction noise					-0.07	-1.29
Mindwandering					-0.10	-1.73
	Adjusted R^2	**F**	**Adjusted R^2**	**F**	**Adjusted R^2**	**F**
Model Statistics	0.04	4.24**	0.05	8.37**	0.07	2.08*

Table 2.8. β = Beta, the standardised regression coefficient; Adjusted R^2 significance levels are for R^2 change F-tests. *p < .05 ** p < .01 *** p < .001

Model 3 explained a significant portion of variance in happiness ratings, demonstrating that distraction overall is correlated with happiness, after additionally controlling for social engagement. Notably, however, controlling for social engagement led to mindwandering no longer predicting a significant proportion of unique variance in happiness ratings. Interestingly, there was a significant relationship between mindwandering and happiness in participants who were engaging with others (zero-order correlation R = -.121, p = .03), and no significant correlation between the two for those who were alone (R = -.084, p = .346).

Study 2

Study 2 was carried out to test the replicability of the results of Study 1, using the same method of data collection. I calculated the minimum sample size required to assess the three main findings, firstly, the relationship between mindwandering and external distractions, secondly the association between distraction and happiness, and thirdly the association between mobile phones and mindwandering and reduced happiness. Based on the effect sizes for our significant findings (smallest effect size mindwandering on happiness, Cohen's $f^2 = 1.235$) and the number of significant variables affecting results in each previous multiple regression, we calculated (using G*Power; Faul, Erdfelder, Buchner, & Lang, 2009) that 82 subjects would be sufficient to detect comparable effect sizes with a power level of 0.8. Whilst this number is smaller than the conventional sample size that might be expected for factor analysis or multiple regression, given the number of predictors, the focus on replicating only the three main findings allowed for a reduced sample size, in conjunction with the power analysis above. Given the smaller sample size I avoided sampling from the same wide age range sampled in Study 1 restricted the age of participants recruited to under 30 years old.

Participants

Using opportunity sampling, 82 participants (39 males) were recruited from a variety of locations within the central London area, in daylight hours across all days of the week (including weekends). The mean age was 16.8 (SD = 4.41, range 12-29).

Results

Participants reported an average time of 48.7 minutes (SD = 44.0, mode = 30) of being engaged in their current activity at the sampling location. 2 participants (3%) reported feeling currently unwell. 76 (92%) of the sample reported engaging in a social activity. Descriptive statistics for all variables of interest are shown in Table 2.9. Once again, the three most prevalent categories of reported distraction were strangers, mindwandering and mobile phones. Like in Study 1 the modal proportional duration reported for each of the external distraction categories was 0% while for mindwandering it considerably more (in this case 50% of the time).

Table 2.9. Descriptive statistics for all variables of interest: Study 2

	% reporting	Mean	St Dev	Skewness	Kurtosis
Happiness		74.3	19.99	-1.06	1.20
Mobile device	78	16.85	17.83	0.82	-0.76
Adverts	70	10.3	14.93	1.73	1.94
Vehicles	61	10.48	16.31	1.69	1.49
Strangers	88	17.48	16.90	0.91	-0.51
B'Ground Music	68	11.83	15.97	1.44	0.83
Animals	48	8.00	13.40	1.83	2.53
Construction noise	45	6.00	11.94	2.56	5.97
Mindwandering	87	19.75	17.55	0.65	-0.95

Table 2.9. Happiness was measured on a scale of 0-100. All mean distraction figures are expressed as percentage duration of the total activity duration. '% reporting' represents the percentage of the sample who reported any level of distraction from the source.

Zero-order correlations

A correlation matrix for all variables of interest can be seen in Table 2.10. There were no significant zero order correlations between age and distraction reports. This was likely due to the more restricted age range of the sample for Study 2. With one exception (construction noise vs. mobile phones, r_s = 0.185, p = .096) all distraction reports were significantly positively correlated with one another, as in Study 1. Happiness was significantly negatively correlated with both distraction from mobile phones and mindwandering, also replicating Study 1. In addition, distraction by adverts and background music was also significantly negatively correlated with happiness in this new sample. Unlike in Study 1, wellness was not significantly correlated with reduced happiness. However, only 2 of 82 participants in this new sample reported feeling unwell at the time of sampling, making it unlikely that such a relationship would be detected.

Table 2.10. Correlation matrix for all variables of interest: Study 2

	1	2	3	4	5	6	7	8	9	10
1. Age										
2. Wellness	.13									
3. Happiness	-.08	.08								
4. Mobile device	.07	.14	**-.31****							
5. Adverts	-.19	.02	**-.33****	**.36****						
6. Vehicles	-.14	.06	-.08	**.33****	**.28***					
7. B'ground Music	-.17	.05	**-.26***	**.47****	**.41****	**.50****				
8. Animals	-.06	.08	.06	**.31****	**.35****	**.44****	**.43****			
9. Strangers	-.05	-.00	.05	**.22***	**.42****	**.43****	**.54****	**.40****		
10. Construction noise	-.08	.12	.04	.19	**.37****	**.41****	**.49****	**.50****	**.48****	
11. Mindwandering	.10	.09	**-.32****	**.43****	**.59****	**.25***	**.43****	**.41****	**.43****	**.49****

Table 2.10. Pearson Correlation Coefficients are shown. * p < .05, ** p < .01

In the same manner as Study 1, EFA using a principal-axis factor extraction and a direct oblimin rotation was used to analyse the factor structure of the distraction sources. The Keyser-Meyer-Olkin measure of sampling adequacy indicated that the sample was adequate (KMO = .842). Bartlett's test for sphericity was significant ($X^2(28) = 217.458$, $p < .001$) suggesting that there were sufficient inter-item correlations for PCA. As in Study 1, only one factor showed an Eigenvalue of greater than 1 and inspection of the scree plot (see Figure 2.2) revealed a clear inflexion after one factor. This factor accounted for 48.25% of the overall variance. As in Study 1 all sources of distraction loaded significantly onto the first factor (see Table 2.11)

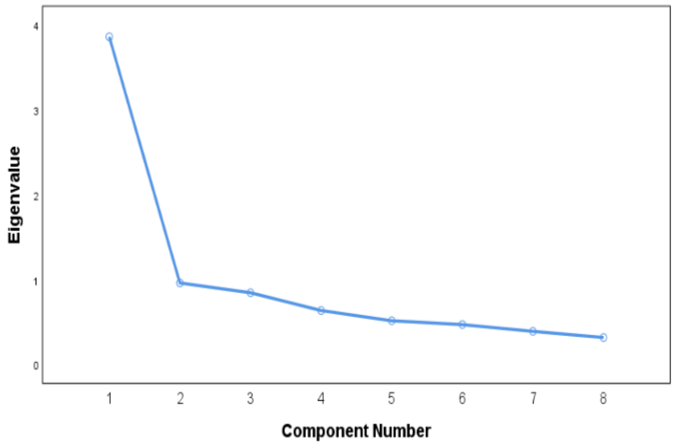

Table 2.11. Component loadings onto single factor in Study 2

Background Music	0.74
Mindwandering	0.68
Strangers	0.67
Construction noise	0.67
Animals	0.64
Adverts	0.62
Vehicles	0.59
Mobile device	0.51

Table 2.11. Component loadings onto single factor in Study 2

Figure 2.2. Scree plot for EFA of distraction sources for Study 2 showing a single factor with an Eigenvalue of greater than 1 and a clear inflexion after one factor.

Predicting mindwandering from external distraction

As in Study 1, a hierarchical multiple regression was conducted to predict mindwandering from levels of external distraction (Table 2.12). Background variables (model 1) did not explain a significant portion of variance in mindwandering (unlike in Study 1). Notably age, which was a significant predictor in Study 1, was insignificant in this model, showing that the decision to restrict the age range of participants had indeed reduced the variance attributable to this variable. Happiness was included as a control variable in model 2, with external distractions in model 3, as in Study 1. Model 3 explained a significant portion of variance in mindwandering and three distraction types significantly explained a unique source of variance in mindwandering: construction noise, adverts and mobile phone use. Thus, as in Study 1, mindwandering could be predicted from the level of external distractions. The results also replicated the finding that adverts and mobile phone distraction predicted significant unique levels of variance in the prediction of mindwandering levels, while finding that in this sample construction noise was also a predictive factor.

Table 2.12. Summary of the hierarchical regression analysis for variables predicting mindwandering: Study 2

	Model 1 - Background variables		**Model 2 - Happiness**		**Model 3 - Irrelevant external distractions**	
	B	t	β	t	β	t
Wellness	0.11	0.96	0.14	1.24	0.01	0.10
Gender	-0.16	-1.43	-0.16	-1.5	0.04	0.39
Age	0.13	1.14	0.10	0.88	0.15	1.63
Happiness			-0.29	-2.65*	-0.18	-1.90
Mobile device					2.13	2.05*
Adverts					0.26	2.36*
Vehicles					-0.09	-0.90
Strangers					0.07	0.62
Background music					0.02	0.14
Animals					0.15	1.33
Construction noise					0.32	2.88**
	Adjusted R^2	**F**	**Adjusted R^2**	**F**	**Adjusted R^2**	**F**
Model Statistics	0.01	1.22	0.08	7.03*	0.47	8.76***

Table 2.12. β = Beta, the standardised regression coefficient; Adjusted R^2 significance levels are for R^2 change F-tests. * p < .05 ** p < .01 *** p < .001

Predicting happiness from external distraction and mindwandering

As in Study 1, a hierarchical regression examined whether distraction levels could predict happiness when controlling for background variables (see Table 2.13).

Table 2.13 - Summary of hierarchical regression analysis for variables predicting happiness: Study 2

	Model 1 - Background variables		Model 2 - Distractor variables	
	β	t	β	t
Wellness	0.03	0.29	0.13	1.08
Gender	-0.08	-0.67	-0.09	-0.78
Age	-0.10	-0.85	-0.13	-1.17
Mobile phone			-0.01	-0.05
Adverts			-0.28	-2.07*
Vehicles			-0.06	-0.47
Strangers			0.23	1.63
Background music			-0.30	-1.93*
Animals			0.29	2.17*
Construction noise			0.25	1.80
Mindwandering			-0.31	-2.03*
	Adjusted R^2	**F**	**Adjusted R^2**	**F**
Model Statistics	-0.02	0.44	0.19	3.46**

Table 2.13. β = Beta, the standardised regression coefficient; Adjusted R^2 significance levels are for R^2 change F-tests. *p < .05 ** p < .01 *** p < .001

As can be seen in Table 2.13, Model 1 did not explain a significant portion of variance in happiness ratings and no individual variable was a significant predictor of happiness. Model 2 explained a significant portion of variance in happiness ratings, replicating the findings of Study 1 that distraction overall is correlated with happiness, after controlling for background variables. In Model 2, four distractions also explained a significant amount of unique variance in happiness. Adverts, background music and mindwandering negatively predicted happiness ratings. Distraction by animals was correlated with higher happiness levels (as in Study 1).

In summary, Study 2 was able to replicate most of the major findings of Study 1. Rates of mindwandering were again found to be closely related to rates of external distraction, and best explained as arising from a single underlying construct. Distraction rates in general significantly predicted happiness, and mindwandering specifically and uniquely predicted lowered mood. Distraction by mobile phones was significantly correlated to reduced happiness, although this relationship was not retained in the multiple regression. In addition, the unexpected association between distraction by animals and increased happiness was also replicated.

Chapter Summary

The findings of the present chapter demonstrated that, in two studies with 524 people undertaking common daily-life activities, all irrelevant external distractions were positively correlated with mindwandering. Indeed, mindwandering duration could be predicted from the duration of external distraction, when controlling for a range of background variables. An exploratory factor analysis of mindwandering and distraction reports suggested a single underlying construct. These results generalize previous research on similarities and differences between mindwandering and distraction beyond task-irrelevant distractions reported in controlled laboratory settings (e.g. Stawarczyk et al., 2014; Stawarczyk, Majerus, Maj, et al., 2011; Stawarczyk, Majerus, Maquet, et al., 2011), and beyond irrelevant distractions experienced during college (e.g. Unsworth, Brewer, et al., 2012; Unsworth, McMillan, et al., 2012), as well as across a wide range of ages. These findings are consistent with the hypothesis of a common underlying attention mechanism (see also Forster & Lavie, 2014; 2016), and supplement the 'Executive Failure' theory of mindwandering (McVay & Kane, 2010).

The findings also clarify that the relationship between mindwandering and external distractions persists in situations of engagement in social activities and, importantly, extends previous research that has typically measured the frequency of mindwandering and distraction reports to a new sampling method which addresses the relationship between the duration of mindwandering and distraction episodes, in further support of the hypothesis that an attention disengagement state should lead to longer durations of both types of attention failures.

In addition, duration of irrelevant distraction by mindwandering and some external distractions was significantly associated with reduced reported levels of happiness. These results replicate and extend Killingsworth & Gilbert's (2010) finding that mindwandering is associated with lower levels of happiness to a different sample, and a different experience sampling method (which allowed for the reporting of longer periods of distraction than previous research using traditional experience sampling). Importantly our results extend into the realm of external distraction, specifically to demonstrate that task-irrelevant distraction by a mobile phone and mood can be observed even in healthy mood ranges, extending previous findings from low mood states (c.f. Cornblatt et al., 1989; Gohier et al., 2009).

Interestingly, in an exception, distraction by 'animals' ("e.g. dogs and birds" were mentioned as examples in the question item) was associated with increased levels of happiness, though only when variables such as wellness were controlled for. Interaction with animals has been previously established to increase the sense of well-being (e.g. Souter & Miller, 2007), however such interactions were intentional, whereas here they were identified as task-irrelevant distractions. In both studies, however, animals did not display a zero-order correlation with happiness, and were also among the least reported of all distractions (2.85% of the duration reported in Study 1; mindwandering and mobile phones were reported around six times this amount; see Tables 2.1 and 2.9), and this may have contributed to the lack of negative impact. In other words, it is plausible that distraction by animals for a substantial duration of time would have reversed, or diminished, the relationship.

A final notable finding of the present chapter is that differences were found in the mean distraction duration reports between adolescent and young adult participants. Specifically, adolescents reported greater levels of distraction from mobile devices and background music during their everyday activities. While adolescence is known to be a period of rapid development in attention control, relatively little is known about the development of the ability to deal with task-irrelevant distraction during this period (see General Introduction, Section 1.6), and how this might translate into differences in everyday experiences compared to adults. It is also clear from the present results that measurement tools which might be employed to predict levels of task-irrelevant distraction in adolescent age groups may need to be sensitive to developmental differences between different groups. In the next chapter I therefore address the issue of performance differences between adolescents and adults on one task which has shown promise as a potential predictor of real-world distractibility, the irrelevant distractor task (Forster & Lavie, 2008a; b).

Chapter 3

Selective attention in adult and adolescent samples

Introduction

As reviewed in greater detail in the General Introduction (Section 1.6) it has been established that executive control functions differ between adolescents and adults in some reaction time (RT) tasks, whilst on other paradigms even younger adolescents achieve adult levels of performance. Adolescents have generally not been found to differ from adults in response related distraction (Huizinga et al., 2006; Ladouceur et al., 2007) whereas they have been shown to display impairments in the face of affective or motivationally relevant distractors (Cohen-Gilbert & Thomas, 2013; A. O. Cohen et al., 2016; Grose-Fifer et al., 2013; Roper et al., 2014). It is therefore unclear whether the effects on attention are due to motivation/emotion control, or the ability to control attention in the face of salient irrelevant distraction, such as those provided by affective or motivational stimuli. It is therefore important to distinguish between these effects with a test of task-irrelevant distraction, which has not previously been reported for adolescent participants. In addition, the results of Chapter 2 suggested that a common underlying attention mechanism might govern experiences of mindwandering and external distraction during everyday activities. Chapter 2 also found age related effects in the levels of distraction reported from different sources. Age was significantly negatively correlated with distraction duration reports from all sources. Adolescent age participants also reported experiencing significantly more distraction from two sources (background music and mobile devices) than did a comparison group of young adults. The primary aim of this chapter was therefore to examine whether there are also changes in the ability of adolescents to selectively control attention in the face of irrelevant distraction in experimental settings, in comparison to adults.

Secondly, the reduction of distractor interference by high perceptual load remains to be widely demonstrated in adolescents, in contrast to adults (e.g. Lavie, 2005; 2010; Lavie et al., 2015 for reviews) and children (Huang-Pollock, Carr & Nigg, 2002; Remington, Cartwright-Finch & Lavie, 2014). Couperus (2011) reported that the reduction of distractor processing under high load conditions did not appear to vary as a function of age in five groups of children between 7 and 18 years old and a group of young adults (mean age 24 years). However, Couperus did not use a standard load manipulation or a concurrent distractor stimulus (due to the constraints imposed by the ERP design), and therefore it remains unclear whether perceptual load can increase attention focus in adolescents.

A third aim of the chapter was to investigate intra-individual variability between typically developing adult and adolescent groups. A recent study using the 'gradual-onset continuous performance task' (gradCPT), a test of sustained attention based on the go/nogo paradigm, reported that reaction time variability (measured as the coefficient of variation – CV – the ratio of the RT standard deviation to the mean), decreased significantly year on year between age 10 and 16, before stabilizing and remaining constant into adulthood (Fortenbaugh et al., 2015). Based on these results, I predicted both that adolescents would display greater reaction time variability (CV) to adults on the irrelevant distractor paradigm, and also that younger adolescents (age 13 and 14) would display increased CV compared to older adolescents (age 16-17).

In addition to examining overall reaction time variability, however, I also aimed to examine the source of variability in greater detail by fitting trial-by-trial RT data to the ex-Gaussian distribution (Leth-Steensen et al., 2000). A comparison between typically developing adults and adolescents using this method has not thus far been reported. In other populations displaying elevated RT variability (such as ADHD sufferers; Leth-Steenson et al., 2000; Williams et al., 2007; Kofler et al., 2013), ex-Gaussian methods have shown that increased variability can result at least partially from an increase in the number of exponentially slow responses (a larger tau). As a result, I hypothesized that adolescents would display a larger tau value than adults.

In the present chapter I report three experiments performed using an adapted version of the irrelevant distractor paradigm (Forster & Lavie, 2008a; b). In this paradigm, participants perform a letter search task within a central circular array with six positions. On a minority of trials a highly salient, but entirely task-irrelevant distractor stimulus (brightly coloured cartoon characters) were presented peripherally (see General Introduction, Section 1.2.1.2). Distractor effects in this task have previously been found to be modulated by perceptual load, with a significant reduction in the effect of the distractor in high load (Forster & Lavie, 2008a; b). However, the cartoon stimuli used in the original version of the irrelevant distractor paradigm may be subject to variability in participants' familiarity with the characters, especially when comparing adult and adolescent groups, in which adolescents may be expected to be more familiar with cartoon images. Behavioral studies have shown that visual search performance can be strongly affected by the level of familiarity with either target and/or distracter objects (Malinowski & Hübner, 2001; Mruczek & Sheinberg, 2005; Wang et al., 1994). Indeed, it has been suggested that load modulation of distraction may be reduced for stimuli with which we have high levels of personal familiarity (He & Chen, 2010; Lin & Yeh, 2014). Thus, adolescents might show increased attentional capture and decreased load modulation in response to stimuli with which they are very familiar, introducing confounds into any developmental comparison. However, given that semantically meaningful distractors seem to produce stronger attentional capture effects (Forster & Lavie, 2008a), it was important to use meaningful stimuli as the irrelevant distractors. One potential candidate for such a stimulus is faces. Faces are salient stimuli (Jenkins et al., 2003; Lavie et al., 2003), due to their high level of sociobiological importance (De Renzi, 2000). As discussed in greater detail in the General Introduction (Section 1.7), faces have been suggested to be a 'special' class of distractor, the processing of which may be mandatory and not be subject to modulation by perceptual load. However, in paradigms which have used anonymous faces, which could be clearly perceived (e.g. Jenkins, Lavie, & Driver, 2005), perceptual load has been found to modulate face processing. I thus employed anonymous faces as distractor stimuli, hypothesising that they would be significantly modulated by perceptual load, in keeping with findings from other task-irrelevant distractor stimuli (Forster & Lavie, 2008a, 2008b, 2011, 2014, 2016).

In Study 3, adult participants completed an adapted version of the irrelevant distractor paradigm (Forster & Lavie, 2008a; b). I replaced the original cartoon images with neutral face distractors. As well as providing an adult baseline of performance against which adolescents could subsequently be compared, Study 3 also allowed me to confirm that this adapted paradigm functioned as a valid measure of irrelevant distraction, in accordance with the predictions of load theory, and previous research using the irrelevant distractor paradigm (Forster & Lavie, 2008b; Forster et al., 2014). Study 4 replicated Study 3 using an adolescent sample (ages 13-17). A combined analysis of both sets of results is then reported, comparing adolescent and adult performance. Subsequently, Study 5 examined a potential alternative explanation for a developmental difference identified in the results relating to the distractor stimuli used.

Finally, should be noted that there is a great deal of variation in the ages of groups labelled 'adolescent' in the research literature (see e.g. van Duijvenvoorde, Peters, Braams, & Crone, 2016). Whilst the precise delineations of the period remain contentious, the ages of 13-17 seem generally accepted as sitting within the adolescent period (e.g. van Duijvenvoorde et al., 2016, fig. 4). My focus in this chapter was on testing the effect of perceptual load on distractor interference in the adolescence period specifically, as opposed to in children (e.g. Huang-Pollock, Carr & Nigg, 2002; Remington, Cartwright-Finch & Lavie, 2014) in which these effects have already been more widely demonstrated. Participants who were aged 13 and over were therefore selected for an 'adolescent' group.

Study 3

Method

Participants

66 adults (25 M, 41 F, age 18-62, mean age 26.05) participated in the study, in return for payment. Participants were selected from the University College London subject pool and tested at on site at UCL. The research was approved by the University College London research-ethics committee. The sample was powered to detect small effect sizes ($f^2 = 0.15$) with 90% power in a subsequent regression analysis (see Study 6).

Stimuli and Procedure

Testing was performed on a Dell Latitude E5550 laptop computer, with a 15.4" monitor (1280x800 pixels), which presented stimuli and recorded responses. The experiment was controlled using MATLAB (Mathworks, Inc.) and the Cogent Toolbox (http://www.vislab.ucl.ac.uk/cogent.php).

Visual Search Task

Participants completed a visual search task adapted from Forster and Lavie (2008b). Participants discriminated whether a target X or N was presented in one of six positions around a circular array, by pressing designated computer keys. In the 'low load' condition, the five non-target positions were occupied by lower-case 'o's. In the 'high load' condition, non-target positions were occupied by five different angular letters from a list of ten (H, K, M, W, T, V, L, Z, F, E). At a viewing distance of 60 cm, the distance from the fixation cross to letters in array was 4.5° of visual angle. All letters were presented in a black font against a light grey background. Target and non-target letters subtended 0.8° of visual angle horizontally and 1° vertically. Each letter was separated by 4.3° dva. Target position and target letter were fully counterbalanced. In 10% of trials, an irrelevant distractor was also presented at fixation (see Figure 1.9). The distractor images were neutral faces from the NimStim set of facial expressions (Tottenham et al., 2009). Faces were counterbalanced across load conditions and gender, with a distractor face appearing once in each condition and an equal number of male and female faces used in each block. A minimum 1° dva was maintained between edges of face and letters.

Each trial began with a fixation cross presented in the center of the screen for 1,000ms. The circular letter array and (in 10% of trials) the distractor were then presented for 200ms. Participants were asked to respond as quickly as possible by pressing the 0 key on the numeric keypad for an X target, and the 2 key for an N target. They were also instructed to ignore the distractor image, if present. A new trial was initiated following a participant's response, or after 3 seconds if they failed to respond. Feedback was given in the form of a computer beep for incorrect responses or failures to respond within 3s. Participants alternated between blocks with high perceptual load and blocks with low perceptual load. Half of the participants began with a low-load block, and half began with a high-load block. Participants received two practice blocks (one high and one low load) of 9 trials, and eight experimental blocks of 60 trials. Each block was preceded by three 'warm-up' trials which were always no-distractor trials. Practice and warm-up trials were excluded from the analysis. Participants scoring 50% accuracy or below in any experimental condition (i.e. those at chance levels of performance) were excluded from subsequent analysis (n = 1), leaving a final sample of 65 (18-62, mean age 25.85).

Results

In all results that follow, I present the effect sizes for each repeated measure and mixed model analysis of variance (ANOVA) as the partial eta squared (η^2_p) and for post-hoc between groups comparisons as the Cohen's *d* (*d*).

Reaction Times

Experimental data for reaction times (RTs) is presented in Table 3.1

Table 3.1. Study 3: RT results

	P	P-A	A
Low	631 (97)	72 (48)	559 (76)
High	892 (172)	51 (83)	841 (138)

Table 3.1. Mean RT (ms) with SDs in brackets as a function of distractor condition (P = distractor present, A = distractor absent, P-A = distractor cost), load level

An ANOVA on was conducted on RT data. Load (low/high) and distractor presence (absent/present) were entered as the within-subjects factors. The ANOVA revealed main effects for load, $F(1,64) = 295.941$, $p < .001$, $\eta^2_p = .822$ with slower reaction times in high load (M = 866, SE = 19) than in low load (M = 595, SE = 10), and distractor presence,

$F(1,64) = 79.276$, $p < .001$, $\eta^2p = .553$ with slower reaction times in the presence of a distractor ($M = 762$, $SE = 15$) than when a distractor was absent ($M = 700$, $SE = 12$). Importantly, the ANOVA also revealed a significant interaction between load and distractor, $F(1,64) = 4.689$, $p = .03$, $\eta^2p = .068$ demonstrating that the effect of a distractor on reaction time was modulated by the load condition. Specifically, distractor effects were reduced in the high load condition (mean % effect = 5.9, SD = 9) compared to low load (mean % effect = 12.9, SD = 9), in accordance with the predications of load theory. Thus this modified task replicated previous research using the irrelevant distractor paradigm (Forster & Lavie, 2008b; Forster et al., 2014), demonstrating that the load modulation of irrelevant distraction can be replicated using irrelevant distractor faces presented at fixation (rather than cartoons presented eccentrically).

Errors

As expected given the emphasis on accuracy, there were a relatively small number of error trials on average. Error rates for participants are displayed in Table 3.2.

Table 3.2. Study 3: Error results

	A	P-A	P
Low Load	6	1	7
High Load	18	5	23

Table 3.2. Error rates are displayed as percentages as a function of distractor condition (P = distractor present, A = distractor absent, P-A = distractor cost)

A 2x2 ANOVA on error rates was conducted. Load (low/high) and distractor presence (absent/present) were entered as the within-subjects factors. The ANOVA revealed main effects for load, $F(1,64) = 124.240$, $p < .001$, $\eta^2_p = .660$ with more errors in high load (M =

20%, SE = 1) than in low load (M = 6%, SE = 1), and distractor presence, $F(1,64) = 16.755$, $p < .001$, $\eta^2_p = .207$ with more errors for distractor present trials (M = 15%, SE = 1) than distractor absent trials (M = 12%, SE = 1). A significant interaction between load and distractor presence was also revealed, $F(1,64) = 7.626$, $p = .007$, $\eta^2_p = .106$ revealing a larger distractor effect on errors in high load (5%) than low load (1%), the reverse of the reaction time. However, I note that this small effect (a 4% increase in errors), amounts to equivalent of one more error trial in high load (as there were only 24 distractor present trials per participant).

Thus, the results from the irrelevant distractor paradigm showed that adults displayed a significant load modulation of distractor effects on mean RTs, with reduced distractor effects under conditions of high perceptual load. In doing so, they conform to the predictions of perceptual load theory (Lavie, 1995) and demonstrate that the modified paradigm employed in this experiment (with distractor faces presented at fixation) replicate the results of other adult cohorts using versions of this paradigm (e.g. Forster and Lavie, 2008a; 2008b; Forster et al., 2014).

Study 4

Following the finding that the adapted irrelevant distractor paradigm could replicate previous results, Study 4 examined the performance of adolescent participants. No previous studies have examined task-irrelevant distraction by socially relevant stimuli (such as faces) in adolescents, although pictures of calm or neutral faces have been as controls when assessing interference by affective stimuli, in response to which adolescents have been reported to display greater impairments than adults (Cohen-Gilbert & Thomas, 2013; Grose-Fifer et al., 2013; Roper et al., 2014; Schel & Crone, 2013; Somerville, Hare, & Casey, 2011). However, even pictures of neutral faces can convey affective information (Suess, Rabovsky, & Rahman, 2013), thus I therefore hypothesized that adolescents would show a greater distractor cost in the irrelevant distractor task in comparison to their adult counterparts.

Method

Participants

143 adolescents (79 M, 64 F, age 13-17, mean age 14.64) participated in the study. This represented the largest sample that could be collected in the time available at the testing location. Informed parental consent was obtained for all participants. The research was approved by the University College London research-ethics committee.

Stimuli and Procedure

Participants were tested at their school, in comparable conditions to university testing rooms (a darkened side room to an unused classroom), providing a visual and auditory environment that aimed to recreate laboratory testing conditions as closely as possible. Other than this, all other apparatus and the visual search task procedure were identical to Study 3.

Participants scoring 50% accuracy or below in any experimental condition (i.e. those at chance levels of performance) were excluded from subsequent analysis (n = 8), as were those with reaction times more than 3 standard deviations from the mean (n = 1) leaving a final sample of 134 (13-17, mean age 14.66). The exclusions were spread across the ages (13yrs = 2, 14yrs = 3, 15yrs = 3, 16-17yrs = 1).

Results

For each experimental variable, mixed model analyses of variance (ANOVA) were used to examine whether age-related differences were evident within the adolescent population, or whether the group could be combined into a single 'adolescent' age category, for subsequent comparison to adult data (see 'comparison analysis' section below). In cases where this was not the case, further analysis determined whether developmental trends were detectable, and whether a coherent 'adolescent' group might be formed from a sub-set of the ages tested.

This approach is consistent with much previous research also showing that adolescence forms a developmental period distinct from adulthood with respect to a variety of cognitive factors (e.g. Defoe, Dubas, Figner, & van Aken, 2015; Ladouceur et al., 2007, see Casey, Jones, & Somerville, 2011; Fuhrmann, Knoll, & Blakemore, 2015 for reviews), but that the specific periods involved may vary for different cognitive skills.

