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Difficult action decisions reduce the sense of agency: A study using the Eriksen flanker task

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ABSTRACT

The sense of agency refers to the feeling that we are in control of our actions and, through them, of events in the outside world. Much research has focused on the importance of retrospectively matching predicted and actual action outcomes for a strong sense of agency. Yet, recent studies have revealed that a metacognitive signal about the fluency of action selection can prospectively inform our sense of agency. Fluent, or easy, action selection leads to a stronger sense of agency over action outcomes than dysfluent, or difficult, selection. Since these studies used subliminal priming to manipulate action selection, it remained unclear whether supraliminal stimuli affecting action selection would have similar effects.

We used supraliminal flankers to manipulate action selection in response to a central target. Experiment 1 revealed that conflict in action selection, induced by incongruent flankers and targets, led to reduced agency ratings over an outcome that followed the participant's response, relative to neutral and congruent flanking conditions. Experiment 2 replicated this result, and extended it to free choice between alternative actions. Finally, Experiment 3 varied the stimulus onset asynchrony (SOA) between flankers and target. Action selection performance varied with SOA. Agency ratings were always lower in incongruent than congruent trials, and this effect did not vary across SOAs. Sense of agency is influenced by a signal that tracks conflict in action selection, regardless of the visibility of stimuli inducing conflict, and even when the timing of the stimuli means that the conflict may not affect performance.

1. Introduction

The sense of agency refers to the feeling that we voluntarily control our actions and, through them, events in the outside world (Haggard & Tsakiris, 2009). This involves establishing a link between our intentions and our actions, and between our actions and their external outcomes. It has been suggested that our experience of agency colours the background of our mental lives (Chambon, Sidarus, & Haggard, 2014b; Gallagher, 2012; Haggard & Tsakiris, 2009), but we become especially aware of it when the smooth flow from intention to action to outcome is disrupted.

Much research has focused on the second link, between actions and outcomes. This has revealed an important signal that informs the sense of agency - the comparison between expected and actual action outcomes (Blakemore, Wolpert, & Frith, 2002; Wegner & Wheatley, 1999). If outcomes match our expectations, we feel that "I did that"; while a mismatch signals a loss of agency. While mismatch signalling partly relies on predictive processes, based on internal signals related to the action system (see Synofzik, Vosgerau, & Newen, 2008 for a review of comparator models), it is essentially *retrospective* since the action outcome must be known for the comparison to be made.

Recent studies have shown that a metacognitive signal about the fluency of action selection also contributes to the sense of agency (see Chambon et al., 2014b for a review). This signal serves to establish a link between our intentions and our actions, and is available before the action is even made, so it can inform our sense of agency *prospectively*. These studies used subliminal priming to manipulate action selection in an agency task (Chambon & Haggard, 2012; Chambon, Moore, & Haggard, 2014c; Chambon, Wenke, Fleming, Prinz, & Haggard, 2013; Sidarus, Chambon, & Haggard, 2013; Wenke, Fleming, & Haggard, 2010). Here, participants make left or right actions according to a target arrow, which are followed by coloured circles – the action outcomes. Participants are then asked to judge how much control they felt over these circles. Unbeknownst to the subject, a small arrow – a prime – is briefly flashed before the target. When the prime is congruent with the target, and points in the same direction, action selection is easy; but when the prime is incongruent with the target, and points in the opposite direction, action selection is impaired, leading to slower reaction times (RTs) and more errors (e.g. Wenke et al., 2010). Results showed

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that the sense of agency over action outcomes was higher following congruently primed actions, compared to incongruently primed actions.

Importantly, outcomes could not be predicted by the action or the prime alone, but depended on the *congruency* between prime and target. Further, the effects of action selection on sense of agency could not be explained by participants relying on a retrospective monitoring of RTs, as these were not correlated with agency judgements. Tellingly, a further experiment manipulated the timing of stimuli to induce either a normal priming effect or a “negative compatibility effect” (NCE; Eimer & Schlaghecken, 1998). In the NCE, congruent primes impair rather than facilitate motor performance. This manipulation reversed the effects of primes on RTs, as expected, but judgements of agency were always higher for congruent priming, in both normal and NCE priming (Chambon & Haggard, 2012). The authors proposed a model in which the very initial action intention, triggered by the prime, could be compared with the executed action. Congruency between the initial intention and action would facilitate a metacognitive signal about action selection, and thus lead to a higher sense of agency. The later motor inhibitory processes that caused NCE would occur downstream of this metacognitive readout of initial intention.

Since these primes were subliminal, participants were not aware that selection fluency was manipulated, and could not strategically decide to use fluency as a cue to agency (Chambon & Haggard, 2012; Wenke et al., 2010). Fluency can be thought of as a continuum between easy, or fluent, perceptual or cognitive processing, to effortful, or dysfluent, processing (Alter & Oppenheimer, 2009). Response conflict is an instance of highly effortful processing (Botvinick & Braver, 2015). Although the experience of selection fluency/dysfluency may be relatively weak, people may have a sense of “something going right/wrong” in congruent or incongruent trials respectively, without being able to identify why they have this feeling (Chambon et al., 2014b; Pacherie, 2008). It has been shown that people can reliably introspect on their experience of ease/difficulty in action selection, using a similar subliminal priming task (Desender, Opstal, & den Bussche, 2014), as well as with conflicting supraliminal stimuli (Morsella et al., 2009). This feeling could then become associated with subsequent events, such as action outcomes (Fritz & Dreisbach, 2013; Winkielman, Ziembowicz, & Nowak, 2015). Interestingly, similar effects are found when measuring agency at the end of a trial (e.g. Chambon & Haggard, 2012) and at the end of a block (Wenke et al., 2010). This suggests that the association between fluency experiences and outcomes could build up over time. Alternatively, the learning of action-outcome relations may be disrupted by dysfluent action selection.

In fact, the studies that used subliminal priming to manipulate selection fluency (e.g. Chambon et al., 2013; Wenke et al., 2010) differ considerably from previous research on the sense of agency, as they are focused on the *instrumental* learning of the relation between specific actions and a number of possible outcomes (Chambon, Filevich, & Haggard, 2014a). From this perspective, expertise with a given environment leads to a growing sense of ease, or flow, in selecting an action, which becomes associated with more predictable outcomes. On the other hand, research on the sense of agency has often focused on the *attribution* of agency. In such studies, action-outcome associations are often well known (Elsner et al., 2002), and may be violated (Kühn et al., 2011), and/or there may be ambiguity about “who” caused a specific outcome, i.e. me vs. another agent (e.g. Wegner & Wheatley, 1999).

Response conflict induced by conscious stimuli has been shown to lead to a reduced sense of agency over one's *actions* (Morsella et al., 2009). However, it remains unclear whether conscious stimuli that influence action selection might also alter the sense of agency over *action outcomes*. One suggestive study set out to manipulate the visibility of primes, while measuring judgements of agency over outcomes (Damen, van Baaren, & Dijksterhuis, 2014). Participants were aware of some primes, but not others. Prime words (“left” vs. “right”) were presented for a short or long duration, producing subliminal or supraliminal priming, respectively. Participants freely chose whether to press a left or right key once the following mask disappeared. Their action triggered a high or low tone after a variable delay, and participants judged their agency over the tone. For the subliminal priming condition, judgements of agency followed the pattern previously reported, i.e. higher ratings for trials in which the action was congruent with the prime, relative to prime-incongruent actions. However, for supraliminal primes, the effects were reversed, and higher ratings were found for prime-incongruent actions. The authors argued that awareness that one's choice might have been biased by external input would reduce one's sense of freedom and, in turn, one's sense of agency.

