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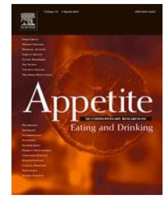

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A Systematic Review of the Effects of Experimental Fasting on Cognition

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Highlights:

- We systematically reviewed the impact of hunger on general cognition
- Results show inconsistent cognitive profile of fasted individuals
- Psychomotor speed and executive functioning show the most consistent deficits
- Future studies should investigate other domains and use established assessments

Abstract

Numerous investigations have been conducted on the impact of short-term fasting on cognition in healthy individuals. Some studies have suggested that fasting is associated with executive function deficits, however findings have been inconsistent. The lack of consensus regarding the impact of short-term fasting in healthy controls has impeded investigation of the impact of starvation or malnutrition in clinical groups, such as anorexia nervosa (AN). One method of disentangling these effects is to examine acute episodes of starvation experimentally. The present review systematically investigated the impact of short-term fasting on cognition. Studies investigating attentional bias to food-related stimuli were excluded so as to focus on general cognition. Ten articles were included in the review. The combined results are equivocal: several studies report no observable differences as a result of fasting and others show specific deficits on tasks designed to test psychomotor speed, executive function, and mental rotation. This inconsistent profile of fasting in healthy individuals demonstrates the complexity of the role of short-term fasting in cognition; the variety of tasks used, composition of the sample, and type and duration of fasting across studies may also have contributed to the inconsistent profile. Additional focused studies on neuropsychological profiles of healthy individuals are warranted in order to better develop an understanding of the role of hunger in cognition.

Keywords: fasting, hunger, cognition, executive function, psychomotor speed, memory

A Systematic Review of the Effects Of Experimental Fasting on Cognition

Despite being a primary need, humans will voluntarily skip a meal or refrain from eating for a short period of time. In a well-fed society, there are a variety of reasons why an individual may abstain from eating including: religious observance, part of a weight-loss regimen, simply being too busy and/or forgetting, or for reasons related to physical or psychiatric illness. Abstaining from eating, regardless of the reason, can reduce energy levels (Roky, Iraki, HajKhlifa, Lakhdar Ghazal, & Hakkou, 2000) and induce negative affect (Choma, Sforzo, & Keller, 1998; Maridakis, Herring, & O'Connor, 2009). Chronic abstention from breakfast can contribute to the pathogenesis of obesity and other negative health outcomes (Timlin & Pereira, 2007). Yet the direct impact of transient reduced caloric intake and associated hunger on cognition are less understood as there is limited extant literature examining these effects.

Breakfast skipping is one of the more commonly studied types of meal abstention and its effects are typically assessed in children, adolescents, and young adults. For school-aged children and adolescents, results of studies assessing the impact of missing breakfast on cognition are equivocal and appear more closely related to baseline nutritional status: limited cognitive and academic deficits are seen in otherwise well-nourished children, whereas stronger deficits are seen in those whose daily nutrition is compromised (i.e., as a result of socioeconomic status) (Bellisle, 2007; Grantham-McGregor, 1995; Hoyland, Dye, & Lawton, 2009; Pollitt, Cueto, & Jacoby, 1998). Moreover, some research suggests that many of the academic benefits of breakfast may be indirect (e.g., an index of higher socioeconomic status; access to free breakfast at school increases school attendance) (Bellisle, 2007; Gibson & Green, 2002; Hoyland, et al., 2009). The relationship of eating habits and breakfast skipping is infrequently studied in adults and adolescents, as these age groups are thought to be less reliant on breakfast and may deliberately delay or substitute it (e.g., substitute caffeine and/or eat later in the day) (Gibson & Green, 2002; Hoyland, et al., 2009).

Understanding the role of single meal abstention can inform our understanding of the impact of prolonged caloric deprivation on cognition. Similar to single-meal abstention, prolonged caloric deprivation occurs when individuals reduce their caloric intake or refrain from eating for prolonged periods of time (e.g., multiple days) for a variety of reasons, including: weight loss, athletic or combat training, mood enhancement, religious purposes, or due to psychopathology (e.g., anorexia nervosa). The impact of caloric deprivation on cognition across these various contexts is not yet established. The limited extant research investigating prolonged caloric deprivation has shown inconsistent impacts on cognition. For example, some studies show no detriment to cognition as a result of prolonged fasting (Guttiérrez, González-Gross, Delgado, & Castillo, 2001; Lieberman, et al., 2008; Shukitt-Hale, Askew, & Lieberman, 1997), others indicate deficits in short-term memory, encoding, attention, reaction time, and/or vigilance (Cheatham, et al., 2009; Choma, et al., 1998; Pönicke, Albacht, & Leplow, 2005).

Understanding the impact of short-term fasting on cognition can also elucidate how prolonged caloric deprivation as a result of psychopathology may impact brain and mind. For example, assessment of patients diagnosed with anorexia nervosa (AN) has revealed a somewhat consistent cognitive profile (Gillberg, et al., 2010; Stedal, Frampton, Landro, & Lask, 2012; Tchanturia, Campbell, Morris, & Treasure, 2005), but it is unclear what is cause and what is consequence of prolonged starvation associated with AN. Research on adults with anorexia indicates that women in the acute phase of the illness have deficits in short-term memory (Nikendei, et al., 2011) and executive functioning – particularly central coherence and cognitive flexibility (Holliday, Tchanturia, Landau, Collier, & Treasure, 2005; Roberts, Tchanturia, Stahl, Southgate, & Treasure, 2007), which often persist after weight restoration (Gillberg, et al., 2010; Nikendei, et al., 2011; Tchanturia, Morris, Surguladze, & Treasure, 2002). However, cognitive deficits can reduce following recovery such that there is no significant difference between those recovered from AN and healthy controls (Tchanturia, et al., 2011). Hence, it is not yet clear whether or not these deficits are endophenotypes of AN, state deficits due to chronic caloric deprivation, or a scar of the disorder. Without a profile of normative fasting, it is difficult to disentangle the impact of starvation or caloric deprivation from the pathogenesis of the disorder.