Reaction Times

Table 3.3. Study 4: RT results

Load Level	**Age 13 (n = 31)**			**Age 14 (n = 41)**			**Age 15 (n = 30)**			**Age 16-17 (n = 32)**		
	P	P-A	A	P	P-A	A	P	P-A	A	P	P-A	A
Low	614 (81)	45	569 (77)	635 (86)	50	584 (70)	630 (86)	55	576 (73)	638 (99)	48	590 (82)
High	864 (162)	35	830 (122)	868 (167)	51	816 (156)	848 (159)	51	797 (126)	904 (171)	63	841 (128)

Table 3.3. Mean RT (ms) with SDs in brackets as a function of distractor condition (P = distractor present, A = distractor absent, P-A = distractor cost), load level and age

The mean RTs for the adolescent age groups (Table 3.3) were analysed in a mixed ANOVA with load (low/high) and distractor presence (absent/present) as the within-subjects factors and age (13, 14, 15 and 16-17) as the between subjects factor. The ANOVA revealed main effects for load, $F(1,130) = 574.589$, $p < .001$, $\eta^2_p = .815$ with slower reaction times in high load (M = 845, SE = 12) than in low load (M = 605, SE = 7), and distractor presence, $F(1,130) = 103.765$, $p < .001$, $\eta^2_p = .444$ with slower reaction times in the presence of a distractor (M = 750, SE = 10) than when the distractor was absent (M = 700, SE = 8), as predicted. However, there was no interaction between load and distractor presence in the adolescent data (F < 1). There was no main effect of age, no two-way interactions between any experimental variable and age, and no three-way interaction between age, load and distractor presence (all F < 1). This suggested that, in the case of experimental RT data, all adolescent age groups could be combined into a single 'adolescent' age category.

Errors

Table 3.4. Study 4: Error results

Error (%)	Age 13 (n = 31)			Age 14 (n = 41)			Age 15 (n = 30)			Age 16-17 (n = 32)		
	A	P-A	P	A	P-A	P	A	P-A	P	A	P-A	P
Low Load	12	0	12	11	1	12	13	0	12	7	2	9
High Load	25	2	27	25	6	31	28	0	28	19	5	24
Mean error rate	19			20			20			15		

Table 3.4. Error rates are displayed as percentages as a function of distractor condition (P = distractor present, A = distractor absent, P-A = distractor cost) and age

Adolescent error rates (see Table 3.4) were analysed in a mixed model ANOVA with load (low/high) and distractor presence (absent/present) as the within-subjects factors and age (13, 14, 15 and 16-17) as the between subjects factor. The ANOVA revealed main effects for load, $F(1,130) = 258.316$, $p < .001$, $\eta^2_p = .666$ with more errors in high load (M = 26%, SE = 1) than in low load (M = 11%, SE = 1), and distractor presence, $F(1,130) = 8.868$, $p = .003$, $\eta^2_p = .072$ with more errors for distractor present trials (M = 19%, SE = 1) than for distractor absent trials (M = 18%, SE = 1). The load*distractor presence interaction was marginally significant, $F(1,130) = 3.724$, $p = .056$, $\eta^2_p = .028$ with a trend towards a larger distractor effect in high load than in low load, in line with the data from Study 3 (low load distractor absent error rate = 10.7%, distractor present = 11.2%; high load distractor absent error rate = 24.4%, high load 27.5%). However, once again this appears to reflect a small increase in errors (a 2.5% increase in errors), equivalent to a difference of less than one error trial in high load. There was also a main effect of age, $F(3,130) = 3.040$, $p = .031$, $\eta^2_p = .066$. As can be seen in Table 3.4, this effect reflects a reduced error rate in ages 16-17, compared to the younger age groups. Post-hoc comparisons showed that the age 16-17 group produced significantly fewer errors (Bonferroni corrected significance with 6 contrasts per condition, $\alpha = .008$) than the other three ages (vs age 13, $t(59) = -2.878$, $p = .006$, $d = 0.78$; vs age 14, $t(68) = -2.956$, $p = .004$, $d = 0.66$; vs age 15, $t(65) = -3.241$, $p = .002$, $d = 0.84$). No other comparisons reached corrected or uncorrected significance. No two- or three-way interactions with age were significant (although the distractor*age interaction trended towards significance, $F(3,130) = 2.664$, $p = .051$, reflecting a larger distractor effect on errors at ages 14 (3.5%) and 16-17 (3.3%) than at ages 13 (0.7%) and 15 (-0.4%); for all other interactions $F < 1$). Therefore, in the case of error rates, it seems that two separate age groups appear in the present results: a 'younger adolescent' group (ages 13, 14 and 15) and an 'older adolescent' group (ages 16-17). Thus, these two groups were taken forward separately for subsequent comparison to adult results.

Response variability

The coefficient of variation (CV; CV = SDRT/MRT) was calculated for distractor absent trials in each load level, in order to produce a measure of intra-individual variability which was independent of variations in mean RT. Distractor absent trials only were selected as a measure of variability as these formed the majority (90%) of the trial sample, so provided a more reliable measure of inter-trial variability. In addition, I wanted to examine variability in a manner that was not affected by the distractor, and which did not overlap with measures of any distractor effect.

Table 3.5. Study 4: Coefficient of variation (CV) results

	Age 13 (n = 31)	Age 14 (n = 41)	Age 15 (n = 30)	Age 16-17 (n = 32)
Low Load	0.28	0.30	0.29	0.26
High Load	0.33	0.34	0.35	0.29
Mean CV	0.31	0.32	0.32	0.28

Table 3.5. CV as a function of load level and age, for distractor absent trials only

Adolescent CV values (Table 3.5) were analysed in a mixed model ANOVA with load (low/high) as a within-subjects factor and age (13, 14, 15 and 16-17) as the between subjects factor. There was a main effect of load, $F(1,130) = 32.509$, $p < .001$, $\eta^2_p = .200$, with greater variability in high load trials ($M = 0.33$, $SE = 0.7$) than in low load ($M = 0.28$, $SE = 0.7$). In addition, there was a main effect of age, $F(3,130) = 4.004$, $p = .009$, $\eta^2_p = .074$, as can be seen in Table 3.5, this effect was primarily attributable to reduced variability in the age 16-17 group compared to other age groups. Bonferroni corrected significance (6 contrasts per condition, $\alpha = .008$) was reached when comparing age 16-17 with both age 15, $t(60) = 2.688$, $p = .008$, $d = 0.61$ and with age 14, $t(71) = 2.708$, $p = .008$, $d = 0.68$. No other comparisons reached corrected significance. Thus, these results appear to replicate the findings of Fortenbaugh et al. (2015) in showing a reduction in response variability across adolescence (seen here in comparing the 16-17 age group to younger adolescents). There was not a significant interaction between age and load ($F < 1$). Therefore, in the case of response variability (and in the same pattern as was revealed with error rates) it seems that two separate age groups appear in the present results: a 'younger adolescent' group (ages 13, 14 and 15) and an 'older adolescent' group (ages 16-17). Thus, these two groups were taken forward separately for subsequent comparison to adult results (see 'comparative analysis' section).

RT distribution analysis

The above results found no developmental trend in mean RTs between the different adolescent age groups but did reveal a trajectory in the development of response variability, with ages 16-17 demonstrating reduced variability in comparison to younger adolescents. This raises questions about the source of the increased variability in the younger age groups. As described in the General introduction (section 1.6.1), increased response variability may result from a simple increase in the standard deviation of all response times, but may also be produced in cases where a subset of responses are abnormally slow. Further clarity can be obtained by subjecting each participant's response distribution curve to an ex-Gaussian analysis. As described in the General introduction (section 1.6.1) ex-Gaussian methods identify three variables: mu (μ), the mean, and sigma (σ), the standard deviation of the 'normal' section of the RT distribution, and tau (τ), the exponential component of the RT distribution. As there were not enough distractor present trials with which to construct reliable RT distributions for each individual, mu, sigma and tau values were only calculated for distractor absent trials. Results are presented in Table 3.6.

Table 3.6. Study 4: response distribution characteristics

	Age 13 (n = 31)	**Age 14 (n = 41)**	**Age 15 (n = 30)**	**Age 16-17 (n = 32)**
μ - Low Load (ms; σ in brackets)	446 (81)	443 (73)	448 (79)	463 (72)
μ - High Load (ms; σ in brackets)	613 (146)	577 (136)	585 (155)	628 (108)
τ - Low Load	124	141	128	127
τ - High Load	216	239	212	214

Table 3.6: Mu (μ) and Sigma (σ) and Tau (τ) as a function of load level and age for adolescent participants in distractor absent trials

Mu

A mixed model ANOVA was conducted on the adolescent mu values. Load level (low/high) was entered as a within subjects factor and age (13, 14, 15 and 16-17) was entered as a between subjects factor. The ANOVA revealed a main effect of load, $F(1,130) = 271.763$, $p < .001$, $\eta^2_p = .676$ with slower responses in high load (M = 599, SD = 122) compared to low load (M = 450, SD = 61). There was no main effect of age, $F(3,130) = 1.255$, $p = .29$ (as expected given the lack of a main effect of age on overall RTs) and no interaction between age and load ($F < 1$). This suggested that, in the case of mu, all adolescent age groups could be combined into a single ‘adolescent’ age category, for subsequent comparison to adults.

Sigma

A mixed model ANOVA was conducted on the adolescent sigma values. Load level (low/high) was entered as a within subjects factor and age (13, 14, 15 and 16-17) was entered as a between subjects factor. The ANOVA revealed a main effect of load, $F(1,130) = 131.467$, $p < .001$, $\eta^2_p = .503$ with larger sigma scores in high load (M = 135, SD = 64) than in low load (M = 78, SD = 26). There was also a main effect of age, $F(3,130) = 3.336$, $p = .022$, $\eta^2_p = .071$. Post-hoc comparisons showed that Bonferroni corrected significance (6 contrasts per condition, $\alpha = .008$) was reached when comparing age 16-17 (M = 90) with age 15 (M = 117) $t(60) = 3.020$, $p = .004$, $d = 0.75$, but in no other comparisons (age 13 M = 106, age 14 M = 113). There was no significant interaction between load and age, $F(1,130) = 2.503$, $p = .062$. Although the pattern was similar to previously, given that the comparison did not reach a corrected level of significance when comparing older adolescents to either age 14 or 13, I decided to combine all the age groups into a single ‘adolescent’ age category for further comparison to adults.

Tau

A mixed model ANOVA was conducted on the adolescent sigma values. Load level (low/high) was entered as a within subjects factor and age (13, 14, 15 and 16-17) was entered as a between subjects factor. The ANOVA revealed a main effect of load, $F(1,130) = 161.294$, $p < .001$, $\eta^2_p = .554$ with larger tau scores in high load (M = 222, SD = 86) than in low load (M = 131, SD = 54). There was no main effect of age, $F(3,130) = 1.054$, $p = .371$ and no interaction between load and age ($F < 1$). This suggested that, in the case of tau, all adolescent age groups could be combined into a single ‘adolescent’ age category, for subsequent comparison to adults.

Thus, the results of the response distribution analysis help to clarify the source of the development in response variability measured using CV. The development in response variability across the adolescent age groups samples appears to primarily consist of a reduction in sigma (representing a reduction in variability within the normal portion of the response distribution), rather than a reduction in tau.

Discussion

The results of the adolescent participants on the irrelevant distractor paradigm showed that, in contrast to Study 3, adolescents did not display a significant load modulation of distractor effects on mean RTs. This result was found consistently across the ages in our cohort (13-17), with no main effect of age or interactions with age for adolescent RTs. This result was unexpected, and contrasts with both our predictions and with the only other investigation into impacts of perceptual load in adolescents (Couperus, 2011), who found that a that the reduction of distractor processing under high load conditions did not vary as a function of age from childhood, through adolescence and into adulthood. I address one potential account for this finding in the 'Study 3-4 comparative analysis' section below, and another in Study 5.

There were no age effects in the RT data, and specifically no indication of increased distraction. However developmental trajectories were detectable in the analysis of both error rates and response variability (CV). With respect to error rates, 13-15 year olds formed a distinct group who made more errors than 16-17 year olds across all experimental conditions. A similar pattern was observed in CV scores: 13-15 year olds formed a distinct group which demonstrated higher response variability to the 16-17 year olds. Response distribution analysis did not show a clear developmental progression. Mu and Tau values did not display any main effects of age or interactions with age. A main effect of age was present for Sigma values, but this was attributable only to a difference between ages 15 and 16-17, with no differences between any other age comparisons.

Studies 3-4: Adults and Adolescents comparison analyses

The results of Studies 3 and 4 appear to demonstrate that different developmental trajectories can be detected for different experimental measures of performance on the irrelevant distractor test. However, this process of development can be further clarified by specifically comparing adult and adolescent performance. In the following section, therefore, I undertook a combined analysis of the datasets from Studies 3 and 4.

Reaction times

Adult RT data was compared with a single adolescent group, in line with the lack of age effects demonstrated in the adolescent RT data (see Table 3.7). Adult RT data was compared with a single adolescent group, in line with the lack of age effects demonstrated in the adolescent RT data.

Table 3.7. Adult and Adolescent comparison of mean RTs, Studies 3 and 4

	Adolescents			**Adults**		
	P	P-A	A	P	P-A	A
Low Load	630 (88)	49	580 (75)	631 (97)	72	559 (76)
High Load	871 (164)	50	821 (135)	892 (172)	51	841 (138)

Table 3.7. Adult and Adolescent comparison of mean RTs (ms, SDs in brackets) as a function of distractor condition (P = distractor present, A = distractor absent, P-A = distractor cost) and age category

A 2(load) x 2(distractor presence) x 2(age group) mixed model ANOVA on RTs revealed no main effect of age category, $F(1,197) = .122$, $p = .727$ (adolescent mean RT = 726, SD = 101; adult mean RT = 731, SD = 101) suggesting that the age groups did not differ by overall RT. In addition, there were no significant interactions with age (distractor presence*age category, $F(1,197) = 1.918$, $p = .168$, $\eta^2_p = .010$ and load*age category, $F(1,197) = 2.898$, $p = .09$, $\eta^2_p = .014$ (although the trend indicates a smaller load effect on the adolescents – mean RT in low load = 605ms, high load 846ms, load effect = 241ms – than the adults – mean RT in low load = 595ms, high load 867ms, load effect = 272ms). There was no three way interaction between load, distractor presence and age category, $F(1,197) = 2.132$, $p = .146$, $\eta^2_p = .011$ therefore despite the significant modulation of distraction by load in adults and the non-significant effect in adolescents, the difference between the groups was not sufficient to result in a significant interaction. However to detect a three way interaction based on this effect size would have required a sample size of 1423 (Erdfelder et al., 2009), which was not feasible within the in the school setting in which the adolescents were tested. Thus, while the adolescents did not show a significant modulation of distraction by load, the it is not possible to confidently conclude that the modulation of distraction by perceptual load was significantly different between the groups.

In addition, it is possible that while the distractor effect appears in both conditions of load, given the main effect of load on reaction time, there may be a scaling effect which obscures such an effect in the adolescents. A normalized measure of the distractor cost (% difference between distractor present and absent trials) at each load level was therefore also analysed using a 2(load) x 2(age group) mixed ANOVA. The ANOVA revealed a significant main effect of load, $F(1,197) = 22.766$, $p < .001$, $\eta^2_p = .104$, with larger distractor effects in low load (10.8%) than high load (6.1%). There was no significant main effect of age, $F(1,197) = 3.178$, $p = .08$, $\eta^2_p = .016$ but there was a significant age*load interaction, $F(1,197) = 5.471$, $p = .02$, $\eta^2_p = .027$. This interaction reflected the fact that while the load effect was highly significant in the adults (adult low load distractor effect = 12.9%, high load distractor effect = 5.9%, load modulation = 7.0%, $t(64) = 5.595$, $p < .001$, $d = 0.78$) it merely trended towards significance in adolescents (adolescent low load distractor effect = 8.7%, high load distractor effect = 6.3%, load modulation = 2.4%, $t(133) = 1.949$, $p = .053$, $d = 0.24$). Post-hoc comparisons between the groups showed that Bonferroni corrected significance (2 contrasts per condition, $\alpha = .025$) was reached when comparing adolescent and adult distractor cost in low load (adolescent mean = 8.7, adult mean = 12.9, $t(197) = -3.329$, $p = .001$, $d = 0.50$), with adolescents demonstrating a significantly reduced distractor cost. There was no difference between groups at high load (see Figure 3.1). Thus, the results unexpectedly indicate a smaller distraction effect in adolescents in low load.

Figure 3.1. Distractor interference effects on the irrelevant distractor paradigm as a function of load level and age category

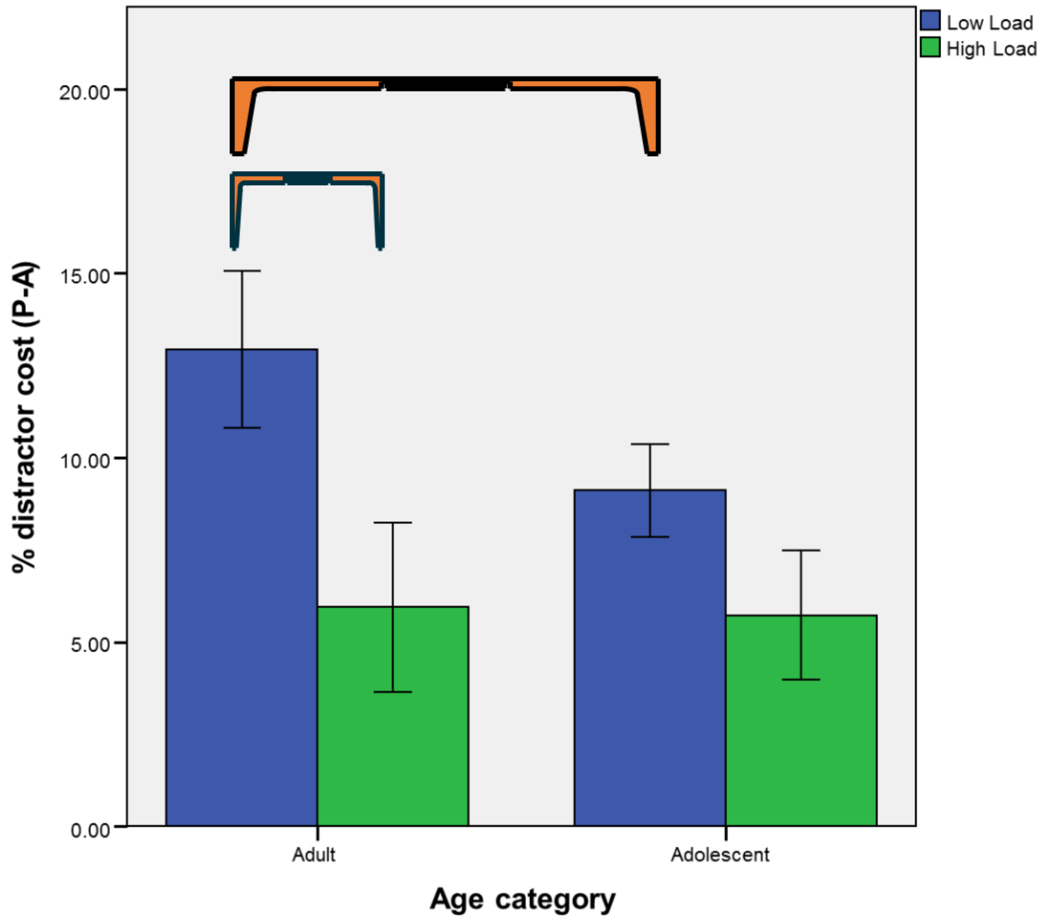

Figure 3.1. Distractor cost to RT (as % difference between distractor present and absent trials) paradigm as a function of load level and age category, between Studies 3 and 4. Error bars represent 95% confidence intervals. Orange bars represent significant t-test comparisons ** p = .01, *** p < .001

Errors

The results of Study 4 had suggested that, in the case of error rates, the adolescent group could be split between younger adolescents (age 13-15) and older adolescents (age 16-17). Table 3.8 therefore displays experimental error rates for adults, and the two adolescent groups which were differentiated in the analysis to Study 4 (younger adolescents age 13-15 and older adolescents age 16-17).

Table 3.8. Adult and adolescent comparison of error rates, Studies 3 and 4

Error (%)	'Young adolescents' Age 13-15			'Older adolescents' Age 16-17			Adult		
	A	A-P	P	A	A-P	P	A	A-P	P
Low Load	12 (7)	0	12 (10)	7 (4)	2	9 (9)	6 (4)	1	7 (9)
High Load	26 (11)	3	29 (14)	19 (11)	5	24 (15)	18 (10)	5	23 (14)
Mean error rate	19			14			12		

Table 3.8. Error rates are displayed as percentages (SDs in brackets) as a function of distractor condition (P = distractor present, A = distractor absent, P-A = distractor cost) and age category

Error rates were compared using a 2 (load) x 2 (distractor presence) x 3 (age group) mixed ANOVA, which revealed a main effect of age group, $F(2,196) = 15.307$, $p < .001$, $\eta^2_p = .135$. As can be seen in Table 3.8, this reflects a gradual decrease in error rates with age. Post-hoc tests revealed that Bonferroni corrected significance (3 contrasts, $\alpha = .017$) was reached when comparing age 13-15 with age 16-17, $t(132) = 3.598$, $p < .001$, $d = 0.75$ and with adults, $t(165) = 6.468$, $p < .001$, $d = 1.05$. The comparison between age 16-17 and adults was not significant, $t(95) = 1.339$, $p = .184$. Thus, in terms of error rates, the 16-17 age group cannot be distinguished from the adult group, whereas ages 13-15 were significantly more error prone than both older adolescents, and adults. There were no significant interactions between age and load ($F < 1$), age and distractor presence, $F(2,196) = 1.709$, $p = .184$ and no three way interaction between age, load and distractor ($F < 1$).

Response Variability

The results of Study 4 had suggested that, in the case of CV, the adolescent group could be split between younger adolescents (age 13-15) and older adolescents (age 16-17). Table 3.9 therefore displays experimental CV values for adults, and the two adolescent groups which were differentiated in the analysis to Study 4 (younger adolescents age 13-15 and older adolescents age 16-17).

Table 3.9. Adult and adolescent comparison of coefficient of variation (CV); Studies 3 and 4

	'Young adolescents' Age 13-15	**'Older adolescents' Age 16-17**	**Adult**
Low Load	0.29 (0.8)	0.26 (0.7)	0.23 (0.6)
High Load	0.34 (0.9)	0.29 (0.5)	0.27 (0.7)
Mean CV	0.31	0.28	0.25

Table 3.9: CV as a function of load level, and age group. SDs in brackets

CV values were compared using a 2 (load) x 2 (distractor presence) x 3 (age group) mixed ANOVA, which revealed a main effect of age group, $F(2,196) = 19.787$, $p < .001$, $\eta^2_p = .168$. As can be seen in Table 3.9, this reflects a gradual decrease in CV with age. Post-hoc tests revealed that Bonferroni corrected significance (3 contrasts, $\alpha = .017$) was reached when comparing age 13-15 with age 16-17, $t(132) = 2.772$, $p = .006$, $d = 0.60$ and also with adults $t(165) = 6.158$, $p < .001$, $d = 1.01$. The comparison between age 16-17 and adults reached uncorrected significance, although they not pass the Bonferroni threshold, $t(95) = 2.249$, $p = .027$, $d = 0.48$. These findings therefore appear to show a developmental trend towards reduced response variability through adolescence and into adulthood. They also replicate the results of Fortenbaugh et al. (2015) in demonstrating increased reaction time variability in adolescents compared to adults. There was no significant interaction between load level and age category (F < 1), although again the power to detect such as effect may have been limited in the present sample.

The larger variability in the distractor absent condition for the adolescents compared to adults may also explain the reduced distractor effect found over the mean RTs. As can be seen in Figure 3.2, the RTs were equivalent in the presence of a distractor across both groups (adolescents mean = 630ms, adult mean = 631ms), however the smaller distractor effect results from longer reaction times in the distractor absent condition in adolescents (580ms) compared to adults (559ms). This difference in mean RTs in the distractor absent condition (our experimental control condition) may therefore be a reflection of increased intra-individual variability in baseline responding in adolescents, which may skew mean RT values, especially in cases with a larger number of responses in the very slow end of RT distribution (Leth-Steenson et al., 2000; Williams et al., 2007). Further clarification in this regard was sought by comparing adult and adolescent RT distributions.

RT distribution analysis

Table 3.10 displays response distribution characteristics for adult and adolescent participants. As examination of adolescent results in Study 4 had not revealed any clear differences between adolescent age groups, all adolescents were combined into a single adolescent age group.

Table 3.10. Adult and adolescent comparison of response distributions; Studies 3 and 4

	Adults	**Adolescents**
μ - Low Load (ms; σ in brackets)	447 (56)	450 (76)

μ - High Load (ms; σ in brackets)	639 (105)	599 (122)
τ - Low Load	112	131
τ - High Load	202	222

Table 3.10. Mu (μ) and Sigma (σ) and Tau (τ) as a function of load level for adult participants in distractor absent trials

Mu

A mixed model ANOVA was performed compare adolescent and adult mu values. The ANOVA revealed no main effect of age category, $F(1,197) = 2.350$, $p = .127$, $\eta^2_p = .012$ suggesting that mean response times within the normal portion of the response distribution were not different between adults and adolescents. There was, however, a significant interaction between load and age category, $F(1,197) = 7.242$, $p = .008$, $\eta^2_p = .035$. The simple main effect of load was larger for adults (Mean load effect on Mu = 192ms, SD = 60) than for adolescents (M = 149ms, SD = 61).

Sigma

A mixed model ANOVA compared adult and adolescent sigma scores. The ANOVA revealed a main effect of age category (adolescent/adult), $F(1,197) = 23.113$, $p <.001$, $\eta^2_p = .105$, with larger sigma values for adolescents (M = 106, SD = 45) compared to adults (M = 81, SD = 33). Therefore, although there is no main effect between groups in the mu values, the normal section of the RT distribution for adolescents has considerably higher variance than that of the adults (see Figure 3.3). There was no interaction between age category and load, $F(1,197) = 1.8$, $p = .181$, $\eta^2_p = .009$, demonstrating that adolescents were more variable than adults across both load conditions.

Tau

A mixed model ANOVA compared adult and adolescent tau scores. The ANOVA revealed a main effect of age category, $F(1,197) = 4.752$, $p = .030$, $\eta^2_p = .024$, with adolescent tau scores ($M = 176$, $SD = 70$) larger than adult tau scores ($M = 157$, $SD = 98$). There was no interaction between load and age category ($F < 1$). Thus, adolescent responses contain a greater number of exponentially slow responses when compared to adults, in both low load (see Figure 3.2) and high load conditions.

Figure 3.2. Comparative analysis of ex-Gaussian curve fit (low-load, distractor absent responses); Studies 3 and 4.

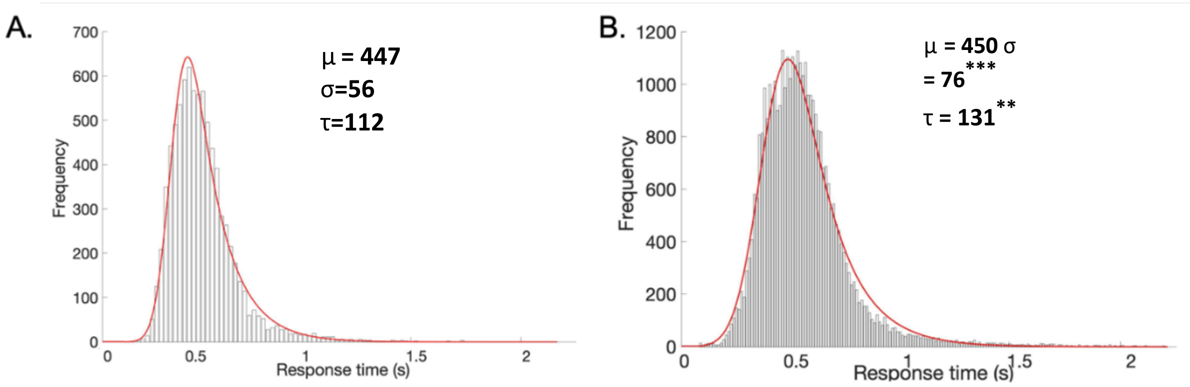

Figure 3.2. Low load response distributions with ex-Gaussian curve fit, showing values of Mu (μ), Sigma (σ) and Tau (τ), for adults (A; Study 3) and adolescents (B; Study 4). Asterisks indicate results for independent t-tests between adult and adolescent groups. ** $p = .01$, *** $p < .001$

Given the finding of a significant difference between age categories in terms of Tau (a measure of the degree that the mean RT is skewed by slow responding) it was important to also test for RT differences between the age groups using median RTs, which are less susceptible to skewing by outlier data. Median RT results are shown in Table 3.11

Table 3.11. Adult and adolescent comparison of median response times; Studies 3 and 4

	Adolescents			Adults		
	P	P-A	A	P	P-A	A
Low Load	595 (76)	39	556 (67)	597 (83)	60	537 (68)
High Load	805 (164)	30	775 (128)	841 (181)	44	797 (133)

Table 3.11. Median RT (ms) with SDs in brackets as a function of distractor condition (P = distractor present, A = distractor absent, P-A = distractor cost), load level and age category

A 2(load) x 2(distractor presence) x 2(age group) mixed ANOVA was conducted on median RTs. The ANOVA revealed no main effect of age category ($F < 1$) suggesting that the age groups did not differ by overall median RT. However, there was a significant interaction with age for load (something which there was also a trend towards in the mean RT data), $F(1,197) = 4.572$, $p = .034$, $\eta^2_p = .023$, with a larger effect of load conditions on adults ($M = 259$ms, $SD = 114$) than on adolescents ($M = 218$ms, $SD = 102$; $t(197) = -2.555$, $p = .011$). A weaker effect of load on adolescent RTs suggests another reason why adolescents failed to show a load modulation on distraction. There was also a significant interaction between age and distractor presence (distractor presence*age category, $F(1,197) = 3.953$, $p = .048$, $\eta^2_p = .020$, with distractors having a significantly larger effect on RT in adults – $M = 52$ms, $SD = 59$ – than in adolescents – $M = 34$ms, $SD = 58$). This appears to indicate that adolescent distraction, in keeping with their response patterns more generally, is more variable than adult distraction, with a greater number of extreme distractor effects. A lower median RT in adolescents (when taken with the lack of such an effect in the mean RT data), suggests that adolescents are often actually less distracted in terms of a distractor effect on RT, but that Again, there was no three-way interaction of load, distractor presence and age category, ($F < 1$), although again the power to detect such an interaction is likely to be weak in the present sample, as discussed previously.