Importantly, Damen et al. (2014) study showed effects of priming on the sense of agency, despite showing little or no effect of either subliminal or supraliminal primes on reaction times. Priming of choices was only found for supraliminal primes, in one of two experiments. Thus, there is little evidence that primes influenced action selection processes in their study. This contrasts with previous reports in which even subliminal primes reliably biased free choices (Kiesel et al., 2006; Klapp & Haas, 2005; Klapp & Hinkley, 2002; O'Connor & Neill, 2011; Schlaghecken & Eimer, 2004; Wenke et al., 2010). Instead, Damen et al. (2014) argued that action primes might influence agency judgements independently of influencing action selection, by affecting higher-order, conceptual representations of action and agency.

The present study aimed to clarify the contribution of action selection processes to sense of agency, using supraliminal stimuli to manipulate action selection across 3 experiments. To additionally test the generalisability of these effects, a novel task was used – the Eriksen flanker task (Eriksen & Eriksen, 1974). This is widely used to induce response conflict, and assess cognitive control dynamics. The flanker task was adapted and combined with the design from the aforementioned subliminal priming studies (Chambon & Haggard, 2012; Wenke et al., 2010). Participants responded according to a target letter (e.g. left for S, right for H), which could appear flanked by congruent (e.g. HHHHH) or incongruent flankers (e.g. SSHSS). A coloured circle appeared after a variable delay, and participants judged their control over that colour. In the incongruent flanker condition, the presence of flankers associated with the alternative action should lead to response conflict, and thus an increase in RTs and errors.

Experiment 1 aimed primarily to test how supraliminal stimuli relevant to action selection would affect the sense of agency in a situation where each action could produce one of a number of outcomes. Damen et al.'s results might suggest that the highest sense of agency would be found in the incongruent condition, when participants had to overcome conscious response conflict. However, if selection fluency has a general effect on the sense of agency then the highest sense of agency should be found in the congruent flanker condition. Additionally, we included a neutral condition, with task-irrelevant flankers (i.e. OOHOO) to try to distinguish facilitation and conflict effects on action (Kopp, Rist, & Mattler, 1996; Mansfield, van der Molen, Falkenstein, & van Boxtel, 2013; Taylor, 1977), and on the sense of agency. Finally, some previous studies measured agency ratings at the end of each trial, while others measured agency ratings at the end of a block. In this study, we exploratorily tested half of the participants with each method, though we did not have any strong prediction about interactions involving rating method.

Importantly, free vs. instructed choice could modulate how awareness of priming stimuli would influence the sense of agency. For subliminal priming, having a higher or lower proportion of free choice trials, relative to forced choice, did not interact with the effects of action selection on agency (Wenke et al., 2010). However, this may be different for conscious priming. A participant who consciously perceives a prime might recruit cognitive control resources to resist its influence, potentially increasing their sense of agency. This possibility was assessed in Experiment 2. Forced choice (i.e. instructed) trials were randomly intermixed with free choice trials. A task-irrelevant target letter indicated a free choice trial, and appeared surrounded by task-relevant flankers (e.g. HHOHH). Hence, actions could be congruent or incongruent with the flankers, whether the action was instructed by the central, attended stimulus, or was endogenously chosen.

Additionally, the timing of stimuli affecting action selection, and thus response conflict, could be important. A sufficient amount of time may be needed between the appearance of biasing information and an instruction/go-signal to develop a clear awareness that one is either following or going against that information. One might then come to have a stronger sense of agency for overcoming external biases. Similarly, if there is enough time, cognitive control processes can inhibit the automatic motor activation induced by primes or flankers, thus abolishing their effects on motor performance (Flowers, 1990; Wascher, Reinhard, Wauschkuhn, & Verleger, 1999). In this case, choosing to go against the prime does not require any additional effort over choosing to go with the prime. Nonetheless, awareness of an external suggestion could still influence one's sense of agency.

To test the impact of the timing of conflicting stimuli, Experiment 3 parametrically varied the stimulus onset asynchrony (SOA) between flankers and target. Flankers could precede the target by 500 ms (−500 SOA) or 100 ms (−100 SOA), be simultaneous with the target (0 SOA), or follow the target after 100 ms (+100 SOA). Maximal congruency effects on performance are found for −100 and 0 SOA conditions, but only small or no effects are found for the −500 and +100 SOA conditions (Eriksen & Schultz, 1979; Flowers, 1990; Taylor, 1977; Wascher et al., 1999; Willemssen, Hoormann, Hohnsbein, & Falkenstein, 2004). We hypothesized that the −500 SOA condition would allow sufficient time for suppression of the flankers, and potentially alter effects of conflict on sense of agency. The −100 SOA condition was expected to still show important effects on action selection, but the clear precedence of the flankers to the target might alter the subjective experience of conflict and agency. The 0 SOA condition should replicate our previous effects. In addition, the +100 SOA condition would serve to assess whether the temporal precedence of flankers or target might influence agency processing. If congruency between a first intention and the action performed is the important comparison for agency, as suggested by Chambon and Haggard (2012), then this condition should not affect agency even if it showed minor effects on performance. Since choice did not interact with fluency effects on agency in Experiment 2, only forced choice trials were used.

2. Experiment 1

2.1. Materials and methods

2.1.1. Participants

The study was approved by the UCL Research Ethics Committee. Twenty-five participants (13 female, *mean* = 23.62, *SD* = 3.98) were recruited, based on an a priori power calculation. For this, we used previous reports of prime compatibility on agency in ratings in operant reaction-time tasks (Chambon et al., 2013), since no previous study to our knowledge had investigated flanker congruency effects on sense of agency over action outcomes. With a Cohen's d_z of 0.66 (Chambon et al., 2013), power = 0.8, and alpha = 0.05, a minimum sample size of 21 was indicated, but a slightly larger number were recruited, in anticipation of possible attrition. Participants gave written informed consent to participate in the study and received payment of £7.5/hour. All were right-handed, with normal or corrected-to-normal vision, did not suffer from colour blindness, and had no history of psychiatric or neurological disorders. There were two groups of participants: odd-numbered participants rated agency on every trial, while even-numbered participants rated agency at the end of each block. One participant in the block-wise rating group was excluded due to difficulties in distinguishing outcome colours.

2.1.2. Apparatus and materials

Participants were seated approximately 50 cm from a computer screen. The experiment was programmed and stimuli delivered with Psychophysics Toolbox v3 (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997), running on Matlab (MATLAB 8.1, The MathWorks Inc., Natick, MA, 2013). During a trial, stimuli were presented in a mono-spaced font, Lucida Console. A fixation cross was presented in 18 point font size. Target letters consisted of S's or H's, while flankers consisted of S's, H's or O's. These were presented in 30 point font size, with the 5 letter array subtending 3.2° visual angle. Participants responded by pressing one of two keys on a keyboard. Outcome stimuli consisted of a circle of 2.8° presented in one of 6 colours (red, blue, green, yellow, orange and pink). Different colours were used in the training phase.

All participants gave agency ratings on a 9-point Likert scale. The trial-wise ratings group completed the rating procedure on the computer. For the block-wise ratings, participants were first asked to rank order the coloured circles (cut-outs) on a sheet of paper, and then gave a Likert rating for each colour.

2.1.3. Design and procedure

The task involved making actions in response to targets, which were surrounded by distracting flankers (see Fig. 1). The action triggered the appearance of a coloured circle – the action outcome. Participants were instructed to pay attention to the relation between their actions and the outcomes that followed, as they were required to judge these relations at the end of each trial or each block, for the respective group. Participants had to respond with a left or right key press according to a central target letter (S or H, respectively). The assignment of target letters to a left or right action was counterbalanced across participants. Participants were instructed to ignore the flankers and focus on the central letter. Flankers could be congruent with the central target – e.g. HHHHH, and thus with the required action; incongruent – e.g. SSHSS; or neutral – e.g. OOHOO (Matchock & Mordkoff, 2007; Taylor, 1977). Flanker-target congruency was randomly varied across trials.