The purpose of the present systematic review is to consolidate and present the literature available to date investigating the impact of short-term fasting on cognitive function in healthy individuals. Studying acutely fasted, healthy adults can lend insight into how fasting can impact cognition in a variety of contexts. Experimental fasting has been used for the better part of a century (e.g. Sanford, 1936) but early reviews of the research note that the findings were prone to methodological and statistical error (Lazarus, Yousem, & Arenberg, 1953; Pastore, 1949). To our knowledge, no reviews of general cognition during normative hunger and/or fasting have been compiled since these early compendia. In addition to providing insight into the biological and psychological role of fasting and satiety, experimental fasting methodology can provide analog data into the role of starvation in disordered eating. A review of experimental fasting studies can provide a platform from which further hypotheses designed to investigate the state impact of starvation on cognitive abilities can be generated.

Method

In order to identify relevant articles, a systematic search of the following databases was carried out: PsycINFO, CINAHL, and PubMed. Additionally, to maximize identification of relevant abstracts we used the same search terms in Google Scholar using the Advanced Scholar

Search function. A hand search of reference sections of included articles was conducted in order to insure that all relevant studies were identified. The terms used in each search are presented in Table 1.

Inclusion and Exclusion Criteria

Articles were included in the systematic review if the research included at least one group of healthy individuals (adults aged >18 years) and/or one group of healthy individuals who also underwent fasting (i.e., studies examining fasting in diabetics could be included if there was also a control group of healthy individuals who fasted). In order to be included, the study had to include assessments without food-related stimuli. Unsurprisingly, fasted individuals, who are otherwise healthy, demonstrate implicit and explicit attentional biases for food-related stimuli (i.e., food bias) (e.g., Placanica, Faunce, & Soames Job, 2002; Seibt, Häfner, & Deutsch, 2007), similar to individuals with eating disorders (Brooks, Prince, Stahl, Campbell, & Treasure, 2011). Food bias is frequently measured with a modified Stroop task known as the “food-Stroop.” Fasted healthy participants show increased interference when food related words replace color words in the task; however, healthy satiated individuals do not show the same bias for food- or emotion-words (Channon & Hayward, 1990; Mogg, Bradley, Hyare, & Lee, 1998). Priming studies (i.e., ones in which a participant viewed or did not view food-related stimuli prior to testing) were only included if one or more tasks did not employ food-related stimuli entirely and data from the control condition were available (e.g., a regular Stroop and a food-related Stroop task administered at different stages of the procedure). If a research design employed both food-related stimuli and neutral stimuli, we only evaluated data pertaining to the neutral stimuli.

Inclusion in the review also required that the fasting procedure was explicit and that the comparison group was not fasted. Religious fasting was acceptable if duration of fasting was monitored by controlling for the time of day for both the onset of fasting and the beginning of the testing session. Both within-subject and between-subject designs were included if fasting and satiety was controlled. There was no specific minimum duration of fasting for inclusion. Only articles that were accepted in a peer-reviewed publication were included.

We had no limitations regarding publication year. We conducted the first stages of the searches for articles in June of 2012. Focused searches of relevant citations and articles that cited included articles were conducted through February 2013. An additional search in July of 2013 showed no additional eligible studies published.

Studies were excluded from the systematic review if the subjects were younger than 18 years old, not human, if the use of non food-related stimuli was integrated with food-related stimuli, if fasting procedures were not clear and controlled to meet the above criteria, or if no healthy controls were used. Also excluded were studies in which data were collected after an overnight fast but no data were collected from non-fasted subjects (either between or within subjects). Correlational studies (e.g., studies using self-reported hunger without reported, controlled fasting) were also excluded as the focus of this study was on the impact of experimental fasting and not on probabilistic and/or self-reported time since eating. Additionally, studies using insulin or glucose clamps in lieu of asking participants to refrain from eating were excluded, as fasting involves a variety of physiological reactions that these methods do not replicate. Similarly, studies in which the comparison group only drank a glucose-containing beverage were omitted, as these may not sufficiently reflect the broad range of physiological and psychological processes associated with food consumption. Table 2 presents the inclusion and exclusion criteria of the study.

Selection and Review Strategy

Study selection occurred in two stages. In Stage 1, the relevant databases, and search engine queries (i.e., Google Scholar), and reference sections of manuscripts were searched as described above. Identified abstracts were imported into citation management software (EndNote X5, Thomson Reuters, Inc., New York, NY) and subsequently exported into a word processor. The abstracts were alphabetized by first author to reduce bias in review. The abstracts of all unique identified studies (N=379, once duplicates were removed) were reviewed in order to determine eligibility. Two reviewers (EB and NO) independently categorized studies into three categories: eligible, questionable eligibility, and non-eligible studies. Full text articles of eligible and questionably eligible (N = 69) abstracts were retrieved for review and final determination on eligibility (Stage 2). Inconsistencies were discussed with a third reviewer (CAT). If a collective decision was not reached, the fourth reviewer was consulted (LS). The total number of studies included at this stage was 9. After the initial articles were established, their references were checked for additional potentially relevant articles; articles that cited the included studies were also retrieved and reviewed in the same process as above. This resulted in 72 additional abstracts, 42 of which were eligible or questionably eligible. After further examination, one additional article was included. Thus, a total of 10 articles are presently reviewed, with data from 612 participants. See Figure 1 for a flow chart depicting the study selection process. Two studies are worth noting as they were methodologically similar to the ones included in our review, but were omitted because participants were fasted in the control condition (Guttiérrez, et al., 2001; Pönicke, et al., 2005). An additional study was not peer reviewed and therefore excluded, however, it met all other criteria (Pender, 2011). A final study was omitted as it was a reanalysis of a data set of an included study; its reanalysis did not alter any of the variables of interest in this review (Martin & Benton, 1999).

Data Extraction.

Presented in Table 3 are the sample size, experimental design, and fasting duration in each study. Table 4 presents the tasks used, as well as what domains the tasks assessed, and whether fasting had a significant impact on the performance in the task. The included studies assessed a variety of domains using tests that were unique to the researchers' lab, well-validated measures available to the public, or a combination of in-house and established tests. The results are ordered by higher-order domain (psychomotor ability, memory, processing speed, visual attention, executive function), and then by subdomain and the tests used to assess them.