Comparison analysis discussion: Studies 3-4

Comparison of adolescent and adult performance on the irrelevant distractor task demonstrated that the main impact of adolescence (compared to adults) in an attention task performance is greater variability of responses (replicating the findings of Fortenbaugh et al., 2015), which is expressed also with a larger tail in an RT distribution.

Specifically, I found that there were significant differences between the age categories in terms of the variability of their responding, which appeared to illustrate a developmental trend. Younger adolescents (13-15) had significantly higher coefficient of variation (CV) scores than older adolescents (16-17). The 16-17 group, in turn, did not perform at adult levels. The finding of increased response variability in adolescents compared to adults replicates previous findings with ADHD (Kofler et al., 2013; Valko et al., 2009) and non-clinical populations (Fortenbaugh et al., 2015).

Decomposing the RT distributions produced by our participants into their constituent components of Mu, Sigma and Tau revealed that adolescents displayed response patterns which are different to those of the adults. They were not slower than adults in terms of the mean of the normal distribution (Mu), however, they showed greater variability within the normal distribution (Sigma) and they *also* produced significantly more ‘exponentially slow’ responses in the tail of the RT distribution (Tau) than did the adults. Thus, adolescents display response distribution differences to adults which have previously been noted in comparisons between adult groups of ADHD sufferers and non-clinical controls (Kofler et al., 2013; Leth-Steensen et al., 2000; Williams et al., 2007).

It is possible that the greater adolescent intra-individual variability revealed in the present results can help to account for the failure to find an effect when analysing mean RTs, such as the absence of load modulation on the distractor effect. Greater variability in adolescents was found to be at least partly attributable to Tau values in the response distribution. Tau provides a measure of the extent to which the mean of the RT distribution overall is skewed by responses in the slow tail. Higher Tau values for adolescents therefore mean that the mean RT will be more heavily skewed - artificially inflated - by a small subset of very slow responses. As a result of this inflated mean value in the control (distractor-absent) condition, difference measures based on comparing this mean RT to the experimental (distractor-present) condition are less likely to find meaningful effects. An artificially elevated baseline mean RT might, for example, explain the otherwise puzzling finding of reduced low load distractor effects on RT for adolescents when compared to adults.

Younger adolescents (age 13-15) were also found to differ from older adolescents and adults in producing higher error rates, while the 16-17 age group performed at adult levels. This replicates findings from a variety of paradigms with affectively neutral stimuli, in which adolescent errors have been reported to reach adult levels between ages 14 and 15 (Aïte et al., 2018; Huizinga et al., 2006; Leon-Carrion, Garcia-Orza, & Perez-Santamaria, 2004; Luna, Garver, Urban, Lazar, & Sweeney, 2004). However, more extended developmental trends have been reported for other paradigms of attention, such as the SART. Stawarczyk et al.

(2014) found that 14-16 year olds produced significantly more errors than a group of young adults using this task. In addition, increased error rates are reported even into late adolescence for paradigms involving affective stimuli, such as emotional faces (A. O. Cohen et al., 2016; Somerville et al., 2011; Tottenham, Hare, & Casey, 2011). At present it is unclear whether these discrepancies reflect differences in the tasks employed (with performance on slightly different tasks maturing at different rates), or whether different tasks may be measuring the same cognitive functions but with different levels of sensitivity.

Study 5

Although one explanation for the smaller distractor effect in low load conditions seen in adolescents (that of increased variability from abnormally slow responses skewing mean RTs more in adolescents more than in adults) has been discussed above, there is another possible explanation that should be considered. This is that the distractor stimuli used were more salient to adult participants, because they were faces of adults, in other words that there could be an age-related bias in face processing, leading to a larger distractor effect for adult participants. Individuals find it easier to recognise faces of their own age than those of a different age (Anastasi & Rhodes, 2005). It has been suggested that this effect occurs because one comes into contact with people of their own age more frequently than those of different ages, thus increasing their expertise in processing and recognising own-age faces (Harrison & Hole, 2009). Therefore, it is possible that the magnitude of the distractor effect produced by the (adult) face stimuli in the irrelevant distractor task was affected by an own-age bias, increasing the distractor effect for adult participants. However, given the continuous exposure that all age groups have to adult faces, a similar ‘expertise’ explanation as used by Harrison and Hole (2009) has underpinned more recent evidence that there may be a processing advantage for adult, compared to non-adult faces, across age groups (Macchi Cassia, 2011).

This might suggest that adult face distractors are likely to be equally preferentially processed by both adult and adolescent groups. It should be noted here, however, that these studies have focused on recognition memory for known faces, rather than attention, and it is not clear whether there should be any impact of expertise on attention capture by anonymous, task-irrelevant distractor faces. In addition I note that he distractor stimuli used, taken from the NimStim set of adult facial expressions (Tottenham, et al., 2009), have been widely used in attentional research with teenagers (e.g. Grose-Fifer et al., 2013; Hare et al., 2008; Somerville et al., 2011; for example demonstrating greater processing of affective versions of the faces than neutral versions) and in adults (Hodsoll, Viding, & Lavie, 2011; Thompson-Booth et al., 2014a, 2014b; Trübutschek & Egner, 2012), without confounding own-age processing biases having been previously noted. Despite this, it remains conceivable that an expertise-based own-age face processing bias in adult participants led to greater interference from the distractor stimuli used.

A further experiment was therefore conducted using adult participants, but with adolescent face distractor stimuli. If an own-age bias in the processing of the distractor stimuli is present, then adolescent face distractor stimuli, presented to adult participants, would combine both a distractor stimulus that is processed less preferentially, and one with which the participants have reduced expertise (Macchi Cassia, 2011). If adolescent faces are less effective at capturing attention than adult faces, then this would be expected to lead to a reduced distractor effect in low load. In addition, if reduced distractor effects due to an own-age bias in face processing was the cause for the absence of a modulation of distraction by load (as seen in adolescents in Study 4), then we would also expect that load would not significantly modulate adult distraction using this paradigm.

Method

Participants

18 adults (4 M, 14 F, age 19-52, mean age 23.9) participated in the study. Equivalent sample sizes have been sufficient to detect load modulations of distraction in previous studies (e.g. Forster & Lavie 2008b). Participants were selected from the University College London subject pool and tested at on site at UCL.

Stimuli and Procedure

Apparatus

The apparatus, stimuli and procedure were identical to those used in Study 3, with one exception. Instead of adult faces, the distractor images consisted of adolescent faces. Faces were drawn from the National Institute of Mental Health Child Emotional Faces Picture Set (NIMH-ChEFS), a database of child and adolescent face images between ages 10-17. Neutral, direct adolescent faces (age 13+) were selected as distractor stimuli. As in Study 3, faces were counterbalanced across load conditions and gender, with a distractor face appearing once in each condition and an equal number of male and female faces used in each block. A minimum 1° dva was maintained between edges of face and letters.

Results

Reaction Times

Experimental data for reaction times (RTs) is presented in Table 3.12.

Table 3.12. Study 5: RT results

	P	P-A	A
Low Load	637 (81)	64 (48)	573 (67)
High Load	858 (161)	29 (76)	829 (134)

Table 3.12. Mean RT (ms) with SDs in brackets as a function of distractor condition (P = distractor present, A = distractor absent, P-A = distractor cost), load level

An ANOVA on was conducted on RT data. Load (low/high) and distractor presence (absent/present) were entered as the within-subjects factors. The ANOVA revealed main effects for load, $F(1,17) = 94.278$, $p < .001$, $\eta^2_p = .847$, with more slower reaction times in high load (M = 843, SE = 34) than in low load (M = 605, SE = 17), and distractor presence, $F(1,17) = 12.657$, $p = .002$, $\eta^2_p = .427$, with slower reaction times in the presence of a distractor (M = 747, SE = 22) than in the absence of a distractor (M = 701, SE = 27). Importantly, the ANOVA also revealed a significant interaction between load and distractor, $F(1,17) = 6.200$, $p = .02$, $\eta^2_p = .267$. Specifically, distractor effects were reduced in the high load condition (mean % effect = 3.2, SD = 10) compared to low load (mean % effect = 11.5, SD = 9), $t(17) = 4.566$, $p < .001$, $d = 0.88$, in accordance with the predications of load theory.

Errors

Error rates for participants are displayed in Table 3.13.

Table 3.13. Study 5: Error rates

	A	P-A	P
Low Load	8	-1	7
High Load	18	1	19

Table 3.13. Error rates are displayed as percentages as a function of distractor condition (P = distractor present, A = distractor absent, P-A = distractor cost)

A 2x2 ANOVA on error rates was conducted. Load (low/high) and distractor presence (absent/present) were entered as the within-subjects factors. The ANOVA revealed main effects for load, $F(1,17) = 54.692$, $p < .001$, $\eta^2_p = .763$, with more errors in high load. There was no main effect of distractor presence ($F<1$) and also no interaction between load and distractor presence ($F<1$), ruling out a speed/accuracy trade-off in the measure of distraction, as also demonstrated by previous research using the irrelevant distractor paradigm (Forster & Lavie, 2008b; Forster et al., 2014), in which the effect of perceptual load on distraction has been found on reaction times rather than accuracy.

Comparison to Study 3

A 2(load) x 2(distractor presence) x 2(experiment) mixed model ANOVA on RTs compared experimental results in Study 3 (with adult face distractors) to Study 5 (with adolescent face distractors). The ANOVA revealed no main effect of experiment, and no significant two- or three-way interactions with experiment (all $F<1$). Therefore, the change of distractor to adolescent faces does not appear to have had an effect on any aspect of reaction times during the task. Figure 3.3 displays a bar graph of percentage distractor effects by load condition between the two experiments

Figure 3.3. Percentage distractor cost by load level in Study 3 and Study 5

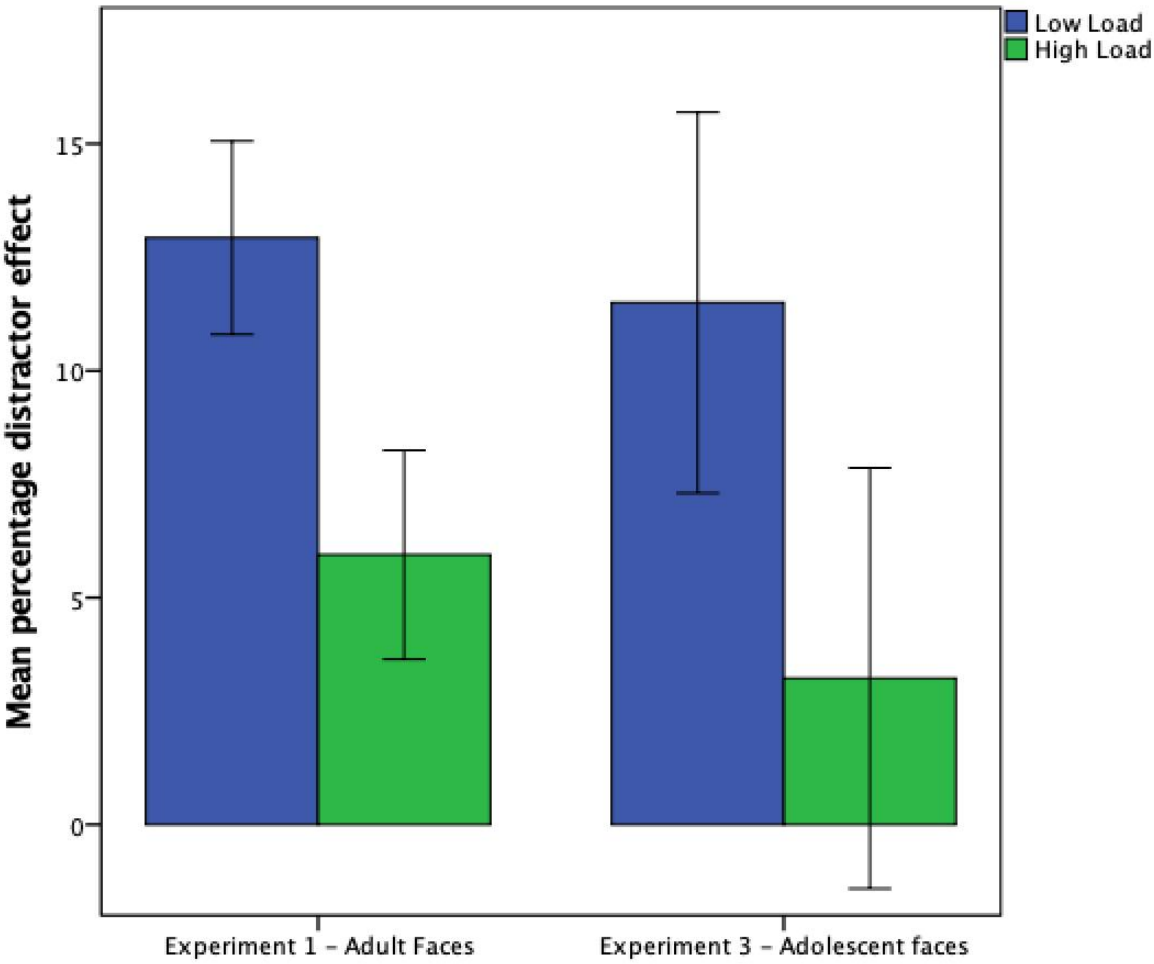

Figure 3.3. Distractor cost to RT (as % difference between distractor present and absent trials), between Study 3 and Study 5. Error bars represent 95% confidence intervals.

The results of Study 5 do not support the existence of an own-age bias towards the facial distractor stimuli in adult participants. Adolescent face stimuli, when used as distractors in the irrelevant distractor task, produced RT effects which both followed the pattern of previous research (Forster & Lavie, 2008b; Forster et al., 2014), and which were indistinguishable from results using adult face distraction in Study 3. This is consistent with previous research from visual search tasks (although not a task in which the face functioned as a task-irrelevant distractor specifically) in which adults displayed no preferential attentional allocation between adolescent and adult faces (Thompson-Booth et al., 2014b). The results suggest that biases which may exist for the recognition of adult faces (Macchi Cassia, 2011) do not influence the interference caused by those faces when they function as anonymous task-irrelevant distractors.

Thus, the results of Study 5 do not suggest that the developmental differences observed on the irrelevant distractor task in Studies 3 and 4 were attributable to a confounding bias in processing the distractor stimuli (Harrison & Hole, 2009). This appears in keeping with one previous study of adult attentional allocation to faces of different ages (although these were not being used as irrelevant distractors. Thompson-Booth et al. (2014b) asked participants to select one ‘‘odd’’ face out among three faces according to eye colour and indicate with a button press if the target face was tilted right or left). Adults displayed no preferential attentional allocation between adolescent and adult faces.

It therefore seems more likely that previously considered explanations regarding the developmental differences in response variability and characteristics may be a more likely explanation. However, it is still potentially possible that adolescents may be more sensitive to an own age bias and would show larger distractor effects in paradigms involving adolescent faces. There is some evidence, for example, that puberty may influence face recognition skills away from caregivers and towards peers (Picci & Scherf, 2016). This is an interesting avenue for future research, however I note that the increased variability seen in the distractor absent trials in adolescents is likely to limit the ability to find a load effect on distraction, regardless of the distractor stimuli (especially when relatively neutral/non-affective stimuli are used).

Chapter Summary

The present chapter established developmental differences in selective attention abilities through ages in the adolescent period, and in comparison to adults, when using the irrelevant distractor paradigm under conditions of high and low perceptual load. In adults there was a significant interaction between perceptual load and distractor processing, replicating previous findings on the modulation of irrelevant distraction by perceptual load in adult participants (e.g. Forster and Lavie, 2008b; Forster et al., 2014). Although the numerical trends for adolescents were also in the direction of load modulation when the distractor effects were calculated as proportional effects to address the load scaling effect of RTs, these were not significant, in contrast to the only previous investigation of perceptual load effects on adolescent distraction (Couperus, 2011), and adolescents also displayed a significantly smaller low load distractor effect in Study 4 than did adults in Study 3 (see Comparison analysis, Studies 3-4). This developmental difference could not be explained by an own age bias in adult participants (Study 5). It is possible that there may be (previously unreported) developmental differences between adolescents and adults in the modulation of distractor effects by perceptual load, however the present sample was not sufficiently powered to detect such a difference, given that it had not previously been hypothesised. However, perhaps the best explanation for the reduced sensitivity to reveal load effects on distraction in the adolescent cohort appears likely to be the findings of significantly increased adolescent intra-individual variability in comparison to adults. This in itself is an important and notable finding (one which replicates and extends previous research; Fortenbaugh et al., 2015). Increased adolescent response variability was driven partially by the production of significantly more 'exponentially slow' responses in the tail of the RT distribution (Tau). The resultant skewing of the mean RT value, especially in distractor absent conditions, may explain the reduced low load distractor effects on RT compared to adults.

In addition to developmental differences, the paradigm produced a range of individual differences effects in the reaction time data of each group. Both adult and adolescent groups displayed levels of between-subjects variation in the magnitude of the distractor effect on RT which were similar to those previously found in individual differences research using the paradigm (Forster & Lavie, 2016). In addition, a good range of individual differences was also found in the measurement of response variability, CV. This was especially true in the young adolescent group, who also displayed more within-subject variability than did either older adolescents or adults (Comparative analysis, Studies 3-4), replicating previous findings (Fortenbaugh et al., 2015). However, it remains unclear whether such differences between individuals translate into measurable behavioural effects. In previous work using the irrelevant distractor task, individual differences in the magnitude of irrelevant distractor interference effects (on reaction times) were able to predict reports of childhood inattentive symptoms in a non-clinical sample of adults (Forster & Lavie, 2016). In another population displaying elevated levels of response variability (adult ADHD sufferers), individual differences in variability has been found to be predictive of behavioural experiences of distraction (Adams, Roberts, Milich, & Fillmore, 2011; Ode, Robinson, & Hanson, 2011). However, such a measure has never been applied to predict real-world distraction in adolescent populations. Thus, the following chapter tests whether individual differences in task performance (in the form of distractor effect on RT and response variability) may be able to function as a predictor of real-world inattention states.

Chapter 4

Predicting distraction experiences in educational settings

Introduction

Chapter 2 examined experiences of distraction in everyday environments, and established that individual differences in reports of distraction duration from a range of sources, both external and internal, provided a reliable measure of distractibility, one which was able to replicate a number of previous experimental findings regarding the structure of attention failures and their and their relationship to mood. While such findings are of theoretical interest, they also raise interesting applied questions. For example, if distraction reports are influenced by attention control and attention focus, then it might be possible to use common experimental measures of attention skills, such a laboratory tests of selective attention, to predict experiences of distraction.

As detailed in the General Introduction (Section 1.7) attention is crucial for learning (Markant et al., 2015; C. Stevens & Bavelier, 2012) and is therefore strongly related to educational success both in school settings (Merrell et al., 2017; Merrell & Tymms, 2001; Sayal et al., 2015) and at university (Unsworth, McMillan, et al., 2012; Wammes, Seli, et al., 2016). While some previous studies have investigated the role between task measures of attention and everyday distraction experiences (Unsworth, Brewer, et al., 2012; Unsworth, McMillan, et al., 2012) in higher education, it remains unclear how the results relate specifically to educational environments and to task-irrelevant distraction (see General Introduction, Section 1.7.2.2). In this chapter, I therefore investigated whether task measures of focused attention in the face of irrelevant distraction can be used to predict the level of focused attention in educational environments. In all experiments I examined the hypothesis that two measures of task performance on the irrelevant distractor task (the degree of interference to reaction time caused by task-irrelevant distractors, and reaction time variability) will be able to predict experiences of distraction in educational environments, as reported using modified versions of the distraction checklist described in Chapter 2. Study 6 tests the hypothesis that task performance will be able to predict university students' reports of real-life distraction during a study session. Specifically in this sample, I predicted that the interference caused by a task-irrelevant distractor to reaction time ('distractor interference') would be a significant predictor of distraction reports. As in Chapter 3, I also measured reaction time variability (in the form of CV). However, whilst RT variability has been shown to be predictive of distraction in specific populations displaying elevated levels of response variability (such as adult ADHD sufferers; Adams, Roberts, Milich, & Fillmore, 2011; Ode, Robinson, & Hanson, 2011), in non-clinical adult populations response variability has not been found to be predictive of distraction (Adams et al., 2011). Response variability in non-clinical adolescent populations also tends to be higher than for adult populations (see Chapter 3; Fortenbaugh et al., 2015), reducing the variance available through which individual differences might be predictive of real-world behaviour. In light of this, I hypothesised that in the initial adult population (Study 6), CV would not be predictive of real-world distraction reports, in contrast to distractor interference.

Following this, Study 7 tests the hypothesis that experimental performance will predict distraction reports in secondary school age students reporting distraction from their previous school lesson. Finally, Study 8 tests the same hypothesis on university students immediately after a lecture, with participants also completing an ADHD screening questionnaire, in an attempt to assess also any relationship to 'state' and 'trait' distractibility.

In addition, as the results of Chapter 2 demonstrated a negative relationship between task-irrelevant distraction and mindwandering, and mood, I additionally measured mood in the present samples. Specifically, Chapter 2 found that mindwandering (and, task-irrelevant distraction from mobile phones in Study 1) were negatively associated with the level of happiness reported. These results replicated and extended Killingsworth & Gilbert's (2010) finding that mindwandering is associated with lower levels of happiness to a different sample, and into the realm of external distraction, specifically task-irrelevant distraction by a mobile phone. Thus, in the present chapter I also tested the hypothesis that there would be a negative relationship between the duration of reported distraction in educational settings and reports of happiness.

General methodology

The three experiments described in the present chapter share a general methodology, in which participants completed a computerised visual search task, and completed a self-report checklist of distraction. These items are described below:

Visual search task

The visual search task was adapted from Forster and Lavie (2008b) and comprised the same task as that described in Studies 3 and 4. Participants discriminated whether a target X or N was presented in one of six positions around a circular array, by pressing designated computer keys. In the 'low load' condition, the five non-target positions were occupied by lower-case 'o's. In the 'high load' condition, non-target positions were occupied by five different angular letters from a list of ten (H, K, M, W, T, V, L, Z, F, E). At a viewing distance of 60 cm, the distance from the fixation cross to letters in array was 4.5° of visual angle. All letters were presented in a black font against a light grey background. Target and non-target letters subtended 0.8° of visual angle horizontally and 1° vertically. Each letter was separated by 4.3° dva. Target position and target letter were fully counterbalanced. In

10% of trials, an irrelevant distractor was also presented at fixation. The distractor images were neutral faces from the NimStim set of facial expressions (Tottenham, et al., 2009), with a distractor face appearing once in each condition and an equal number of male and female faces used in each block. A minimum 1° dva was maintained between edges of face and letters.

Each trial began with a fixation cross presented in the centre of the screen for 1,000ms. The circular letter array and (in 10% of trials) the distractor were then presented for 200ms. Participants were asked to respond as quickly as possible by pressing the 0 key on the numeric keypad for an X target, and the 2 key for an N target. They were also instructed to ignore the distractor image, if present. A new trial was initiated following a participant's response, or after 3 seconds if they failed to respond. Feedback was given in the form of a computer beep for incorrect responses or failures to respond within 3s. Participants alternated between blocks with high perceptual load and blocks with low perceptual load. Participants received two practice blocks (one high and one low load) of 9 trials, and eight experimental blocks of 60 trials. Half of the participants began with a low-load block, and half began with a high-load block in the order ABBABAAB or BAABABBA. Each block was preceded by three 'warm-up' trials which were always no-distractor trials. Practice and warm-up trials were excluded from the analysis.

Self-report distraction checklist

As a number of the sources of distraction on the distraction checklist described in Chapter 2 (e.g. construction noise and animals) are less likely to regularly disrupt attention in educational settings, the checklist was adapted for use in educational environments. Given the desire to focus on education-specific distractions (and to create a checklist which could be used in schools; see Study 7), the items on the checklist were developed through a schoolteacher focus group on prominent sources of distraction in educational settings. Following an initial brainstorming session where teachers reported common distractions in lessons, some items were amalgamated into distraction categories (e.g. ‘tapping’, ‘shouting’, ‘background music’, ‘humming’ and ‘background talking’ were amalgamated into a category of ‘background noise’). Items were discarded if they did not clearly identify a source of distraction (for example, the teachers identified several factors which were likely to increase distraction, but which did not identify a clear source, such as ‘tiredness’, ‘boredom’ and ‘cognitive overload’). Subsequently, items were selected for the checklist if at least 50% of the group agreed that the item was ‘a significant source of distraction for students in average lessons’. This produced seven categories of distraction sources: ‘people around you (friends, classmates, teachers etc)’, ‘background noise (music, talking, tapping, shouting etc)’, ‘social networking (alerts, posts, updates, messages etc)’, ‘other functions/apps on your phone/tablet/computer (games, internet browsing etc)’, ‘displays in the room (posters, maps, artwork etc)’, ‘unrelated thoughts (“mindwandering”)’ and ‘looking out of the window’.

When completing the checklist, participants reported, for each of the different task-irrelevant distraction sources, for how long their attention was diverted away from their main focus towards that source, (using a slider bar from 1-15 minutes, with the option to write a time if more than 15 minutes). Following this, questions recoded background variables relevant to distraction in educational settings, namely age, gender, interest in the topic being studied, the subject of study, and whether the study session involved working alone (or with others) or work on a computer. Finally, participants rated their happiness during the period on a scale of 0-100, and their wellness (whether they felt ‘well’ or ‘unwell’ during the period).

Study 6

Method

Participants

Adult participants were the same participants as those reported in Study 3. 66 adults (age 18-62, mean age 26.05, including 11 mature students of age 30 or over) participated in the study, in return for payment. The sample size was large enough to detect small effect sizes in a planned linear regression model with 8 predictors (see Table 4.2) with 90% power. Data collection stopped after the day's testing in which the target sample size (n = 59) was achieved. Participants were selected from the University College London subject pool and tested at on site at UCL. The research was approved by the University College London research-ethics committee.

Stimuli and Procedure

A visual search task was performed as described in the 'General methodology' section above.

Self-report distraction checklist

In addition, participants completed a self-report distraction checklist for educational environments, as described in the 'General methodology' section above, reporting experiences of distraction during their their last study session (one participant, who was not a university student, was removed at this stage, to leave a population of university students reporting on a period of academic study). A 'study session' was defined as 'the last time today that they had to complete a task requiring close focused attention'.

The checklist was as described in the general methodology section, with the following changes. Firstly, additional questions allowed participants to indicate where their study session occurred (options were '1 - lecture theatre or library', '2 - own home', '3 - computer room', '4 – coffee shop' and '5 – other, e.g. office'), and the length (in minutes) of the session. Participants reporting a study session of longer than one hour were instructed to recall only the last hour. The order of taking the questionnaire and the experiment was counterbalanced. Testing took place from 11am onwards to allow time for students to have experienced some period of study prior to testing (four of the sample arranged an earlier testing time of 10am, allowing them to report experiences from a 9am class).

Participants scoring 50% accuracy or below in any experimental condition (i.e. those at chance levels of performance) were excluded from subsequent analysis (n = 1), and one participant did not complete a distraction checklist due to technical issues, leaving a final sample of 63 (24 M, 39 F, age 18-62, mean age 25.4).

Results

Mean interest in the topic of study was 60.9 (SD = 25.4). Mean happiness during the study session was 60.2 (SD = 21.0). Only one participant reported feeling unwell during the study session. 'social networks, 'mindwandering' and 'people around you' were the three most commonly reported sources of attention lapse in the study session (see Figure 4.1). Participants reported working in three different locations from the options given: 'lecture theatre or library' (n = 33), 'own home' (n = 24) and 'computer room' (n = 6).

Figure 4.1. Proportional duration of distraction reports from different sources in the last study session in Study 6

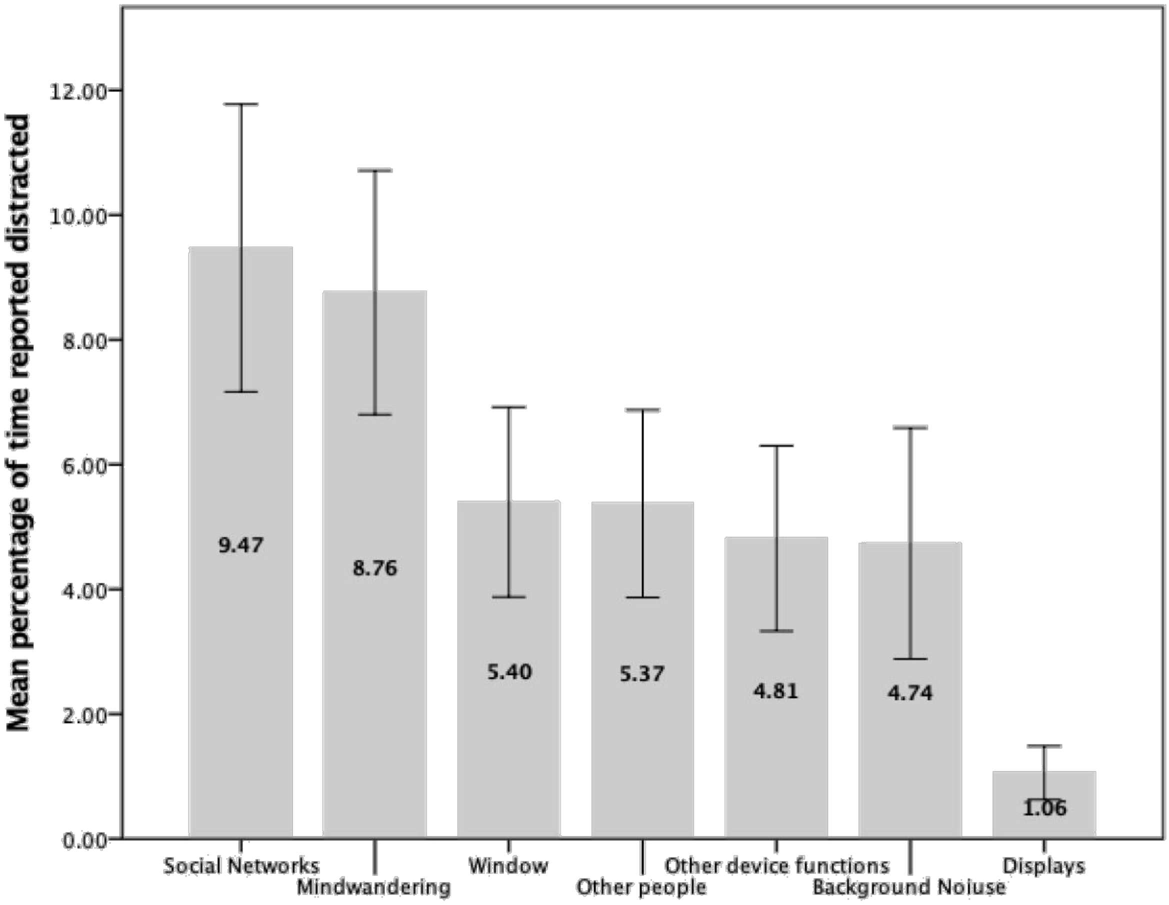

Figure 4.1. Values represent the mean percentage duration of distraction reported for each source during the participant's last study session in Study 6. Error bars +/- 2SE

Experimental performance

Experimental performance data is the same as that presented in Study 3. As in Study 3, distractor absent trials only were selected as a measure of variability.