Outcome colours were dependent on both the congruency condition and the action performed. Thus, each action (left vs. right) was associated with three outcomes, one for each congruency condition (cf. Wenke et al., 2010). The condition-to-colour mapping varied across the blocks, so participants had to learn the action-outcome relations anew in each block, and were informed of this. The six outcome colours were rotated in a Latin square across the 6 blocks, and the block mapping was randomised. Each colour appeared once in each experimental condition, thus cancelling out any idiosyncratic colour preferences. To ensure that the frequency of each coloured outcome was equal despite differences in error rates across flanker-action congruency conditions, error trials were replaced at the end of a block. Additionally, the action-outcome interval was varied orthogonally to the congruency factor. This was not a variable of interest, but served as a dummy variable, ensuring that participants were exposed to a range of experiences, varying from low sense of agency (for delayed outcomes) to high sense of agency (for less delayed outcomes; Haggard, Clark, & Kalogeras, 2002; Wenke et al., 2010).

Participants were asked to judge how much control they felt over the coloured circles that were triggered by their actions (Chambon & Haggard, 2012; Wenke et al., 2010). For the trial-wise rating group, a 9-point Likert scale was presented at the end of each trial, where 1 was labelled “No Control” and 9 was labelled “Total Control”. The block-wise ratings group completed a ranking and rating procedure on a paper sheet at the end of each block. Participants were instructed to rank order coloured circles on the sheet across 6 rankings, from “Most Control” to “Least Control”. After ranking, participants gave a rating of their sense of control on the Likert scale described above.

The study started with a training block of 24 trials, to allow participants to get acquainted with the experiment and the agency ratings procedure. Participants were given a chance to ask questions and repeat the training if desired. To avoid colour mapping repetitions, different colours were used during the training and experimental phases. At the end of the study, participants completed a short debriefing questionnaire.

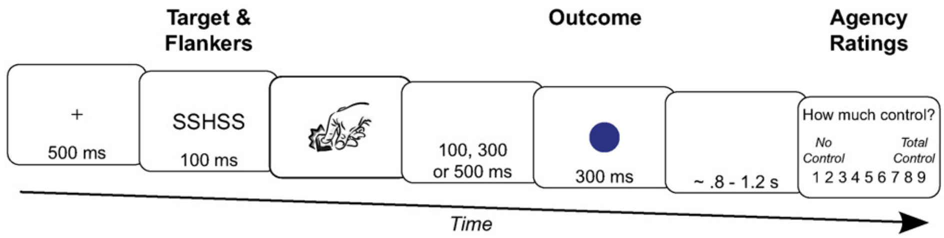

Fig. 1. Timeline of an example incongruent trial, for the trial-wise rating group. Participants responded according to a central target letter, surrounded by distractors. This triggered the appearance of a coloured circle, after a variable delay. Participants gave agency ratings at the end of each trial, for the trial-wise rating group; or completed a ranking/rating procedure at the end of each block, for the block-wise rating group.

2.1.4. Timeline

Each trial started with a fixation cross presented for 500 ms. The flankers and target array appeared for 100 ms (Gratton, Coles, & Donchin, 1992; Rodríguez-Fornells, Kurzbuch, & Münte, 2002). Participants responded to the target within a 1.2 s window. If the response was correct, an outcome colour followed the response after a variable delay of 100, 300 or 500 ms. Outcome duration was 300 ms. If an incorrect response or no response was given, a black cross was presented for 300 ms. For the trial-wise rating group, the agency rating scale appeared after 800 to 1200 ms, and remained on the screen until a response was given. For both groups, the inter-trial interval varied randomly between 1 and 1.5 s. Each block consisted of 72 trials, and there were 6 blocks overall. At the end of each block, the block-wise rating group completed the ranking/rating procedure. All participants were allowed to take short breaks between blocks.

2.1.5. Data analysis

For the block-wise ratings group, rating sheets were coded and the data computerised. Any blocks where mistakes were made in the ranking/rating procedure were excluded from analysis. Mistakes could involve mismatches between the ranking and rating, or the repetition of a colour name. This resulted in the exclusion of 1 block in 2 participants, and 2 blocks in another participant.

Reaction times (RTs), error rates and agency ratings were submitted to a 2 × 3 mixed-design analyses of variance (ANOVA). The between-subjects factor was group: trial- or block- wise ratings group; and the within-subjects factor was flanker-action congruency: congruent, neutral or incongruent. Planned comparisons were used to test differences between congruency levels. For the block-wise ratings group, agency ranks were submitted to a Friedman's non-parametric test to assess the main effect of flanker-action congruency. Wilcoxon pairwise tests were used for planned comparisons. Within subjects 95% confidence intervals were obtained for the main effect of congruency (Loftus & Masson, 1994).

2.2. Results

2.2.1. Action selection

Analyses of RTs showed a significant effect of flanker-action congruency ($F_{(2,\,44)} = 64.46$, $p < 0.001$, $\eta_p^2 = 0.75$; see Fig. 2.a), but no effect of group nor interaction (*Fs* < 1). Planned comparisons revealed that RTs were significantly slower (*ps* < 0.001) in the incongruent condition (*mean* = 514.78, *SD* = 67.84) compared to the neutral (*mean* = 487.42, *SD* = 70.99) and congruent conditions (*mean* = 475.02, *SD* = 65.25). RTs were also significantly slower in the neutral compared to the congruent condition ($p = 0.004$; see Fig. 1).

Analyses of error rates revealed a significant main effect of congruency ($F_{(2,\,44)} = 18.55$, $p < 0.001$, $\eta_p^2 = 0.46$, Greenhouse-Geiser correction; see Fig. 2.b). Planned comparisons showed that participants made significantly more errors in the incongruent (*mean* = 9.82%, *SD* = 8.39%) compared to neutral (*mean* = 5.79%, *SD* = 5.65%; incongruent vs. neutral: $p = 0.001$), and congruent conditions (*mean* = 4.29%, *SD* = 4.79%; incongruent vs. congruent: $p < 0.001$). The neutral condition also led to significantly more errors than the congruent condition ($p = 0.017$). Additionally, there was a significant main effect of group ($F_{(1,\,22)} = 5.73$, $p = 0.026$, $\eta_p^2 = 0.21$), as the trial-wise ratings group made significantly more errors than the block-wise ratings group. This presumably reflects higher task difficulty for the trial-wise rating group, as they had to give agency ratings in each trial, which meant they had to press different keys. In contrast, the block-wise rating group could focus exclusively on responding to the target, and could keep their fingers on the response keys throughout a block. Finally, there was no significant interaction between group and congruency ($F_{(1,\,22)} = 2.65$, $p = 0.10$, $\eta_p^2 = 0.11$, Greenhouse-Geiser correction). However, this result should be interpreted with particular caution, because our study may not have had sufficient statistical power to investigate interactions involving between-subjects effects of group.

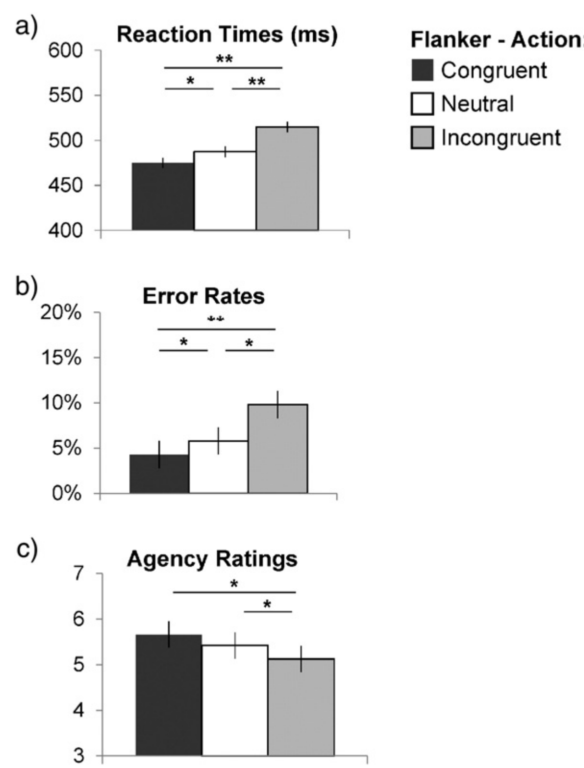

Fig. 2. Results for Experiment 1. Panel a) shows the mean reaction times across flanker-action congruency conditions (collapsed across groups), and panel b) shows mean error rates. Both facilitation and conflict effects can be seen in RTs and error rates. Yet, panel c) reveals that mean agency ratings show only an effect of conflict, such that agency ratings were significantly reduced following incongruent relative to neutral and congruent trials. Error bars show the within subjects 95% confidence intervals for the main effect of congruency. *$p < 0.05$, **$p < 0.001$.

