Your intentions matter: The selection of an orthogonal feature of an intended object influences attentional control

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Abstract

The ability to act purposefully demands formulating intentions in the form of mental representation of actions required to achieve a purpose. Goal-directed behavior also needs apt control of attention for its completion. Here, by using a selective attention task for stimuli presented with an intended/unintended orthogonal feature, we attempted to understand the underlying mechanisms of how our intentions to get self-chosen outcomes modulate attentional and inhibitory processes. Results show a processing advantage for intended outcomes and no disadvantage for unintended or unselected outcomes compared to a neutral outcome. The findings support the role of intention in monitoring and control of action outcomes, as suggested by the dynamic theory of intention.

Keywords: intention; intentional action; free-choice; cognitive control; selective attention; inhibitory control

Introduction

Pursuing a goal requires effective action planning along with the ability to control one's actions in real-time. This control over action-outcome sequences forms the basis for our sense of agency. Intentions are considered as an essential factor contributing to the sense of agency mechanisms (Chen, Zou & Zhang, 2023; Sarma & Srinivasan, 2021; Vinding, Pederson & Overgaard, 2013). Besides, intention as a cognitive concept has been utilized by many theories and models of agency and action control (Brass & Haggard, 2008; David, Newen, & Vogeley, 2008; Hommel, 2009). Regardless, the role of intentions as a cognitive mechanism has been largely incomprehensive. Partly due to its similarity with beliefs and desires and partly due to its usage as a term equivalent to the goal an individual has.

Similarly, in folk psychology and philosophical accounts, intention has been argued regarding its definition and functions (Brand, 1984; Mele, 1989). Classical causal theories of action (Davidson, 1980; Goldman, 1970) regard them as simply action initiators or mental causes for actions and analogous to beliefs/desires. However, such accounts are inadequate in analyzing complex goal-directed action-perception sequences that require anticipatory monitoring and control. Besides, the phenomenology of actions, too, is neglected by such causal theories. Therefore, it becomes important to treat intentions as having more expansive cognitive mechanisms, distinguishable from beliefs and desires (Kumar & Srinivasan, 2021; Pacherie, 2006). Also, to be distinct from merely a goal representation, intentions can be conceptualized as a set of mental representations that allow our perceptual and motor abilities to attain that goal (Sakai, 2008; Wu, 2023).

In this paper, we follow a hierarchical framework of intentions that accounts for the motivational and control aspects of actions together with their experiential characteristics (Pacherie, 2008). According to Pacherie's (2006) dynamic theory of intentions, intentions play a crucial role not only in the initiation and execution of the action but also in controlling or monitoring its effects. In this hierarchical model of action control, multi-level intentions are responsible for motivational and control aspects of our actions, namely, distal or future-directed, D-intentions; proximal or present-directed, P-intentions; and motor, M-intentions. D-intentions are responsible for an abstract/conceptual level action planning for its goal content, adjoining beliefs and desires. P-intentions inherit the action plan from D-intentions and perform heterogeneous functions, such as initiating the action, guiding its transition, and monitoring its outcomes. While P-intentions implement the control functions of guiding and monitoring at a rational or situational level, M-intentions perform similar functions at a sensory-motor or lower level.

Following a hierarchical framework, we investigated the role intentions play in monitoring the effects of our actions, operationalized as the attentional processing of the outcome produced via intentional action. Our motivation for the current study came from earlier findings showing the influence of intentions on the implicit sense of agency. Participants not only show greater intentional binding [1] but also a processing advantage in terms of faster responses when the inten-

[1] Compression in the subjective experience of time between intentional action and its outcome (Haggard, Clark, & Kalogeras, 2002)

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tion and outcome of their actions are congruent (Ranjan & Srinivasan, 2019). The attentional mechanisms behind such intention-influenced processing are not known. Furthermore, understanding the role of intentions in attentional control also becomes crucial given the appropriate control of attentional processes is what determines the success of goal-directed actions (Bari et al., 2020; Yantis, 2016).