Results

Psychomotor Ability

Psychomotor ability was assessed with either a tapping task, a count of how many times a participant can tap one or two fingers, or a version of a reaction time test, wherein a trigger stimulus indicates a participant should respond via button press. Reaction time tests came in two forms: (a) simple, where a button was pressed at the presentation of a single stimulus, or (b) choice or discriminant, where different stimuli required different buttons to be pressed. Additionally, Doniger, Simon, and Zivotofsky (2006) reported results from a "Catch Game" in which "[p]articipants 'catch' a 'falling object' by moving a 'paddle' horizontally on the computer screen so that it can be positioned directly in the path of the falling object" (p. 807).

Tapping. Two studies found that fasted participants were significantly slower completing a two-finger tapping task than non-fasted participants (Green, Elliman, & Rogers, 1995; Green, Elliman, & Rogers, 1997). When assessed for duration of fasting, only the 24h fasted group showed this effect, whereas those who skipped one, two, or no meals did not show a deficit

(Green, et al., 1995). In contrast, Doniger, et al. (2006) found no difference for the fasted and non-fasted conditions using a tapping task in a within-subjects design.

Reaction Time. Three studies showed no significant differences in simple reaction times between fasted and fed groups (Green, et al., 1995; Green, et al., 1997; Owen, Scholey, Finnegan, Hu, & Sunram-Lea, 2012). One study demonstrated significant slowing in choice reaction time when fasted (Roky, et al., 2000) while another demonstrated that the placebo (fasting) group was faster than the glucose-drink condition (with no other significant differences between groups) (Owen, et al., 2012). As assessed by the “Catch Game,” individuals in the fasted condition had significantly slower executions of the first move, which may also have contributed to a slower overall score (Doniger, et al., 2006). The second study in which a deficit was observed tested individuals during Ramadan fasting (Roky, et al., 2000); slow reaction time was seen only on the sixth day of fasting and the authors suggested this slowing may have been better accounted for by fatigue. However, Tian, et al. (2011) also tested participants during Ramadan fasting and found that fasted athletes performed better in a choice reaction time task.

Memory

A variety of tasks were used to assess the impact of fasting on several domains and components of memory, however, memory tasks were inconsistently classified across studies. For consistency, we operationally classified short-term memory (STM) tasks as those that required the immediate and/or short-delayed recall of information without having to mentally manipulate that information. Working memory (WM) tasks were defined as those requiring mental manipulation of information in a short period of time (Baddeley, 2003). STM and WM were largely assessed using verbal stimuli (e.g., lists of words or numbers), though several studies used nonverbal stimuli. One study (Sunram-Lea, Foster, Durlach, & Perez, 2001) used the California Verbal Learning Test (CVLT). The CVLT primarily assesses proactive interference (forgetting items due to categorical similarity with other items), but includes elements of a variety of memory and learning processes (Delis, Freeland, Kramer, & Kaplan, 1988) that include components of both short- and long-term memory (LTM). In the CVLT, participants are asked to remember a list of items immediately after hearing them, after a short delay, and then again after a long delay. The last task of the CVLT is a recognition task that measures discriminability. Sunram-Lea, et al. (2001) also utilized the Rey-Osterrieth Complex Figure Task, in which participants copy a complex shape and reproduce it again after a short and long delay. Green, et al. (1997) used a Rapid Visual Information Processing (RVIP) task, which has elements of attention, processing speed, and working memory; for brevity, the RVIP tasks will be reported only in the WM section below. Finally, Benton and Parker (1998) used a modified Brown-Petersen (i.e., trigrams) task (1958, cited in Benton and Parker), in which participants had to recall a trigram of letters in order after counting backwards by three for an allotted period of time.

Short-term Memory-Verbal. Generally, fasted participants were able to recall or recognize a list of words or numbers as well as non-fasted participants in several studies or conditions within experiments (Doniger, et al., 2006; Green, et al., 1995; Green, et al., 1997; Owen, et al., 2012; Sunram-Lea, et al., 2001). However, fasting significantly impacted several conditions and tasks. On the CVLT, regardless of glucose intake, those who ate breakfast recalled the most words in both the short delay cued- and free-recall; fasted participants trended toward recalling significantly fewer words in the immediate free-recall condition for List A but not List B (Sunram-Lea, et al., 2001). Benton and Parker (1998) presented inconsistent differences between experiments: in experiment one, fasted participants had slower word recognition time with un-impacted accuracy; in experiment three, breakfast eaters recalled significantly more words. Using the International Shopping list as the dependent variable, Tian, et al. (2011) found a one-way interaction of time of day and fasting such that a detriment in performance on the task was limited to the afternoon (4:00 pm) testing session when fasted, and not seen at the morning (9:00 AM) session.

Short-term Memory-Nonverbal. In a nonverbal recognition task, in which participants were asked to identify a series of memorized geometric shapes from matrices, participants generally performed worse when fasted. This effect was most evident at the first repetition of the task, and at the mid-day and afternoon portion of fasting (Doniger, et al., 2006). On an in-house designed task, fasted participants performed slower on a spatial-memory task, but did not differ on accuracy (Benton & Parker, 1998). Fasting did not impact performance on the Rey-Osterrieth Complex Figure Task (Sunram-Lea, et al., 2001) or Corsi blocks (Owen, et al., 2012).

Working Memory. There was relatively little impact of fasting on working memory. Individuals who did not eat breakfast and did not receive a glucose drink recalled fewer trigrams and showed no improvement over trials compared to individuals who ate breakfast and/or ingested a glucose drink; similarly, those who drank glucose but ate no breakfast did not differ from those who ate breakfast (Benton & Parker, 1998). While there was a significant effect of time of day on a one-back and one-card learning measure, there was no effect of fasting and no interaction of fasting and time of day on performance on these tasks (Tian, et al., 2011). No aspect of the Rapid Visual Information Processing task was significantly impacted by fasting (Green, et al., 1997); a nearly identical task, dubbed the “Bakan Vigilance Task,” was not impacted by fasting in an earlier study (Green, et al., 1995).