2.2.2. Agency ratings

The ANOVA on agency ratings revealed a significant main effect of congruency ($F_{(2, 44)} = 4.70$, $p = 0.014$, $\eta_p^2 = 0.18$; see Fig. 2.c). Planned comparisons confirmed that the incongruent condition (*mean* = 5.13, *SD* = 1.57) led to significantly lower ratings compared to the congruent (*mean* = 5.66, *SD* = 1.74; incongruent vs. congruent: $p = 0.013$), and the neutral condition (*mean* = 5.42, *SD* = 1.63; incongruent vs. neutral: $p = 0.039$), whereas the congruent and neutral conditions were not significantly different ($p = 0.21$). There was no significant effect of group ($F_{(2, 44)} = 1.29$, $p = 0.29$, $\eta_p^2 = 0.013$), nor a significant group x congruency interaction ($F_{(1, 22)} = 0.30$, $p = 0.59$, $\eta_p^2 = 0.055$).

For the block-wise group, agency ranks were also analysed, and results showed a significant main effect of congruency (χ^2 (2) = 8.73, p = 0.013). Planned comparisons replicated the pattern of results seen for the agency ratings: the incongruent condition (*median* = 3.25, *SD* = 0.99) led to significantly lower agency ranks than the congruent condition (*median* = 4.00, *SD* = 0.66; incongruent vs. congruent: $Z = -2.57$, p = 0.010, $r = -0.37$), and the neutral condition (*median* = 3.50, *SD* = 0.50; incongruent vs. neutral: $Z = -2.27$, $p = 0.024$, $r = -0.33$); whereas there was no significant difference between congruent and neutral conditions ($Z = -0.99$, $p = 0.32$, $r = -0.14$).

2.3. Discussion

Experiment 1 showed that flanker-action congruency influenced action selection as predicted. The sense of agency over action outcomes was significantly reduced following dysfluent action selection, compared to fluent selection. This replicates recent work demonstrating a prospective contribution of action selection processes to the sense of agency (Chambon & Haggard, 2012; Chambon et al., 2013; Sidarus et al., 2013; Wenke et al., 2010), and generalises the finding across different behavioural tasks. So far, most studies used subliminal priming to manipulate action selection (cf. Chambon et al., 2014b), or assessed agency over the *action* (Morsella et al., 2009). To the best of our knowledge, the present study is the first to show a reduction in the sense of agency over *action outcomes* following dysfluent action selection, even though participants could consciously perceive the stimuli that influenced action selection.

Previous studies (Chambon & Haggard, 2012; Chambon et al., 2013; Sidarus et al., 2013; Wenke et al., 2010) used subliminal priming to manipulate action selection in order to preclude the explicit awareness that one's action was manipulated. Additionally, this increased uncertainty about the outcomes, since they were contingent on both the action and the congruency between the (invisible) prime and the action. That is, as the primes were not consciously perceived, the relation between prime-action congruency and specific outcomes could not be represented, hence outcomes were never fully predictable. In contrast, as participants were aware of the flankers in the present study, they could learn the full contingency schedule between the letter strings and outcome colours. For example, in a given block, participants could learn that the letter array "SSSSS" was followed by a green circle, whereas "HHSHH" was followed by a red circle. Debriefing confirmed that most participants were aware of this relation. Moreover, the causes of difficulties in action selection, i.e. incongruent flankers, were now clearly available to participants. Nevertheless, the same effects of action selection fluency on agency ratings were found, irrespective of perceptual awareness of the stimulus trigger.

Moreover, there was no significant difference in the fluency effects on agency across the two rating procedures, i.e. trial- vs. block- wise ratings. While the same effects had been shown using both procedures, this was the first study to combine them. Previous studies suggest that action selection fluency affects agency online (Chambon et al., 2014c; Chambon et al., 2013). Additionally, the association between different fluency experiences and ensuing outcomes can be retained in memory, at least for long enough to accumulate over the course of a block of trials, as seen here and in Wenke et al. (2010).

The inclusion of a neutral condition allowed us to distinguish an enhanced sense of agency due to facilitation of action selection, from a reduction of agency due to response conflict. Only the effect of conflict in action selection yielded a significant modulation of agency ratings (see Fig. 2). When flankers were congruent with the central target, participants were faster and made less errors, than when the flankers were neutral. Additionally, incongruent flankers led to significantly slower RTs and more errors, compared to neutral flankers. However, while agency ratings were significantly lower following incongruent flankers, compared to neutral and congruent flankers, the trend for higher ratings following congruent compared to neutral flankers was not statistically significant.

It should be noted that other baseline conditions, and different tasks, could yield a different pattern of facilitation/conflict (Jonides & Mack, 1984). The present study used task-irrelevant stimuli as neutral flankers, which yielded both facilitation and conflict effects on performance. As congruency effects on agency ratings are smaller than congruency effects on RTs, the absence of a facilitation effect could result from a lack of statistical power within-subjects. Additionally, between-subjects design resulted in a small sample in each group, giving relatively low statistical power for investigating between-subjects effects and interactions. These considerations mean that null between-subjects effects should be interpreted with particular care. Importantly, however, these between-subjects effects did not form the focus of our predictions. The key predictions, and therefore the key results, come from main effects of congruency on agency ratings. In our design, these are based on within-subjects comparisons. Further, our results are consistent with those obtained with the subliminal priming paradigm (Chambon & Haggard, 2012). There, the reduction in agency ratings following incongruent, compared to neutral primes, was larger than the increase in ratings following congruent primes, though neither was statistically significant. A positive sense of agency may be a "default state" (Blakemore et al., 2002; Sidarus et al., 2013). Reduced agency may be triggered by disruptions in the intention-action-outcome chain, which may produce a salient experience relevant to agency judgement (Chambon et al., 2014b).

Our results contrast sharply with those of Damen et al. (2014). That study reported higher agency ratings when participants chose an action incongruent with a supraliminal prime, compared to when they chose a prime-congruent action. Importantly, free choice trials were used in their study, whereas here participants had to follow the instruction of a central flanker. Experiment 2, therefore, investigated whether choice may interact with the effects of flanker congruency on sense of agency, when biasing stimuli are consciously perceived. Free and forced choice targets were randomly intermixed, such that actions could be congruent or incongruent with the flankers, whether the action was instructed by the central, attended stimulus, or was endogenously chosen.

3. Experiment 2

3.1. Materials and methods

3.1.1. Participants

Participant recruitment and study approval was as in Experiment 1. Twenty-four participants were tested (13 female, *mean* = 21.50, *SD* = 3.02).

3.1.2. Design and procedure

Testing conditions and stimuli were the same as in Experiment 1, except that instead of a neutral flanker condition, the letter O now served as a neutral target in free choice trials. In free choice trials, the neutral target was surrounded by flankers associated with a left or right action. For example, if the array "SSOSS" was presented, participants could choose whether to act congruently with the flankers and make a left action, or act incongruently with the flankers and choose a right action. Thus, flanker-action congruency was not related to the stimuli, but rather reflected the participants' action choice. In forced choice trials, the congruent or incongruent conditions were as described in Experiment 1. The new 2 (choice: free vs. forced) × 2 (congruency: congruent vs. incongruent) design meant that 8 outcome colours were used, 4 associated with each hand, 1 per choice × congruency condition. The colours were Latin square rotated across 8 blocks of 64 trials, and the condition-colour block mappings were randomised.

