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Brief article

Adjustments of response speed and accuracy to unconscious cues

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ABSTRACT

Controlling response parameters like the speed and accuracy of responses allows us to adjust our behavior according to particular situational task demands. We investigated whether exertion of cognitive control over speed–accuracy settings is not exclusively based on conscious representations, but can also be elicited by stimuli that are not consciously represented. Participants were instructed to point and click on a target, with a cue signaling before each response whether to prioritize accuracy of the response over speed, or vice versa. In half of the trials, the cue was masked to prevent a conscious representation of the cue. With visible cues, response patterns showed typical speed–accuracy tradeoffs, with faster and less accurate responses after speed cues, and slower but more accurate responses after accuracy cues. Crucially, this was found with masked cues as well. Our results are in line with recent findings on the relation of consciousness and cognitive control processes like task-set activation and response inhibition: masked cues are able to impact on cognitive control processes.

1. Introduction

In many tasks, there is an inverse relation between speed of task execution and accuracy with which the task is performed (Kounios & Smith, 1995; Ratcliff, 2002; Woodworth, 1899). Faster responses entail less accuracy, and accurate responses require more time, which is referred to as a speed–accuracy tradeoff (SAT). While this tradeoff itself seems to be inevitable (if effort is constant), the characteristics of the tradeoff, i.e., the degree to which accuracy or speed is prioritized over the other, can flexibly be adjusted. This setting of the SAT-criterion is oftentimes regarded as a deliberate process under cognitive control (Gold & Shadlen, 2007; Oberauer, 2009; Osman et al., 2000; Rinkenauer, Osman, Ulrich, Müller-Gethmann, & Mattes, 2004). It is assumed that people “select or change their position along a continuum of speed versus accuracy” (Rinkenauer et al., 2004, p. 261). This allows us to strategically control our internal speed–accuracy-setting to account for particular task demands like time constraints. This notion is also supported by the neuronal basis of the SAT, which has been linked to the basal ganglia and specifically to pre-SMA (Bogacz, Wagenmakers, Forstmann, & Nieuwenhuis, 2010; Forstmann et al., 2008), structures typically associated with internally generated processes (Halsband, Matsuzaka, & Tanji, 1994).

In this study, we investigated whether the SAT-criterion can be impacted on not only by consciously experienced stimuli, but also by masked stimuli that we are not aware of. Besides direct implications for the underlying mechanisms of the SAT, this research question also addresses broader issues like the function of consciousness in the control of behavior. According to theories of cognitive control, speed–accuracy-adjustments can be classified as

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cognitive control processes (Allport, 1989; Monsell, 1996). The setting of decision criteria, which is presumably a core mechanism of speed–accuracy adjustments, is seen as an essential control function in task execution (Monsell, 1996). Likewise, the working memory model by Oberauer (2009) lists prioritization of speed versus accuracy as typical executive functions. This view is in line with the basic idea that cognitive control processes are characterized by the ability to allow for flexible behavior (Kunde, Reuss, & Kiesel, 2012). Emphasizing either speed or accuracy allows us to flexibly adjust our behavior to situational demands (e.g., time pressure, fatal consequences of error).

Recently, evidence accumulated that masked stimuli are able to trigger processes that were traditionally deemed to depend on conscious stimulus representations. A number of studies demonstrated that specific cognitive control processes like inhibition of responses or activation of different task-sets can be elicited by stimuli that are not consciously represented by the actor (Lau & Passingham, 2007; Mattler, 2006; Reuss, Kiesel, Kunde, & Hommel, 2011; van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008). These control processes are triggered when a stop-signal or a task cue are presented unconsciously. Yet, other processes like sequential conflict adaptation processes seem to depend on conscious representations of the event that calls for such adaptation (Ansorge, Fuchs, Khalid, & Kunde, 2011; Kunde, 2003). Thus, it remains unclear whether this unconscious impact is restricted to particular control processes, and which critical attributes determine the possibility of such an impact. Investigating whether speed–accuracy-adjustments might be triggered by unconscious information thus helps to further define the functional role of consciousness in the control of behavior.