Long-Term Memory. There were limited impacts of fasting on long-term memory. In Sunram-Lea, et al. (2001) study, the long-delay free-recall condition of the California Verbal Learning Test was not impacted by fasting. In the cued-recall (discriminability) task, those who fasted performed worse than those who ate a standardized breakfast or lunch, while those who ate lunch performed the best of these groups. This indicates that skipping a meal reduces performance in this task, but eating lunch may be particularly beneficial, perhaps due to a time of day effect. Owen, et al. (2012) reported no significant differences between fasted and non-fasted individuals in either a long-delayed free-recall or recognition task.

Processing Speed

Performance on many of the tasks in the studies included in this review relied on processing speed – including the Bakan vigilance and Rapid Visual Information Processing tasks (Green, et al., 1995; Green, et al., 1997) and Catch Game (Doniger, et al., 2006). Doniger, et al. (2006) were the only researchers who included a task that specifically assessed processing speed: the Staged Information Processing Test in which participants identified whether or not the solutions to a series of single-digit, two-digit, or three-digit arithmetic problems equaled four (for brevity and comprehensibility these data are not shown in Table 4). The problems were presented at three speeds: slow, medium, and fast. The authors reported accuracy, response time, and the standard deviations (i.e., variance) of response times for each speed and condition. On fasting days, the following conditions had significantly slower reaction times: single digit medium and fast, two-digit slow and medium, three digit slow and medium. More variable response times occurred in single digit medium, two digit slow, two digit medium, three digit slow, and three digit medium tasks. Accuracy was poorer only in the two digit slow and medium condition. Thus, the main decrement related to fasting and processing speed, as assessed by this task, was seen in reaction time on moderately difficult trials.

Visual Attention

Two studies assessed visual attention, however, fasting had limited impact in this domain. Green, et al. (1995) utilized a modified flanker task in which participants were asked to identify the central figure within a string of distractor stimuli on a computer screen (e.g, BBABB vs. AABAA); there were no reported differences on any aspect of the task between fasted and non-fasted participants. Using the Identification Task, in which participants had to press "yes" if a playing card presented on computer screen was red and "no" if it was not red, Tian, et al. (2011) found that reaction time was faster in the fasted condition in the morning session (9:00 AM); accuracy was not reported.

Executive Functioning

Executive functioning was assessed in a variety of domains using a variety of tasks. The primary domains assessed were: interference (i.e., cognitive control) assessed using Stroop and inhibition using go/no-go tasks (Doniger, et al., 2006; Owen, et al., 2012; Stewart & Samoluk, 1998); set shifting and cognitive flexibility was assessed using a task based on the Wisconsin Card Sorting Task (WCST; Berg, 1948) (Piech, Hampshire, Owen, & Parkinson, 2009) (described bellow). Abstract reasoning using the eponymous section of the Graduate Management Admissions Test (GMAT) (Benton & Parker, 1998), and a problem solving task (similar to matrix reasoning, in which the participant must select a shape that completes increasingly complex figures) (Doniger, et al., 2006).

Interference. There were limited impacts of fasting on more traditional measures of cognitive control and interference. Three studies utilized a Stroop task and there was generally no impact of fasting on performance: two studies (Doniger, et al., 2006; Stewart & Samoluk, 1998) found trend-level declines in performance (in terms of accuracy and reaction time) when fasted (*P*s $\leq$ .10, but > .05), and one (Owen, et al., 2012) reported no significant impact of fasting, though the fasted group had the lowest accuracy and longest reaction times. There was no significant difference between the fasting and non-fasting conditions in any aspect of a go/no go test (Doniger, et al., 2006).

Cognitive Flexibility. Set-shifting was assessed using a computerized task similar to the WCST (Piech, et al., 2009): there were two categories (faces and buildings) from a “deck” of cards that participants had to select, participants initiated selection of one category, and feedback was provided intermittently to confirm the category selection was correct or to illustrate the category was incorrect. After several blocks of feedback, the correct category either changed (requiring an “extradimensional” shift, or ED) or did not shift (requiring an “intradimensional shift,” or ID). Participants were not explicitly informed of the shift in rules, but had to ascertain that the rules had shifted based on performance feedback. Each participant completed both a fasted and sated condition after viewing a picture slideshow. Half of the participants viewed appetitive food and the other half viewed flowers (participants viewed the same slideshow both times).[1] The results showed that all participants who had been primed with pictures of appetitive food had reduced accuracy in the task and this effect was enhanced as a result of fasting. Additionally, fasted individuals had slower reaction time regardless of ID or ED shifts, and that sated individuals only expressed slowing at ED shifts.

Abstract/Logical Reasoning. Two studies assessed the domain of abstract and logical reasoning. In a problem solving task wherein participants had to fill in the missing block of a 2X2 matrix to complete an image, participants were significantly less accurate when fasted

(Doniger, et al., 2006). There was no significant difference on the abstract reasoning section of the Graduate Management Admission Test (Benton & Parker, 1998).

Discussion

We synthesized the results of 10 studies that systematically examined the impact of fasting on healthy individuals. We limited our search parameters to focus on several domains, and ensured that included studies used only neutral stimuli in the tasks themselves (i.e., that were not food related stimuli). The results of the studies in this review demonstrate equivocal effects of fasting on cognition in healthy adults: no one cognitive function was impacted consistently and a number of confounds may have affected these results. It is clear that additional studies are needed to better understand the impact of short-term fasting on cognition in healthy individuals.