All participants gave agency ratings at the end of each trial, thus the trial timeline was the same as the trial-wise group in Experiment 1. Only 2 action-outcome intervals were used (200 and 400 ms), to reduce the overall number of conditions. As in Experiment 1, the study began with a training block of 32 trials, and ended with a debriefing questionnaire.

3.1.3. Data analysis

Reaction times were submitted to a 2 × 2 ANOVA, with choice (free vs. forced) and flanker-action congruency (congruent vs. incongruent) as within-subjects factors. Agency ratings were submitted to a similar ANOVA, with action-outcome interval (200 vs. 400 ms) as an additional within-subjects factor. For free choice trials, the proportion of flanker congruent choices was analysed with a one-sample *t*-test against a 0.5 chance level. For forced choice trials, error rates were analysed with a paired-samples *t*-test comparing congruent and incongruent conditions. Within subjects 95% confidence intervals for pairwise comparisons were calculated separately for free and forced choice trials (Pfister & Janczyk, 2013).

3.2. Results

3.2.1. Action selection

Analyses of RTs revealed no significant main effect of choice ($F_{(1, 23)} = 1.65$, $p = 0.21$, $\eta_p^2 = 0.067$), a significant main effect of congruency ($F_{(1, 23)} = 20.76$, $p < 0.001$, $\eta_p^2 = 0.47$; see Fig. 3.a), and a significant choice × congruency interaction ($F_{(1,23)} = 5.67$, $p = 0.026$, $\eta_p^2 = 0.20$). Simple effects *t*-tests showed a significant congruency effect for forced choice trials, i.e. slower RTs for the incongruent (*mean* = 544.28, *SD* = 88.73) than the congruent condition (*mean* = 513.09, *SD* = 83.49), and a similar modest trend for free choice trials (free congruent: *mean* = 515.27, *SD* = 88.85; free incongruent: *mean* = 525.50, *SD* = 96.85; one-tailed, free: $t_{(23)} = -1.72$, $p = 0.050$, Cohen's $d_z = -0.35$; forced: $t_{(23)} = -4.68$, $p < 0.001$, Cohen's $d_z = 0.96$). Additionally, incongruent trials led to significantly slower RTs in forced compared to free choice ($t_{(23)} = -2.18$, $p = 0.040$, Cohen's $d_z = 0.44$). Choice did not affect RTs in congruent trials ($t < 1$).

In free choice trials, flanker congruent choices were made in 57.47% (*SD* = 5.72) of trials (see Fig. 3.c). A one sample *t*-test showed that the proportion of flanker-congruent choices was significantly different from chance ($t_{(23)} = 6.40$, $p < 0.001$, Cohen's $d_z = 1.31$). For forced choice trials, a paired samples t-test on error rates showed that the incongruent condition (*mean* = 19.33%, *SD* = 11.73) led to significantly more errors than the congruent condition (*mean* = 14.85%, *SD* = 10.15; $t_{(23)} = -4.39$, $p < 0.001$, Cohen's $d_z = -0.90$; see Fig. 3.b).

3.2.2. Agency ratings

An ANOVA on agency ratings revealed a significant main effect of congruency ($F_{(1, 23)} = 12.70$, $p = 0.002$, $\eta_p^2 = 0.36$). Flanker-incongruent actions (*mean* = 6.25, *SD* = 1.07) led to lower agency ratings than flanker-congruent actions (*mean* = 5.80, *SD* = 1.23; see Fig. 3.d). Critically, there was no significant main effect of choice ($F_{(1, 23)} = 1.48$, $p = 0.24$, $\eta_p^2 = 0.061$), nor a significant choice by congruency interaction ($F_{(1, 23)} = 2.32$, $p = 0.14$, $\eta_p^2 = 0.092$).

There was a marginal effect of action-outcome interval ($F_{(1, 23)} = 3.65$, $p = 0.069$, $\eta_p^2 = 0.14$), such that ratings for the long interval (400 ms; *mean* = 6.08, *SD* = 1.10) were higher than for the short interval (200 ms; *mean* = 6.01, *SD* = 1.12). These results are inconsistent with previous findings using other tasks (Chambon & Haggard, 2012; Chambon et al., 2014c; Haggard et al., 2002; Sidarus et al., 2013). In previous studies, using a wider range of intervals, higher ratings were

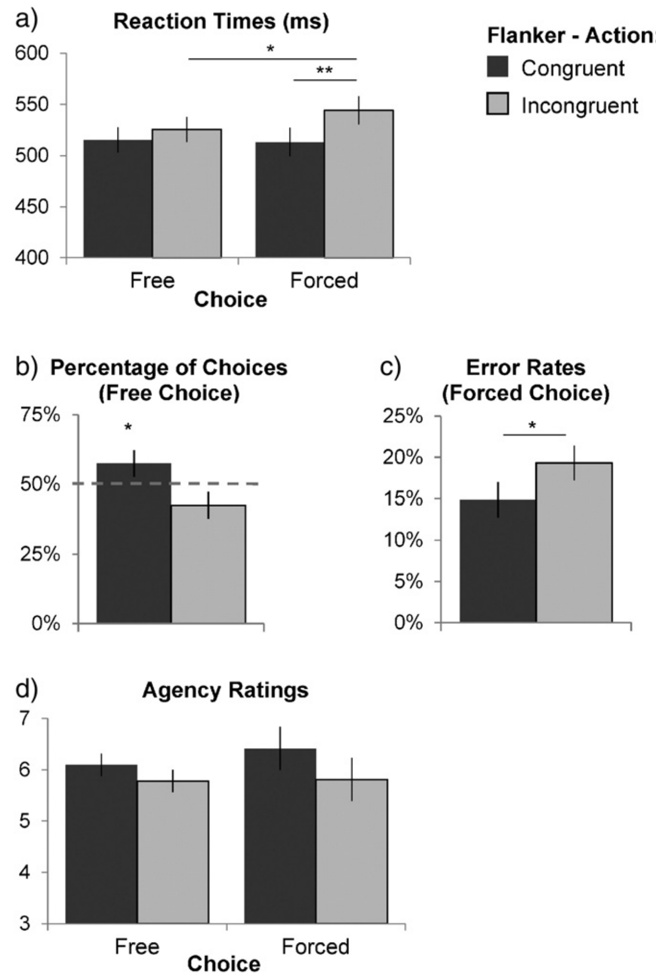

Fig. 3. Results for Experiment 2. Panel a) shows the mean reaction times for free and forced choice trials, and flanker-action congruency conditions. Congruency effects were larger for forced choice trials, and RTs in incongruent trials were slower in forced choice conditions. Panel b) shows the percentage of trials in which participants chose the action that was congruent or incongruent with the flankers in free choice trials, revealing a bias towards flanker-congruent choices. For forced choice trials, panel c) shows the mean errors rates in flanker-congruent or incongruent actions, with more errors being made in incongruent trials. Finally, panel d) shows that, for mean agency ratings, there was only a main effect of flanker-action congruency, with lower ratings following flanker-incongruent actions, for both free and forced choice trials. Error bars show the pairwise within subjects 95% confidence intervals, calculated separately for free and forced choice trials. *$p < 0.05$, **$p < 0.001$.

found for shorter intervals, recalling Hume's concept of temporal contiguity as a cue for causation (Hume, 1740). Importantly, action-outcome interval did not interact with the factors of interest – choice and congruency (*Fs* < 1). Since action-outcome interval was not a factor of interest, this factor will not be discussed further.

3.3. Discussion

Experiment 2 showed that action selection was influenced by flankers in both free and forced choice trials. Flankers biased choice, such that participants were ~7% more likely to 'freely' select actions corresponding to the flanker suggestion, compared to against it. Similar biases have been found using subliminal priming (Mattler & Palmer, 2012; Schlaghecken & Eimer, 2004; Wenke et al., 2010). Flanker-incongruent actions led to significantly slower RTs in forced choice trials, with a similar trend in free choice trials. Additionally, incongruent forced choice trials led to significantly slower RTs than incongruent free choice trials. Hence, the cost on performance of freely choosing an action incongruent with the flankers was smaller than the cost of following an instruction with incongruent flankers. Consistently, a greater flexibility for changes of mind has been shown for free, compared to forced, choices (Fleming, Mars, Gladwin, & Haggard, 2009). Crucially, response conflict, induced by supraliminal flankers, significantly reduced the sense of agency over action outcomes for both instructed and freely chosen actions.