In the current study, we used a novel experimental design to gauge how and what aspects of attentional selection during perception of action outcomes are modulated by intentions. For this purpose, we used the Eriksen flanker task (Eriksen & Eriksen, 1974), which offers a unique opportunity to investigate the selective attention processes. We embedded an arrow-based flanker task (Stoffels & Van der Molen, 1988) in a free-choice task. Participants first chose the color for the arrows and then performed the flanker task. We operationalized intentions using this free-choice, where participants pressed a mousekey (intentional action) to get the desired color of arrows (outcome). Here, the intentionally selected/chosen feature, color for the arrows, was orthogonal to the response feature in the flanker task, the target arrow's direction. This allowed us to check how relevant information is enhanced and irrelevant information is suppressed under the influence of our intentions to get a specific outcome.

There were two aims of our study. First, to demonstrate a baseline effect of intentions. For this, we used two conditions - base (no flankers) and neutral flanker conditions, which do not involve the engagement of attentional inhibition (Eriksen & Eriksen,1974). When we decide or choose a goal, we intend to achieve it by preparing perceptual-motor levels with the goal content. This would mean that the intention will facilitate the processing of the target object with the selected/chosen color, that is, an enhancement mechanism, evident by faster response times (Ranjan & Srinivasan, 2019). Hence, we expected participants to respond faster to the intended color than neutral and unintended colors for the baseline condition.

The second aim involved investigating the relationship between flanker congruency and intention/outcome congruency. For this, congruent and incongruent flanker conditions were used, where attentional inhibition is required when flankers are incongruent. For intention congruency, the arrows were presented in three different colors, serving as three different outcomes of the intentional choice - intended (selected choice), unintended (unselected choice), and a third neutral color (named as other). The third neutral/other outcome allowed us to compare different mechanisms for intended and unintended outcomes.

As explicated by earlier works (Chang & Egeth, 2019; Ridderinkhof, 2002; Sawaki & Luck, 2010; Yantis, 2016), both enhancement and suppression processes are at play during attentional control. Drawing support from these studies, we formulated certain potential mechanisms to explain the connection between intentions and attentional processes. Since, in our design, all the arrows were of the same color in a

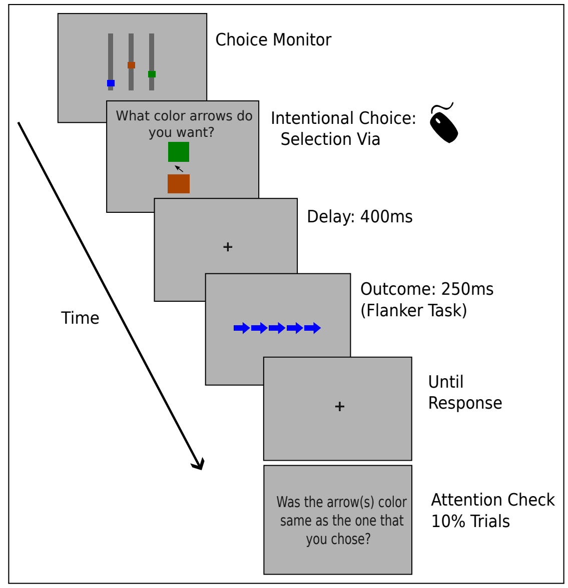

Figure 1: Trial structure.

trial, there could be interference in suppressing incongruent flankers presented with the chosen color because of the intentional value. Similarly, owing to a sort of devaluation due to non-selection during the choice, there could be two plausible mechanisms for the unintended color. There could be faster suppression when flankers are incongruent or slower activation in other flanker conditions, evident by faster or slower response times compared to the neutral color. Based on this, we hypothesized a significant interaction between intention congruency and flanker congruency.