Concretely, adjustments of speed–accuracy settings differ from processes like task-set activation as they do not determine *which* response is executed. While task-set activation and inhibition processes both directly alter which response is given to a stimulus (or shall not be given in the case of inhibition), speed–accuracy settings alter *how* a particular response is selected and executed. Both types of processes thus allow for behavioral flexibility depending on situational demands (which is a hallmark of cognitive control processes), but do so in different ways. Notably, conflict adaptation, which possibly depends on consciousness, also does not alter response execution, but stimulus processing (e.g., Wendt, Luna-Rodriguez, Kiesel, & Jacobsen, 2013). Our results are thus also suited to speak to the question whether unconscious impact on a control processes is restricted to processes that directly alter which responses are executed.

2. Experiment

We employed an aiming task in which rapidly changing time constraints were signaled by cues that were either visible or masked, and analyzed whether adjustments of speed and accuracy depend on the visibility of the cue. Participants were instructed to move a pointer toward a target with a cue signaling beforehand whether they should respond fast because of a time constraint or whether they should hit the target area as accurate as possible. With the cue signaling how speed–accuracy settings have to be adjusted to perform the task successfully, a variation of the cues' visibility allowed us to determine whether such adjustments depend on a conscious representation of the cue or not.

2.1. Participants

Twenty-four students (five males, mean age 21 years) of the University of Würzburg participated in the experiment in fulfillment of course requirements or payment (6 Euro). All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment. The experimental session lasted approximately one hour.

2.2. Apparatus and stimuli

The experiment took place in a dimly lit room. An IBM compatible computer with a 17 in. VGA-Display with a resolution of 640 × 480 pixels and the software package E-Prime™ were used for stimulus presentation and response sampling. Viewing distance to the monitor was about 50 cm. Responses were executed by moving the mouse pointer onto the target and then clicking the left mouse button. All stimuli were presented in white on a black background. The letters *v* and *b* functioned as cues, presented in Courier New font, a point size of 20. Forward masks and backward masks consisted of three hash tags (###) followed by a string of three % signs (%%%), presented in bold Courier New font, a point size of 20. An arrow pointing upwards served as the pointer the participants controlled. The target consisted of 9 concentric circles, with the outer circle having a diameter of 12 cm on the screen. The innermost circle (extending 1.2 cm), denoting the center of the target, was filled with red color. The target was presented either in the upper left or the upper right corner of the screen, with its center being located at 75% of the height and 25% (from the left respectively right side) of the width of the screen (for an illustration, see target in Fig. 1).

2.3. Procedure and design

The sequence of events in a trial is depicted in Fig. 1. Each trial started with a central fixation cross extending 0.7 × 0.7 cm presented for 500 ms. Following the fixation cross, two forward masks were presented: first three hash tags (40 ms), and then three % signs (30 ms). In trials with masked cues, the cue was presented for 30 ms, followed by two backward masks that were identical in form and duration to the forward masks. The cue either indicated that responses had to be executed within 600 ms (speed cue), or that there was no time limit and responses should be especially precise (accuracy cue). In trials with visible cues, the cue was presented for 100 ms, and the backward mask was omitted (so that the cue-target stimulus-onset-asynchrony was identical for trials with masked and non-masked cues). The target display, also featuring the pointer at the center of the screen, appeared after an interval of 500 ms and remained either for 600 ms (after a speed

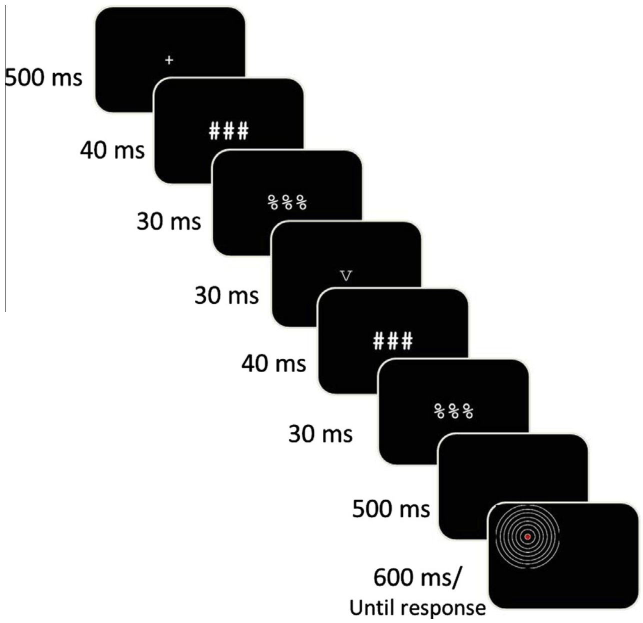

Fig. 1. Sequence of stimuli in a trial featuring a masked cue. In trials with non-masked cues, the cue was presented for 100 ms instead of 30 ms, and the backward mask was omitted.