Zero-order correlations

A correlation matrix for all variables of interest displaying significant relationships to other variables can be seen in Table 4.1. CV did not correlate significantly with any other variable (the strongest correlation was with distraction from 'background noise' - r_s = -0.15, p = .23) so it was excluded from the matrix.

The duration of distraction reported for the different sources of distraction were significantly positively correlated to one another in 17 of the 21 comparisons made. Notably, mindwandering was positively correlated with all external distraction sources.

Age displayed a significant negative relationship to ‘other functions on your device/table’. It is likely that the negative trends also observed between age and distraction from ‘people around you’, ‘social networks’, ‘background noise’ and ‘mindwandering’ (all $r_s > -0.19$, all $p < .11$) would have been significant in a larger sample (as in Study 1 in Chapter 2).

Distractor RT interference on the experiment was significantly positively correlated with distraction from ‘people around you’, ‘social networks’, background noise’ and ‘other functions on your device/tablet’, thus demonstrating that distraction experiences in everyday life can correlate to experimental performance on laboratory measures of distractibility.

Happiness displayed a significant negative relationship with mindwandering duration reports ($r_s = -0.45$, $p = .001$). No individual external distractions displayed a significant correlation to happiness, and neither did any background variables.

Interest in the topic of study was not significantly correlated to any source of distraction, in contrast with some previous reports which have found negative correlations between self-reported interest and mindwandering rates in educational settings (Hollis & Was, 2016; Kane, Smeekens, et al., 2017). Interest was, however, significantly negatively correlated to group work, and significantly positively correlated to computer use.

Wellness was not included in Table 4.1 because it displayed limited correlations with other variables. Wellness was significantly correlated with CV (r_s = -0.33, p = .01), but not with any other measured variable (the next strongest correlation was with mindwandering, r_s = 0.13, p = .30). Given that I had no prior hypothesis about this relationship, I do not discuss it further here.

Table 4.1. Zero-order correlation matrix for variables of interest: Study 6

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Distractor interference	-												
2. People around you	**0.27***	-											
3. Window	0.02	0.16	-										
4. Social Networks	**0.31***	**0.43****	**0.36****	-									
5. Background noise	**0.27***	**0.30***	**0.29***	**0.72****	-								
6. Other functions on device	**0.39****	**0.51****	**0.37****	**0.67****	**0.57****	-							
7. Mindwandering	0.21	**0.48****	**0.46****	**0.57****	**0.44****	**0.61****	-						
8. Displays	-0.06	0.23	**0.38****	0.24	0.00	**0.30***	**0.37****	-					
9. Happiness	-0.12	-0.07	-0.18	-0.09	-0.15	-0.16	**-0.45****	0.03	-				
10. Interest in study topic	0.06	0.01	0.21	0.16	0.17	0.09	0.08	0.18	0.18	-			
11. Group work	0.03	0.22	**-0.28***	-0.11	-0.12	-0.03	-0.09	0.00	0.06	**-0.32***	-		
12. Computer use	0.10	-0.11	-0.19	-0.06	0.00	0.04	-0.21	0.01	0.22	**0.29***	0.04	-	
13. Age	-0.15	-0.22	-0.06	-0.20	-0.24	**-0.26***	-0.20	0.00	0.16	0.16	0.10	-0.01	-

Table 4.1. Pearson Correlation Coefficients are shown. * p < .05, ** p < .01

Factor Analysis

An exploratory factor analysis (EFA), with principal-axis factor extraction conducted on the study session distraction reports (Figure 4.2) showed that all distraction sources loaded onto a single factor around or above 0.4, the threshold suggested for the practical significance of a loading value (Stevens, 2012). In addition, the scree plot showed a clear inflexion after one factor. Therefore, all attention failure reports were combined into a single 'study distraction' latent variable.

Figure 4.2. Factor loadings and scree plot for EFA on distraction variables

A

	Component 1
Social networks	0.834
Other device functions	0.812
Mindwandering	0.76
Background noise	0.71
People around you	0.534
Window	0.495
Displays	0.391

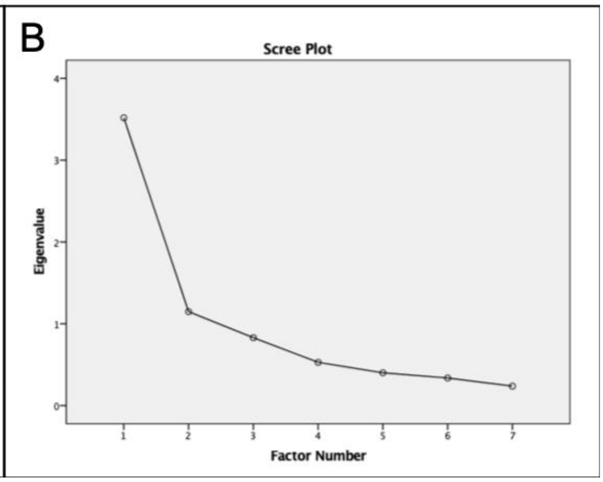

Figure 4.2. Component loadings (panel A) and scree plot (panel B) for the EFA of the distraction sources reported from the last study session in Study 6. As all distraction reports were positively correlated with one another (see Table 4.1), an oblique (direct oblimin) rotation was used.

This 'study distraction' latent variable displayed a significant correlation with distractor interference effects on the search RT (r_s = 0.36, p = .004). Thus, distractor interference in the experiment was sensitive to predict distraction reports at the level of the latent variable. There was no correlation between the latent variable and CV (r_s = -0.10, p = .43). Study distraction also displayed a significant negative correlation with age (r_s = -0.27, p = .03), although it was not significantly correlated to happiness (r_s = -0.21, p = .10).

To assess potential differences between study locations, an ANOVA was conducted on the 'Study distraction' latent variable, with the study location (lecture theatre or library/own home/computer room) as the between subjects factor, representing the three different location categories reported. There was no main effect of study location, $F(1,61) = .001$, $p = .978$, suggesting that study location did not significantly impact distraction reports (although I not that it is possible that the study lacked the power to assess small effects caused by the different locations, especially given that only 6 participants reported one of the locations – computer rooms). Study location was therefore not included in further analyses.

Multiple regression analyses

Predicting study distraction

A multiple regression analysis was conducted to assess whether distraction during the previous study period (in the form of the 'study distraction' latent variable) could be predicted from experimental performance, when controlling for background variables (Table 4.2).

Table 4.2 - Multiple regression analysis for factors predicting distraction in the previous study session: Study 6

	Model 1 - Background variables		**Model 2 - Happiness**	
	β	t	β	t
Age	-0.30	-2.21	-0.27	-2.03
Gender	0.08	0.59	0.01	0.09
Interest	0.25	1.77	0.22	1.58
Group work	0.00	0.01	-0.01	-0.07
Computer use	-0.12	-0.87	-0.15	-1.13
Test order	-0.08	-0.66	-0.05	-0.43
Distractor interference			0.30	2.34*
	Adjusted R^2	**F**	**Adjusted R^2**	**F**
Model Statistics	0.05	1.53	0.12	3.16*

Table 4.2. β = Beta, the standardised regression coefficient; adjusted R^2 significance levels are for R^2 change F-tests ** $p < .01$ *** $p < .001$

Level 1 control variables (age, gender, computer use, group work, interest in the topic of study and testing order) were not significant predictors of classroom distraction, either individually or as a collective model. Controlling for all these variables, distractor RT interference was a significant positive predictor of Study distraction in Level 2.

Predicting happiness

A second multiple regression analysis was conducted to assess whether happiness could be predicted from distraction variables, when controlling for background variables (Table 4.3). Level 1 consisted of control variables relevant to ratings of happiness (age, gender, wellness and interest in the topic of study). As only mindwandering displayed a significant zero-order correlation with happiness (see Table 4.1), this alone was taken forward and entered into Level 2 of the regression model.

Table 4.3 - Summary of the multiple regression analysis for variables predicting happiness: Study 6

	Level 1 - Background variables		Level 2 - Mindwandering	
	β	t	β	t
Age	0.10	0.77	0.03	0.23
Gender	-0.08	-0.61	-0.01	-0.10
Interest	0.18	1.35	0.23	1.95
Wellness	-0.01	-0.06	0.04	0.33
Mindwandering			-0.45	-3.71***
	Adjusted R^2	**F**	**Adjusted R^2**	**F**
Model Statistics	0.07	1.00	0.18	13.73***

Table 4.3. β = Beta, the standardised regression coefficient; adjusted R^2 significance levels are for R^2 change F-tests *** p < .001

Level 1 control variables were not significant predictors of happiness, either individually or as a collective model. Controlling for all these variables, mindwandering was a significant negative predictor of happiness in Level 2.

An alternative model which examined whether a latent variable formed from only external distractions was predictive of reduced happiness was insignificant.

Study 6 Discussion

The present results replicate the findings of Chapter 2 in that reports of task-irrelevant external distractions (and mindwandering) in everyday life situations tend to be positively correlated, and that they can be described as arising from a single underlying construct in an exploratory factor analysis. Notably, the present results also extend the findings of Chapter 2 by demonstrating that this latent variable formed from distraction reports can be uniquely predicted from attention task measures of irrelevant distraction in a population of students (including both young adults and mature students) in academic environments. Specifically, the distractor cost to reaction time ('distractor interference') was significantly predictive of distraction in the present cohort. Importantly, as the attention task measures were significant predictors of an individual's classroom distractibility levels while controlling for interest in the study session, the results demonstrate an important contribution of attention ability above and beyond motivation. This extends previous findings that have found positive associations between this experimental measure and everyday mindwandering reports in adults (Forster & Lavie, 2014), as well as adult self-reports of childhood inattentive symptoms (Forster & Lavie, 2016). The finding that, in a non-clinical adult sample, response variability is not predictive of distractibility replicates previous findings (Adams et al., 2011), as hypothesised. As response variability in non-clinical adult populations also tends to be lower than for adolescent populations (see Chapter 1; Fortenbaugh et al., 2015), the between-subjects variance through which individual differences might be detected is also reduced in a commensurate fashion. As a result, the variable is less likely to prove sensitive enough to provide a valid prediction of real-world behaviour.

The findings also extend those of Chapter 2 on the relationship between mindwandering and happiness. When controlling for background variables, mindwandering reports were a significant predictor of reduced happiness. External distractions, however, did not display a significant relationship to happiness.

Two points of weakness in the present experiment are due to the potential variations in what was classed as a study session, and the immediacy of the experience to the testing. The sample reported completing study sessions across a number of different locations, all of which may have contained a variety of different tasks and distraction types. Although I note that no clear difference was found between the distraction reports and the various locations, such variety makes clear conclusions and generalisations more challenging. In addition, although participants were asked to report only the last hour of their study session, the variety in lengths of the sessions reported (and the fact that there was no guarantee that the study session had taken place immediately before testing, or sometime earlier in the day) are likely to increase the potential for recall biases to affect the distraction reports. It can be noted, however, that as with previous data I have reported using distraction duration, the present results do not rely on absolute levels of distraction duration, or on the presence or duration of specific distractors. Instead the present results demonstrate that task-irrelevant distraction during an attention task can predict task-irrelevant distraction in a real-life setting, a relationship that appears to persist despite the variation in absolute levels of different distractions within and across individuals. However, in subsequent experiments in this chapter more controls were put in place over both the activity and the recall period, in order to reduce the potential impact of memory confounds.

Study 7 thus further examines the ability of task performance to predict distraction reports, in a new sample population and setting; that of adolescents in secondary school. Previous research has established that typically developing adolescents appear to show greater response variability than adults (Fortenbaugh et al., 2015; Chapter 1). Neuropsychological findings have demonstrated that individual differences among populations with elevated intra-individual reaction time variability may act as a predictor of inattention states (Adams et al., 2011; Kofler et al., 2013). These findings led me to also predict a positive association between intra-individual reaction time variability in the task and duration of irrelevant distraction in the classroom. Given the findings of the previous experiment I also predicted positive correlation between the individual magnitude of the distractor cost and the duration of reported distraction.

Study 7

Method

Participants

Participants were the same school student sample as reported for Study 3. 143 (64 Female) secondary school students (M age= 14.64, range 13-17) participated. Informed parental consent was obtained for all participants. No participants had a diagnosed special educational need (SEN). The research was approved by the UCL research-ethics committee.

Stimuli and Procedure

A visual search task was performed as described in the ‘General methodology’ section above. The task was administered at the participants’ school during the school day, with participants attending testing immediately after a regular school lesson.

Self-report distraction checklist

In addition, participants completed a self-report distraction checklist for educational environments, as described in the ‘General methodology’ section above, reporting experiences of distraction during their last full school lesson (the one they had experienced immediately before attending the experiment). The checklist was identical to that used in Study 6, with two exceptions. Firstly, the words 'study session' were changed to 'school lesson' throughout. Secondly, as all participants were attending from school lessons of a uniform duration, the questions regarding the location and duration of the session were removed and replaced with the question 'what subject was the lesson that you have just had?'. The order of taking the checklist and the experiment was counterbalanced

Participants completed the same irrelevant distractor task as in Study 6. Participants scoring chance accuracy (50%) or below in any experimental condition were excluded (n = 8), as were those with reaction times more than 3 standard deviations from the mean (n = 1) leaving a final sample of 134 (13-17, mean age 14.66). The exclusions were spread across the ages (13yrs = 2, 14yrs = 3, 15yrs = 3, 16-17yrs = 1).

Cognitive Abilities Test

As an additional control, I also collected a measure of general cognitive abilities (a proxy for IQ). Unsurprisingly there is a close relationship between attention control skills and fluid intelligence (e.g. Unsworth, Fukuda, Awh, & Vogel, 2014; see Heitz, Unsworth, & Engle, 2005, for a review). It is important to reveal, therefore, that any predictive tool is able to explain variation in distraction reports above and beyond that simply explained by cognitive abilities. Therefore, a measure of cognitive abilities (the CAT; Smith, Fernandes, & Strand, 2001), was recorded. The CAT level D (Smith et al., 2001) is a standardised battery of cognitive tests commonly taken by school children in the first school term of secondary school. It has good reliability (Smith et al., 2001) and correlates very highly with well-validated IQ test scores for children and adolescents (Calvin, Fernandes, Smith, Visscher, & Deary, 2009; Deary, Strand, Smith, & Fernandes, 2007). CAT test data was not collected specifically for this study; instead existing CAT scores were supplied by the school. Although the relationship between intelligence and classroom distraction has not previously been directly tested, attention tasks can predict general school attainment even above and beyond intelligence (Steinmayr et al., 2010). As a result, I predicted that experimental measures would predict distraction reports, even when controlling for general cognitive ability.

Results

Mean interest in the lesson was 59.0 (SD = 26.1). Mean happiness during the lesson was 65.1 (SD = 23.9). Seven participants reported feeling unwell during the lesson. ‘People around you’, ‘mindwandering’ and ‘background noise’ were the three most commonly reported sources of attention lapse in the classroom (see Figure 4.3).

Figure 4.3. Proportional duration of classroom distraction reports from different sources: Study 7

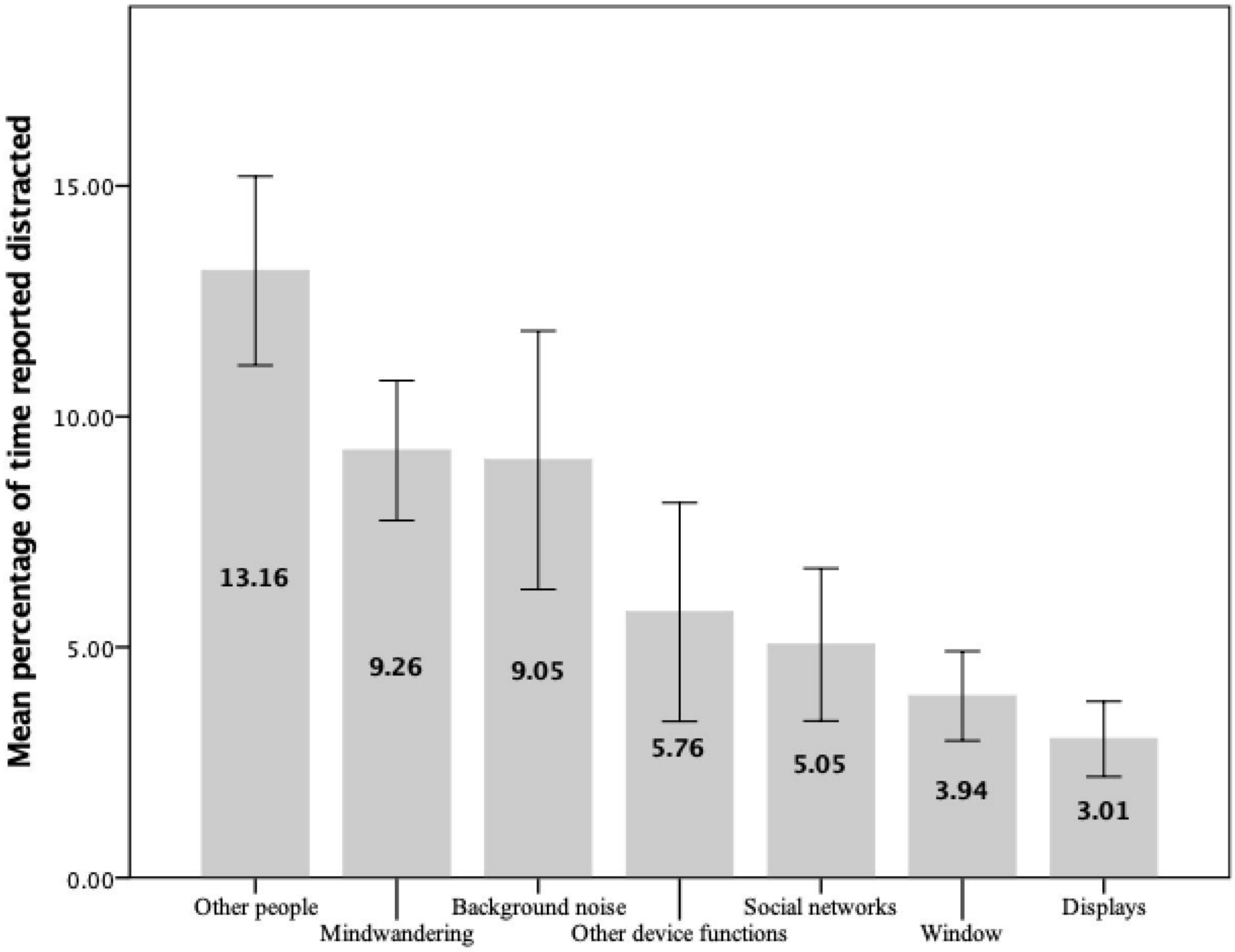

Figure 4.3. Values represent the mean percentage duration of distraction reported for each source during the preceding school lesson. Error bars +/- 2SE

Zero-order correlations

A correlation matrix for variables of interest can be seen in Table 4.4.

The durations of distraction reported for the different sources of distraction were significantly positively correlated in 15 of the 21 comparisons made. Mindwandering was significantly positively correlated with all external distraction sources apart from ‘people around you’ (r_s = 0.17, p = .051).

Distractor RT interference on the experiment was significantly positively correlated with ‘background noise’ and ‘other functions on your device/tablet’, replicating the findings of Study 6 that distraction experiences in everyday life can correlate to experimental performance. In addition, and in contrast to the findings of Study 6, some distraction sources from the checklist were also significantly correlated to CV in the experiment, specifically ‘people around you’ and ‘social networks’. Thus, in a population of adolescents, everyday distraction experiences also significantly correlated with response variability as well as distractor interference.

Happiness displayed a significant negative correlation with mindwandering duration reports, in keeping with Study 6. However, unlike Study 6 the present results also demonstrated a number of significant negative correlations between individual external distractions and happiness. ‘people around you’, ‘social networks’, looking out of the window’, ‘background noise’ and ‘other functions on your device/tablet’ were all significantly correlated to reduced mood. Thus, in an adolescent sample, a larger number of distraction sources appear to be associated with mood.

Interest in the topic of the lesson was significantly correlated with a number of distraction sources, including ‘looking out of the window’, ‘displays in the room’ and ‘mindwandering’. The correlation with mindwandering is in keeping with previous findings in educational settings (Hollis & Was, 2016;

Kane et al., 2017), although not with the findings of Study 6. Interest in the topic of the lesson was also strongly positively correlated to happiness.

Measured variables which were not included in Table 4.4 (for ease of reporting, and because they displayed limited correlations with other variables) were computer use, wellness and age. Computer use was significantly negatively correlated with distractor interference (r_s = -0.18, p = .04), but not with any other measured variable (the next strongest correlation was with 'interest in the lesson', r_s = 0.13, p = .12). As a result, computer use was included in follow-up regression analyses predicting distraction from distractor interference (see below). Wellness was positively correlated with mindwandering reports (r_s = 0.22, p = .01), but not with any other measured variable (next strongest correlation with 'looking out of the window', r_s = 0.16, p = .07). Age was negatively correlated to CAT score (r_s = -0.20, p = .02) and positively correlated to distraction by 'social networks' (r_s = 0.19, p = .03), but not to any other variable (next strongest correlation with 'group work', r_s = 0.15, p = .09). Given the restricted age range of the present sample, the weaker relationships between age and distraction reports appear to be in keeping with the findings of Study 2 in Chapter 2. The relationship between age and CAT score may perhaps have been due to a self-selection bias among those agreeing to participate in senior years. However, I note that a negative correlation between age and CAT score and age means that any positive developmental effects on attention control are less likely to be simple artifacts of intelligence. Given that I had no prior hypothesis about these relationships, I do not discuss them further here.

Table 4.4. Zero-order correlations between all variables of interest for Study 7

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1. Distractor interference	-											
2. Response variability (CV)	-0.03	-										
3. People around you	0.04	**0.23****	-									
4. Window	-0.14	0.08	**0.22***	-								
5. Social Networks	0.09	**0.24****	**0.31****	**0.25****	-							
6. Background Noise	**0.19***	0.13	**0.47****	0.09	**0.36****	-						
7. Other functions on device	**0.19***	0.17	**0.26****	0.14	**0.68****	**0.46****	-					
8. Mindwandering	0.07	0.15	0.17	**0.31****	**0.34****	**0.50****	**0.52****	-				
9. Displays	0.02	0.08	0.04	**0.52****	**0.23****	0.03	0.11	**0.29****	-			
10. Happiness	-0.12	0.12	**-0.22***	**-0.24****	**-0.29****	**-0.26****	**-0.19***	**-0.29****	-0.16	-		
11. Interest in lesson	-0.02	0.08	-0.17	**-0.26****	-0.14	-0.12	-0.08	**-0.23****	**-0.21***	**0.62****	-	
12. CAT aptitude score	-0.12	-0.03	-0.04	-0.02	**-0.19***	-0.07	**-0.23***	-0.14	-0.13	**0.28****	0.14	-

Table 4.4. Pearson Correlation Coefficients are shown. * $p < .05$, ** $p < .01$

Factor analysis

An exploratory factor analysis (EFA), with principal-axis factor extraction conducted on the classroom distractibility reports (Figure 4.4) showed that all classroom distractions loaded onto a single factor above 0.4, the threshold suggested for the practical significance of a loading value (Stevens, 2009). The scree plot revealed an inflexion after the first factor which, together with the factor loadings, suggested a single latent variable solution could be formed for further analysis. Therefore, all attention failure reports were combined into a single ‘classroom distraction’ latent variable.

Figure 4.4. Component loadings (panel A) and scree plot (panel B) for EFA on distraction sources reported from the last classroom lesson in Study 7

A

	Component	
	1	2
Other mobile functions	0.78	-0.264
Social networking	0.751	-0.091
Mindwandering	0.73	0.061
Background noise	0.693	-0.409
People around you	0.536	-0.252
Classroom displays	0.404	0.777
Looking out of the window	0.486	0.687

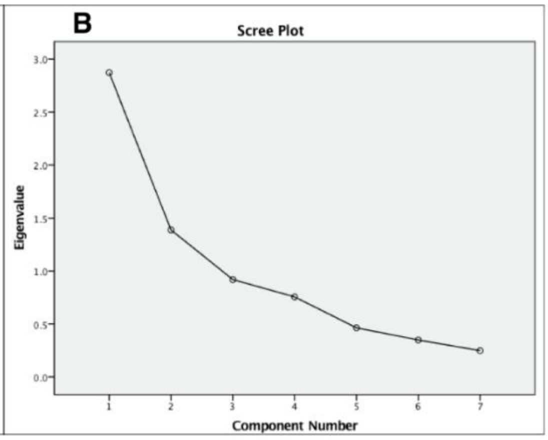

Figure 4.4. Component loadings (panel A) and scree plot (panel B) for the EFA of the distraction sources reported from the last school lesson in Study 7. As all distraction reports were positively correlated with one another (see Table 3), an oblique (direct oblimin) rotation was used.

The ‘classroom distraction’ latent variable displayed a significant correlation with distractor interference effects on search RT (r_s = 0.18, p = .04), as well as with intra-individual RT variability (r_s = .23, p = .008). Thus, both of the performance measures from the experiment were sensitive enough to predict distraction reports at the level of the latent variable in the adolescent sample. In addition, classroom distraction was significantly negatively correlated to CAT aptitude scores (r_s = -0.18, p = .05), and to happiness reports (r_s = -0.33, p < .001).

Multiple regression analyses

Predicting classroom distraction

A multiple regression analysis (Table 4.5) was conducted to assess whether distraction during the previous lesson (in the form of the 'classroom distraction' latent variable) could be predicted from experimental performance, when controlling for background variables (age, sex, wellness, group work, computer use, generalized cognitive abilities and interest in the lesson).

Table 4.5. Multiple regression model for factors predicting distraction in the previous classroom lesson

	Model 1 - Background variables		**Model 2 - Experimental performance variables**	
	β	t	β	t
Computer use	-0.11	-1.14	-0.12	-1.3
Age	-0.04	-0.38	0.02	0.238
Sex	0.13	1.46	0.14	1.624
Group work	0.01	0.06	0.03	0.36
CAT aptitude score	-0.17	-1.78	-0.13	-1.447
Interest in lesson	-0.14	-1.52	-0.15	-1.703
Distractor RT effect			0.23	2.296*
Response variability (CV)			0.21	2.584*
	Adjusted R^2	**F**	**Adjusted R^2**	**F**
Model Statistics	0.04	1.86	0.116	5.817**

Table 4.5. Note. β = Beta, the standardized regression coefficient; Adjusted R^2 significance levels are for R^2 change F-tests * $p < .05$

Level 1 control variables (computer use, group work, age, sex, CAT score and interest in the lesson) were not significant predictors of classroom distraction, either individually or as a collective model. Controlling for all these variables, both distractor RT interference and response variability (CV), were significant positive predictors of classroom distraction in Level 2.

The variance explained by distractor interference was largely independent of that explained by CV; distractor interference explained 3.7% and CV 4.7% of the variance in distraction (above and beyond all control variables) when entered individually, and 8.6% when entered together. As the variance explained by the two together approached the sum of the variance that each factor explained individually, they represent relatively independent predictors of distraction in our model (as can also be seen in the weak correlation between the two variables in Table 3.6).

Predicting Happiness

A second multiple regression analysis was conducted to assess whether happiness could be predicted from distraction variables, when controlling for background variables (Table 4.6). Level 1 consisted of control variables relevant to ratings of happiness (age, gender, wellness, and interest in the topic of study). CAT score was also included in Level 1 as a result of the significant zero-order correlation between this and happiness ratings (Table 3.5). Six of the distraction sources displayed significant negative correlations to mood. As the sample size was not large enough to detect individual effects for this number of predictors, the classroom distraction latent variable (which was also significantly negatively related to happiness) was entered into Level 2 of the regression model.

Table 4.6 - Summary of the multiple regression analysis for variables predicting happiness

	Level 1 - Background variables		**Level 2 - Mindwandering**	
	β	t	β	t
Age	0.006	0.084	0.001	0.01
Gender	-0.053	-0.755	-0.03	-0.437
Interest	0.564	7.932***	0.538	7.629***
Wellness	-0.206	-2.951**	-0.183	-2.642**
CAT score	0.215	2.976**	0.186	2.58*
Classroom distraction			-0.169	-2.361*
	Adjusted R^2	**F**	**Adjusted R^2**	**F**
Model Statistics	0.420	18.351***	0.442	5.573*

Table 4.6. Note. β = Beta, the standardized regression coefficient; Adjusted R^2 significance levels are for R^2 change F-tests * p < .05, ** p < .01, *** p < .001

Of level 1 control variables, ‘interest in the lesson’ and ‘CAT score’ were both significant positive predictors of happiness ratings, whilst ‘wellness’ was a significant negative predictor. Controlling for all these variables, classroom distraction was a significant negative predictor of happiness in Level 2.

Study 7 Discussion

The present results extend the findings of Study 6 by demonstrating that reported levels of classroom distractibility in secondary school pupils can be uniquely predicted from both attention task measures of irrelevant distractor cost to task performance and intra-individual RT variability, and that this was found across different lesson characteristics (e.g. computer use and group work), ages (13-17) and genders. In addition, the present results show that task performance measures are able to remain significantly predictive of distraction reports when including additional controls (for generalized cognitive abilities) and in a design which reduced the potential impact of memory biases on reporting.