Generalizability and Validity. Most notable in the studies included in this review are the inconsistencies in the results and within the experiments themselves. There were a variety of fasting conditions (i.e., duration and motivation), samples (i.e., size, demographic composition, geographic location), and/or procedures (i.e., task batteries, testing settings). In terms of fasting conditions, some assessments were administered during religious fasting (Doniger, et al., 2006; Roky, et al., 2000; Tian, et al., 2011), whereas others were self-selected volunteers from undergraduate psychology courses (e.g. Green, et al., 1995; Green, et al., 1997). Fasting durations of included studies ranged from 2h (Owen, et al., 2012) to 24h (Green, et al., 1995) with three (Green, et al., 1995; Roky, et al., 2000; Tian, et al., 2011) directly comparing duration in some capacity (to which there were limited or no differences when the duration of fasting was the independent variable). Methods of monitoring and controlling fasting duration varied within each study, however, there were limited demonstrable effects of fasting duration. Time of day was an independent variable in several studies. In the afternoon, participants generally did worse in tasks assessing memory, attention, and/or mental rotation. For several tasks, this decrement was not limited to the fasting condition, and, in fact, on fasting days the afternoon group did better (Doniger, et al., 2006; Green, et al., 1995; Sunram-Lea, et al., 2001; Tian, et al., 2011). Other studies saw no time of day effects on any measure (Green, et al., 1997; Roky, et al., 2000). Time of day appears to be an important variable in understanding the impact of fasting on cognition and we recommend that it be controlled for or incorporated into designs in future research.

Demographic composition was varied. Gender composition ranged from all men (Roky, et al., 2000; Tian, et al., 2011) to all women (Green, et al., 1995), or was not stated (Green, et al., 1997; Sunram-Lea, et al., 2001). Most assessed the impact of fasting in young adults (18-25), though many studies did not report the age of their participants. Interestingly, neither age nor gender was explored as an independent variable in any of the studies. Therefore, it is impossible to determine if fasting differentially affects performance in men or women, if it has a greater impact on older or younger individuals, and whether or not either of these factors interact with time of day or length of fasting. There is some evidence to suggest that there are sex differences in neural activity related to hunger and satiety (Del Parigi, et al., 2002; Führer, Zysset, & Stumvoll, 2008), which may then translate into gender differences in attention to food-related stimuli (Frank, et al., 2010; Uher, Treasure, Heining, Brammer, & Campbell, 2006). Therefore, future studies investigating gender differences are certainly warranted. To our knowledge, there is no research examining the effect of age on neural correlates to hunger and satiety. While measuring effects of fasting in undergraduates or young adults can be useful to show that an effect can be demonstrated *somewhere*, other populations and age groups could be informative (Henrich, Heine, & Norenzayan, 2010). Samples in the present study were from Singapore, Morocco, Canada, the United Kingdom, and Israel; cultural impacts of meal abstention on cognition should also be examined as, for example, meal size and nutritive content, as well as circadian rhythm can vary by culture (Henrich, et al., 2010).

The study designs and cognitive tests utilized in the studies were diverse, ranging from novel memory tests (e.g., trigrams) (Benton & Parker, 1998) to comprehensive computer-administered batteries (Doniger, et al., 2006), several Stroop tasks (Stewart & Samoluk, 1998), or a combination of standardized psychomotor, attention, and memory tasks (Green, et al., 1995; Green, et al., 1997). Some studies used a single task (Piech, et al., 2009), while others had an extensive battery (Doniger, et al., 2006). Processes assessed ranged from basic psychomotor abilities (tapping speed and/or reaction time) (Green, et al., 1995; Green, et al., 1997; Tian, et al., 2011) to higher-level reasoning tasks and executive function (Benton & Parker, 1998; Piech, et al., 2009). There was also a variety of study designs, including both within-subject (e.g., Doniger, et al., 2006; Green, et al., 1995) and between subject designs (e.g., Benton & Parker, 1998; Stewart & Samoluk, 1998). While the variety of fasting conditions, populations assessed, study designs, and testing batteries could be informative for generalizability, the inconsistency of the results reported in the present review inhibits the ability to draw conclusions of the impact of acute fasting on cognition. It is entirely possible that the conflicting findings are due to design and testing issues. Additional research is needed to demonstrate external validity of the findings described above using standardized or replicable batteries and assessing domains that have been understudied to date. Finally, while three studies in this review state that they used a double blind procedure (Benton & Parker, 1998; Owen, et al., 2012; Sunram-Lea, et al., 2001), it is difficult to design a study investigating fasting that is truly “blind,” or “double blind;” therefore it is possible that expectancy bias from the experimenter and/or compensatory effort from the participants may impact internal validity. Despite the limitations and inconsistencies of the procedures of the studies reported here, there were several important findings related to the impact of fasting on various cognitive domains.

There were few instances where fasting was associated with changes in accuracy on a task, however, most of the deficits reported were in the form of slowed reaction time. In assessments that specifically investigated psychomotor abilities (e.g., tapping, reaction time, choice reaction time), fasting consistently impacted tasks requiring stimulus discrimination in choice reaction time, however, the direction of these differences is unclear. Deficits in finger tapping are typically seen in individuals with severe psychopathology (e.g., schizophrenia) or traumatic brain damage (Arnold, et al., 2005). Therefore, one possible explanation for the present findings is that they are a secondary effect, while fatigue or reduced effort and motivation are more primary (Arnold, et al., 2005; Prigatano, 1999). It is important for future research to disentangle motivation and fatigue associated with fasting and psychomotor ability to determine which can better account for results seen across tasks.

Processing speed, when assessed directly, appeared to be marginally impacted by fasting, with reduced reaction time and variable deficits in accuracy (Doniger, et al., 2006). A recent large meta-analysis found processing speed to be trait-like (Sheppard & Vernon, 2008), and acute periods of fasting may not affect cognitive or neural structures associated with it. However, prolonged fasting, restriction, or malnourishment may be more likely to impact processing speed (e.g., Allen, et al., 2012; Gillberg, et al., 2010; Grantham-McGregor, 1995).