cue) or until a response was given (after an accuracy cue). When participants responded too slowly after a speed cue, an error feedback stating "Zu langsam!" ("Too slow!" in German) was displayed for 2000 ms. After response execution, a fixed time interval of 1000 ms elapsed before the next trial started.

Participants were instructed to move the pointer as precisely as possible to the center of the target before responding (clicking the mouse) when an accuracy cue was presented. Likewise, in the case of a speed cue, they were instructed to move the pointer and to respond as fast as possible in the time limit of 600 ms, even if the response is not very accurate. Finally, they were instructed that when they do not perceive a cue (i.e., when the cue was masked), they should respond both as quickly and as accurate as possible.

The experiment started with a practice block that consisted of 16 trials all featuring non-masked cues to allow participants to become familiar with the task. The experiment consisted of fourteen blocks with 32 trials each. Within each block, the sequence of cues, the visibility of each cue, and the position of the target (upper left or upper right) was randomized. Participants were allowed self-paced pauses between the blocks. After this main experiment, a cue identification test consisting of 192 trials in which participants had to identify the cue instead of responding to the target closed the experimental session. The sequence of stimuli in a trial of the identification test was the same as in the main experiment, with the exception that target stimuli were always presented for 600 ms, so that the cue could not be inferred from the target duration. Participants had to indicate the identity of the cue by pressing the respective button on a keyboard. There was no time pressure to do so to avoid subliminal priming effects on these free decisions (e.g. Kiesel et al., 2006; Schlaghecken & Eimer, 2004), and responses could only be given after an interval of 400 ms after target offset (for a similar procedure see Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003).

2.4. Results

We analyzed RT (time from target onset until the mouse was clicked) and accuracy (linear distance from the point the response was given to the center of the target) depending on whether a speed cue or an accuracy cue was presented visible or masked (see Fig. 2).

With visible cues, participants responded 475 ms faster after a speed cue than after an accuracy cue (406 ms vs. 881 ms), $t(23) = 19.41$, $p < .001$ (see Fig. 2a). Additionally, participants' responses were 18 mm more accurate after an accuracy cue than after a speed cue (3 mm vs. 21 mm distance from the center of the target), $t(23) = 12.54$, $p < .001$ (Fig. 2b).

With masked cues, participants responded 14 ms faster after a speed cue than after an accuracy cue (754 ms vs. 768 ms, Fig. 2c), $t(23) = 2.51$, $p = .019$. Additionally, participants responses were 0.5 mm more accurate after an accuracy cue than after a speed cue (5.3 mm vs. 5.8 mm distance from the center of the target, Fig. 2d), $t(23) = 2.40$, $p = .025$. The pattern of results both with visible and with masked cues thus reveals a SAT that is accordant with the presented cue. Significantly faster responses are associated with significantly less accurate responses after a speed cue, and significantly more accurate responses are associated with significantly slower responses after an accuracy cue.

As an overall indicator of a SAT, we calculated the percentage increase in response speed after speed cue compared to accuracy cue (i.e., difference in RT after speed cue vs. accuracy cue, divided by RT after accuracy cue),