The results thus suggest that a focused attention task measure can provide useful predictions of distraction across different class settings and pupils across a range of ability and motivation levels. In addition to extending the findings of Study 6, this represents a significant advance on previous research, which has typically concentrated on ADHD assessments at primary school (Hoerger & Mace, 2006), as well as a previous demonstration that response inhibition of incongruent colour names (in the Stroop colour-naming task) can discriminate between the top and bottom quartiles of attention ratings at school, but which did not control for any of the aforementioned factors (Das et al., 1992; Papadopoulos et al., 2002).

One question raised by the present results (given that the time periods over which participants were reporting were more tightly controlled in the present experiment than in Study 6) is the degree to which the relationship between distractor interference on the irrelevant distractor task may provide insight into transient states of distractibility, or more stable traits. Previous research has linked distractor interference to childhood reports of ADHD symptoms, suggesting the existence of a relatively stable 'attention-distractibility' trait (Forster & Lavie, 2016). However, the existence of a distractibility trait would not preclude differences in states of inattention in particular circumstances. In order to investigate this question in more depth, I conducted a follow-up experiment designed to investigate the extent to which distractor interference explained variance in distraction reports, above and beyond an existing trait measure of inattention (an ADHD diagnostic checklist), while also specifying tighter controls on the time periods involved in the recall of distraction states.

I hypothesised that the ADHD diagnostic questionnaire would be a significant predictor of distraction reports in the previous lecture. However, on the basis that both the distraction checklist and the irrelevant distractor task are likely to be sensitive to fluctuating states of attention focus, I predicted that distractor interference would explain variance in distraction reports over and above that explained by the ADHD questionnaire. In keeping with Study 6 I hypothesised that, in this adult sample, response variability would not be predictive of distraction reports, in contrast to the adolescent participants.

Study 8

Method

Participants

123 adults (35 M, 88 F, age 18-42, mean age 21.4) participated in the study, in return for payment. The sample size was doubled from Study 6 to allow for the potential of a significant mediation of the regression strength by the ADHD questionnaire. Collection stopped after the day's testing in which the target sample size (n = 118) was achieved.

Participants were selected from the University College London subject pool, with additional stipulations that they had to be completing an educational course which involved lectures. Participants were tested on site at UCL. The research was approved by the UCL research-ethics committee.

Stimuli and Procedure

A visual search task was performed as described in the 'General methodology' section above. Participants attended testing immediately after the completion of a standard course lecture.

Self-report distraction checklist

In addition, participants completed a self-report distraction checklist for educational environments, as described in the 'General methodology' section above, reporting experiences of distraction during the lecture that they had just attended (the one they had experienced immediately before attending the experiment). The checklist was identical to that used in Study 6 (apart from wording modifications to alter 'study session' to 'lecture'). Participants completed the distraction checklist immediately after the completion of the consent procedure, in order to minimize possible biases or inaccuracies in recalling distraction during the lecture. Participants were instructed to report distractions for the last 50-minute period of their lecture (common policies at London universities divide lectures into 50-minute periods).

Adult ADHD Self-Report Scale (ASRS)

Following completion of the distraction checklist and the visual search task, participants completed the World Health Organization Adult ADHD Self-Report Scale (ASRS; Kessler & Üstün, 2004), an 18 item questionnaire based on ADHD symptomatology which has been widely validated and found to be a reliable indicator of ADHD symptoms in both adolescent and adult populations (e.g. Adler et al., 2006; Kessler et al., 2005, 2007; Rösler, Retz, & Stieglitz, 2010), including, specifically. college students (Gray, Woltering, Mawjee, & Tannock, 2014).

Participants scoring 50% accuracy or below in any experimental condition (i.e. those at chance levels of performance) were excluded from subsequent analysis (n = 2), leaving a final sample of 121 (18-42, mean age = 21.5).

Results

Mean interest in the lecture was 68.5 (SD = 17.4). Mean happiness during the lecture was 60.8 (SD = 16.0). Only one participant reported feeling unwell during the lecture.

Distraction reports

‘People around you’, ‘mindwandering’ and ‘social networks’ were the three most commonly reported sources of attention lapse during the lecture (see Figure 4.5).

Figure 4.5. Proportional duration of distraction reports from different sources in the last lecture in Study 8

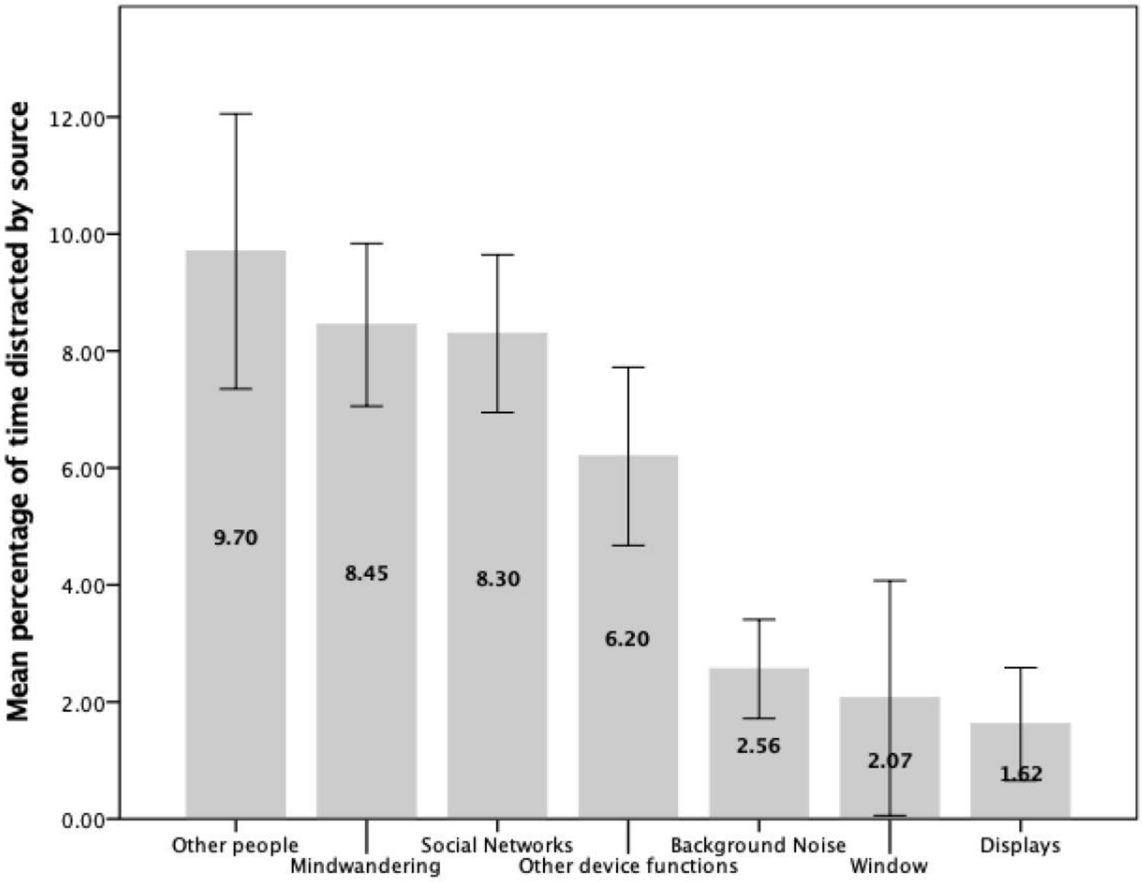

Figure 4.5. Values represent the mean percentage duration of distraction reported for each source during the participant's last study session. Error bars +/- 2SE

Experimental performance

Experimental performance descriptives are shown in Table 4.7. In keeping with previous experiments, response variability (CV) was calculated for distractor absent trials only.

Table 4.7. Experimental performance: Study 8

	LOW LOAD			HIGH LOAD		
	P	**P-A**	**A**	**P**	**P-A**	**A**
RT (ms)	**607 (106)**	**70 (46)**	**537 (79)**	**869 (165)**	**50 (59)**	**819 (147)**
CV			0.23 (0.5)			0.28 (0.6)
Accuracy (%)	92 (7)	2 (6)	94 (4)	82 (12)	3 (9)	85 (7)

Table 4.7. Mean RT (ms), response variability (CV) and accuracy rates with SDs in brackets as a function of distractor condition, and load level

An ANOVA on RT results with the factors of load and irrelevant-distractor conditions revealed a main effect of load, $F(1,120) = 617.627$, $p < .001$, , $\eta^2_p = .838$. RTs were longer in the high load than in the low load condition, confirming that the perceptual load manipulation was effective in increasing the task difficulty. There was also a main effect of irrelevant-distractor presence, $F(1,120) = 273.159$, $p < .001$, $\eta^2_p = .695$, with slower reaction times in the presence of a distractor. In addition there was a significant interaction between load and distractor presence, $F(1,120) = 10.089$, $p = .002$, $\eta^2_p = .078$, with the effect of the distractor on reaction times significantly reduced in high load compared to low load (see Table 4.7). Adjusting for a scaling effect on RTs in higher load the mean proportional distractor effect also demonstrated a significant reduction in high load (low load = 12.9%, high load = 6.1%, $t(120) = 7.463$, $p < .001$, $d = 0.92$). Therefore, the load manipulation was effective at reducing the effect of the irrelevant distractor, in keeping with previous findings with adults in Studies 3 and 5.

An ANOVA on accuracy results revealed, similarly to the RT results, a main effect of load, $F(1,120) = 163.951$, $p < .001$, $\eta^2_p = .577$, with more errors in the high load than in the low load condition. There was also a main effect of irrelevant-distractor presence, $F(1,120) = 21.169$, $p < .001$, $\eta^2_p = .150$, with more errors in the presence of a distractor. There was no significant interaction between load and distractor presence, $F(1,120) = 1.390$, $p = .241$, $\eta^2_p = .011$, suggesting the absence of a speed-accuracy trade-off, however given the small size of the distractor effect on errors (2.5% on average) this data may have been less sensitive to reveal an interaction than RT data.

Zero-order correlation matrix

A correlation matrix for variables of interest can be seen in Table 4.8. Reports of attention lapses from the different distraction sources were significantly positively correlated in 11 of 21 comparisons. Thus, the consistency of the relationship was reduced in comparison to the previous data reported in Chapter 2 and in Studies 6 and 7 previously. Mindwandering reports were significantly positively correlated with reported duration of distraction from 'other device functions' and 'social networks'.

In contrast to our hypothesis, distractor interference was not significantly correlated to any distraction source. Thus, these results failed to replicate the findings of Studies 6 and 7, in which distractor interference was significantly correlated to a number of different task-irrelevant distractions. Distractor interference was, however, significantly correlated to ADHD trait scores, in line with the findings of Forster and Lavie (2016). ADHD trait scores were positively correlated to reports of distraction from social networks, but not to any other source of attention lapse. Response variability (CV) did not display any significant correlations to any other variable (strongest correlation with mindwandering, $r_s = 0.17$, $p = .06$, all other $p > .28$) and so was not included in Table 4.8.

Group work displayed significant positive correlations with four distraction sources: 'people around you', 'looking out of the window', 'social networks' and 'background noise'.

Happiness ratings displayed significant negative correlations to the reported duration of 'mindwandering' and also duration of distraction by 'other device functions'.

Other measured variables which were not included in Table 4.8 (for ease of reporting, and because they displayed limited correlations with other variables) were wellness and interest in the lecture. Interest was significantly correlated with happiness ratings (r_s = 0.37, p < .001), in keeping with Study 7, but with no other measured variable (next largest correlation with age, r_s = 0.12, p = .19). Wellness was not significantly correlated with any other variable (strongest correlation with 'group work', r_s = -0.17, p = .07).

Table 4.8. Zero-order correlation matrix: Study 8

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Distractor interference	-												
2. People around you	-0.04	-											
3. Window	-0.03	**0.81****	-										
4. Social networks	0.05	**0.30****	0.17	-									
5. Background noise	-0.02	**0.60****	**0.48****	**0.22***	-								
6. Other device functions	0.04	0.12	0.05	**0.31****	0.12	-							
7. Mindwandering	0.02	0.16	0.04	**0.19***	0.12	**0.54****	-						
8. Displays	-0.11	**0.21***	**0.25****	-0.01	**0.26****	0.03	0.15	-					
9. Happiness	-0.02	-0.07	-0.05	-0.14	-0.02	**-0.20***	**-0.42****	0.02	-				
10. ASRS ADHD score	**0.24****	0.00	-0.03	**0.35****	0.12	-0.02	0.00	0.03	-0.17	-			
11. Computer use	-0.09	-0.12	-0.12	0.13	0.02	0.16	-0.01	-0.16	0.02	-0.10	-		
12. Group work	-0.08	**0.25****	**0.19***	**0.21***	**0.23***	0.10	0.00	0.03	0.16	0.05	0.02	-	
13. Age	0.02	**0.18***	**0.25****	0.00	0.10	0.18	0.07	0.11	0.00	-0.06	0.07	**0.20***	-

Table 4.8. Pearson Correlation Coefficients are shown. * $p < .01$, ** $p < .001$

Factor Analysis

An exploratory factor analysis (EFA), with principal-axis factor extraction conducted on the lecture distractibility reports (Figure 4.6 – Panel A) showed two factors with an Eigenvalue of greater than 1 (cumulatively explaining 59.3% of the variance).

Figure 4.6. Factor loadings and scree plot for EFA on distraction variables

A.

	Factor 1	Factor 2
Other People	0.966	0.261
Window	0.818	0.126
Background noise	0.628	0.22
Displays	0.28	0.101
Other device functions	0.15	0.873
Mindwandering	0.164	0.612
Social Networks	0.278	0.359

B.

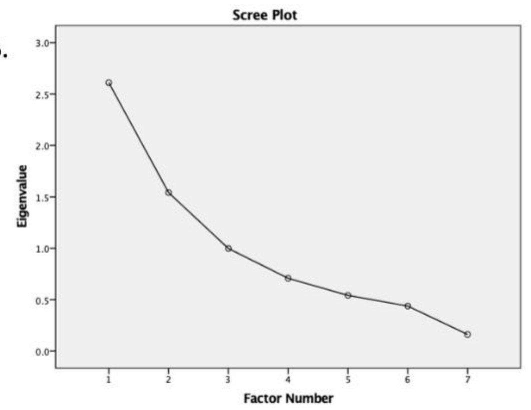

Figure 4.6. Component loadings (panel A) and scree plot (panel B) for the EFA of the distraction sources reported from the last lecture in Study 8. As distraction reports were generally positively correlated with one another (see Table 3.10), an oblique (direct oblimin) rotation was used.

Inspection of the factor loadings showed that ‘people around you, ‘looking out of the window’, and ‘background noise’ loaded strongly onto the first factor, perhaps suggestive of an underlying construct for ‘environmental distractions’. ‘other device functions’ and ‘mindwandering’ loaded strongly onto the second factor, with the remaining sources inconclusive across two or three factors. Thus, in contrast to previous experiments, mindwandering and environmental distractions did not load strongly onto a single factor.

In addition, latent variables formed from the first two factors of the EFA were also not significantly correlated with any experimental variable (or with the ADHD trait questionnaire scores), so they were not taken forward for further analysis and were not included in Table 4.8 above. As a result, it was not possible to construct a latent variable representing distraction during the lecture.

Multiple regression analyses

Predicting distraction

The lack of a clear underlying factor governing distraction reports, in addition to the lack of zero-order correlations between distractor interference in the experiment and distraction reports in the lecture, meant that it was not possible to run a regression analysis predicting lecture distraction based on experimental performance, as was performed in Studies 6 and 7.

Predicting happiness

A multiple regression analysis was conducted to assess whether happiness could be predicted from distraction variables, when controlling for background variables (Table 4.9). Level 1 consisted of control variables relevant to ratings of happiness (age, gender, wellness and interest in the topic of study). Mindwandering and 'other device functions', the two distraction sources that displayed a significant zero-order correlation with happiness (see Table 4.8), were taken forward and entered into Level 2 of the regression model.

Table 4.9. Summary of the multiple regression analysis for variables predicting happiness in the last lecture: Study 8

	Level 1 - Background variables		Level 2 - Distraction	
	β	t	β	t
Age	-0.053	-0.59	-0.027	-0.329
Gender	-0.039	-0.434	-0.039	-0.479
Interest	0.371	4.185***	0.333	4.106***
Wellness	0.025	0.282	0.05	0.621
Mindwandering			-0.429	-4.595***
Other device functions			0.055	0.577
	Adjusted R^2	**F**	**Adjusted R^2**	**F**
Model Statistics	4.65**	0.86	0.26	12.96***

Table 4.9. β = Beta, the standardised regression coefficient; Adjusted R^2 significance levels are for R^2 change F-tests *** p < .001

Of the Level 1 control variables, 'interest in the lecture' was a significant positive predictor of happiness. No other control variables predicted significant unique variance in happiness ratings. Controlling for all these variables, mindwandering was a significant positive negative predictor in Level 2, however 'other device functions' no longer displayed a significant relationship to happiness.

Study 8 Discussion

The present experimental results again showed that adults displayed a significant load modulation of distractor effects on mean RT. Accuracy results displayed no interaction between load and distractor effect, ruling out a speed-accuracy trade-off in the measure of distraction. However, in contrast to Studies 6 and 7 distractor interference was not found to be significantly related to any reports of distraction from the various distraction sources.

Response variability was also found not to be related to distraction reports, replicating the findings from an adult sample in Study 6.

Distractor effects at low load were found to be significantly correlated with scores on the ASRS ADHD trait questionnaire (Kessler & Üstün, 2004). This finding is consistent with previous findings suggesting that distractor interference is governed, at least partially, by a relatively stable 'attention-distractibility' trait (Forster & Lavie, 2016). However, the aim of the experiment was also to assess whether distractor interference was able to predict variance in distraction reports that might also have been attributable to more transient states of inattention. In light of the lack of a coherent latent variable describing distraction in the lecture, and the weak correlations between distractor interference and individual distraction sources, it was not possible to assess this second aim.

Chapter Summary

This chapter demonstrates a number of novel findings. Firstly, that individual differences in the magnitude of distractor interference to RT on the irrelevant distractor task were able to predict the duration of experiences of distraction in educational settings, in both an adult sample (Study 6) and in adolescent school students (Study 7). Higher distractor effects in low load were predictive of higher scores on a latent variable formed from durations of reported distractions. These findings demonstrate that a focused attention task may provide a measure of distractibility that can be generalized across different educational settings, and across students of a range of ability and motivation levels and ages. In light of this, an objective computerized measure of focused attention may be able to be used alongside the more common practice of relying on teacher or instructor reports of attention problems. Instead of relying on teacher ratings alone, the inclusion of academic, observational, and desk measures has been shown to provide a stronger discriminator between clinical and non-clinical attention problems (Atkins, Pelham, & Licht, 1985). A task-based measure of distractibility in addition to these tools would potentially allow for more accurate and comprehensive assessment of focused attention in educational settings.

A second finding of the chapter was that, in common with Chapter 2, reports of distraction durations from a variety of sources, both internal and external, tend to be positively correlated with one another and are often best described as resulting from a single underlying construct. This was found in Studies 6 and 7. Although in Study 8 a single latent variable was not able to be formed, positive correlations were still generally present between distraction sources.

A third finding was that, in an adolescent sample, response variability on the experiment was a significant predictor of distraction reports (Study 7), whereas this was not the case for adult samples (Studies 6 and 8). This novel finding extends research on distractibility in other populations with elevated response variability (such as ADHD sufferers) into an adolescent sample, and also suggests that individual differences in response variability may provide an age-specific measure for predicting distractibility.

The final notable finding from the chapter is regarding the relationship between attention and mood. The results of Chapter 2, reporting results from a range of both adult and adolescent participants, revealed that mindwandering duration appeared to be consistently related to reports of reduced happiness, with external distractions displaying a somewhat less consistent pattern. The findings of this chapter reinforce these conclusions. In all the results presented in this chapter, mindwandering duration was reported as displaying a significant negative correlation with mood. In adolescent participants, however, a number of other external distractions were significantly correlated to happiness, and the latent variable of all distraction reports was predictive of happiness in a multiple regression. Thus, it may be that the connection between attention states and mood is stronger in adolescents, consistent with the idea of adolescence as a period of emotional arousability associated with reduced regulation of arousal and mood states (e.g. Heller & Casey, 2016; Larson, Moneta, Richards, & Wilson, 2002; Steinberg, 2005).

Given the close relationships found between mindwandering and external distractions in both Chapter 2 and the present chapter, in the next chapter I assess whether interpolated testing, a simple intervention previously shown to reduce mindwandering in an educational setting, can also be used to reduce experiences of distraction from external stimuli during university seminars.

Chapter 5

Reducing distraction experiences in educational settings

Chapter introduction

In Chapters 2 and 4, reports from a diverse range of participants demonstrated a close relationship between mindwandering and external distraction, in both everyday and educational settings. In both chapters, reports of mindwandering and external distraction were able to be described as belonging to a single, unitary factor. This builds on previous research into the similarities and differences in attention lapses from these two sources (as discussed in the General Introduction, Section 1.3). Further understanding of this relationship, as well as practical applications for educational practices, can be gained from examining the effect of interventions on experiences of distraction and mindwandering in educational settings. One potential possibility for such an intervention might be manipulating the level of perceptual load in focal educational tasks. However, as a significant modulation of focus by perceptual load in adolescents was not observed in Chapter 3, this was not taken forward as an intervention method to increase attention focus.

Instead, I sought to investigate whether interpolated testing could be successfully used to reduce instances of mindwandering and external distraction in a novel educational setting. As discussed in the General Introduction (Section 1.8.1) 'interpolating testing' describes the provision of recall opportunities (often in the form of quiz questions) throughout learning sessions. In addition to the benefits of retrieval activities for memory (see e.g. Roediger & Butler, 2011; Roediger & Karpicke, 2006 for reviews; Rowland, 2014 for a meta-analysis), interpolated testing has been found to promote learning of new material (usually within the same learning session; Pastötter & Bäuml, 2014; Yang et al., 2018 for reviews), as well as reducing self-reported rates of mindwandering during learning from video lectures (Szpunar, Khan & Schachter, 2013; Szpunar, Jing & Schacter, 2014). Importantly, these effects appear to be primarily restricted to task-irrelevant mindwandering, rather than thoughts related to the lecture content (Jing, Szpunar & Schacter, 2016). If interpolated testing has the effect of reducing task-irrelevant mindwandering then, given the findings of Chapters 2 and 4, we might expect that other forms of attentional lapse, such as distraction from task-irrelevant external stimuli, would also be positively affected by such an intervention. Therefore, the first aim of Chapter 5 was to examine whether an interpolated testing intervention reduced distractibility by external stimuli, in addition to mindwandering.

In addition, the mechanism (or mechanisms) behind the benefits of interpolated testing remain unclear (see General Introduction, Section 1.8.1.1), for example whether the attentional effects arise from the same source as the learning effects. Yang et al. (2018) divide theories proposed to account for the forward testing effect into explanations which involve a motivational component (also likely to facilitate attentive processing, for example increased post-test effort devoted to encoding and retrieval; Cho, Neely, Crocco, & Vitrano, 2017; Neely & Cho, 2015; or increased expectancy of future tests, Weinstein, Gilmore, Szpunar, & McDermott, 2014), and those which involve changes to either encoding or retrieval processes, independent of attentional allocations to future information (e.g. Soderstrom & Bjork, 2014; Szpunar, McDermott, & Roediger, 2008; Tullis, Finley, & Benjamin, 2013; Wissman, Rawson, & Pyc, 2011). While some previous research has suggested that the effects of interpolated testing on learning and those on attention may be separable, the relationship between testing, attention and learning was not tested specifically (Jing, Szpunar, and Schacter, 2016). If interpolated testing supports new learning by facilitating attentive processing, then we might expect that the degree of facilitation in attention (indexed for example in the scale of reduction in mindwandering reports) would mediate the improvements seen in learning. The absence of this relationship would be suggestive of more independent mechanisms separately contributing to the effects on learning and those on attention. A second aim of the chapter was therefore to examine whether, following an interpolated testing intervention, reductions in reports of mindwandering and external distraction mediated any improvements in learning.

Another aim of the chapter was to examine whether previous findings on the effects of interpolated testing could be generalised to a live educational setting. Whilst standard testing effects on learning have been shown in authentic classroom environments (Bangert-Drowns, Kulik, & Kulik, 1991; McDaniel, Anderson, Derbish, & Morrisette, 2007), the forward testing effect has yet to be demonstrated in such settings. For example, Szpunar et al. (2014, 2013) asked individual participants to watch video lectures in their experiments. Although the rates of mindwandering reported in response to their probe questions appeared comparable to measurements of mindwandering rates recorded in 'live' lecture settings (e.g. Lindquist & McLean, 2011; Wammes, Seli, et al., 2016), it is unclear whether an interpolated testing intervention in a live setting will have the same effect as when individual participants are watching a video. Yang et al. (2018) identify the testing of the forward testing effect in real classroom settings as an important future direction for research, one which I aimed to address in the present chapter.

Participants in Study 9 therefore participated in an interpolated testing intervention during two small group teaching seminars, one of which contained interpolated testing, while the other contained control 'restudy' periods. At the end of each session, participants completed both a cumulative test on the content of the seminar, and a survey of their levels of distraction and mindwandering. The results of Chapter 2 suggested that retrospective estimates of distraction duration could provide reliable results which replicated findings using other measurement paradigms. In addition, when considering interpolated testing specifically, it can be noted that Szpunar, Khan and Schachter (2013) report similar results when using a retrospective questionnaire taken at the end of the session (Szpunar et al., 2013; Experiment 1) to when using probe questions (Szpunar et al., 2013; Experiment 2). I compared the impact of interpolated testing on reports of mindwandering and external distraction, compared to the restudy control condition, and examined how these reports related to learning. Given the findings of Chapter 2 that both MW and ED are associated with happiness, I also examined whether a testing intervention would have an effect on the level of happiness. Specifically, if the intervention reduces the experience of task-irrelevant mindwandering and distraction then it might also be predicted to lead to an increase in happiness. Finally, as interest in the current activity has previously been associated with higher rates of mindwandering (Kane, Smeekens, et al., 2017; Lindquist & McLean, 2011; Unsworth & McMillan, 2013), levels of interest were also examined, in order to ensure that effects on attentional processes could be differentiated from more general effects on task engagement.

Study 9

Method

Participants

A total of 122 undergraduate students (ages 19 – 25 M = 20.3 yrs, 14 male, 108 female) participated in the study. The larger sample than that used in interpolated testing research previously was to allow for as much power as possible in the planned between-subjects mediation analysis. No participants had a history of neurological or psychological impairment. Participants undertook small-group teaching sessions ('seminars') in Psychology at University College London. Three cohorts of students participated in the study, in successive teaching terms between January 2018 and January 2019. Within each cohort, students were divided into four seminar groups. Group sizes ranged from 6-14. Seminars were delivered by two instructors, each responsible for two groups of students per cohort. All participants provided informed written consent to participate in the experiment. The research was approved by the University College London research-ethics committee.

Materials and procedure

Two 50-minute teaching sessions were chosen for the testing intervention. These were the topics of 'Critical evaluation of research' and 'Analysis and argument'. Each seminar was divided into three roughly equal segments taking between 10-12 minutes (see Figure 5.2). Both seminars consisted primarily of instructor-delivered information, with occasional short discussion activities. The order of 'testing' and 'restudy' conditions was counterbalanced across instructors, so that for each instructor one group was in the 'tested' condition each week while the other was in the 'restudy' condition. Each participant therefore received one 'tested' and one 'untested' seminar (see Figure 5.1).

Figure 5.1. Counterbalancing of study design across three cohorts of students

	Cohort 1 - Jan 2018			
	Instructor A		**Instructor B**	
	Group 1	**Group 2**	**Group 3**	**Group 4**
S1 - Critical evaluation	T	R	T	R
S2 - Analysis and argument	R	T	R	T
	Cohort 2 - Oct 2018			
	Instructor A		**Instructor B**	
	Group 5	**Group 6**	**Group 7**	**Group 8**
S1 - Critical evaluation	T	R	T	R
S2 - Analysis and argument	R	T	R	T
	Cohort 3 - Jan 2019			
	Instructor A		**Instructor B**	
	Group 9	**Group 10**	**Group 11**	**Group 12**
S1 - Critical evaluation	T	R	T	R
S2 - Analysis and argument	R	T	R	T

Figure 5.1. Counterbalancing of study design across three cohorts of students. T = test seminar. R = restudy seminar

Students were told at the start of the seminar that at the end of each section there would be a chance to solidify the learning that had taken place in that segment. Figure 5.2 demonstrates the experimental procedure. At the end of each section, participants in the ‘test’ group completed a 2-minute-long quiz (5 multiple-choice questions) on the content covered, whilst students in the ‘restudy’ group were encouraged to review their notes or the seminar materials (which were available via Moodle). At the end of the third segment, both groups completed a phenomenological survey (3 minutes) on their experiences during the seminar, and then answered a final test on the full seminar content, consisting of different questions to those used in the interpolated quizzes (5 minutes). The Seminar 1 final test consisted of 12 multiple-choice questions and the Seminar 2 final test consisted of 10 multiple-choice questions. Quizzes were completed using an online study platform (Moodle; Moodle Pty Ltd) and questionnaires using Qualtrics survey software (Qualtrics, Provo, UT).

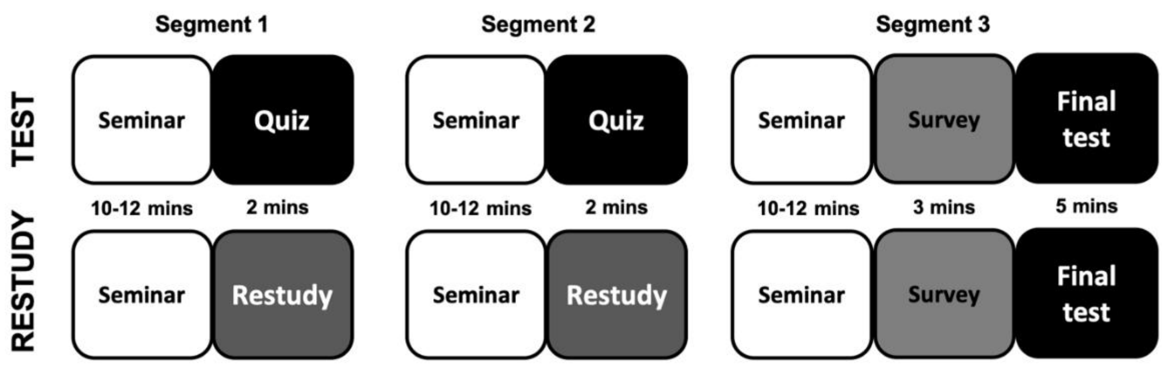

Figure 5.2. Design of Study 9 for test and restudy conditions within each 50-minute seminar session.