Memory was one the most frequently studied cognitive functions with seven of the ten studies assessing it in some capacity (Benton & Parker, 1998; Doniger, et al., 2006; Green, et al., 1995; Green, et al., 1997; Owen, et al., 2012; Sunram-Lea, et al., 2001; Tian, et al., 2011). Short-term memory was the primary focus of the studies included in this review, which limits inferences that can be made regarding whether, and how, need-state impacts other memory modalities (e.g., working, long-term, or visuospatial memory). The results showed that accuracy of recall in verbal short term memory was not impacted by fasting, but time to respond was (Benton & Parker, 1998; Green, et al., 1995; Green, et al., 1997; Owen, et al., 2012; Sunram-Lea, et al., 2001). Future work should expand on the domains and tasks used to assess memory and learning as a result of acute fasting.

There were no differences in visual attention associated with fasting, yet there is evidence that reduced blood glucose decreases attention capacity (Mohanty, Gitelman, Small, & Mesulam, 2008; Scholey, Sunram-Lea, Greer, Elliott, & Kennedy, 2009). Given the focus in the literature on performance in attentional bias to food-related stimuli in healthy, fasted individuals (e.g., Mogg, et al., 1998; Seibt, et al., 2007) and in samples of individuals with disordered eating (Brooks, et al., 2011), it is surprising that general visual attentional function was only directly assessed in two studies (Green, et al., 1995; Tian, et al., 2011). Further study is needed to assess the impact of fasting on attention to disentangle altered attention function from atypical, biased attention to food-related stimuli.

Finally, fasting had inconsistent impacts on executive functioning. It may be that fasting does not cause enough of a deficit in the resources needed to complete tasks assessing set shifting (e.g., WCST), interference (e.g., Stroop tasks), and behavioral inhibition (e.g., go/no-go tasks) as these do not vary greatly in the absence of severe pathologies or brain injury (MacLeod, 1991; Nigg, 2000). Piech and colleagues (2009) suggest that motivation has greater influence on cognition than physiological state: in their study, pictures of appetitive food reduced available attentional resources regardless of fasting. There was also a lack of significant effect of fasting on "classic" Stroop task performance in three studies in the present review (Doniger, et al., 2006; Owen, et al., 2012; Stewart & Samoluk, 1998), which also exemplifies limited impact of caloric deprivation on executive functioning; however, each fasted condition in each study either exhibited the lowest accuracy or the slowest completion time. Similarly, periods of prolonged starvation as a result of AN generated minimal, but consistent, deficits in "classic" Stroop performance across eating disorders (Dobson & Dozois, 2004). Further research using other assessments of executive functioning are merited, particularly ones that do not rely on reaction time as a dependent variable.

Limitations and Future Directions

Although this review presents the results of several studies investigating how fasting and meal abstention may impact cognition, it is not without limitations. We were necessarily specific with our search terms, and, as a result, there is a possibility that we were unable to identify studies with keywords or aspects of cognition we did not use. Initial searches with broader terms yielded hundreds of results per term, or several thousand articles total. For example, in PsycINFO, "hunger & memory" alone yielded 1083 articles while "hunger & 'working memory'" yielded 429 with few duplicate articles. Many additional studies that were excluded from the present review utilized methodologies and populations that could be an avenue for future research and reviews. Namely, there were a number of studies in which fasted participants drank either a glucose-containing beverage or a placebo, that included children, and/or that included individuals with physiological or psychological pathology. The purpose of this review was to assess the impact of fasting on general cognition; therefore we also omitted a large body of experiments examining bias to food-related stimuli in healthy individuals who are fasted. Additionally, we did not include articles that were not accepted for publication in peer-reviewed journals and, therefore, other sources of information (e.g., "gray literature," manuscripts under peer-review, dissertations, and theses) may have contained intriguing trends. We also excluded correlational studies that featured self-reported hunger and time since last eating in order to focus on experimental designs; this is another avenue for additional reviews and research. Despite these limitations, the present review provides a synthesis of a limited body of research that can inform research investigating a variety of fields. By completing additional controlled experiments to address some of the limitations discussed here, we can better address how meal abstention impacts cognition and the brain, and increase our understanding of both normative and abnormal functioning.

Conclusions

The present review synthesizes extant literature examining fasting and several elements of cognitive functioning. The results present an inconsistent and incomplete profile of what is and is not impacted during normative fasting and its associated hunger. The present review demonstrates that, similar to early reviews investigating studies of the relation of hunger and cognition, the field still has yet to demonstrate consistent and/or meaningful findings. Future studies should continue to investigate additional cognitive modalities, especially in the domains of attention, memory, and executive function.

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Footnotes

[1.] While we omitted studies assessing attentional bias to food stimuli and/or that used food in the tasks themselves, Piech and colleagues (2009) primed half of their subjects with pictures of food. Subjects did not complete any cognitive tasks while viewing the pictures, therefore, this study met the inclusion criteria.

Table 1: Search terms used in each database

Root	Search Term
Fasting	Stroop
Caloric restriction	Tower
Food restriction	Towers
Hypoglycemia	Tower task
Food deprivation	Trails
Hunger	Trail making
	Brixton
	CPT
	continuous performance task
	WCST
	Wisconsin Card Sorting
	Card sorting
	Set-shifting
	Cognitive flexibility
	Tapping test
	Reaction time

Table 2:
Inclusion and exclusion criteria for studies

Inclusion Criteria	Exclusion Criteria
At least one group is over 18 *and* healthy	No group is over 18 *and* healthy
Human subjects only	No human subjects
At least one group of healthy controls	No group of healthy controls
Fasting must have occurred	No fasting (i.e. probabilistic hunger)
Cognitive tests as dependent variable and at least one test contains no food-related stimuli	Cognitive tests not used and/or imaging study only
	Stimuli used are only food-related

Notes: If any of these were deemed to be ambiguous by the two raters (EB and NO), third (CAT) and fourth (LS) reviewers were asked to determine if criteria were met.

Table 3
Descriptive statistics for each study.