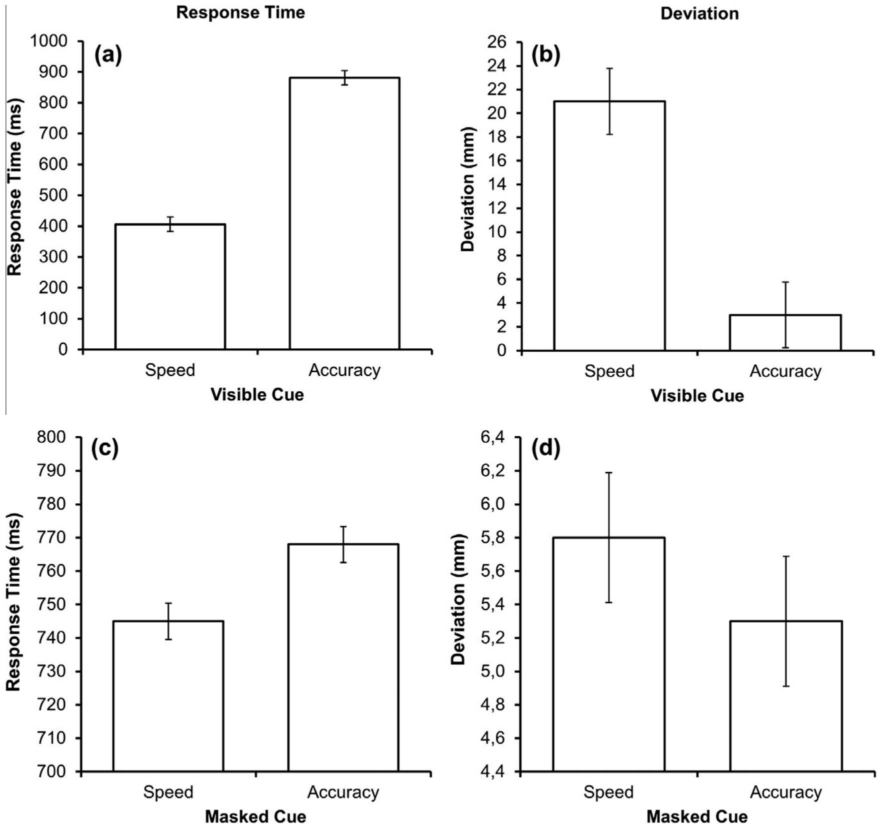

Fig. 2. Panel (a) shows RTs (in ms) after visible speed cues (left bar) and visible accuracy cues (right bar). Panel (b) shows the distance of the response (in mm) from the center of the target to the point clicked, again for visible speed and visible accuracy cues. Panel (c) and (d) depict the same for masked cues. Error bars represent within-subject confidence intervals (95%). Both visible and masked cues lead to adjustments of response speed and accuracy: Faster responses after speed cues compared to accuracy cues, and more precise responses after accuracy cues compared to speed cues.

and the percentage increase in accuracy after an accuracy compared to a speed cue. These two values were averaged and multiplied by 100, and thus yielded an SAT index that represents how much faster and how much more accurate, percentage wise, the response is after the accordant cue. With visible cues, we observed an SAT index of 69.0, $t(23) = 51.195$, $p < .001$. With masked cues, the SAT index amounts to 4.93, $t(23) = 2.913$, $p = .008$, indicating an overall behavioral adaptation according to masked cues.

Cue visibility was assessed by computing the signal detection measure d', treating the cue *b* as signal and the cue *v* as noise. Participants' discrimination performance for the masked cues was $d' = 0.19$, 54.1% correctly identified, with a mean hit rate of 51.3% and a mean false alarm rate of 43.2%. This value did not significantly deviate from zero, $t(23) = 1.57$, $p = .129$, indicating that the masked cues were not consciously perceived. To further test whether an effect of masked cues on speed–accuracy settings is found without cue visibility, we adopted a procedure suggested by Greenwald, Klinger, and Schuh (1995; see also Draine & Greenwald, 1998; Greenwald, Draine, & Abrams, 1996). We assessed the relationship between cue visibility and speed–accuracy-adaptations by regressing the SAT index of each participant onto this participant's d' score, and analyzed whether this regression would predict a significant SAT index when d' is zero (Fig. 3). The analysis revealed a marginally significant beta coefficient, $t(23) = 2.02$, $p = .055$, and, importantly, a significant intercept, $t(23) = 2.32$, $p = .030$. The latter indicates that a significant effect of masked cues on speed and accuracy could be observed with invisible cues if they were perfectly masked. To further scrutinize whether the effect emerges in the absence of conscious cue representations, we selected a third of the participants with cue identification