Methods

Participants

We used G*Power software (Faul et al., 2007) to calculate the apriori sample size, which indicated that at least 19 participants were required to obtain a statistical power of 0.8 at $\alpha = 0.05$ for significant two-way interaction with moderate effect size ($f = 0.25$) and significant mean difference of effect size $d = 0.6$ (from a pilot study). A total of 25 volunteers (aged 21 to 28 years, seven females) participated in the study. All participants had normal or corrected-to-normal vision.

Stimuli and Apparatus

The experiment was created using PsychoPy 2023.1.3 (Peirce, Hirst, & MacAskill, 2022) and performed on a standard IBM PC with a 100Hz refresh rate and 1920x1080 resolution screen. Participants sat at a distance of ~80 cm in a dimly lit room and responded using a standard keyboard and mouse. The stimuli consisted of colored arrows for the flanker task of size 0.9º presented on a gray background. There were four kinds of arrows: base (> or <), neutral (−− < −− or −− > −−), incongruent (>><>> or <<><<), and congruent (>>>>> or <<<<<). The stimuli were presented in three distinct colors: blue, brown, and green (the target and flankers shared the same color). The central target arrow was presented at the fixation, and the flankers were presented at an eccentricity of ±1.2º and ±2.2º on either side of the central fixation.

Design and Procedure

In every trial, participants were asked to choose a color for the arrows from the two options with the help of a mouse click on the relevant color. On the choice screen, the question "What color arrows do you want?" was presented 5º above the center, and two color boxes were presented at ±3º from the center vertically. Two options out of three colors were given randomly in every trial. Following this, after a fixed delay of 400ms, the arrows were presented for 250ms. A fixation cross was presented at the center of the screen after that, and participants had to respond to the central target arrow direction using the "H" (left) and "J" (right) keys on the keyboard. Fixation remained until the participants responded with an inter-trial interval set to 1000ms. Arrows could come up in three different colors: intended (selected choice), unintended (unselected choice), or a third neutral (not in the choice options) color. The trial structure for the experiment is shown in Figure 1.

Each participant completed 360 trials (consisting of 4 flanker conditions [base, neutral, congruent, incongruent] x 3 choice outcome conditions [intended, other, unintended] with 30 replications each) after a 40-trial practice round. All conditions were randomized and presented an equal number of times. Additionally, we included catch trials to check their attentiveness. In these catch trials, the participants were asked a confirmatory question after the flanker task about whether the color of the arrows matched their choice. The practice session had 25% catch trials, while the main session had 10% catch trials. The participants were encouraged to actively choose to get arrows in their desired color, and no information regarding the outcome probability was given. A choice monitor screen was also presented before every trial, depicting color ratios for the choices participants made up to that trial. It was also explained to the participants that, in general, they could try to select colors evenly and, if needed, observe the choice monitor bars for help.

Data Analysis

Data was preprocessed and analyzed using Python v3.10 packages (Vallat, 2018; Van Rossum & Drake, 2009; Waskom, 2021). Individual data from participants was first checked for any choice bias. Two participants were removed, one with color choice bias (proportion for one color was less than 10%) and another with position bias (proportion for one position was less than 10%) in their choices. Data from one more participant was removed due to low catch trial accuracy (<60%). Data from 22 participants was analyzed after removing responses faster than 100ms (∼1% of total trials) and outliers using the 3 SD rule (∼1% of total trials). For outlier removal and further analysis, Response Times (RTs)

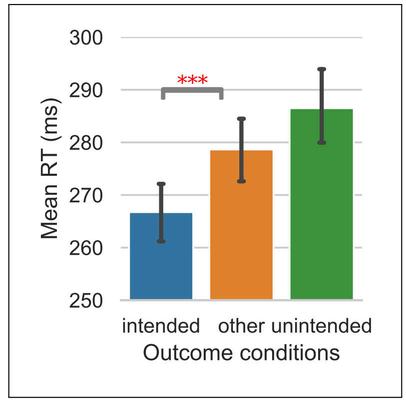

Figure 2: Mean RTs for baseline conditions.
Note: Error bars represent the 95% confidence intervals. y-axis truncated for better visibility. ***: $p < .001$

for each participant were log-transformed to reduce skewness and fulfill the assumptions of a linear model. Mean RTs were analyzed after removing incorrect trials (∼3% of total trials). The Greenhouse-Geisser correction was applied when the sphericity assumption was violated. As a supplementary statistic, the JZS Bayes factor in support of the alternate hypothesis was calculated. For plotting the results, 95% within-subject confidence intervals of the mean (Cousineau & O'Brien, 2014) were used.