Importantly, whereas previous investigations using interpolated testing have been analysed at a between-subjects level (Szpunar, Khan and Schachter, 2013, Szpunar, Jing & Schachter, 2014; Jing, Szpunar & Schachter, 2016) this design allowed for the analysis of the effect of the experimental manipulation to be assessed at a within-subject level.

Self-report distraction checklist

The checklist used was the same as that described in the Chapter 3. The checklist asked students to provide information on their experiences of inattention during each seminar session, as well as recording other information relevant to attention in educational settings. Participants reported for how long over the course of the seminar their attention was diverted away from the main focus of the seminar, towards different task-irrelevant distractions. The distraction sources were: 'people around you (friends, classmates, teachers etc.)', 'background noise (music, talking, tapping, shouting etc.)', 'social networking (alerts, posts, updates, messages etc.)', 'other functions/apps on your phone/tablet/computer (games, internet browsing etc.)', 'displays in the classroom (posters, maps, artwork etc.)', 'unrelated thoughts ("mindwandering")' and 'looking out of the window'. Finally, background variables were recorded by the questionnaire, namely age, gender, interest in the topic being studied (on a scale of 1-100). Following this, participants rated their current level of happiness on a scale of 1 (extremely unhappy) to 100 (extremely happy). Finally, respondents reported their age, gender, and current state of wellness (by responding '*yes'* or '*no'* to the question '*Are you currently well (health wise)?*').

Results

In all results that follow, I present the effect sizes for each repeated measure and mixed model analysis of variance (ANOVA) as the partial eta squared (η^2_p) and for post-hoc between groups comparisons as the Cohen's *d* (*d*).

Six participants only attended one of the two teaching sessions, leaving full data for 116 participants for repeated measures analysis. A series of paired t-tests were conducted to assess the effect of the interpolated testing manipulation. Given that 'interest in the seminar' presented a potential moderator in the effect of the intervention on both learning and attention, this was assessed first. Interpolated testing was not significantly associated with any change in interest in the seminar (restudy mean = 66.34, SD = 21.3; interpolated test mean = 65.26, SD = 22.1; t(115) = -0.63, p = .530, *d* = .07). Given that the intervention had no effect on interest, it was therefore not included as a covariate in subsequent analyses.

Secondly, the effect of the intervention on learning was assessed. Mean scores in the final test differed between the two seminar topics ('Critical evaluation of research' = 65.1%, 'Analysis and argument' = 62.4%), so test scores were converted into z-scores to allow comparison across conditions and seminar topics (restudy z-score mean = -0.13, SD = 1.1; interpolated test z-score mean = 0.17, SD = 0.9). The effect of the manipulation on performance in the final test was found to be significant, t(115) = 2.63, p = .01, *d* = .27, with participants achieving significantly better test scores in testing seminars than in restudy seminars. This replicates the findings of Szpunar et al. (2013; 2014) and the broader literature on the forward effects of interpolated testing on learning.

In order to further test the replicability of previous findings of the effect of interpolated testing, I next assessed the effect of the intervention on mindwandering. As expected given the small-scale seminar setting, figures for the reported duration of mindwandering (measured as a percentage of total seminar duration) appeared far lower than those reported in previous studies using video or real-life lecture settings (restudy mean = 6.78, SD = 6.5; interpolated test mean = 5.21, SD = 5.0). Regardless, a paired t-test showed that the testing intervention was effective in significantly reducing mindwandering rates, $t(115) = 2.22$, $p = .028$, $d = .025$, in line with the findings of Szpunar et al. I note, however, that it is difficult to directly compare between different measures of mindwandering (such as previous research involving the frequency of responses to probe questions and the present methodology involving duration estimates; see General Discussion 6.3.1).

Next, the effect of the intervention on reports of external distractions (see Table 5.1) was analysed using a 2x5 repeated measures ANOVA with test condition (test/restudy) and distraction source (other people/window/social networks/background noise/other device functions) as within subjects factors.

Table 5.1. Descriptive statistics and paired t-test results for within-subjects analysis of external distractions

	Other people	Window	Social Networks	Background Noise	Other device functions
Restudy	5.12 (5.4)	1.09 (2.5)	3.83 (5.3)	1.16 (2.6)	3.22 (7.9)
Interpolated test	4.82 (8.8)	1.11 (2.2)	3.23 (4.8)	1.06 (3.0)	2.52 (9.6)
Difference	-0.30	+0.02	-0.50	-0.10	-0.70

Table 5.1. Mean (SD in brackets) values are shown for percentage of seminar duration reported experiencing external distractions in each condition.

The ANOVA revealed a significant main effect of distraction source, $F(4,112) = 20.079$, $p < .001$, $\eta^2_p = .424$, indicating that some sources of distraction were reported for significantly longer duration than others (see Table 5.1). However, there was no main effect of condition, and no interaction between condition and distraction source (both $F < 1$). Thus, although four of the five reported distractions were reported less frequently in the testing condition, the intervention did not appear to lead to any significant change in reports of external distraction durations, nor did it appear to affect different sources of external distraction in different ways. I note, however, that it is not possible from this data to conclude that interpolated testing does not have any modulating effect on external distractions. Further testing using other sources of external distraction, and other measures of distraction such as frequency reports, may be required to explore this issue in greater detail.

To establish whether the difference between the significant effect of interpolated testing on mindwandering and the non-significant effect on external distraction was statistically significant, I conducted a 2x2 repeated measures ANOVA. Condition (test/restudy) and attention lapse (mindwandering/external distraction) were entered as the within-subjects factors (external distraction was calculated as the average duration of distraction across all sources). A significant interaction between condition and lapse would indicate that interpolated testing affected the constructs differently. The size of the sample was adequate to detect an interaction with a small effect size (η^2_p ³ 0.15) with 90% power (J. Cohen, 2013; Erdfelder et al., 2009), given the correlation between attention lapse measures ($r = 0.28$). The ANOVA revealed main effects of condition, $F(1,112) = 4.471$, $p = .037$, $\eta^2_p = .038$, with reduced attention lapses in the test condition, (restudy $M = 2.37$, testing $M = 1.95$) and a main effect of lapse, $F(1,112) = 56.31$, $p < .001$, $\eta^2_p = .335$, with mindwandering reported for longer durations than each average external distraction (MW mean duration = 2.98%, EDs mean duration = 1.34%). However, the interaction between condition and lapse only approached significance, $F(1,112) = 3.461$, $p = .065$, $\eta^2_p = .030$. Thus, although interpolated testing reduced mindwandering and did not significantly modulate external distraction, the present analyses did not allow the conclusion that interpolated testing modulates these constructs to a significantly different extent. It is possible that splitting external distraction reports across five sources affected the sensitivity of the measure when compared to a single mindwandering measure. Alternatively, other methods of collating external distraction reports, such as using latent variables (which were not able to be formed from the external distraction reports in the present experiment), may allow for a more accurate comparison between constructs.

Finally, the effect of the intervention on happiness was assessed using a paired t-test. Interpolated testing was not associated with a significant increase in happiness during the seminar (restudy mean = 61.54, SD = 19.4; interpolated test mean = 64.64, SD = 19.4; $t(115) = 1.46$ $p = .147$, $d = .16$).

Correlations

Correlations among all measures are presented in Table 5.2, collapsing across experimental conditions. Six participants only attended one of the two seminars, therefore providing a total of 238 sets of results. There were 20 reports of being unwell at the time of completing the seminar.

Table 5.2. Zero-order correlations: Study 9

	1	2	3	4	5	6	7	8	9
1. Test z-score	-								
2. Interest in seminar	0.05	-							
3. People around you	-0.11	**-0.16***	-						
4. Window	-0.12	**-0.21****	**0.19****	-					
5. Social Networks	-0.02	**-0.15***	**0.35****	0.05	-				
6. Background Noise	**-0.22****	**-0.13***	0.07	**0.28****	0.05	-			
7. Other device functions	-0.04	**-0.22****	0.09	0.02	**0.27****	0.02	-		
8. MW	-0.09	**-0.33****	**0.27****	0.12	**0.23****	**0.41****	0.01	-	
9. Happiness	0.00	**0.49****	**-0.14***	**-0.25****	**-0.18****	-0.10	**-0.15***	**-0.31****	-
10. Wellness	-0.02	-0.07	-0.03	0.04	-0.06	-0.04	-0.05	0.01	-0.04

Table 5.2. Pearson Correlation Coefficients are shown. * p < .05, ** p < .01

Relationships between sources of attention failure

The duration of distraction reported for the different sources of distraction were significantly positively correlated to one another in seven of the 15 comparisons (see Table 5.2). Mindwandering correlated significantly with ‘people around you’, ‘social networks’ and ‘background noise’.

Predicting test performance and interest in the seminar

Test performance was only significantly related to one distractor variable (background noise). Mindwandering rates were not found to be significantly associated with test performance. This is in contrast to Szpunar et al. (2013), who found a relationship between mindwandering and test performance in both ‘interpolated testing’ and ‘restudy’ groups. Learning (post-test performance) was, interestingly, also not significantly related to interest in the seminar, in contrast to previous findings (Kane, Smeekens, et al., 2017; Lindquist & McLean, 2011; Unsworth & McMillan, 2013). Interest in the seminar was, however, significantly negatively related to all sources of attention failure (including, most strongly, mindwandering). This is consistent with predictions that task engagement should be negatively associated with mindwandering (Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015).

Happiness and wellness

Happiness displayed a significant negative correlation to five of the six sources of attention failure. The strongest of these was to MW, replicating previous research which has linked mindwandering rates to reduced happiness in everyday environments (see General introduction, Section 6.4, as well as Chapter 2), but happiness was also significantly correlated to the external distractions from ‘people around you’, ‘social Networks’, ‘looking out of the window’ and ‘other device functions’. Happiness was also strongly positively correlated to interest in the seminar. Wellness was not significantly correlated with any other variables.

Factor Analysis

Consistent with the results of Chapters 2 and 4, reports of external distraction from different sources tended to be positively correlated with one another. To further investigate the structure and relationship between our distraction measures, an exploratory factor analysis (EFA) was conducted on distraction reports across both experimental conditions. However, as in this chapter the aim was specifically to compare the effects of an intervention on mindwandering and external distraction, mindwandering was not included in the EFA, which was used to investigate the structure of external distraction reports only. An EFA using a principal-axis factor extraction was used to analyse the factor structure of the distraction sources. For interpretation of the factors (and given that we had already demonstrated that the factors tended to be positively correlated with one another) an oblique (direct oblimin) rotation was used.

The Keyser-Meyer-Olkin measure of sampling adequacy indicated that the sample was adequate (KMO = .536), although the KMO value was in the lower bounds of acceptability (Kaiser, 1974), suggesting a relative lack of shared variance between variables. However, Bartlett's test for sphericity was significant ($X^2(10) = 74.807$, $p < .001$) suggesting that there were sufficient inter-item correlations for EFA. The EFA showed 2 factors with an Eigenvalue of above 1, cumulatively explaining 56.01% of the variance (see Figure 5.3), and the scree plot also showed a slight inflexion after 2 factors.

Figure 5.3. Component loadings (panel A) and scree plot (panel B) for the EFA of the distraction sources reported from the seminars in Study 9

A.

Factor loadings		
	Factor	
	1	2
Social Networks	0.943	
People	0.35	0.171
Other functions	0.293	
Window		0.827
Background Noise		0.334

B.

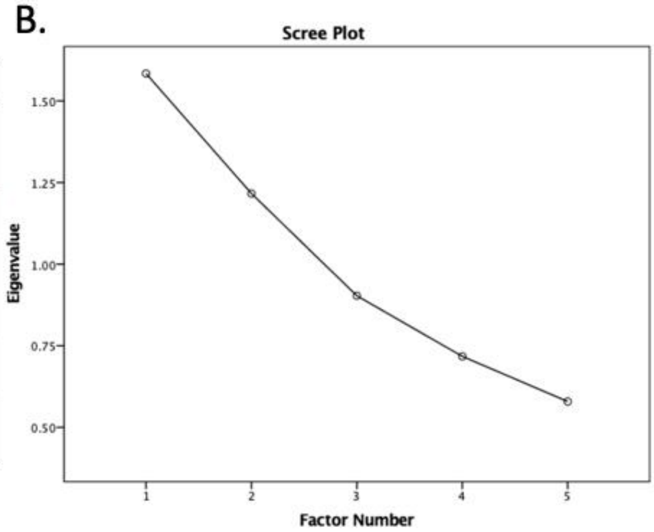

Figure 5.3. Component loadings (panel A) and scree plot (panel B) for the EFA of the distraction sources reported from the seminars in Study 9. N.B. EFA factor loadings for 2 factor solution. Loadings below 0.1 are omitted.

Inspection of the factor loadings showed that ‘social networks’ loaded strongly onto the first factor, whilst ‘looking out of the window’ loaded strongly on the second factor. The remaining sources were inconclusive, loading onto either factor at below the 0.4 practical significance loading value (Stevens, 2009). Given the inconclusive nature of the factor loadings, and concerns regarding the sampling adequacy raised by the KMO test, it was therefore not possible to reduce the dimensionality of the external distraction data into latent variables.

Mindwandering, interpolated testing and test performance: mediation analysis

In common with previous studies, I found that interpolated testing was associated with both improved test scores and reduced mindwandering rates. However, the structure of this relationship has not previously been investigated. A repeated measures design, as employed in this study, allowed me to test whether the reduction in mindwandering reports between conditions mediated the improvement in test scores, using a repeated measures mediation analysis. I therefore conducted a two condition within-subjects mediation analysis using the MEMORE model (Montoya & Hayes, 2017). MEMORE can be used to estimate the total (c), direct (c'), and indirect (ab) effects of the testing intervention on test scores through mindwandering. The total effect of the intervention on test z-scores was significant, as was the direct effect of the intervention when discounting the effect of mindwandering (see Figure 5.4). Bootstrapping (10,000 samples) was used to construct bias-corrected 95% confidence intervals for size of the effect of test condition on z-scores indirectly via mindwandering duration. The confidence interval for the indirect effect included zero (-0.086 to 0.022) indicating that there was not a significant mediation.

Figure 5.4. Within-subjects mediation analysis of the influence of changes in mindwandering duration on changes in test performance as a function of test condition

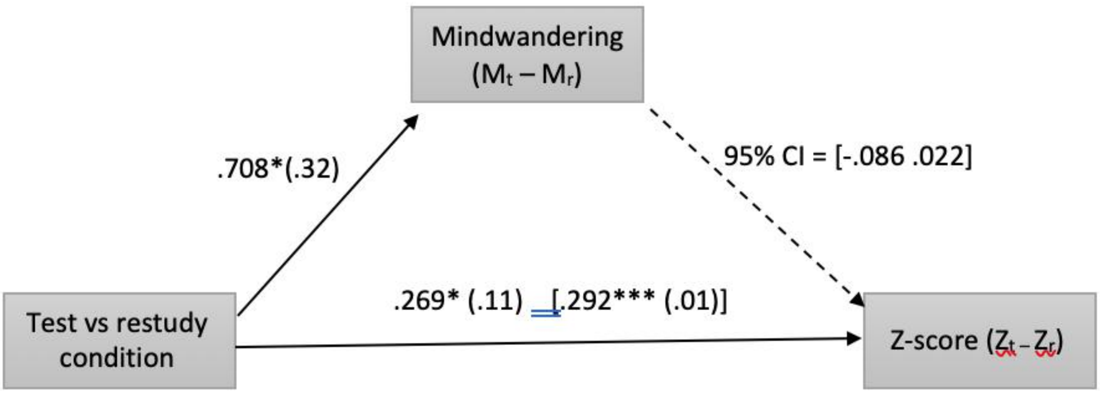

Figure 5.4. Within-subjects mediation analysis of the influence of changes in mindwandering duration on changes in test performance as a function of test condition. Unstandardized coefficients are presented with standard errors in brackets. Total effect is shown in square brackets. M_t = MW in test

condition. M_r = mindwandering in restudy condition. Z_t = Z-score in test condition. Z_r = Z-score in restudy condition. Solid lines = significant effect. Dashed lines = insignificant effect.

Thus, the effect of the intervention on mindwandering was not found to be a significant mediating factor in the change in test performance between conditions. The effect of the testing intervention on mindwandering appears to have been relatively independent of the effect it had on learning. This novel finding, which has interesting implications for the theoretical understanding of the effects of interpolated testing, especially the 'facilitation of attentive processing' account, will be examined further in the chapter discussion.

Chapter Summary

The results presented in this chapter expand on previous research into interpolated testing effects by demonstrating that the beneficial effects of interpolated testing for learning can be observed in a novel, applied educational setting - small group teaching sessions. In addition, the results expand on the findings of Chapters 2 and 4, further demonstrating positive correlations between mindwandering and various external distractions. However, when using an intervention theorized to facilitate attentive processing in an educational setting, this close relationship did not translate into common effects on both constructs. Whereas mindwandering was significantly reduced during 'test' compared to 'restudy' seminars, external distractions were not. However, the ANOVA comparison of the effects of the testing condition between mindwandering and external distraction was non-significant, although suggestive. Further investigation will therefore be needed to reveal more conclusively whether educational interventions of this kind may have different effects on mindwandering and external distraction. Furthermore, although both mindwandering and learning were significantly affected by the testing intervention, a mediation analysis revealed that these appear to be relatively independent effects, as the change in mindwandering rates did not mediate the change in test scores. These findings provide insight into the relationship between mindwandering and external distraction, and the potential mechanisms of interpolated testing effects.

An important finding from the present results is the demonstration that the forward effects of testing on learning can be demonstrated in a live educational setting. Students performed significantly better on the final test of learning after their ‘test’ seminar than after their ‘restudy’ seminar. The benefits of interpolated testing for the learning of complex academic material have previously been demonstrated in the context of video lectures (Jing et al., 2016; Szpunar et al., 2014, 2013; Yue, Soderstrom, & Bjork, 2015) and for the learning and comprehension of text passages (Healy, Jones, Lalchandani, & Tack, 2017; Wissman et al., 2011; Zhou, Yang, Cheng, & Ma, 2015). Interpolated testing has also previously been associated with a significant reduction in mindwandering reports (Szpunar et al., 2013; 2014). However, the present results are the first to demonstrate the beneficial forward effects of interpolated testing in a live teaching session (identified by Yang et al., 2018, as an important future direction for research on the forward testing effect).

Furthermore, the present results also raise the possibility that the effects of testing on learning and their effects on mindwandering may be, at least partially, separable. My results above examined this relationship more explicitly than has been previously performed, using a repeated measures mediation analysis. Changes in mindwandering rates did not significantly mediate the changes in test performance between conditions, thus suggesting that the effect of the intervention on each participant’s learning was not simply the result of improvements in attentive processing. The relative independence of these effects in these results suggests that a general facilitation of attentive processing (Szpunar, 2017) is unlikely to entirely account for the effects of interpolated testing on both learning and mindwandering. I note, however, that this relationship might be expected to be stronger in environments with higher baseline mindwandering rates. The present results build on indirect results which have also suggested that these effects may be separable. Jing et al. (2016) found that although the testing group performed better on the final cumulative test, there were no differences between groups in the level of mindwandering reported in response to the probe questions. Szpunar et al. (2013) also reported no interaction of the regression slopes for the relation of mindwandering to learning between testing and restudy conditions, suggesting that although testing reduced mindwandering and increased learning, it did not affect the relative influence of mindwandering on learning. Instead it seems more likely that the effects of interpolated testing on learning and attention arise at least partially independently, as a result of a number of mechanisms being activated concurrently.

Chapter 6

General discussion

6.1. Overview of findings

The present thesis provides new theoretical insights into the link between mindwandering and external distraction, two ubiquitous features of mental life which can have many deleterious psychological and behavioral consequences, as well as between these attention lapses and mood. The thesis also advances knowledge of the application of experimental findings on attention to real-life situations, most notably educational settings. Specifically, factor analysis of mindwandering and distraction reports collected in everyday environments (including educational settings) suggested a single construct underlying attention lapses from both various external sources of distraction and, importantly, mindwandering too (Chapters 2 and 4). Reports of attention lapses were also correlated with reduced levels of happiness (Chapters 2, 4, 5). This association with happiness was most consistent in the case of mindwandering, replicating previous research findings, but was also found in the case of distractibility by some external sources, extending previous attention research on distraction and mood to a healthy range of mood in non-clinical samples. Methodologically, through the collection of distraction duration reports, this thesis also establishes a replicable tool for the measurement of the self-reported duration of everyday distraction and mindwandering experiences, which complements findings from other measurement methods (Chapters 2, 4, 5). The research reported in this thesis also suggests some of the experimental correlates of such real-world experiences of attention lapses, demonstrating that attention task performance can predict distraction in educational environments (at least under some circumstances), in both adult and adolescent samples. These findings hold when controlling for a range of other variables such as interest in the topic and general intelligence (Chapters 3-4). However, developmental differences in task performance (as revealed in Chapter 3) may be important in determining which performance measures act as correlates of real-world distractibility. Specifically, while distractor interference on task response times was found to be predictive of real-world distraction in both adult and adolescent samples, response variability was also a predictor for adolescent, but not adult, participants (Chapter 4). Methods to improve attention focus were also examined. Increased perceptual load in an experimental task significantly modulated distraction levels in adults, thus replicating previous work and extending it to the case of reduced processing of distractor faces at fixation. However, perceptual load did not modulate distraction levels in adolescents, though it did affect their response variability (Chapter 3). The experience of distraction was not affected by interpolated testing in university lessons, however mindwandering was reduced and recall improved (Chapter 5). Next, I discuss all these findings in greater detail and outline their implications for our understanding of the relationship between mindwandering, external distraction and mood in everyday settings, changes in attention focus abilities during adolescence, and methods which might be used both to predict and mitigate such experiences.

6.2. Relationship between mindwandering and external distraction

The present thesis establishes that mindwandering durations tend to be significantly associated with higher levels of irrelevant distraction from a variety of external sources present in everyday life and in educational environments (Chapters 2, 4, 5). Indeed, the duration of irrelevant distraction reported could predict the duration of mindwandering during everyday activities (Chapter 2), including when happiness as well as wellness, age, gender, city size and regional average income were controlled for. Moreover, in four out of five cases reported in the thesis, exploratory factor analyses of all distraction reports (including mindwandering) produced a clear one-factor solution, onto which all sources of distraction, importantly including mindwandering, loaded significantly (Chapters 2, 4). In the remaining case (Study 8), I note that the inconclusive EFA result was not due to mindwandering forming a separate factor, but rather due to a reduction in the strength of relationship between all distraction sources. Additional analyses on the largest sample studied in the present thesis (Chapter 2) suggested that mindwandering was not simply included in the distraction factor because it was a single measure against multiple measures of external distraction. Another single factor (age), which also correlated with external distractions, was not incorporated into a single factor, suggesting that data was sensitive to reveal more than one factor, even in the absence of multiple measures of the mindwandering variable. The finding of significant positive correlations between a broad range of task-irrelevant external distractions and mindwandering support the hypothesis that task-irrelevance plays a critical role in the positive relationship of distraction and mindwandering (although I note here that I did not examine this relationship in the context of task-relevant distraction as well). Forster and Lavie (2014) found that the very same distractor stimuli correlated significantly with mindwandering when they were task-irrelevant, but not when they were task-relevant (congruent or incongruent with the target response). Measuring distractions in the rich daily life environment in the present thesis, specifically defined as diversions from people's main focus, allowed this thesis to specifically examine distraction by task-irrelevant stimuli.

The EFA finding of a common factor shared across mindwandering and the diverse forms of irrelevant daily-life distractions, provides further generalisation of the hypothesis of a common underlying attention mechanism (see also Forster & Lavie, 2014; 2016), and supplements the 'Executive Failure' theory of mindwandering (McVay & Kane, 2010), in which mindwandering in daily life represents a failure to proactively sustain attention towards task-relevant stimuli, in the same manner as external distraction. I note, however, that in the real world a state of reduced attention focus could either be due to an executive control failure to maintain focus on the current task or activity goal (e.g. Lavie 2000; 2010; Lavie et al. 2004), or, in some cases, could be intentional (e.g. 'allowing' one's focus to shift away during boring tasks; Seli, Risko, & Smilek, 2016). This would not represent a failure of executive control but rather setting additional task-unrelated goals (e.g. to check your mobile phone for new messages). Although the measure used did not explicitly interrogate participants about their intentions, the relationship between mindwandering and distraction was established across participants reporting being engaged in a primary activity in an educational setting (Chapters 4, 5). It was also established across participants involved in a social activity who are less likely to wish to distract themselves from their social engagement (Chapter 2). In addition, it is notable that the findings that different types of irrelevant distraction can predict mindwandering, including both unpleasant sources of distraction which are unlikely to be attractive for a deliberate shift of attention (e.g. construction noise), and more pleasant sources (e.g. background music) or those that can provide another task-unrelated goal (such as social media posts or other apps on mobile devices), which may involve an intentional shift of attention. This suggests that both cases of intentional and unintentional disengagement from the current attention focus (see Seli, Carriere, & Smilek, 2014; Seli et al., 2016), share a close relationship with mindwandering.

The findings of the present thesis generalize previous research on similarities and differences between mindwandering and distraction, beyond task-irrelevant distractions reported in controlled laboratory settings (e.g. Stawarczyk et al., 2014; Stawarczyk, Majerus, Maj, et al., 2011; Stawarczyk, Majerus, Maquet, et al., 2011), and beyond irrelevant distractions experienced during college (e.g. Unsworth, Brewer, et al., 2012; Unsworth, McMillan, et al., 2012), as well as across a wide range of ages, including adolescent school students. The findings also clarify that the relationship between mindwandering and external distractions persists in educational settings. Importantly, the present research extends previous research that has typically measured the frequency of mindwandering and distraction reports to address the relationship between the duration of mindwandering and distraction episodes, in further support of the hypothesis that an attention disengagement state should lead to longer durations of both types of attention failures.

6.2.1. Alternative accounts for the relationship between mindwandering and external distraction: meta-awareness, current concerns and time perception

The diverse distractions measured resulted in a significant variation in the average duration of distraction reported across the various experiments reported, yet in most cases these distraction durations remained significantly correlated with the duration of mindwandering. The finding of a consistent positive association between mindwandering and the different types of external distraction reported, despite the large variation in the durations of different distractions, is important when considering the reliance of mindwandering reports on meta-awareness. Although I note that conscious awareness of being distracted is equally required for measures of both mindwandering and external distraction (given that both are based on subjective reports), one could perhaps argue that reporting mindwandering relies more on meta-awareness abilities compared to reports about being distracted from an external stimulus (for example for distractor stimuli that provoke a strong sensory sensation, e.g. a loud noise). If this were the case, an alternative account to our hypothesis of a state of reduced attention focus mediating the association of the two could be raised in terms of the awareness factor involved in subjective reports. Specifically, one could propose that the relatively lower meta-awareness of mindwandering may result in a person relying on their (sometimes clearer) awareness of being distracted by an external stimulus in their mindwandering reports. As such, we might therefore expect that the strength of the relationship to mindwandering is a function of the reported duration of an external distraction. This does not seem to be the case. For example, in Chapter 2 the duration of distraction by 'construction noise' was amongst the shortest of the reported distractions (4% and 6% on average in Study 1 and Study 2 respectively), while the duration of distraction by mobile devices reported was 17% of the time in both studies, nevertheless they were both positively correlated with mindwandering. Similarly, distraction by adverts was reported to last 8% (Study 1) and 10% (Study 2) of the time, yet this was significantly predictive of mindwandering duration in the regression model for both studies. In contrast, 'strangers', one of the most reported distractions (in terms of both duration and the number of people reporting it in both studies) was only predictive of mindwandering rates in Study 1. Similarly, in Studies 7 and 8 (Chapter 4), 'people around you' was the most reported distraction source in both experiments, but did not correlate significantly to mindwandering, whereas all other external distractions in Study 7, for example, did.

Equally, reports of mindwandering do not seem to have been based on the durations of external distraction episodes, as might also be expected in the case of a failure of meta-awareness of mindwandering. As an example, a participant in Chapter 2's studies who was aware that they had diverted their attention from their current focus to an advertising poster for a short duration might then decide to report a similarly short duration of mindwandering as well. In this case we would expect a similar average duration for mindwandering and adverts, however mindwandering duration was in fact close to double the duration reported for distraction by adverts. Nor could the sum duration of external distraction reported account for the 17% duration reported for mindwandering, given that it is both unclear how a person would sum up partly overlapping experiences of distraction, and that a straight sum amounts to a far longer duration than the reported duration for mindwandering. Finally, in Chapter 2 the modal duration for all external distractions was 0, while for mindwandering the modal duration was longer (10% in Study 1 and 50% in Study 2), again suggesting that mindwandering reports are not being based on meta-awareness of the experiences of external distraction.

In addition, while it can be easily imagined how being distracted by some sources (such as an advert) might trigger mindwandering related to the distraction, this seems far less likely for some of the other reported distractions (e.g. 'construction noise' in Studies 1 and 2, or 'looking out of the window' in Studies 6-9). One widely accepted factor in the occurrence of mindwandering is the current concerns hypothesis (Klinger, 1978; see also McVay & Kane, 2010; Smallwood & Schooler, 2006), which suggests that the goals, wishes, and desires of an individual may lead to certain thoughts having greater incentive value than incoming perceptual information. Some external stimuli are more likely to tap into current concerns (e.g. advertising will often be designed to do so, as will content on social media), whilst others are less likely to relate to current goals and wishes etc. (e.g. construction noise, classroom displays or looking out of the window). Despite this, the relationship found between duration of mindwandering and external distractions persists across the sampled distractions. This suggests that the relationship is not simply the result of mindwandering being triggered by external stimuli which relate to, and perhaps activate, current concerns. In addition, there is no clear reason why the duration of an external distraction should correlate significantly with the duration of any mindwandering episode that they might trigger. For example, if external distraction from construction noise were to trigger mindwandering about how the building might look when it is finally built, there seems to be little reason to suppose that a longer noise duration would lead to a longer train of thought about the finished building.