Our results additionally show that the discrepancy between our findings and those of Damen et al. (2014) cannot be explained by whether participants could freely choose which action to perform, or had to follow an instruction. Although null effects should be interpreted with care, the absence of an interaction between choice and congruency seen here is consistent with a previous subliminal priming study (Wenke et al., 2010). In Wenke et al.'s (Wenke et al., 2010) study, free and forced choice trials were intermixed, and free choices were effectively biased by subliminal primes, similarly to our results. On the other hand, Damen et al. (2014) found little effect of sub- or supraliminal primes on choice, possibly due to the exclusive use of free choice trials. This could have allowed participants to decide which action to make before the beginning of a trial, and thus before the prime was presented. In fact, it has been shown that priming effects seen in blocks of intermixed free and forced choice trials are abolished in blocks with only free choice trials (Klapp & Haas, 2005; Schlaghecken & Eimer, 2004).

Nonetheless, Damen et al. (2014) did find priming effects on agency. The authors argued that the observed reduction in the sense of agency when following a conscious prime could have been due to a reduced sense of freedom. Using only free choice trials could have potentially increased the overall sense of freedom experienced in the task, relative to mixed conditions, rendering a reduction in that perceived freedom, due to conscious biases, more salient. This sense of freedom may affect agency at a higher, conceptual level, and independently of action selection.

Another relevant difference between the two studies, which is related to action selection, lies in stimulus timing. In Damen et al., the prime preceded the go signal by 250 ms in the supraliminal priming condition, and there was no time limit for response. In contrast, in our study, flankers and targets were presented simultaneously, speed was emphasised, and a tight response window was imposed. Hence, a 'sufficient' amount of time may be necessary for a realisation that one's actions are being biased, and thus override the normal relation between selection fluency and sense of agency. To assess whether the timing of conflict stimuli may influence the sense of agency, the interval between flankers and target onset was parametrically varied in Experiment 3.

4. Experiment 3

4.1. Materials and methods

4.1.1. Participants

Participant recruitment and study approval was as in Experiments 1 & 2. Twenty-six participants were tested (13 female, mean age = 23.08, $SD = 3.63$). One participant was excluded as she did not follow instructions, and sometimes used only one hand to press the left and right key.

4.1.2. Design and procedure

Testing conditions were the same as in Experiment 2, but with only forced choice trials. Additionally, the flanker-target stimulus onset asynchrony (SOA) was randomly varied across the trials. Flankers could appear: 500 ms before target onset (−500 SOA); 100 ms before target onset (−100 SOA), simultaneously with the target (0 SOA); or 100 ms after the target (+100 SOA). To accommodate the varying SOA conditions, target duration was now set to 150 ms (Wascher et al., 1999). Flankers were displayed until the target duration elapsed. Action-outcome intervals were also changed to 100 and 500 ms to enhance the discriminability of the 2 intervals, while keeping the experimental session short.

Each block included 4 outcome colours, one per action × congruency condition, orthogonal to the flanker-target SOA conditions. To obtain a similar number of trials per SOA × congruency condition to the previous experiments, 12 blocks of 64 trials were used. To ensure that each outcome colour appeared only once for each action x congruency condition, 12 colours were used overall in the experiment. These were rotated with a Latin square across the 12 blocks, in groups of 4, and the block mappings were randomised. The 12 colours were shown to participants at the beginning of the study to confirm that they could reliably distinguish them. Participants were also instructed that the colours or the relation between action and colours could change across blocks, so they needed to learn them anew in each block. As in the previous experiments, the study began with a training block of 32 trials, and ended with a debriefing questionnaire.

4.1.3. Data analysis

RTs and error rates were submitted to a 4 × 2 repeated measures ANOVA with the factors flanker-target SOA (−500, −100, 0, +100) and flanker-action congruency (congruent vs. incongruent). Agency ratings were submitted to a similar ANOVA that additionally included the factor action-outcome interval (100 vs. 500 ms). Greenhouse-Geisser corrections were used whenever the sphericity assumption was violated. Bonferroni adjusted post-hoc tests were used to probe the main effect of SOA. The SOA × congruency interactions were investigated with paired samples t-tests, with a Bonferroni adjustment, to test congruency effects across SOAs. Within subjects 95% confidence intervals for the pairwise differences between congruency conditions were calculated separately for each SOA (Pfister & Janczyk, 2013).

4.2. Results

4.2.1. Action selection

Analyses of RTs revealed significant main effects of SOA ($F_{(3,\ 72)} = 240.77$, $p < 0.001$, $\eta^2_p = 0.91$), and congruency ($F_{(1,\ 24)} = 60.40$, $p < 0.001$, $\eta^2_p = 0.72$), and a significant SOA × congruency interaction ($F_{(1,\ 24)} = 9.28$, $p < 0.001$, $\eta^2_p = 0.28$). Post-hoc tests to explore the main effect of SOA showed that all pairwise comparisons between SOAs were significant ($ps < 0.001$). As Fig. 4.a shows, RTs were faster with earlier presentation of the flankers. Probing the SOA × congruency interaction revealed significant congruency effects at each SOA ($ps < 0.001$), except at −500 SOA ($t_{(1,\ 24)} = -1.04$, $p = 0.31$, Cohen's $d_z = -0.21$).

Analyses of error rates showed no significant effect of SOA ($F_{(1,\ 24)} = 1.08$, $p = 0.36$, $\eta^2_p = 0.04$), a significant main effect of congruency ($F_{(1,\ 24)} = 31.61$, $p < 0.001$, $\eta^2_p = 0.57$), and a significant SOA × congruency interaction ($F_{(1,\ 24)} = 5.01$, $p = 0.003$, $\eta^2_p = 0.17$). Post hoc tests revealed significant congruency effects for −100 and 0 SOA (−100 SOA: $t_{(1,\ 24)} = -5.08$, $p < 0.001$, Cohen's $d_z = -1.02$; 0 SOA: $t_{(1,\ 24)} = -3.54$, $p = 0.002$, Cohen's $d_z = 0.71$), but not for −500 or +100 SOA (−500: $t_{(1,\ 24)} = -0.39$, $p = 0.70$, Cohen's $d_z = -0.078$; +100: $t_{(1,\ 24)} = -1.58$, $p = 0.13$, Cohen's $d_z = -0.32$; see Fig. 4.b).

4.2.2. Agency ratings

Analyses of agency ratings revealed a marginal main effect of congruency ($F_{(1,\ 24)} = 3.99$, $p = 0.057$, $\eta^2_p = 0.14$), in the predicted direction: incongruent flankers (*mean* = 6.42, *SD* = 1.57) led to lower ratings compared to congruent flankers (*mean* = 6.67, *SD* = 1.47; see Fig. 4.c). Notably, there was no main effect of SOA ($F_{(3,\ 72)} = 0.87$, $p = 0.46$, $\eta^2_p = 0.035$), and no interaction between SOA and congruency ($F_{(3,\ 72)} = 0.40$, $p = 0.75$, $\eta^2_p = 0.017$). The absence of SOA effects on agency ratings can be clearly observed in Fig. 4.c.