Author	Year	Country	Design	Total N	N Fasted	% Female	N Sated	Age (years)[a]	Time Fasted	Design Notes
Stewart & Samoluk	1995	Canada	Between	32	17	78	15	M = 21.8 SD = 1.9	5.5h	
Green, Elliman, Rogers	1995	England	Within	21	21	100	21	Range: 18 - 25	24h, 2m, 1m	AM and PM group: each completed 3 levels of deprivation skipping meals; m = meal
Green, Elliman, Rogers	1997	England	Between	82	42	Not Stated	40	Range: 18 - 31	Not Stated	Skipped breakfast, lunch or no meal (controlled) in AM or PM: fasted/incentive (22); fasted/no incentive (20); satiated/incentive (20); satiated/no incentive (20)
Benton & Parker (Exp. 1)	1998	Wales	Between	33	Not Stated	48	Not Stated	M = 21.3 (SD not stated)	≤ 16h	
Benton & Parker (Exp. 2)	1998	Wales	Between	80	15	100	†	M = 22.63 (SD not stated)	Not stated (testing took place at 9:00 AM)	† Ate or skipped breakfast (exact time not controlled): Breakfast/Glucose (28) Breakfast/Placebo (25) Fasting/Glucose (12)
Benton & Parker (Exp. 3)	1998	Wales	Between	184	40	74	††	M = 22 (SD not stated)	Not stated	††Ate or skipped breakfast (exact time not controlled): Breakfast/Glucose (55); Breakfast/Placebo (51); Fasting/Glucose (38)

Table 3 Continued

Author	Year	Country	Design	Total N	N Fasted	% Female	N Sated	Age (years)[a]	Time Fasted	Design Notes
Roky, Iraki, HajKhlifa, Ghazal, Hakkou	2000	Morocco	Within	10	10	0	10	20 - 28	9-16h	Religious fasting
Sunram-Lea, Foster, Durlach, & Perez	2001	England	Between	60	10	Not Stated	40	M = 21.8 Range: 18 -28	9 - 12 hours	10 participants per cell: Fasting, Breakfast, Lunch with either glucose or placebo
Doniger, Simon, Zivotofksy	2006	Israel	Within	46	46	65	46	22.4 SD = 2.1	12 – 16 hours	Religious Fasting; computerized, standardized battery
Piech, Hampshire, Owen, Parkinson	2009	Wales	Within (Mixed Model)	16	16	56	16	Not Stated	5h	Repeated measures: a participant saw flowers or food (not both), then completed measures
Tian, Aziz, Png, Nutr, Wahid, Yeo, Png	2011	Singapore	Within	18	18	0	18	M = 20.9 SD = 3.3 Range: 17 - 29	14h & 24h	Religious fasting
Owen, Scholey, Finnergan, Hu, Sünram-Lea	2012	England	Within (Latin Square)	30	30	Not Stated	30	M = 20 Range: 18 - 25	2h & 12h	Control group was glucose enhancement; six-way, crossover, double blind study

Notes: Martin & Becker (1999) is a reanalysis of the data in Benton and Parker (1998; experiment 2); the reanalysis did not impact the results reported in this review; [a]All available information pertaining to age is presented in this table as it was presented in each article.

Table 4
Data Extraction

Domain/Modality	Author	Year	Test	Affected by hunger?	Describe Effect
Psychomotor Speed					
Tapping					
	Doniger, Simon, & Zivotofksy	2006	Finger Tapping	No	
	Green, Elliman, & Rogers	1997	Two-Finger Tapping	Yes	Slower when fasted
	Green, Elliman, & Rogers	1995	Two Finger Tapping	Yes	Slower when fasted (24h fast only)
Reaction Time					
	Green, Elliman, & Rogers	1995	Simple RT	No	
	Green, Elliman, & Rogers	1997	Simple RT	No	Hunger was slower, but not significant
	Owen, Scholey, Finnegan, Hu, & Sünram-Lea	2011	Simple RT	No	
	Owen, Scholey, Finnegan, Hu, & Sünram-Lea	2011	Choice RT	Yes	Faster in placebo compared to glucose
	Roky, Iraki, HajKhlifa, Ghazal, Hakkou	2000	Movement RT (choice RT)	Yes	Sixth day only; fasting performed worse.
	Tian, Aziz, & Png, Nutr, Wahid, Yeo, & Png	2011	Detection Task	Yes	Fasting better[b]
	Doniger, Simon, & Zivotofksy	2006	Catch Game	Yes (trend)	Time to make first move only; total score trend (p = .06)

Table 4 Continued

Domain/Modality	Author	Year	Test	Affected by hunger?	Describe Effect
Memory					
STM-Verbal					
	Sunram-Lea, Foster, Durlach, & Perez	2001	Wechsler Digit Span	No	
	Green, Elliman, & Rogers	1995	Immediate Free Recall	No	
	Green, Elliman, & Rogers	1997	[Immediate] Free Recall	No	
	Benton & Parker	1998; Exp.1	Word List Recall	Yes	slower; no effect on accuracy
	Benton & Parker	1998; Exp. 3	Word List Recall	Yes	Fasted & placebo recalled fewest words[c]; breakfast eaters did the best regardless of glucose
	Tian, Aziz, & Png, Nutr, Wahid, Yeo, & Png	2011	International Shopping List Recall	Yes	Fasting worse[c]
	Sunram-Lea, Foster, Durlach, & Perez	2001	Modified CVLT IFRCa	Yes (trend)	Fasting worse (p = .06)
	Sunram-Lea, Foster, Durlach, & Perez	2001	Modified CVLT IFRCb	No	
	Sunram-Lea, Foster, Durlach, & Perez	2001	Modified CVLT SDFR	Yes	Fasted & Placebo recalled fewest words[c]; breakfast eaters did best
	Sunram-Lea, Foster, Durlach, & Perez	2001	Modified CVLT SDCR	Yes (trend)	Main effect of condition (p = .05); breakfast eaters did best[b]
	Owen, Scholey, Finnegan, Hu, & Sünram-Lea	2011	Immediate Word Recall	No	
	Owen, Scholey, Finnegan, Hu, & Sünram-Lea	2011	Immediate Word Recognition	No	
	Green, Elliman, & Rogers	1997	Recognition Memory	No	