Results

Baseline results

RT results A 2x3 repeated measures ANOVA for the base and neutral flanker conditions with three outcome conditions yielded the main effect of outcome manipulation (Fig. 2), $F(2, 42) = 10.8$, $p < .001$, $n_p^2 = 0.34$. The main effect of flankers, $F(1, 21) = 0.03$, $p = .855$, $n_p^2 = 0.001$, and the interaction effect, $F(2, 42) = 0.62$, $p = .534$, $n_p^2 = 0.029$, were not significant.

Paired comparisons with Bonferroni correction showed significantly faster responses for the intended condition (266ms) compared to unintended (286ms, $t(21) = 4.46$, $p < .001$, $d = 0.25$, $BF_{10} = 138$) and other (278ms, $t(21) = 3.39$, $p = .008$, $d = 0.21$, $BF_{10} = 15$) conditions. We observed a clear RT advantage for the intended outcome compared to the unintended and neutral/other outcomes, supporting our primary hypothesis. The unintended outcome had slower mean RT than the neutral/other outcome (∼8ms), but the difference was non-significant, $t(21) = 1.09$, $p = .846$, $d = 0.064$, $BF_{10} = 0.378$.

Accuracy results A 2x3 repeated measures ANOVA on accuracy data showed a significant main effect of flanker manipulation with slightly lower accuracy for the base condition (∼98%) compared to the neutral condition (∼99%), $F(1, 21) = 7.1$, $p = .024$, $n_p^2 = 0.26$. The main effect of intention, $F(2, 42) = 1.54$, $p = .218$, $n_p^2 = 0.06$, and the interaction effect,

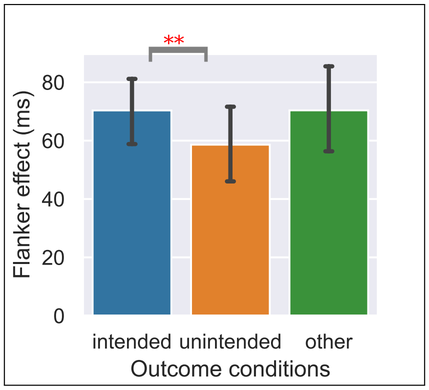

Figure 3: Flanker effect.
Note: Error bars represent the 95% confidence interval of the difference. **: p < .01

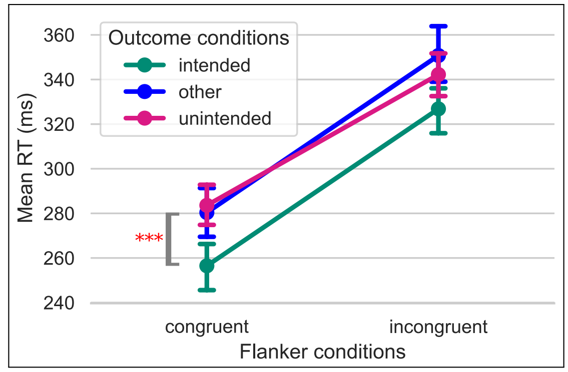

Figure 4: Line plot for all the conditions.
Note: Error bars represent the 95% confidence intervals. y-axis truncated for better visibility. ***: p < .001

$F(2, 42) = 0.08$, $p = .887$, $n_p{}^2 = 0.003$, were not significant. While the intended outcome showed faster RTs than the other and unintended outcome, no difference was found in accuracy.