Finally, there was a trend towards a main effect of action-outcome interval ($F_{(1,\ 24)} = 3.27$, $p = 0.083$, $\eta^2_p = 0.12$), with long intervals (500 ms; *mean* = 6.57, *SD* = 1.47) leading to higher agency ratings than short intervals (100 ms; *mean* = 6.53, *SD* = 1.50). There was also a marginal interaction between congruency and action-outcome

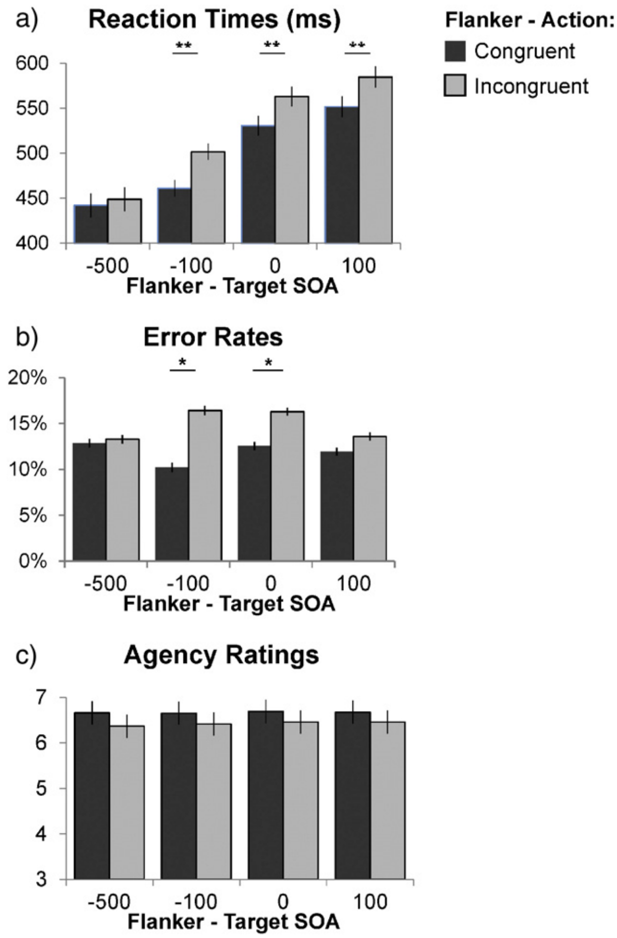

Fig. 4. Results for Experiment 3. Panel a) shows mean reaction times across flanker-target stimulus onset asynchronies (SOAs), and flanker-action congruency conditions. There were congruency effects at all SOAs except − 500 ms. On panel b) the mean error rates per condition are shown, with larger congruency effects at − 100 and 0 SOAs. Finally, panel c) depicts the mean agency ratings across conditions, and only reveals a main effect of congruency, with incongruent trials leading to lower ratings than congruent trials, regardless of flanker-target SOA. Error bars show the within subjects 95% confidence intervals for the congruency pairwise differences, for each SOA. * - $p < 0.05$, ** - $p < 0.001$.

interval ($F_{(1, 24)} = 3.48$, $p = 0.074$, $\eta_p^2 = 0.13$), which was not a focus of prediction, and so was not explored further. The remaining interactions were not significant (*ps* > 0.18). Both action-outcome interval results are inconsistent with previous priming studies (Chambon & Haggard, 2012; Chambon et al., 2014c; Sidarus et al., 2013). Even though the difference between the two intervals was increased, relative to Exp. 2, varying the flanker-target SOA may have changed the perception of the subsequent action-outcome interval, and disrupted its normal effects on agency. Since action-outcome interval was not a manipulation of interest, this will not be discussed further.

4.3. Discussion

Results showed that flanker effects on action selection were modulated by the flanker-target SOA. As predicted, flankers had no effect on action selection at − 500 SOA, but incongruent flankers did lead to performance costs with the other SOAs (see Fig. 4.a and 4.b). Additionally, there was a gradual increase in RTs with increasing SOA, possibly due to an alerting effect of early flankers, also found in previous studies (Flowers, 1990; Taylor, 1977; Wascher et al., 1999; Willemssen et al., 2004). Critically, there was no significant interaction between flanker-target SOA and congruency on agency ratings. That is, incongruent conditions led to (marginally) lower agency ratings than congruent conditions, but did so similarly across flanker-target SOAs (see Fig. 4.c), including SOAs where flankers had no performance effects.

These results are inconsistent with the hypothesis outlined above of an interaction between the timing of conflict during action selection and the direction of fluency effects on agency. That hypothesis suggested that SOAs favouring successful inhibitory cognitive control might lead to higher agency ratings for incongruent, rather than congruent flankers. At − 500 SOA, we found efficient inhibitory cognitive control, resulting in no congruency effect on RTs or error rates, yet sense of agency was still higher for congruent than incongruent trials. Therefore, the results of Damen et al. (2014) cannot be explained by a longer time delay between a biasing influence and action allowing the recruitment of cognitive control to efficiently overcome those biases.

The dissociation seen here between congruency effects on motor performance and on agency ratings is, however, consistent with Damen et al. (2014), where priming influenced agency but not action selection. The authors argued that the effects were independent of selection fluency, but rather due to priming of conceptual representations of action, or to influencing the experience of freedom. A dissociation between motor effects and agency was also found in a subliminal priming study, using NCE priming (Chambon & Haggard, 2012). It was proposed that congruency between an initial prime's suggestion and the executed action could serve as a fluency signal that would increase the sense of agency.

However, neither of these proposals can fully account for our results, since they would predict that only congruency between the *first* intention and the action should matter. Our results show that the appearance of incongruent flankers 100 ms *after* the target still affected the sense of agency, even though the action performed remained congruent with the first intention, which was presumably triggered by the target. Therefore, it seems that holding conflicting intentions is key for the observed reduction in the sense of agency, rather than the precise dynamics of the selection process. Importantly, this condition still led to congruency effects on motor performance, consistent with earlier reports (Eriksen & Schultz, 1979; Taylor, 1977). Action selection processes take time, and will be susceptible to disruptions occurring within a given time window. When using arrow stimuli in the flanker task, no performance effects were found with a + 100 SOA (Wascher et al., 1999). Thus, the window in which action selection can be disrupted may vary depending on whether the stimulus is imperative in nature.

Our results are compatible with a view of the sense of agency as resulting from an integration of information about conflict over a wider time-window than the time-window of action selection. It has been argued that fluency/conflict signals are relatively non-specific with respect to their sources, and have only a general influence (Winkielman et al., 2015). The temporal sensitivity of such signals, and of their integration in the sense of agency, may be low relative to the precise temporal dynamics of action selection and execution. To better characterise this window of temporal integration, future studies could include more flanker-target asynchrony values. In particular, one might ask whether flankers continue to influence the sense of agency even when presented so late that they no longer influence reaction times.

5. General discussion

Overall, our results suggest that the sense of agency over an action outcome is informed by cognitive processes occurring prior to action execution, particularly those processes involved in initiating a correct rather than an inappropriate action. In many situations, action control requires identifying an appropriate target, and then selecting and initiating the corresponding action, while avoiding the influence of distractors. The feeling of control over the consequences of action is influence by these processes. Part of the content of agency judgements appears to derive from monitoring processes that detect response conflict during action selection.

Interestingly, we found that sense of agency was insensitive to the specific dynamics of conflict at the level of motor performance. Thus, the prospective, premotor signals that influence sense of agency appear to signal a disruption in action selection whenever conflict emerges, regardless of whether the conflict is successfully resolved, and of how performance is affected (cf. Chambon & Haggard, 2012). Additionally, this putative monitoring system can integrate information about action selection in a time window that is broader than that which affects selection at a motor level. Moreover, the effects of action selection on the sense of agency can be independent of the effects of choice, and of the effects of being aware of influences on one's action or choice. That is, regardless of whether we have a choice in what to do, and whether we are aware of stimuli that could bias our decisions, dysfluent or difficult action selection can lead to a reduction in our sense of agency over action outcomes. Finally, we have shown that these effects generalise across tasks.