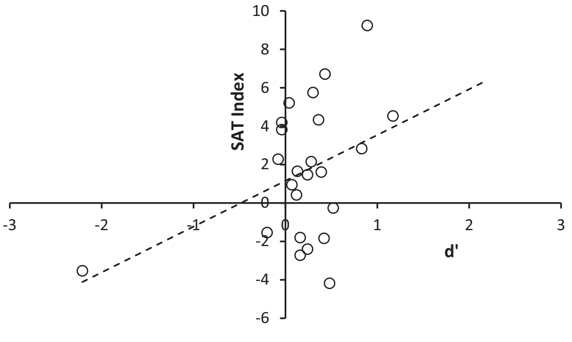

Fig. 3. Individual d'-values and the according SAT Index of each participant. The intercept point of the regression line and the y-axis indicates an effect at a theoretical point of absolutely zero cue visibility.

performance closest to zero (thus also excluding one large negative outlier) for further analysis. This subgroup of 8 participants showed absolutely no ability to identify the masked cues, $d' = 0.001$, $t(7) = 0.027$, $p = .979$. However, they still adjusted their responses according to the masked cues, as indicated by a significant SAT index, $t(7) = 3.41$, $p = .011$.

3. Discussion

We investigated whether the speed–accuracy setting for an aiming task can be influenced by masked cues. Participants responded faster and less accurate when a cue signaled the priority of speed, compared to when a cue signaled the priority of accuracy. Critically, this was found both when cues were visible and when cues were masked.

The results thus confirm that we are able to flexibly control the way a response is executed depending on particular situational demands that are rapidly changing. Under time pressure, we are able to increase the speed with which a response is executed at the expense of response accuracy, and vice versa. While this can be done deliberately on the basis of consciously perceived cues, the results show that speed–accuracy-adjustments also occur when only masked stimuli signal situational demands.

In this respect, the adjustment of speed–accuracy settings queues up with other cognitive control processes that have been found to be able to be elicited unconsciously (Reuss et al., 2011; van Gaal, Ridderinkhof, van den Wildenberg, & Lamme, 2009; van Gaal et al., 2008). While the effects of unconscious stimulation are small, which is constantly found in the literature, they are still of theoretical importance by demonstrating that conscious representations are not a strict prerequisite for the exertion of control processes. Traditionally, cognitive control processes have been conceptualized as purely intentional and conscious operations (e.g., Dehaene & Naccache, 2001; Jack & Shallice, 2001), which is contradicted by these results.

Besides evoking only comparatively small effects, there are other restrictions of unconscious stimulation. It is important to note that participants were explicitly instructed to utilize the cues to adjust executive parameters accordingly, so that they intended to utilize the cues in this particular way. It was hypothesized that such a direct link between an explicit stimulus and the associated cognitive process is necessary to enable an impact of masked stimuli (Kunde et al., 2012). Such a mechanism would be able to explain why a study by Bijleveld, Custers, and Aarts (2010) failed to find an unconscious impact on speed and accuracy. Here, participants were rewarded for solving mathematical problems (with reward declining with increasing response times, and no reward with errors), while a preceding reward cue signaled whether a high or low reward is at stake in the current trial. While visible reward cues lead to speed–accuracy-adjustments (accuracy is emphasized with high possible rewards), masked reward cues did not. Notably, whereas speed and accuracy cues are explicitly linked to the appropriate adjustment, the reward cues signaled the potential reward, but only (at best) implied which strategy might be most suited for the situation. Overall, the contradicting results in fact illustrate that an explicit instruction to engage particular processes might be necessary to enable unconsciously triggered adjustments.

With speed–accuracy settings, it seems plausible that besides consciously triggered control, a form of unconsciously induced control is possible, as both offer distinct advantages. As is obvious in our results, conscious control leads to sizeable effects, which is desirable in situations in which it was determined on the basis of apparent situational demands that a particular speed–accuracy setting is required. However, failure to consciously notice such situational demands can be disastrous if the speed–accuracy setting were not adjusted at all. Here, the ability to unconsciously pick up subtle stimuli that have been associated with particular speed–accuracy settings and automatically adjust the accordant executive parameters accordingly is potentially very beneficial. This is in line with the assumption of both a controlled mode and an automatic mode of control (Kahneman, 2002).

To conclude, our results show that speed–accuracy settings are not only adjusted when the reasons of doing so are known to the actor, but can also be elicited by masked stimuli that are presumably not consciously perceived by the subject. These findings complement and extend hitherto findings that some cognitive control processes are susceptible to unconscious stimulation. We demonstrated that this influence is not restricted to changes *which* response is given to a target stimulus, but is also able to modulate *how* a particular response is executed.

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