Table 4 Continued

Domain/Modality	Author	Year	Test	Affected by hunger?	Describe Effect
STM-Verbal *(continued)*	Doniger, Simon, & Zivotofksy	2006	Verbal Memory	No	
	Benton & Parker	1998; Exp. 3	Wechsler Story	Yes	Fasting did worst, regardless of drink
STM-Nonverbal					
	Doniger, Simon, & Zivotofksy	2006	Nonverbal Memory	Yes	Fast day poorer immediate recognition[d]
	Sunram-Lea, Foster, Durlach, & Perez	2001	ROCF	No	
	Benton & Parker	1998; Exp.1	Spatial Memory (in-house)	Yes	Slower (no effect on accuracy)
	Owen, Scholey, Finnegan, Hu, & Sünram-Lea	2011	Corsi Blocks	No	
Working Memory					
	Green, Elliman, & Rogers	1995	Bakan Vigilance	No	
	Green, Elliman, & Rogers	1997	Rapid Visual Information Processing (RVIP)	No	
	Tian, Aziz, & Png, Nutr, Wahid, Yeo, & Png	2011	One Card Learning	No[a]	
	Tian, Aziz, & Png, Nutr, Wahid, Yeo, & Png	2011	One-Back	No	
	Benton & Parker	1998; Exp.2	Brown-Petersen task (Trigrams)	Yes	Fasted group did not improve; any glucose intake improved performance
	Owen, Scholey, Finnegan, Hu, & Sünram-Lea	2011	Serial Threes	Yes	faster with glucose (no effect on accuracy)
	Owen, Scholey, Finnegan, Hu, & Sünram-Lea	2011	Serial Sevens	Yes	faster with glucose (no effect on accuracy)

Table 4 Continued

Domain/Modality	Author	Year	Test	Affected by hunger?	Describe Effect
LTM					
	Sunram-Lea, Foster, Durlach, & Perez	2001	Modified CVLT LDFR	No	
	Sunram-Lea, Foster, Durlach, & Perez	2001	Modified CVLT LDCR	Yes	Eating breakfast better than fasting
	Sunram-Lea, Foster, Durlach, & Perez	2001	Modified CVLT LD Recognition	No	
	Owen, Scholey, Finnegan, Hu, & Sünram-Lea	2011	Delayed Word Recall	No	
	Owen, Scholey, Finnegan, Hu, & Sünram-Lea	2011	Delayed word Recognition	No	
Processing Speed					
	Doniger, Simon, & Zivotofksy	2006	Staged info. Processing	Yes	See text[f]
Visual Attention					
	Green, Elliman, & Rogers	1995	Modified Flanker	No[a]	
	Tian, Aziz, & Png, Nutr, Wahid, Yeo, & Png	2011	Identification Task	Yes	Fasting better

Table 4 Continued

Domain/Modality	Author	Year	Test	Affected by hunger?	Describe Effect
Executive Function					
Stroop					
	Doniger, Simon, & Zivotofksy	2006	Stroop	Yes (trend)	Fast day poorer accuracy (*p* = .07)
	Stewart & Samoluk	1995	Stroop	Yes (trend)	Decrease in color-naming speed (*p* = .1)
	Owen, Scholey, Finnegan, Hu, & Sünram-Lea	2011	Stroop	No	Fasting group had worst accuracy and RT
Cognitive Flexibility					
	Piech, Hampshire, Owen, & Parkinson	2009	Modified WCST	Interaction	Fasting increases errors; less variable RT (sated individuals had slower ID shifts)
	Doniger, Simon, & Zivotofksy	2006	Go-No Go	Yes	Response time slower[a]; accuracy not affected
Abstract Reasoning					
	Benton & Parker	1998; Exp. 3	GMAT Abstract Reasoning	No	
	Doniger, Simon, & Zivotofksy	2006	Problem Solving	Yes	Fast day poorer accuracy[a]
Miscellaneous					
Verbal Fluency	Doniger, Simon, & Zivotofksy	2006	Verbal Function (fluency)	Yes	Fast day poorer accuracy
Mental Rotation	Doniger, Simon, & Zivotofksy	2006	Visual Spatial Processing	Yes	Fast day poorer accuracy[d]

Notes: [a]Main effect of time of day, but no interaction; [b]significant interaction of time of day X fasting (morning, fasted better); [c]significant interaction time of day (morning, fasted worse) [d]Significant time of day X fasting interaction (early afternoon poorer); [e]Significant time of day interaction (late afternoon poorer);[f]due to the complexity of these data, time of day effects are not reported here; not all studies assessed time of day.

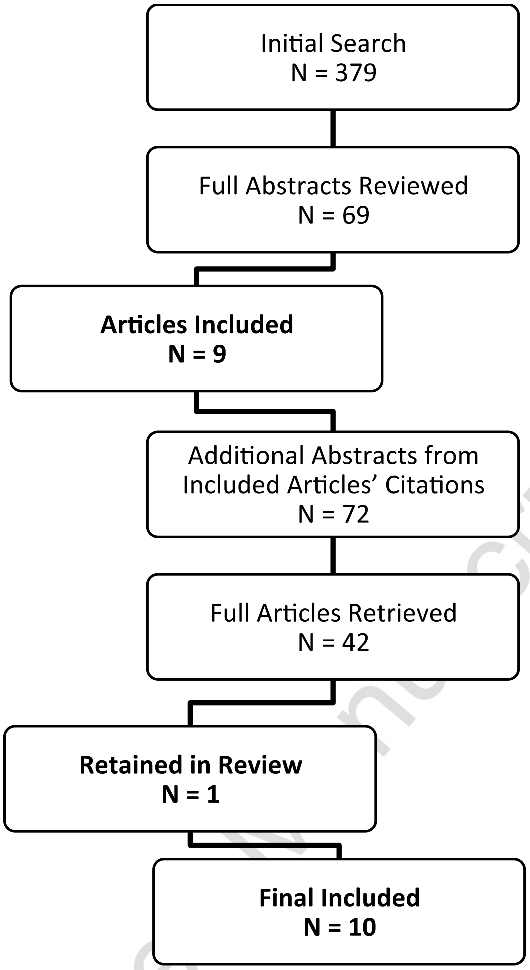

Figure 1. Flow chart depicting process of screening articles for inclusion