Our results imply that the sense of agency depends on some internal signal related to selecting between alternative actions. In that regard, our results are compatible with 'metacognitive' theories of agency (Metcalfe & Greene, 2007). Where might these internal signals be found within the motor system? The supplementary motor area (SMA) is necessary for triggering the automatic inhibition processes thought to underlie NCE priming, whereas upstream regions such as the pre-SMA are not (Sumner et al., 2007). Such automatic inhibition processes were not found to disrupt the sense of agency (Chambon & Haggard, 2012). The pre-SMA has in turn been implicated in monitoring response conflict, elicited both by conscious and unconscious stimuli (van Gaal, Scholte, Lamme, Fahrenfort, & Ridderinkhof, 2010). Relatedly, the premotor cortex, but not the primary motor area, has been shown to contribute to metacognitive judgements of perceptual confidence (Fleming et al., 2014). More specific to the present findings, an fMRI study (Chambon et al., 2013) used the subliminal priming paradigm to study congruency effects on the sense of agency. This study showed that the dorsolateral pre-frontal cortex was sensitive to response conflict, and was associated with the angular gyrus, wherein higher activity was linked to a greater reduction in agency ratings. Together, these studies suggest that the metacognitive monitoring of action selection that informs the sense of agency, may rely on higher-order action representations in premotor and prefrontal areas, rather than low-level motor signals in the primary motor cortex.

Importantly, the congruency effects on agency seen here are not due to a retrospective inferential process, but rely on prospective signals from action monitoring processes. As the flankers were clearly visible, one might be tempted to think that the observed effects could result from a retrospective comparison between the flankers and the target, or action, namely at a conceptual level. However, this would imply that neutral flankers would lead to a loss of agency, as they were visibly different from the target. Instead, the effects seen here appear specifically related to *conflict* in action selection. Experiment 1 showed no significant difference between congruent and neutral flankers, but only a significant reduction in agency following incongruent flankers. Although such null effects should be interpreted with care, especially due to potentially low statistical power, they suggest that a perceptual or conceptual mismatch may not be sufficient to explain our results. Rather, an incongruent action plan should be triggered at some stage, for a reduced sense of agency. In fact, subliminal priming was used in previous studies to manipulate action selection but preclude such post-hoc, conceptual inferences. This method showed a consistent trend for a larger cost of conflict on agency ratings than a facilitation effect (Chambon & Haggard, 2012). Our Experiment 3 is also consistent with a prospective account: the presence of conflicting motor plans during the trial led to a loss of agency, even when the interval between flankers and target was sufficient to resolve the conflict. The subjective experience of conflict may linger, even after the motor conflict has been resolved. Conflict signals are especially motivationally significant since they can indicate a need to adjust subsequent behaviour (Botvinick & Braver, 2015; Holroyd & Yeung, 2012). As such, they may have a greater impact on the sense of agency than fluency experiences. Additionally, a positive sense of agency may be a 'default', and thus we are especially sensitive to disruptions to the normal flow of voluntary action (Chambon et al., 2014b).

Our results clearly contrast with some reports that effort or difficulty can *enhance* sense of agency (cf. Damen et al., 2014; Demanet, De Baene, Arrington, & Brass, 2013). Why, then, do effort and conflict sometimes increase sense of agency, and sometimes reduce it? The relation between fluency or effort and the sense of agency is complex and remains poorly understood (Nahmias, 2005; Pacherie, 2008). Often when intentional actions unfold without any obstacles, the sense of fluency can result in a strong sense of agency, as "*everything went according to plan*". Yet, effort can also enhance the sense of agency. When a need for cognitive control can be anticipated, some proactive conflict processing (Braver, 2012) may become part of the action plan. This may highlight the sense of self, and of being engaged with task at hand. In contrast, when disruptions are unexpected, executive control will be triggered reactively by conflict signals. We speculate that these two sources of cognitive control may have different effects on sense of agency. In particular, proactively embedding effort into the action plan may be associated with an increase in the sense of agency (*I knew it would be tricky, but I managed it*), however, the unexpected or unwanted need for added effort could instead lead to a reduction in our sense of agency (*suddenly I had to deal with all these things*).

In addition, the context or the framing of a task could modulate how conflict influences agency. In Damen et al.'s study, each action triggered a specific outcome (a beep with a given pitch) after a variable delay (0–600 ms). Participants were instructed that sometimes they would cause the beep to occur (the outcome), but other times it would be caused by the computer. Thus, the task and the agency question were framed in terms of *attributing* the cause of the outcome to the self, or to another. Also, subliminal and supraliminal priming were randomised, so participants presumably experienced wide variations in degree of influence from the primes. In contrast, our studies focused on the *instrumental* aspect of agency, as participants were asked to judge the *strength* of the relation between various actions and outcomes, rather than invoking alternative agents. That is, our study focused on 'concomitant variation' between a single agent's different instrumental actions and their outcomes, rather than on attribution of outcomes to agents. Both processes are relevant to agency, but conflict between alternative actions might have different effects on each of them. Further research is needed to clarify the conditions under which conflict can enhance, rather than reduce, the sense of agency.

Our results are consistent with previous proposals that the sense of agency integrates information from multiple sources (Synofzik et al., 2008), and over time (Chambon et al., 2014b; Farrer, Valentin, & Hupé, 2013). In addition to retrospective processes related to outcome monitoring, there is also a prospective component related to action selection (see Fig. 5). Action selection monitoring can detect conflicting intentions and prospectively signal a loss of agency. After this, outcome monitoring can assess action outcome intervals and outcome identity for a mismatch with predictions or expectations, and retrospectively signal a loss of agency. If the smooth flow between intention – action – outcome remains unperturbed, the sense of agency can remain at a default level. Additionally, higher-order beliefs and contextual information can also influence the sense of agency (Moore & Fletcher, 2012; Synofzik et al., 2008). We found that choice, awareness of biases and timing of conflict did not interact with the effects of selection fluency. However, they may make independent contributions to the sense of agency, depending on context, or other cues.

6. Conclusion

Across the experiments reported here, the sense of agency was prospectively informed by monitoring the processes of action selection. When conflicting intentions were present, the sense of agency over

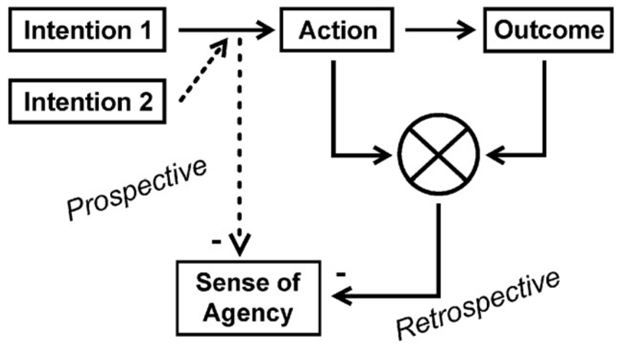

Fig. 5. Prospective and retrospective contributions to the sense of agency. The sense of agency is prospectively informed by monitoring action selection. When this action monitoring system detects an intention that conflicts with the to-be-executed intention, it sends a signal indicating a loss of agency. Once the action outcome is known, this can be compared with a prediction of the outcome, based on the executed action. When there is a mismatch between the predicted and actual outcomes, an outcome monitoring system can retrospectively signal a loss of agency. If the normal flow from intention, to action, to outcome is disrupted, the sense of agency is reduced.

action outcomes was reduced. The effect of conflict on the sense of agency was independent of awareness of the causes of conflict, of free vs. instructed action selection, and of the timing of conflicting information during action selection. Finally, these effects generalised across tasks, from subliminal priming of actions, to the Eriksen flanker task, thus revealing a new approach for further investigating prospective contributions to the sense of agency.

These findings support the view that the sense of agency is especially sensitive to a disruption in the normal flow of intentional action, from an intention or goal to its corresponding action, to the desired/expected consequences (Chambon et al., 2014b; Haggard & Chambon, 2012). Importantly, fluency of action selection was independent of the actual statistical contingency between actions and outcomes in these experiments. Selection fluency does not guarantee successful agency: one can know exactly what to do, and still fail to produce an intended outcome. However, selection fluency may serve as a useful heuristic to guide our sense of agency, as it often predicts successful outcomes (Haggard & Chambon, 2012). Prospective agency processes based on action selection may thus help to bridge the time gap between action and outcome.

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