Intention and Stimulus congruency analysis

Flanker effect results The flanker effect is obtained by subtracting RTs of congruent trials from incongruent ones. We conducted a repeated measure ANOVA on this difference for the outcome conditions, which yielded a significant result (Fig. 3), $F(2, 42) = 3.8$, $p = .050$, $n_p{}^2 = 0.15$. Paired comparisons with Bonferroni correction showed a significantly larger flanker effect for intended (70ms) compared to unintended (58ms), $t(21) = 4.0$, $p = .008$, $d = 0.44$, $BF_{10} = 17$, while similar flanker difference compared to other (69ms, $t(21) = 0.98$, $p = .367$, $d = 0.12$, $BF_{10} = 0.29$). The unintended and other conditions did not differ significantly, $t(21) = 1.49$, $p = .309$, $d = 0.28$, $BF_{10} = 0.5$.

These results implied that the processing facilitation for the intended outcome was similar in both congruent and incongruent flankers, while the unintended outcome might be getting suppressed better or/and facing an initial processing (activation) disadvantage (Fig. 3).

RT results We further performed a 2x3 repeated measure ANOVA on mean RTs to unveil the probable mechanisms discovered in the flanker effect analysis. Results showed a significant main effect of flanker manipulation, $F(1, 21) = 86.73$, $p < .001$, $n_p{}^2 = 0.81$. Paired comparisons with Bonferroni correction showed that the congruent (273ms) condition was significantly faster than the incongruent condition (340ms), $t(21) = 9.3$, $p < .001$, $d = 1.15$, $BF_{10} > 10^5$.

The main effect of outcome manipulation, $F(2, 42) = 12.33$, $p < .001$, $n_p{}^2 = 0.37$. Paired comparisons with Bonferroni correction showed that the intended (291ms) was significantly faster than the unintended (312ms, $t(21) = 5.1$, $p < .001$, $d = 0.31$, $BF_{10} = 536$) and other (315ms, $t(21) = 3.8$, $p < .001$, $d = 0.33$, $BF_{10} = 40$) conditions, while no significant difference was observed between the other and the unintended condition, $t(21) = 0.199$, $p = .839$, $d = 0.01$, $BF_{10} = 0.22$.

There was also a significant interaction (Fig. 4), $F(2, 42) = 3.9$, $p = .050$, $n_p{}^2 = 0.16$. Post-hoc tests (Bonferroni corrected) showed faster responses for the congruent-intended (256ms) condition compared to congruent-unintended (284ms), $t(21) = 7.56$, $p < .001$, $d = 0.41$, $BF_{10} > 10^{4,}$ and congruent-other (280ms), $t(21) = 3.35$, $p = .011$, $d = 0.32$, $BF_{10} = 14$. On the contrary, for the incongruent trials, the intended (327ms) and unintended (342ms) conditions did not differ significantly, $t(21) = 2.26$, $p = .210$, $d = 0.17$, $BF_{10} = 1.2$, while the intended and other (351ms) condition were significantly different, $t(21) = 3.19$, $p = .032$, $d = 0.3$, $BF_{10} = 10$. The unintended and other conditions were not significantly different for both, congruent, $t(21) = 0.82$, $p = .419$, $d = 0.07$, $BF_{10} = 0.3$, and incongruent, $t(21) = 1.18$, $p = .248$, $d = 0.11$, $BF_{10} = 0.41$ flanker conditions. Figure 5 shows the contrast between congruent and incongruent conditions for the difference between different outcome pairs.