When measuring the duration of attention failure, time perception abilities may also play a role in the accurate measurement of distraction. As discussed above, all report-based measures of distraction and mindwandering (whether of frequency or duration) require the subject's conscious meta-awareness that they are either being distracted (e.g. by some task-irrelevant stimulus) or that their mind has wandered off, however it is clear that providing duration estimations is also subject to a person's time perception and estimation abilities (e.g. Eagleman, 2008, for review). Importantly, none of the results in the present thesis rely on the absolute levels of distraction duration reported, or on the presence or duration of specific distractors. Instead the results demonstrate the relationship between distraction and mindwandering durations to each other, and to levels of happiness. I find that these relationships persist despite the variation in absolute levels of different distractions within and across individuals (Chapters 2, 4, 5). The patterns in the results also hold when only shorter (up to 5 minutes) durations are reported (Study 1), which suffer less from reduced ability to estimate time durations compared to longer durations. Overall, the study of frequency and duration of attention failure are complementary research strands, both of which will need to be pursued for a full understanding of the experience and consequences of different attention states.

Overall, I argue that the variability in distractor stimuli, reported durations and number of people reporting each (as well as the likely differences in each individual's current concerns across the samples taken), makes it highly unlikely that the correlation between external distraction and mindwandering is driven by mindwandering duration reports being based on the duration of distraction by the external stimuli. Instead the findings are suggestive of a shared mechanism of reduced attention focus leading to greater durations of both mindwandering and external distraction, although this conclusion requires a more direct investigation. An attention focus account could be strengthened in further studies by the inclusion of a separate measure of attentional focus, independent of distraction reports. This would allow for the measurement of distraction and mindwandering during different states of attention focus, and therefore the differentiation of attention lapses due to reduced attention focus (as compared to those resulting from particularly distracting environments, for example).

6.2.2. Distinctions between mindwandering and external distraction

It should be noted that the finding of the present thesis – that mindwandering and external distraction can often best be explained by a single underlying construct (Chapters 2, 4) – does not of course imply that these are isomorphic. Significant differences should remain between the source (being internally, versus externally, generated), the content (thoughts can be entirely abstract, while external distractions are always related to an external stimulus by definition) and the underlying neural correlates. Visual cortex regions related to distractor stimulus perception have been shown to be involved in external distraction (e.g. de Fockert, Rees, Frith, & Lavie, 2001; Rees, Frith, & Lavie, 1997), while the default mode network (DMN) is known to be associated with mindwandering (Mason et al., 2007), and some DMN regions (medial prefrontal cortex, the posterior cingulate cortex/precuneus, and left middle temporal gyrus) specifically show greater activity during mindwandering compared to external distraction (Stawarczyk, Majerus, Maquet, et al., 2011). Mindwandering has also been found to be associated with a larger pre-trial pupil dilation, compared to external distraction during a vigilance task (Unsworth & Robison, 2016). Overall, despite these differences between mindwandering and external distraction, the correlations between mindwandering and external distraction reported in the present thesis were found here to be consistent, and replicable, in a range of environments and during a wide variety of everyday distraction sources and activities including, specifically, a variety of educational settings. Despite this, however, when using an intervention theorised to facilitate attentive processing in an educational setting, this close relationship did not translate into common effects on both constructs (Chapter 5). Whereas mindwandering was significantly reduced during 'test' compared to 'restudy' seminars, external distractions were not. This could perhaps be due to stronger capture of attention by external sources in this setting. Further investigation will therefore be needed to reveal more conclusively whether educational interventions of this kind may have different effects on mindwandering and external distraction.

It is also interesting to consider the situations in which the EFA produced less consistent patterns of underlying relationships between mindwandering and external distraction, compared to previous datasets reported in this thesis. One example is Study 8 in Chapter 4. Distraction reports from this experiment revealed that three of the external distraction sources ('looking out of the window', 'background noise' and 'displays'; see Figure 4.5) were reported as distracting participants for only very short durations of time on average (2.5% of the time or less). These items were all reported for nearly twice as long (or more) in classrooms (See Figure 4.3). Thus, it is possible that the distraction checklist items, which were created in consultation with secondary school teachers, were not all equally applicable as to a lecture environment as they had been to classroom (Study 7) or study (Study 6) environments. The complexity and variety of everyday environments, even within educational settings, may mean that specific distraction sources are difficult to predict. It should be stressed that the hypotheses tested in the current thesis do not rely on the presence or absence of any one specific source of distraction. Thus, whilst other future work may attempt to more accurately determine the most prevalent sources of distraction between different settings (and between different individuals), this thesis demonstrates that a generic distraction measurement tool can be used across a range of environments with multiple different distraction sources.

6.2.3. Duration and frequency in reports of attention states

One important difference between the inattention findings in the present thesis and most previous research into attention (as well as mood; see section 6.4 below) is that participants here provided a measure of duration of distraction and mindwandering, rather than frequency. As discussed in the General Introduction (Section 1.5), probe questions which collect frequency of responses are often limited by ignoring the inter-probe interval, and often preclude the concurrent reporting of mindwandering and external distraction. The results presented in this thesis provide two new pieces of evidence in this regard. Firstly, longer proportional durations (of the total task or activity) of mindwandering are positively correlated with longer proportional durations of external distraction. This provides a new insight into the relationship between the duration of periods of distraction and mindwandering in everyday life, demonstrating that a state in which external distraction is prevalent is also likely to involve increased mindwandering. Secondly, the results link longer proportional durations of distraction and mindwandering to reduced mood. These findings complement the results of previous investigations which have found a relationship between the frequency of mindwandering and mood (Killingsworth & Gilbert, 2010; Franklin et al., 2013), and extend these both to duration of mindwandering episodes and to external distractions.

An interesting discrepancy in the duration results presented in the present thesis is that the duration estimates from participants in educational environments are all between 5% and 9% duration (Chapters 4, 5). These figures are less than half of the proportional durations reported from participants sampled in everyday life (Chapter 2). This does not seem to fit the pattern from probe investigations which have measured the frequency of mindwandering, in which rates have generally been found to be similar in educational environments and everyday life settings. For example, in ‘untested’ lecture settings (including both video and real-life lectures), mindwandering has commonly been reported in response to between 30% and 45% of probe questions (Hollis & Was, 2016; Kane, Smeekens, et al., 2017; Lindquist & McLean, 2011; Risko et al., 2012; Szpunar et al., 2014, 2013; Wammes, Boucher, et al., 2016; Wammes, Seli, et al., 2016), the same range as has been reported for probe studies in everyday life (Kane, Gross, et al., 2017; Killingsworth & Gilbert, 2010; Poerio et al., 2013). Smallwood (2013a) distinguishes between the ‘why’ and the ‘how’ of mindwandering, in other words between processes related to the occurrence of mindwandering, as distinct from those related to the process itself. Thus, some influential theories of mindwandering, such as the current concerns hypothesis (Klinger, 1978; Smallwood & Schooler, 2006) or the executive failure theory of mindwandering (McVay & Kane, 2010) primarily provide predictions regarding the occurrence of mindwandering episodes, rather than explaining the ongoing process by which the episode may be maintained with continuity, or indeed the process by which an episode may be disrupted. The results from the present thesis, in combination with previous probe studies of mindwandering frequency, suggest that mindwandering episodes may be being produced at the same rate in both educational and everyday settings, but that the educational settings have more mechanisms to disrupt them being maintained for a longer duration. Naturally, it is difficult to draw direct comparisons between frequency measures of mindwandering using probe questions and measures of duration. A duration estimate of 7% (Chapter 5) and a positive mindwandering report in response to 40% of probe questions (as reported by Szpunar, Khan and Schachter, 2013) are not necessarily incompatible. Indeed, in the case of relatively frequent but short-lived bouts of mindwandering both results could describe the same set of data. At the very least, however, such discrepancies illustrate the need for measures that are able to provide insights into the ongoing process of attention lapses, as well as simply the frequency of their occurrence.

The present results show a relationship between states of mindwandering and external distraction over relatively short timescales (while a minority of participants in Chapters 2 and 4 reported over longer time periods, the mean time period over which distractions were reported across all studies was under 1 hour). It is possible, however, that the constructs may be more dissociable at general trait levels. For example, in a recent questionnaire of 'attentional style' which specifically aimed to differentiate between externally and internally oriented 'attention styles' (Van Calster, D'Argembeau, & Majerus, 2018), responses to questions targeting mindwandering and external distraction loaded onto separate factors. Such a difference at a trait level could perhaps be driven by other stable factors such as working memory capacity, with which mindwandering and external distraction have also been found to sometimes display a different relationship to one another. For example, higher working memory capacity has been positively correlated with mindwandering frequency, at least in tasks that are fairly undemanding on working memory executive control resources (Levinson, Smallwood, & Davidson, 2012). In contrast, in tasks involving a greater demand on executive control, higher working memory capacity has been negatively correlated to mindwandering frequency (e.g. Kane et al., 2007; Kane, Gross, et al., 2017; McVay & Kane, 2009; 2010), a relationship that has also been reported for external distractions (Stawarczyk et al., 2014), potentially reflecting failures of attentional control (e.g. Lavie et al. 2004). Thus, the relationship between attention failure and working memory capacity is complex and is likely to depend on an interaction between an individual's working memory capacity and the level to which the current task places demands on working memory executive control resources.

6.3. External distraction, mindwandering and mood

The findings presented in this thesis also extend into the field of mood. Reports of attention lapses were correlated with reduced levels of happiness (Chapters 2, 4, 5). In Study 1, for example, both mindwandering and task-irrelevant distraction from mobile phones were negatively associated with the level of happiness reported. Study 2 replicated the negative correlations with happiness for mindwandering and mobile devices, though once variance shared with control variables and all other distractions was accounted for in a multiple regression, mobile devices were no longer associated with reduced levels of happiness. Instead, distractions from adverts and background music significantly predicted reduced happiness. In Study 7 (using an adolescent sample), in addition to mindwandering, 'people around you', 'social networks', looking out of the window', 'background noise' and 'other functions on your device/tablet' were all significantly correlated to reduced mood. A latent variable formed from all distraction sources in this experiment was a significant predictor of reduced mood (Chapter 4). In Study 9, using a young adult sample during university seminars, 'people around you', 'social networks', 'looking out of the window' and 'other device functions' were all significantly correlated to reduced mood (Chapter 5). While the negative association between mindwandering and mood appeared consistently throughout the data presented in the present thesis, the associations between different external distraction durations and reduced mood were somewhat less consistent. Partly this might be attributable to external distraction reports being split by different sources, whereas mindwandering reports were reported as a single category, reducing the power of each individual source to predict mood. It is therefore plausible that in different settings different specific distraction sources may have stronger relationships to mood, based either on their prevalence or their ability to interfere with the ongoing task.

This data suggests that in addition to the well-documented effects on task-performance, some failures of attention focus may have emotional repercussions. The relationship established has been found across a wide range of mood, spanning both very low and very high scores (from 0-100) and with overall healthy mood averages all ranging around the UK mean (range of mean happiness scores for all samples in the present thesis = 60-75, UK mean happiness = 68.2; Helliwell, Layard & Sachs, 2017). The results thus suggest that the former associations between mood and susceptibility to irrelevant distractions (e.g. Cornblatt et al., 1989; Gohier et al., 2009; Mialet, Pope, & Yurgelun-Todd, 1996) or mindwandering (e.g. Deng et al., 2014; Mrazek et al., 2013; Smallwood et al., 2007; Stawarczyk et al., 2012) established for low mood states and depression represent one end of a wider-held relationship established across the full spectrum here. I note that in addition to a range of different educational settings and tasks (Chapters 4, 5), these findings were also established across gender, a wide age range (from teenagers to the elderly), and in a variety of everyday activities and contexts (including both outdoor and indoor activities), in six different UK cities and towns of varying population size and regional income (Chapter 2). An individual's state of wellness was found to be a significant predictor of happiness (replicating findings of Røysamb, Tambs, Reichborn-Kjennerud, Neale, & Harris, 2003) and, in addition, 'interest in the topic of study' was a predictor of increased mood ratings (Chapter 4, 5). However, the findings held when wellness, interest, and all of the aforementioned background variables were specifically controlled for.

6.3.1. Age-related differences

One interesting pattern that appears worthy of further investigation, however, is that samples which were, on average, younger, reported more negative correlations between a greater number of external distraction sources and mood (Chapters 2, 4, 5). For example, in Chapter 2 a sample of mean age 31.7 (Study 1) reported only a significant correlation between mobile device distraction and happiness, whereas a replication study with a mean age of 16.8 reported three external distractions as being significantly associated with reduced mood. Similarly, in Chapter 4, adolescent participants (Study 7) reported significant negative correlations with happiness for five of the six external distraction sources, as well as with mindwandering. In contrast, adult participants (mean age 26.1) in Study 6 displayed no significant correlations between any external distraction source and happiness (although, again, mindwandering was correlated with reduced happiness). These discrepancies could perhaps be due to some difference in the specific educational environments and activities between the two studies (classroom learning vs personal study). It may also be the different age groups might have different relationships with particular distraction sources. For example, the weaker relationship between mobile devices as a unique predictor of happiness in both Study 2 and Study 9 might be attributed to the younger age of the study sample. It is possible that younger samples (including adolescences and younger adults) have fewer negative associations with distraction by mobile devices than do older samples, leading to a weaker relationship with happiness. However, the results may also reflect the increased emotional arousability associated with puberty and adolescence (Steinberg, 2005), whereby reduced regulation of arousal and mood states (e.g. Heller & Casey, 2016; R. W. Larson et al., 2002; Steinberg, 2005) leads to lapses in attention focus, or variations in interest in the topic of study, having greater emotional impacts than in adults. Future research specifically focusing on age, distraction and happiness would be important to establish the role of age in this relationship.

In light of this, it is also interesting that while there is a relationship between age and the levels of reported attention failures (Chapter 2), replicating previous research with adolescents (A. O. Cohen et al., 2016; Olesen et al., 2007; Stawarczyk et al., 2014), age and happiness were not found to correlate significantly in the present thesis (Chapters 2, 4). In addition, participants across all age groups reported relationships between distraction durations and reduced happiness (Chapters 2, 4, 5). One hypothesis to explain these apparently discrepant results is that there may be a varying 'baseline' of level of distractibility which changes with age, a baseline which in turn only relates to happiness when exceeded. This idea merits further investigation.

It can also be noted that a similar age-related pattern appears in the relationship between interest in the topic and mood. A significant positive correlation between interest and mood was reported in Study 7 (mean age = 14.7, $r = .62$), Study 9 (mean age = 20.3; $r = .49$) and Study 8 (mean age = 21.5, $r = .37$). This relationship was not found in Study 6 (mean age = 25.9, $r = .18$). One possibility might have been that the freedom to choose material for private study (as was the case for participants in Study 6) led to a generally higher, and less variable, level of interest in the topic. However, as mean ratings of interest in the study session in Study 6 were comparable to those reported for the classroom lessons in Study 7, and lower than those reported for the lecture in Study 8, the freedom to choose material does not seem to have led to higher mean interest scores. Another possibility is that age is mediating the relationship between interest and mood. Although this remains to be tested directly, the linear relationship between the age of the samples in the present thesis and the strength of the relationship between interest and mood is consistent with such a hypothesis. Although emotional variability declines in late adolescence and for most individuals this variability stabilizes in early adulthood (Larson et al., 2002), 'adolescent' behaviour patterns in relation to emotion may still be present even up to the age of 21 (Cohen et al., 2018), compared to adults in their mid-twenties.

Thus, the data in this thesis are consistent with an explanation where reduced emotional regulation in adolescent and younger adult populations lead to a range of factors (including external distractions, but also, for example, interest in the current activity) possessing stronger relationships to mood than might be present in older populations. It is interesting to note that mindwandering does not seem to clearly follow this pattern, displaying significant negative associations with mood across all samples taken, and no obvious trends in this relationship with regard to the age of the sample.

6.3.2. Directions of causality between attention lapses and mood

With respect to any causal inference regarding the relationship between attention focus and mood, the findings of this thesis are open to two plausible interpretations. Previous research on the effects of induced low levels of mood supports a potential interpretation in terms of lower mood causing vulnerability to distraction (Pacheco-Unguetti & Parmentier, 2014) and mindwandering (Ruby, Smallwood, Engen, & Singer, 2013; Smallwood, Fitzgerald, Miles, & Phillips, 2009; Smallwood et al., 2007). However, Stawarczyk, Majerus, & D'Argembeau (2013) demonstrated that manipulations of induced negative mood can result in increased mindwandering, which in turn predicted subsequent negative affect (see also Poerio, Totterdell & Miles, 2013), thus suggesting a bidirectional relationship. It remains unclear whether these effects extend to the full range of mood, for example whether induced positive mood would have similar effects on both mindwandering and mobile phone distractions. These are interesting topics for further research.

An alternative causal interpretation comes from Killingsworth and Gilbert (2010) findings that in a time-lag analysis on their repeated measures data (of both mindwandering and a wide range of daily life mood), happiness tended to be lower in the sampling period after, rather than before, reports of mindwandering. This suggests that mindwandering can cause (as well as maintain, as per Stawarczyk et al., 2013) a reduced level of happiness. The extension of the association of mindwandering and lower levels of happiness to external distractions may suggest that attention focus can play a role in creating, or at least maintaining, a higher level of happiness. This interpretation is also consistent with previous suggestions that mindfulness can induce a better sense of well-being (Brown & Ryan, 2003). Future research using repeated sampling will be necessary in order to further establish the important and potentially causal relationship between attention focus and happiness.

6.3.3. The role of social interaction in attention lapses and mood

An interesting further question raised by the results of this thesis concerns the relationship between distraction, mindwandering and mood in relation to social interaction. The present findings demonstrated that social interaction is related to increased happiness (Chapter 2), and conversely that aloneness is related to reduced happiness, in replication of previous research (e.g. Argyle & Crossland, 1987; Burt, 1987; Csikszentmihalyi & Larson, 2014; Diener, 2000; Lu, 1999). Little research however has explored whether being engaged in a social interaction has any bearing on mindwandering or distraction, and the subsequent relationship between these constructs and happiness. In one example, Kane, Gross, et al., (2017) asked college students to repeatedly complete a detailed experience sampling questionnaire on the content of their off-task thoughts, as well as providing information on their current efforts to concentrate, activity and emotional context. They found that social interaction (vs. aloneness) was not associated with a change in the level of mindwandering, while in the present study social interaction was significantly associated with reduced mindwandering levels (as well as reduced durations of mobile phone distractions) in the wider population sampled. More importantly, Kane, Gross, et al. did not examine whether the social context affected the relationship between mindwandering and mood or reports of external distractions. Study 1 demonstrated that social engagement does play a role in the relationship between mindwandering and reduced levels of happiness (mindwandering no longer predicted happiness in a regression model when social engagement was controlled for), but mobile phone distractions remained a significant predictor of happiness. These results suggest that social interaction is a potentially important moderator to be taken into account in future studies.

Importantly, the relationship between mindwandering and external distractions was found across both conditions of aloneness and social interaction (Chapter 2). This is an important extension of previous laboratory research since the nature of social engagement activity is rather different to laboratory task engagement. As mentioned above, social interaction is likely to involve reduced likelihood of intentional mindwandering and distraction compared to during a laboratory task. Another notable difference may be in the degree of cognitive challenge provided by the focal task; a social activity such as chatting with a friend is likely to be somewhat less demanding on executive control compared to most laboratory tests of attention, while at the same time such social interaction can be more attention-engaging overall due to a higher level of interest. Reduced executive control is expected to lead to both increased mindwandering and irrelevant distractions, while increased demand on attention is expected to reduce both (e.g. Forster & Lavie, 2009). Different social interactions would also involve different demands on both attention and executive control (for example, work lunch with your boss is likely to increase the demand on executive control). The present findings that the relationship between mindwandering and external distractions, and their link to mood, persists in social engagement despite this great variability in the demands on cognitive functions provide an important generalisation of previous research.

6.4 Predicting distraction in educational settings

The present thesis establishes that attention task performance can predict distraction in educational environments, at least under some circumstances. Reported levels of distractibility (both from students undertaking a session of private study, and from secondary school pupils after a classroom lesson; Chapter 4, Studies 6 and 7) could be uniquely predicted from attention task measures of irrelevant distractor cost to task performance. In both an adult and an adolescent sample, task performance measures were able to remain significantly predictive of distraction reports when including additional controls (for age, gender, computer use, group work, generalized cognitive abilities and interest in the topic of study). The results thus suggest that a focused attention task measure can provide useful predictions of distraction across different educational settings, and for students across a range of ability and motivation levels. This extends previous findings with adults that have found associations between impairments in performance on the experimental measures of attention control and increases in everyday mindwandering reports (Forster & Lavie, 2014; Unsworth, Brewer, et al., 2012; Unsworth, McMillan, et al., 2012) and adult self-reports of childhood inattentive symptoms (Forster & Lavie, 2016). In school settings, these results are generally consistent with previous results that task-measures of attention can be used to assist ADHD assessments at primary school (Hoerger & Mace, 2006), as well as a previous demonstration that response inhibition of incongruent colour names (in the Stroop colour-naming task) can discriminate between the top and bottom quartiles of attention ratings at school (Das et al., 1992; Papadopulos et al., 2002). However, as these studies also did not control for any of the aforementioned factors, this thesis represents a significant advance on such research. It also extends previous findings which have assessed attention skills through the use of teacher ratings (Breslau et al., 2009; Breslau et al., 2010; Rabiner et al., 2004; Merrell & Tymms, 2001; Merrell et al., 2013; Merrell et al., 2016; Sayal et al., 2015). Instead of relying on teacher ratings alone, the inclusion of academic, observational, and desk measures has been shown to provide a stronger discriminator between clinical and non-clinical attention problems (Atkins et al., 1985). Thus, a task-based measure of distractibility in addition to these tools would potentially allow for more accurate and comprehensive assessment of focused attention in the classroom. Further research may therefore focus on extending the present findings to assess the predictive value of using a range of measurements of inattention within educational settings.

It is interesting to note that although the distractors in the experimental task were presented visually, task performance was able to predict distraction from multiple sources, including auditory stimuli. This is consistent with previous evidence that visual attention (as varied by visual perceptual load) can determine the extent of processing and neural response to unattended (or less attended) task-irrelevant auditory stimuli (Molloy et al., 2015; Molloy, Lavie, & Chait, 2018; Raveh & Lavie, 2015). In addition, selective attention task performance was able to predict classroom distraction, even when controlling for intelligence (Chapter 4, Study 7). This is in line with previous findings that some attention tasks can predict general school attainment (Checa et al., 2008; Checa & Rueda, 2011) even above and beyond intelligence (Steinmayr et al., 2010). Steinmayr et al., for example, found that 'quality of sustained attention' (measured as the percentage error rate in a task which required the continuous solving of easy arithmetic problems) incrementally contributed to the prediction of school performance above and beyond intelligence. In university students, attention task performance has also been found to correlate with SAT scores (Unsworth, Brewer, et al., 2012; Unsworth, McMillan, et al., 2012). However, such findings do not inform as to the mechanisms through which such a relationship might be produced. These present findings demonstrate one such potential mechanism, whereby students with reduced selective attention abilities report experiencing increased duration of distraction during everyday learning experiences (Chapter 4). From these results (as well as those of Steinmayr et al., 2010), it is possible that distraction in the educational settings may act as a moderating factor in the relationship between intelligence and school achievement, affecting the extent to which intelligence is able to be used successfully in school and university lessons.

Despite the success in predicting distraction reports in some settings, however, one question arising from the present thesis is why the demonstrated relationship between distractor interference and distraction reports was not observed in every experiment (e.g. Chapter 4, Study 8). It is possible that the lack of a counterbalanced testing order in this experiment (the distraction checklist was always taken first so that participants' recall of the lecture was freshest) may have meant that completing the checklist provided a cue to refocus their attention, especially for those who had been very distracted in the lecture. This might have led to a reduced distractor effect in the experiment. However, the mean percentage distractor interference effect in low load in Study 8 (12.9%) is the same as that found for a similar sample of young adults in Study 6, so this does not appear to support such a 'refocusing' account. I note that, in the present results, it is not only the experimental performance that is not a successful predictor of distraction experiences. The ADHD trait questionnaire was also only significantly correlated to one distraction source ('social networks'). Therefore, neither measure that was hypothesized to predict distractibility did so in this setting. It is possible that for both the ADHD questionnaire and the distractor interference there may have been reduced between-subjects variation (which would reduce the variance available for individual differences effects) because of the sample of students from a relatively high-performing student population. However, at least in the case of distractor effects, the variation in effects in distractor interference in Study 8 (mean distractor interference = 13%, SD = 8) is not reduced in comparison to Study 6 (mean distractor interference = 13%, SD = 9) or Study 7 (mean distractor interference = 9%, SD = 8), in which individual differences *were* predictive of distraction reports. Thus, it is not currently clear what factors might have led to the divergent results in this experiment. Further work predicting distraction states from task performance measures may be required to understand this result further.

6.4.1 Predicting adolescent distraction from response variability

The findings that, in addition to distractor interference on task performance, intra-individual variability was a significant independent predictor of classroom distractibility in adolescents, but not in adult samples (Chapter 4), has notable implications. RT variability has previously been shown to be predictive of distraction in other populations displaying elevated levels of response variability (such as adult ADHD sufferers; Adams et al., 2011; Kofler et al., 2013). This extends findings on the impact of response variability from ADHD to a non-clinical population of adolescents. In this context, it is notable that some recent models of ADHD (e.g. Johnson et al., 2007; O'Connell et al., 2009; Van der Meere, 2010) propose a link between the arousal system and the attention system, whereby hypo-arousal and fluctuating reaction times are related facets of ADHD-related cognitive dysregulation (James, Cheung, Rijsdijk, Asherson, & Kuntsi, 2016). Adolescence is a period of hyper-arousal (Steinberg, 2005), in which emotion and arousal levels are unstable and inconsistent (e.g. Heller & Casey, 2016; Larson et al., 2002). Thus, it is conceivable that the emotional dysregulation associated with this developmental period may also have attentional correlates, in a similar manner to arousal dysregulation theories of ADHD. The present results provide some initial support for such a suggestion by demonstrating that adolescence is a period associated with variable attentional, as well as emotional, states. Future researchers may wish to analyse this hypothesis in more detail.

It is noteworthy that the predictive relationship between RT variability and classroom distractibility was found even when variability was measured on distractor-absent trials only, and that these variables represented relatively orthogonal predictors in a regression model.

Thus, response variability and distractor interference appear to reflect different facets of focused attention, for example variability may reflect more general levels of executive control over task-focused attention. Indeed, executive cognitive control is known to be a distinct ('late selection') mechanism, dissociable from 'early selection' mechanisms of focused attention (Lavie, Hirst, de Fockert & Viding, 2004), which may therefore follow different developmental trajectories. This is also consistent with neuroimaging findings that greater levels of response variability are associated with reduced correlation between task-related activity and deactivation of the default mode network (Esterman, Rosenberg, & Noonan, 2014; Weissman, Roberts, Visscher, & Woldorff, 2006; see Castellanos & Aoki, 2016 for a review). The interplay between DMN and networks involved in top-down executive control was found in these studies to coincide with fluctuations in response time variability, thus giving rise to a hypothesis that DMN activity may interfere with behavioural responses, leading to response patterns such as those seen in ADHD (Sonuga-Barke & Castellanos, 2007). Thus, response variability in adolescents (and its predictive relationship with distraction reports) may represent a failure to regulate and control spontaneous neural fluctuations arising in the default mode network, in relation to the task demands on focused attention (Kelly, Uddin, Biswal, Castellanos, & Milham, 2008; Sonuga-Barke & Castellanos, 2007). The relationship between such fluctuations and the behavioural and emotional fluctuations previously documented for adolescents (Buchanan, Eccles, & Becker, 1992; R. W. Larson et al., 2002; Schmid, Stadler, Dirk, Fiege, & Gawrilow, 2016) remains to be clarified, however.

6.5 Performance on modified task-based measures of irrelevant distraction in adolescents and adults

6.5.1 Response Variability

The results reported in this thesis found that there were significant differences between adult and adolescent age categories in terms of a number of response characteristics on the irrelevant distractor task. Most notably, adolescents had significantly higher variability of responding (coefficient of variation; CV) scores than adults across both load levels. Although participants aged 16-17 displayed significantly reduced response variability compared to the younger adolescent age groups, they still displayed increased variability in relation to adults. This finding is interesting in light of the results of Fortenbaugh et al. (2015), who found that the 'breakpoint' at which the regression line stabilized at 'adult' performance was 16.4 years. The present results demonstrate that, in the case of the irrelevant distractor task, older adolescents of age 16-17 still display elevated CV levels in comparison to adults. It is likely that, in the context of a trend towards reduced CV throughout adolescence, the exact age at which 'adult' performance is reached will vary according to the task. I note, for example, that the CV scores reported by Fortenbaugh et al. (2015) for adolescent participants on their gradCPT task (CV = 0.14) were somewhat lower than those found in the present data (CV for 16-17 year olds in low load = 0.26, high load = 0.29). Given that the reaction times reported by Fortenbaugh et al. are slower than those reported for all tasks in the present thesis, it is likely that the lower CV results for the gradCPT task are due to lower levels of arousal in the task (a sustained attention task requiring only intermittent responding, rather than one requiring trial by trail responding such as that reported in the present thesis. Arousal levels are known to be linked to response variability (James et al., 2016; Johnson et al., 2007). Fortenbaugh et al.'s CV results are also lower than those found for adolescents completing other tasks of selective attention which require more frequent responding. For example, Epstein et al. (2011) reported that their control group of non-clinical adolescents produced CV figures of between 0.25 and 0.35 across 5 common attention control tasks), further emphasizing the fact that response variability on different tasks may vary, in addition to maturing at different rates.

Decomposing the RT distributions produced by our participants into their constituent components of Mu, Sigma and Tau revealed that adolescents showed greater variability within the normal distribution (Sigma) and also produced significantly more 'exponentially slow' responses in the tail of the RT distribution (Tau) than did the adults Chapter 3), whilst there was no difference between groups in terms of the mean of the normal distribution (Mu). In comparison to adults, adolescents therefore seem to display response patterns somewhat comparable to same-age comparisons between ADHD and typically-developing cohorts, where differences in mean reaction times have been found to result from greater variability (in both normal and ex-Gaussian portions of the distribution) rather than slower motor processing speed (Kofler et al., 2013). Thus, data from the analysis of response distributions also supports a possible link between behavioural patterns in adolescence and those seen in conditions of impaired attention such as ADHD.