The ANOVA results showed a significant interaction between the flanker and intention congruency, supporting our

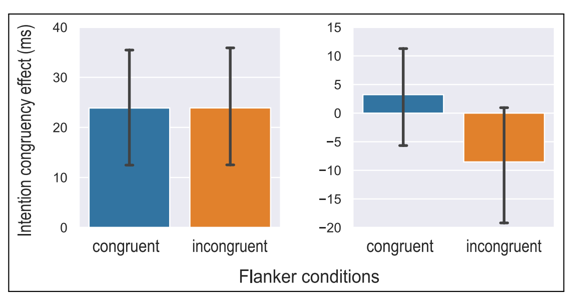

Figure 5: Intention congruency effect, obtained by subtracting RTs of one outcome condition from another outcome condition. (left) Other-Intended. (right) Unintended-Other.
Note: Error bars represent the 95% confidence interval of the difference.

hypothesis. It showed that the intended outcome yielded faster RTs compared to the other outcomes in both the flanker conditions, indicating an advantage (Fig. 5 (left)). This eliminated the possibility of the intended outcome facing any interference in suppression during conflict resolution due to the shared feature between the central target and flankers.

In contrast, there was a non-significant difference between the intended and unintended outcomes for the incongruent condition, suggesting that it is the unselected choice rather than the selected one that might interact with inhibitory control. While the difference between unintended and other outcomes in the incongruent condition was non-significant, there was a mean difference of ∼9ms, with an unintended outcome being faster than the other outcome, which indirectly implied the possibility of unintended features being suppressed better (incongruent in Fig. 5 (right)). Besides, in the congruent condition, unintended and other outcomes did not differ significantly, suggesting no disadvantage for the unintended one (congruent in Fig. 5 (right)).

Accuracy results We also checked the accuracy [2] data by conducting a 2x3 repeated measures ANOVA, which showed a significant main effect of flanker manipulation with lower accuracy for the incongruent condition (∼90%) compared to the congruent condition (∼99%), $F(1, 21) = 29.1$, $p < .001$, $n_p{}^2 = 0.58$. The main effect of intention, $F(2, 42) = 2.7$, $p = .165$, $n_p{}^2 = 0.08$, and the interaction effect, $F(2, 42) = 1.8$, $p = .183$, $n_p{}^2 = 0.07$, were not significant.

Discussion

How do intentions influence attentional control? Our study indicates that intentions influence attentional processing in the form of a processing advantage. We found that intentionally chosen outcomes exhibit this processing advantage via feature enhancement. Our findings also support the dynamic theory of intentions (Pacherie, 2006), specifically that the intentions perform monitoring or controlling functions beyond the execution of the action. This monitoring of the action outcome influences attention, which can be visualized within an intention-action-perception sequence (Fig. 6) as part of the perception-action cycles (Hurley, 2001) to attain a goal.

One possible way of explaining the enhancement in processing is in terms of rewards associated with the outcome. The outcomes in the current study had no reward value associated with them, that is, no extrinsic valence. This suggests that selecting a color with the intention of getting the arrows in that respective color itself serves as an intrinsic valence for future-directed attention and action via goal/effect anticipation. Accordingly, intentions provide a motivational value/bias for appropriate attentional selection of the action effects. It is to say that intentions finetune the sensory-motor control for the feature(s) of the action's target (Wu, 2023). This might also contribute to the experience of being in control of one's action and its consequences (Gallagher, 2020).

[2] https://figshare.com/articles/figure/AccuracyPlots/25794631

A similar offline biasing mechanism for online action control, in the form of intentional or attentional weighting, is also proposed by the theory of event coding (TEC). It assumes that the high-level processes direct low-level processes towards the task-relevant stimulus information that is required for the impending action through top-down weighting of features in the common-coded event files (Memelink & Hommel, 2013). However, in our study, choosing a color feature is orthogonal to the flanker task, and the colors were not associated with any specific action, that is, left or right arrows. Moreover, an intentional choice for outcomes is not the same as cueing/priming of the color feature presented in the flanker task. Hence, our results cannot be completely ascribed to TEC's intentional weighting mechanism, which is limited in theorizing the role of intention only at the action preparation stage in contrast to the hierarchical model of intentions (Mylopoulos & Pacherie, 2019).