These links are also relevant when considering what may drive this difference in variability between the two age groups, both in terms of global variability and more specifically in terms of exponentially slow responding. Two potential factors which are already known to be different between adolescents and adults can be suggested. Firstly, the reduced frontal control that adolescents may have over task performance (as described in the chapter introduction and general introduction section 1.6) may result in greater performance variability, rather than increased distraction by irrelevant stimuli. Participants performing the task may experience competition between engaging in a task and allowing themselves to be distracted by irrelevant processes (such as mindwandering, attending to internal emotional information, or external stimuli). If adolescents suffer such lapses more frequently than adults, then this may result in greater variability in responding. A second, related, factor is that adolescents may experience greater fluctuations in mood or emotions (within the period of doing the task), which could promote task disengagement by providing more frequent or salient internal stimuli to attend to. Adolescence is widely recognized as a period of flux, in which emotion and arousal levels are unstable and inconsistent (e.g. Larson et al., 2002; Heller & Casey, 2015). These results demonstrate that such instability can also be extended to attentional processes, in keeping with some recent models of ADHD (e.g. O'Connell et al., 2009; Johnson et al, 2007) which link the arousal system and the attention system.

I note here that it is possible that some of the increased variability in adolescent responding could be attributable to their testing location (within their school, rather than in a university testing room), even though an experimental environment was created which replicated standard laboratory conditions. However, this appears unlikely to account for the findings because the results established a developmental progression in CV, despite the fact that all adolescents were tested within the same setting. This progression is also in line with testing performed in other settings (Fortenbaugh et al., 2015). In addition, it is not clear on this account why students whose response variability would be most affected by the school setting would also be the ones who reported the highest levels of distraction during their classroom lesson (given the significant positive correlation between these variables). As a result, this suggests that the difference to adults reflects a developmental effect rather than a settings effect.

6.5.1.1 Perceptual load and CV

Analysis of response variability demonstrated that an increase in perceptual load had the effect of increasing global response variability (as measured by CV) across all population groups (Chapters 3, 4). These changes in global response variability can be further analysed with reference to the response distribution analysis. At both load levels, it was possible to construct response distribution curves for participants (Chapter 3). These revealed that an increase in perceptual load served to increase all three of the measures of response distribution (Mu, Sigma and Tau). Therefore, the increase in CV found at high load is attributable to both an increase in variability within the normal portion of the RT distribution, and also to a greater number of exponentially slow responses outside of this distribution, as indicated by a larger Tau value in high load than in low load (Chapter 3). This increase in variability cannot be solely attributed to the increase in RTs between load conditions, as CV provides a measure of variability which accounts for changes in baseline RT. Thus, in addition to the widely reported finding that reaction times are significantly slower in high perceptual load tasks (Lavie, 1995, 2005, 2010), the present thesis demonstrates that increases in perceptual load also increase response variability, over and above those resulting simply from increases in RT.

6.5.2 Errors

In addition, I found that young adolescents (age 13-15) produced significantly more errors than adults (Chapters 3, 4). The finding of increased adolescent error rates in comparison to adults mirrors the findings of a variety of paradigms used to investigate executive function, for example in Go/No-go tasks (A. O. Cohen et al., 2016; Somerville et al., 2011; Tottenham et al., 2011), the Stroop task (Aïte et al., 2018; Huizinga et al., 2006; Leon-Carrion et al., 2004), anti-saccade tasks (Luna et al., 2004), flanker tasks (Grose-Fifer et al., 2013) the sustained attention to response task (SART; Stawarczyk et al., 2014), visuospatial WM (Olesen et al., 2007) or perceptual discrimination tasks (Vetter, Pilhatsch, Weigelt, Ripke, & Smolka, 2015). Thus, error rates on the irrelevant distractor task appear to follow a similar developmental pattern to many other common tests of cognitive control. Given the ongoing maturation of the cognitive systems underlying performance monitoring in adolescence (e.g. van den Bos, van Dijk, Westenberg, Rombouts, & Crone, 2009; van Duijvenvoorde, Zanolie, Rombouts, Raijmakers, & Crone, 2008; Velanova, Wheeler, & Luna, 2008), this finding is not surprising. However, within this general trend for increased errors in adolescence, performance has been reported to reach adult levels at different times for different tasks. For example, Stawarczyk et al. (2014) found that 14-16 year olds produced significantly more errors than a group of young adults on the SART, whereas Luna et al. (2004), using an anti-saccade task, reported adult levels of error rates by age 14. The present thesis found that ages 13-15 produced significantly more errors than adult groups, but that performance in the 16-17 group could not be distinguished from adults, closely matching the reports of (Grose-Fifer et al. (2013) using a letter flanker task. At present it is unclear whether these discrepancies reflect differences in the tasks employed (with error-monitoring performance on slightly different tasks maturing at different rates), or whether different tasks may be measuring the same cognitive error monitoring functions but with different levels of sensitivity. One final relevant point raised by the present thesis is to observe that, for paradigms which involve relatively infrequent distractor trials, such as the design used in the present research, increased error rates can lead to larger proportions of distractor present trials being discounted from RT analyses. This consideration will need to be taken forward for future use of the irrelevant distractor paradigm (and similar designs) with developmental populations, for example by research which determines the maximum proportion of distractor present trials that can be included before habituation effects reduce their effectiveness.

6.5.3. Distractor processing

One conclusion that can be drawn from this thesis is that neutral adult facial stimuli capture attention when presented as task-irrelevant distractors, and that, in adults, the extent of the distraction produced by them (in terms of the cost to reaction time) can be significantly modulated by perceptual load (Chapters 3-4). It has been suggested that face processing may operate entirely independently of perceptual load (Lavie, Ro & Russell, 2003), and that face perception has its own specific capacity limits (Thoma & Lavie, 2013). However, these results were obtained when the faces provided distraction in a task-relevant manner. The present thesis demonstrates that task-irrelevant face distractors can be modulated by perceptual load, even when they are fully perceived and processed (presented at fixation for 200ms). This is in contrast to the results reported for one previous study into the load modulation of task-irrelevant distraction by faces (Sato & Kawahara, 2014) in which interference from distractor faces (presented peripherally for 100ms) was found not to be modulated by perceptual load. However, the peripheral and very fast presentation of distractor faces raises doubts about the visual acuity with which they can be perceived (Mäkelä et al., 2001; see also Chapter 3, chapter introduction).

One unexpected finding in the present thesis regards the load modulation of distraction in adolescents (Chapter 3). Perceptual load was not found to significantly modulate distraction in adolescents in the original ANOVA analysis (Study 4), when the effects were calculated on the mean RTs. However, when the distractor effects were calculated as proportional effects to address the load scaling effect of RTs the numerical trend was for the same load modulation as in adults (i.e. reduced distractor interference in high perceptual load but this only reached marginal significance). Thus clearly there was a weaker effect of load on distractor interference in the adolescents compared to adults. This is unexpected, given the consistent effects of perceptual load previously reported both for adults (Lavie, 2005, 2010; Murphy, Groeger, & Greene, 2016) and children (Huang-Pollock et al., 2002; Remington, Cartwright-Finch, & Lavie, 2014), as well as the one previous study which has examined perceptual load across a number of age ranges, including children, adolescents and adults (Couperus, 2011). The results could also not be explained by an own-age bias in the attention capture effects of the distractor stimuli (Study 5). A related unexpected finding regarding distractor processing was that adolescents also displayed a significantly smaller low load distractor effect in Study 4 than did adults in Study 3 (see Comparison analysis, Studies 3-4). A likely explanation for both of these findings appears to be significantly increased adolescent intra-individual variability in comparison to adults (as discussed in section 6.5.1 above). Increased intra-individual variability in adolescents will make differences between experimental conditions difficult to detect, especially when using measures such as mean RTs which are more greatly skewed by abnormally slow responding (Tau) in adolescents than in adults. This would account for both a reduced distractor effect, and consequently a reduced modulation of that effect by load.

Finally, regardless of the possible source of the reduced distractor effect observed in the adolescent participants, some conclusions regarding adolescent distractor processing may still be drawn from the results. For example, the present results suggest that the elevated levels of distraction from affective or motivationally-relevant distractors previously reported for adolescents in comparison to adults (e.g. Cohen-Gilbert & Thomas, 2013; Cohen et al., 2016; Grose-Fifer et al., 2013; Roper et al., 2014) are unlikely to be due to the adolescents' inability to control attention in the face of salient task-irrelevant distraction. Adolescents in the present thesis did not show elevated levels of task-irrelevant distraction, indeed the effect of the distractor in low perceptual load was significantly reduced compared to adults (explanations for this are discussed in the paragraph above). Thus, it appears that the interference produced by emotional stimuli in previous research is likely to arise as a result of differences in the processing of their affective and motivational relevance by the different age groups.

6.6 Reducing distraction in educational settings

Previous research has demonstrated that perceptual load may be able to ameliorate deficits in attention control found in some clinical conditions, such as anxiety (Bishop, Jenkins & Lawrence, 2007) and ADHD (Forster et al., 2014). Thus, it might be imagined that perceptual load might also provide a practical intervention for minimising individual and group differences in attention control skills in other settings, such as for adolescents, whose attention control skills may not be fully developed. However, while the load modulation of distraction was not significantly different between adult and adolescent samples (Chapter 3), the fact that adolescents did not display a significant load modulation suggests that further research will be required before interventions can be considered which might aim to reduce distraction based on manipulating levels of perceptual load in the learner.

6.6.1 Interpolated testing

In contrast, the results presented in this thesis expand on previous research into interpolated testing effects by demonstrating that the beneficial effects of interpolated testing for learning can be observed in a novel applied educational setting - small group teaching sessions (Chapter 5). This finding has a number of implications for the current understanding of the effects of interpolated testing, and opens new avenues for further research, as will be discussed in the sections below.

6.6.1.1 Interpolated testing in a live educational setting

An important finding from the present thesis is the demonstration that the beneficial effects of interpolated testing on learning can be demonstrated in a live educational setting (Chapter 5). Students performed significantly better on the final test of learning after their 'test' seminar than after their 'restudy' seminar. The benefits of interpolated testing for the learning of complex academic material have previously been demonstrated in the context of video lectures (Szpunar et al., 2013; Szpunar et al., 2014; Jing et al., 2016; Yue et al., 2015) and for the learning and comprehension of text passages (Wissman et al., 2011; Healy et al., 2018; Zhou et al., 2015), however the present results are the first to demonstrate the improved learning after interpolated testing in a live teaching session (identified by Yang, Potts & Shanks, 2018, as an important future direction for research on the forward testing effect). They also generalise the beneficial effects to a new educational format – that of small group seminar teaching – using a within-subjects design which was counterbalanced to avoid bias from changing seminar topics. As well of being of relevance to university-level learning, the seminar settings used in the present study may be of relevance to schools, as they more closely resemble standard classroom environments (especially for the smaller classes sometimes found at higher levels such as post-16 courses). Whilst the present results cannot be generalised to schools without further research, they do at least give an indication that the effects of interpolated testing are not limited to lecture environments.

The results presented here suggest that the reduction of mindwandering rates observed following interpolated testing (Chapter 5) is an effect which is observable even in the context of lower baseline mindwandering figures. Jing et al. (2016) did not observe a significant reduction in mindwandering during a video lecture in a 'tested' group compared to a 'restudy' group (23.6% of probes for the untested group and 20.8% for the tested group). This baseline mindwandering rate in this study was lower than that commonly reported elsewhere, in which frequencies of between 30% and 45% have been reported in 'untested' video and real-life lecture settings (Hollis & Was, 2016; Kane, Smeekens, et al., 2017; Lindquist & McLean, 2011; Risko et al., 2012; Szpunar et al., 2014, 2013; Wammes, Boucher, et al., 2016; Wammes, Seli, et al., 2016). Schacter and Szpunar (2015) speculate that the effect of interpolated testing on mindwandering may be restricted to environments in which rates of mindwandering are high, however the present findings suggest that interpolated testing may be associated with reductions in mindwandering even in such environments where mindwandering rates are less than half those reported in everyday life (Chapters 2, 5). It may therefore be that some other feature of the procedure used by Jing et al. is responsible for the null effect on mindwandering. For example, the procedure used for the 'tested' group was also somewhat different to that employed in other studies, involving free recall of information rather than the quiz questions used by Szpunar et al. (2013; 2014). It may therefore be that 'free recall' procedures, such as used by Jing et al. (2016), are less effective at reducing mindwandering rates than conventional testing or quizzing. Alternatively, the larger sample and repeated measures design of the present study may simply have resulted in more power to detect smaller changes in rates between conditions. Further research that clarifies which techniques are most successful at reducing mindwandering in different educational settings may help to adapt instructional practices effectively to meet different demands.

6.6.1.2 Interpolated testing and the relationship between mindwandering and external distraction

One interesting observation arising from the use of interpolated testing in the present thesis regards the relationship between mindwandering and external distraction. Although the results from elsewhere in the present thesis provided grounds for a hypothesis that mindwandering and external distraction would be similarly affected by an intervention theorised to facilitate attentive processing (Chapters 2, 4), the results reported in Chapter 5 do not support this hypothesis. Whereas the testing condition significantly reduced reports of mindwandering duration, external distraction was not significantly reduced. Interpolated testing does not, therefore, seem to have exerted the same level of effect on external distractions as on mindwandering.

As discussed in more detail above (general discussion 6.3), a close relationship between mindwandering and external distraction does not imply isomorphism. One distinction which may be helpful for explaining possible differences between mindwandering and external distraction in the context of an interpolated testing intervention is between intentional and unintentional attention lapses. Wammes et al. (Wammes, Boucher, et al., 2016; Wammes, Seli, et al., 2016) used probe responses which allowed participants to distinguish between intentional and unintentional mindwandering; rates of unintentional mind wandering were relatively low, and did not increase over the course of a lecture, whereas intentional mindwandering did). Interestingly, different forms of mindwandering were associated with different aspects of test performance. Intentional mindwandering rates correlated negatively with daily quiz scores (r_s = -.21), whereas unintentional mindwandering was significantly negatively associated with end-of-term exam scores (r_s = -.20). Whilst the intentional/unintentional divide is clearly a useful construct for mindwandering, it does not map as comfortably onto all forms of external distraction, for example the focus on task-irrelevant background noise seems more likely to be an unintentional lapse. Conversely, distraction by looking out of the window seems more suited to intentional distraction. The room used for all seminars in this study was on the 4th floor, providing a constant, and relatively mundane, visual scene of London's rooftops. As such it seems unlikely to have possessed the sort of salient, captivating visual features that might have unintentionally attracted attention. Although the results of Chapter 2 suggested that both cases of intentional and unintentional external distraction are likely to share a close relationship with mindwandering, it is conceivable that interpolated testing may affect one more than the other (though Wammes et al. did not investigate interpolated testing, so this is necessarily speculative). Larger samples and more specific measurements of distractions and intentionality would be required to determine if interpolated testing has different effects on different external distractions, depending on the relative likelihood of the distraction acting as an intentional or unintentional distraction.

6.6.1.3 Separable effects of interpolated testing on attention and learning

As well as demonstrating some of the applied benefits of interpolated testing in new settings, the present thesis also advances our theoretical understanding of the mechanisms underlying the effects. As discussed in the General Introduction (Section 1.9.1.1), the forward benefits of testing on learning have been theorized to arise from a number of potential mechanisms (Yang et al., 2018). Of particular interest is the question of whether the effects of testing on learning and their effects on mindwandering may be, at least partially, separable. Szpunar (2017) argues that interpolated testing may enhance attentive processing of new (post-test) material, thus positing a shared mechanism from which both the positive effects of interpolated testing on both learning and attention may result.

The results of the present thesis do not support such a ‘general facilitation of attention’ account. When using a repeated measures mediation analysis to analyse the extent to which improvements in each participant’s learning were mediated by reductions in their mindwandering, changes in mindwandering rates did not significantly mediate the changes in test performance between conditions (Chapter 5). Thus, learning improvements as a result of the interpolated testing intervention do not appear to be mediated by improvements in attentive processing. In addition, the finding that the intervention significantly reduced mindwandering, but not external distraction, also suggests that attentional processes are not being generally facilitated. As previously noted, the relationship between mindwandering and learning might perhaps be expected to be stronger in environments with higher baseline mindwandering rates, however even in such environments some previous results have provided grounds to suspect that that these effects might be separable. Jing et al. (2016) reported that an interpolated testing intervention that failed to lead to a reduction in mindwandering, but which was still associated with improved performance on a final test. However, Jing et al. did not specifically test the relationship between testing, attention and learning. Szpunar et al. (2013) also reported no interaction of the regression slopes for the relation of mindwandering to learning between testing and restudy conditions, suggesting that although testing reduced mindwandering and increased learning, it did not affect the relative influence of mindwandering on learning.

Instead it seems more likely that the effects of interpolated testing on learning and mindwandering arise at least partially independently, as a result of a number of mechanisms being activated concurrently. Some of these mechanisms may have attentional elements, and others which may not. For example, Weinstein et al., (2014) used an interpolated testing paradigm to examine the learning of five lists of words, in which half of the tested and untested groups were given warning of an upcoming test final test and half were not. Prior to each new list, participants indicated how likely they believed they were to receive a test on each studied list. Weinstein et al. found that the test expectancy of the 'untested/unwarned' group decreased across lists and that their recall in a final test was significantly worse, in comparison to other groups (see also Yang, Potts, & Shanks, 2017). It seems plausible that the expectation of an upcoming test led participants in the 'tested' or 'warned' groups to increase their level of focus on the task materials (and vice versa for the 'untested/unwarded' group). However, Weinstein et al. note that their findings could also be explained through the testing facilitating list-specific processing, an encoding effect that would not rely on attentional processes to the same extent. Weinstein et al. conclude that it is most likely that both effects are co-occurring. The present results support such a hypothesis.

6.6.1.4 Mindwandering and task engagement during interpolated testing

The demonstration of forward testing effects on mindwandering in a low baseline mindwandering environment also implies that the effect is not reliant on relatively low levels of task engagement, as suggested by Szpunar (2017). One criticism of the studies of Szpunar et al. (2103; 2014) was that the use of a video lecture on statistics may have resulted in a relative lack of engagement with the material, which in turn would be expected to lead to higher rates of mindwandering (Smallwood & Andrews-Hanna, 2013; Smallwood and Schooler, 2015). The present results help to clarify aspects of this relationship by recording mindwandering, learning and 'interest in the seminar', and by comparing them both within and between subjects. Consistent with the predictions of Smallwood and Andrews-Hanna (2013) engagement (as indexed by reports of interest in the seminar) was at times found to be significantly negatively correlated to mindwandering, as well as to other sources of attention failure (Chapters 4, 5). However, the interpolated testing intervention (which significantly improved learning and reduced mindwandering) had no effect on interest. Learning (post-test performance) was also not significantly related to interest in the seminar, in contrast to previous findings (Kane, Smeekens, et al., 2017; Lindquist & McLean, 2011; Unsworth & McMillan, 2013; although Wammes, Seli, et al., 2016 did find that pre-term motivation to learn was not predictive of final test performance). These results suggest that although task engagement does appear to have a replicable relationship with mindwandering, the effects of interpolated testing on both learning and mindwandering do not appear to be simply a function of motivation or general task engagement.

6.7 Implications for future research

The findings of the present thesis suggest a number of interesting and potentially fruitful directions for future research, which will be discussed below.

6.7.1 Relationship of mindwandering and external distraction

Further investigations may find it interesting to assess in greater detail the boundary conditions between mindwandering and external distraction. In light of the findings of the present thesis that these constructs are closely related, but not isomorphic (and that their occurrence in everyday life can often, though not always, be accurately described as arising from a single underlying factor), elucidating the factors underlying such distinctions may be an interesting direction. Combined methods which assess both the frequency and the duration of attention lapses may be important for such questions. This research would not simply be of theoretical interest. It would also guide future interventions, such as that reported in Chapter
5. As an example, a clearer understanding of the boundary conditions between experiences of mindwandering and external distraction would be able to predict whether future educational programs may have different effects on mindwandering and external distraction, or may guide the design of educational settings and activities to minimise both mindwandering and external distractions most effectively. Interpolated testing designs using larger samples in live lecture environments, and employing combined measures of frequency and duration of attention lapse, might further clarify whether such interventions can be considered effective at reducing external distraction. In addition, future research may benefit from more clearly distinguishing between intentional and unintentional attention lapses in educational environments, given that they have been shown to display relationships with different aspects of task performance (Wammes et al., 2016 b). Interpolated testing may have different effects on different attention lapses, depending on the relative likelihood of the distraction acting as an intentional or unintentional distraction.

6.7.2 Predicting attention lapses in educational settings

The task measure of irrelevant distraction was able to successfully predict distraction duration experiences for adolescent students in a school lesson and for adult students during a session of personal study but did not do so for students in a lecture setting (Chapter 4). While one potential future avenue for research might be to understand in more detail the exact contextual features which determine whether task-based measures are able to predict real-world distraction, and whether they vary between individuals, this is likely to be a complex task. A more fruitful initial development of the results presented in this thesis might be to assess whether a combined measure of distractibility, for example one involving composite of teacher and self-assessments of attention skills *in addition* to task performance might provide a better prediction of distraction reports. A range of measurements has previously been found to predict attention problems more accurately than teacher assessments alone (Atkins et al., 1985), but more recent work assessing the best combination of such measures to use and the limits of their predictive ability have been lacking. The results of this thesis suggest one potential strand that could be included in a composite measurement of distractibility for education (in the form of the RT interference caused by a task-irrelevant distractor), and suggest that the time may be ripe for further developments in the prediction of such a crucial component of educational success.

6.7.2.1 Response variability in adolescents

RT variability predicting distractibility in adolescents, but not young adults, raises questions regarding the developmental trajectory of focused attention skills. Specifically, it may provide a measure of the development of 'late selection' attention mechanisms which rely on top-down cognitive control regulating spontaneous fluctuations in the default mode network (Lavie, Hirst, de Fockert & Viding, 2004; Kelly et al., 2008; Sonuga-Barke & Castellanos, 2007). However, the development of response variability through adolescence has been very little researched previously (cf. Fortenbaugh et al., 2015). Thus, the results of the present thesis suggest that further research into the development of response variability in adolescents is merited, as well as its relationship to attention skills and the development of broader cognitive control networks.

In addition to the above, this thesis raises the possibility that tools to predict distractibility in everyday life settings may need to be attuned to the specific response characteristics of the target population (given that developmental differences may mean that different performance measures may be predictive of distractibility in different populations). The replication of the finding that elevated response variability might be predictive of real-world distraction in adolescents raises a number of interesting further questions for research. Most notably, this provides grounds for further exploration of the theoretical links between adolescence and clinical conditions of impaired attention such as ADHD, in which RT variability has previously been shown to be predictive of distraction (Adams et al., 2011; Kofler et al., 2013). Data from this thesis therefore raises the possibility that the emotional dysregulation associated with the period of adolescence may also have attentional correlates, in a similar manner to arousal dysregulation theories of ADHD (e.g. Johnson et al., 2007; O'Connell et al., 2009; Van der Meere, 2010). Future researchers may wish to analyse this interesting hypothesis in more detail.

6.7.3 External distraction, mindwandering and mood

One important future direction for research linking attention and mood is to establish more clearly the causal links between attention states and mood states. Previous research on the direction of causality between these has been inconsistent with evidence of mood changes both preceding (Pacheco-Unguetti & Parmentier, 2014; Ruby et al., 2013; Smallwood et al., 2009) and following lapses in attention (Killingsworth & Gilbert, 2010). The present thesis demonstrates that the measurement of duration of distraction experiences (rather than frequency) can also illustrate links between attention focus and mood. Measurements of both duration and frequency will need to be pursued for a full understanding of the experience, and consequences, of different attention states, however duration measures may be especially important when assessing links to mood. Rumination (a mode of mindwandering characterised by extended periods spent passively focusing on personal problems) is specifically associated with reduced mood and mood disorders (Moore et al., 2013; Nolen-Hoeksema, 2000; Nolen-Hoeksema & Morrow, 1993), illustrating that longer periods of attention lapse may be disproportionately associated with mood. Indeed, uncontrollable rumination is a better predictor of reduced mood in daily life than mindwandering rates more generally (Kuehner, Welz, Reinhard, & Alpers, 2017). Thus, future research which employs measurements of both frequency and duration of distraction experiences, and which employs repeated sampling over time (to allow for causal inferences) is called for. A greater understanding of these relationships may have important clinical implications. For example, therapies which aim to reduce the frequency of negative ruminations in order to improve mood have reported positive results (Driessen & Hollon, 2010; Hofmann & Smits, 2008), however such therapies could potentially be adapted to also take into account tendencies to be excessively distracted by external stimuli.

It may also be necessary to distinguish more clearly between external distraction and mindwandering in terms of their relationships to mood. The present thesis demonstrates that the relationships between external distractions and reduced mood may be less consistent than that between mindwandering and mood, however it is unclear whether this may be due to differences between the sources of attention lapses, or simply the result of measurement techniques employed in the present thesis (such as splitting external distraction reports into a number of different sources, but retaining mindwandering as a single, unitary category). Work which analyses the content of mindwandering and its relationship to mood has been recently reported, where intentional (Seli, Schacter, Risko, & Smilek, 2017), interesting (Franklin, Mrazek, et al., 2013) and future-oriented mindwandering (Ruby et al., 2013; Smallwood & O'Connor, 2011) have all been associated with improved mood ratings, whereas past-oriented mindwandering is associated with negative moods (Poerio et al., 2013; Ruby et al., 2013) . More research will be needed however to better understand whether comparable relationships may occur for different sources of external distraction and mood (as is suggested by the findings of Chapters 2 and 4). In addition, future investigations should also look to include a separate measure of attentional focus (or a measurement of perceptual load), independent of distraction reports. This would allow for the measurement of distraction and mindwandering during different states of attention focus, and therefore the differentiation of attention lapses due to reduced attention focus, as compared to those resulting from particularly distracting environments, for example.

6.7.4 Interpolated testing in educational environments

Yang et al. (2018) call for further investigation of the mechanisms underlying the forward testing effect on learning. However, in light of the present results, future investigations should also prioritise the examination of the wider benefits of testing (on both learning and attentive processing, for example), and the extent to which these arise from similar or separate underlying mechanisms. As demonstrated by the results presented in Chapter 5, such research could be performed in real-life educational settings and still provide theoretical insights into the mechanisms of interpolated testing. In addition, such research may bring applied benefits by testing the effects of different interpolated testing regimes.

I note here with interest that the attentional effects of interpolated testing may in fact hold greater promise for educational applications than the memory benefits. At present there is a lack of clarity about whether the interpolated testing effect on memory persists in the long term (given that most studies have measured learning immediately after the learning session). There is, however, clearer evidence of longer term harm to learning from attention lapses such as mindwandering, for example over the course of a university semester (Lindquist & McLean, 2011; Wammes, Boucher, et al., 2016; Wammes, Seli, et al., 2016). Thus, the evidence presented in this thesis demonstrating that interpolated testing is able to reduce mindwandering in a live educational setting provides strong reason for future studies to examine the longer-term educational benefits of such interventions, over and above the demonstration of improved short-term learning.

6.8 Conclusions

In summary, the present thesis contributes to our understanding of the relationship between mindwandering and external distraction in a wide range of everyday environments (including multiple towns and cities and various primary activities), and also specifically in educational settings (both in university and in school). Importantly, all of these investigations were conducted in real world environmental settings (as opposed to laboratory environments, or videos in the case of educational settings). Mindwandering and distraction reports were closely related, and often described as resulting from a single underlying construct. In addition, the thesis clarifies the relationship between attention and mood in such settings. Reports of attention lapses were also reliably correlated with reduced levels of happiness, though more strongly for mindwandering than external distraction. The thesis also established the potential for these states to be predicted using task-measures of attention focus. The results demonstrated that distractor interference on task response times was able to predict the duration of real-world distraction reports in both adult and adolescent samples, whilst response variability was also a predictor for adolescents. The thesis also replicated the effects of perceptual load on irrelevant distractor processing in adults and generalised this effect to distractor stimuli of neutral adult faces. Finally, the thesis advances the understanding of the potential for an educational intervention, in the form of interpolated testing, to be used to mitigate the occurrence, and harmful effects, of attention lapses. Interpolated testing was found to reduce mindwandering and improve recall but did not significantly affect external distraction. The findings demonstrate the potential for laboratory insights into selective attention to be applied usefully to educational settings, but also highlight the importance of considering the relationship between different types of attention lapse, and mood, in ecologically valid environments, if such applications are to be successful.

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Appendix

1. Distraction checklist (studies 2 and 3)

BrainFocus Ltd

Participant ID: Location:

How long have you been here (in minutes)?

Over this time, how often and for how long (in minutes) did you divert your attention from your focus by attending to (please indicate with an X anywhere on the scale):

Your Mobile Phone (or tablet)

How often? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If more, please specify

For how long overall? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If longer, please specify

A form of advertising

How often? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If more, please specify

For how long overall? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If longer, please specify

Passing vehicles (cars, motorcycles, buses, airplanes etc)

How often? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If more, please specify

For how long overall? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 specify

Strangers passing by

How often? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If more, please specify

For how long overall? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 specify

Background music

How often? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If more, please specify

For how long overall? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If longer, please specify

Birds, dogs, or other animals

How often? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If more, please specify

For how long overall? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If longer, please specify

Construction work

How often? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If more, please specify

For how long overall? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 specify

Unrelated thoughts ("mind wandering")

How often? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If more, please specify

For how long overall? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If longer, please specify

Anything else diverted your attention? Please specify______________________

How often? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 If more, please specify

For how long overall? 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 specify

For the time period reported above, were you alone? with others? How many?....
What's their relation to you? Family friends colleagues Specify if other……….
Please rate your general level of happiness over the past hour on a scale of 1 (extremely unhappy) to 100 (extremely happy): ………….

Are you currently well (health wise)? Yes No
Please specify if health-related thoughts contributed to mindwandering Yes No

What is your gender? Male Female

What is your date of birth?

Is English your first language? Yes No
No but English has been my primary language since (please specify year):…