Intentions, presumably owing to their cognitive implementation, can also have processing effects on unintended outcomes. Faster RTs for the unintended outcome compared to the neutral outcome, although not significant, in the incongruent condition suggest that the incongruent flanker arrows were suppressed faster when presented with unintended color. It is similar to a proactive distractor suppression mechanism, where the sensory processing of a task-relevant distractor is suppressed in advance (Di Bello et al., 2022; Geng, 2014). The anticipation of an unwanted color outcome makes it equivalent to a distractor for the intention. However, this interpretation is indirect and requires follow-ups since the difference in RTs was non-significant.

Our study has implications for models of cognitive control. Various models (Botvinick et al., 2001; Cohen, 2017) have addressed the mechanisms involved in cognitive control, which either is based on the control exercised earlier (proactive) or based on reaction to stimulus congruency, as in Stroop and Flanker tasks (reactive). In the current study, we showed that reactive control is influenced by intentions, that is, in terms of whether the stimulus outcome is intended or not. Hence, dichotomizing proactive and reactive control does not give a complete picture of cognitive control processes. Rather, such models need to incorporate mechanisms associated with intentions in situations demanding cognitive

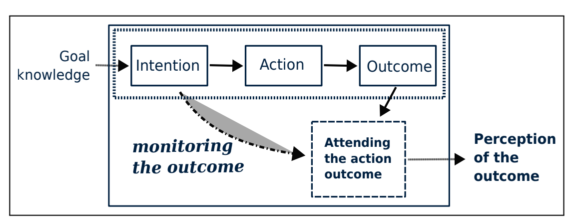

Figure 6: Schemata of intention-action-perception sequence. The enhancement of the intended object is due to the outcome monitoring function of intention, indicated by the curved dashed line.

control since it is not strictly a proactive or reactive control at work, but whether a stimulus feature is intended or not is pivotal.

Our results also hold significance for a long-standing debate within cognitive sciences on whether higher cognitive processes influence early perceptual processes. In our study, from the hierarchical framework perspective, it is the P-intentions that play a primary role since our design involved trial-by-trial selecting the color and attending to the arrows. Faster RTs in the flanker task could be due to processing advantage at different attentional selection stages - early sensory sampling and/or later response selection (Cohen, Sparling-Cohen, & O'Donnell, 1993). The advantage at the early stage can have implications for the notion of "cognitive penetrability." Recent philosophical work tends to argue for cognitive penetration of attention and perceptual processing by intentions, drawing support from computational models on visual attention (Wu, 2017).

Our study has two limitations. Since freedom of choice gets constrained by asking participants to try choosing the outcomes somewhat equally, one limitation of our study is a control condition to show the contrast between voluntarily chosen and instruction-based actions or action outcomes. This is also important for clarifying the role of expectation and attention. The color outcomes in our study were presented randomly. While implicit expectations might not play any role due to unpredictable outcomes, explicit expectations due to cueing/priming could still interact with attentional processing (Simon, Schachtner, & Gallen, 2019; Zuanazzi & Noppeney, 2018).

Another issue in the current design stems from the conceptual overlap between unintended and neutral/other conditions, which was included for comparison purposes. Although the colors during choice were randomized, the role of the third color as a neutral outcome was undermined by the fact that the information related to its choice was available to the participants in every trial on the choice monitor screen, even when it was not presented as an option to choose. This could also be a possible reason for the inconclusive statistical difference between the two outcomes, which requires careful manipulation in future designs.

Conclusion

Attentional processes play a fundamental role in the process of goal realization, which demands intentional control. In this study, we showed how intentionally chosen outcome impacts attentional selection in an orthogonal task. Our results demonstrated the influence intentions hold over attentional mechanisms, bridging the gap between philosophical/folk notions of intention, attention, and action. Based on our findings, we argue for investigating intentions and their mechanisms from a hierarchical perspective and including intentions as a major factor in cognitive control. Further, we plan to run drift-diffusion models on the behavioral data to shed light on the relation between intention and the attentional sampling process. Since, for some of our results, the p-value was exactly in the middle, .05, we plan to replicate the observed effects in the follow-up studies.

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