Cognition 128 (2013) 271–279

Contents lists available at SciVerse ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Complete unconscious control: Using (in)action primes to demonstrate completely unconscious activation of inhibitory control mechanisms

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ARTICLE INFO

Article history:
Received 2 November 2012
Revised 28 April 2013
Accepted 30 April 2013

Keywords:
Unconscious
Inhibition
Self-control
EEG
Inaction

ABSTRACT

Although robust evidence indicates that action initiation can occur unconsciously and unintentionally, the literature on action inhibition suggests that inhibition requires both conscious thought and intentionality. In prior research demonstrating automatic inhibition in response to unconsciously processed stimuli, the unconscious stimuli had previously been consciously associated with an inhibitory response within the context of the experiment, and participants had consciously formed a goal to activate inhibition processes when presented with the stimuli (because task instructions required participants to engage in inhibition when the stimuli occurred). Therefore, prior work suggests that some amount of conscious thought and intentionality are required for inhibitory control. In the present research, we recorded event-related potentials during two go/no-go experiments in which participants were subliminally primed with general action/inaction concepts that had never been consciously associated with task-specific responses. We provide the first demonstration that inhibitory control processes can be modulated completely unconsciously and unintentionally.

1. Introduction

Are you in control of your own behavior? A large body of evidence suggests that actions can be initiated unconsciously (Libet, 1985) and unintentionally (Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trotschel, 2001), which calls into question the concept of free will and the plausibility of complete conscious control over behavior (cf., Newell & Shanks, in press). However, behavioral control is more than mere action initiation – many critical aspects of behavioral control involve inhibiting (rather than executing) actions. Weight loss, smoking cessation, emotion regulation, and saving money all involve the use of inhibitory control over actions that would otherwise occur (i.e., eating, smoking, emoting, and spending, respectively). According to several influential theories, nonconscious behaviors are relatively inflexible and primarily involve the reproduction of well-learned associations (Bargh, 1990; Kruglanski et al., 2002). Thus, an over-eater's automatic reaction to perceiving food is the desire to eat, a smoker's automatic reaction to perceiving a cigarette is the desire to smoke, and so forth. An important question, then, is whether conscious thought is necessary to engage inhibitory control processes that can override actions when they are initiated, or whether inhibitory processes can also be initiated unconsciously and unintentionally.

Recently, a number of studies have demonstrated that subliminal stimuli can unconsciously activate inhibition processes. However, the stimuli in these studies unconsciously activate inhibitory processes only *after* the stimuli have already been consciously associated with task-spe-

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http://dx.doi.org/10.1016/j.cognition.2013.04.012

cific inhibitory responses (D'Ostilio and Garraux, 2012; Hughes, Velmans, & de Fockert, 2009; Praamstra & Seiss, 2005; Van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008). For example, participants who consciously form implementation intentions to inhibit fear-responses to frightening stimuli (e.g., "When I see blood, I will remain calm") automatically inhibit their emotions to subsequent fear-relevant stimuli, whereas participants who merely form goals to remain calm (e.g., "I will remain calm") but do not form stimulus-inhibition associations do not (Gallo, Keil, McCulloch, Rockstroh, & Gollwitzer, 2009). As a result, the literature on unconscious engagement of inhibition suggests that (a) consciousness is in fact required for inhibitory control (i.e., during pre-inhibition tasks or instructions in which target-stimuli are consciously associated with an inhibition response within the context of the task) and (b) willful intent is also required (i.e., participants form a goal/desire to modulate inhibition processes in response to target-stimuli as part of the task procedure).

Of relevance, individuals are frequently motivated to pursue general activity or inactivity without concern for the specific behaviors pursued or foregone (Albarracin, Hepler, & Tannenbaum, 2011; Albarracin et al., 2008). Consequently, exposing individuals to stimuli associated with the general concept of inaction (action) has been shown to increase (decrease) behavioral inhibition in diverse tasks even though these stimuli were never associated with task-specific responses (Hepler et al., 2012a,b). These behavioral inhibition results would seem to support the conclusion that inhibitory control can be activated unconsciously and unintentionally, without prior conscious input. Although behavioral inhibition can result from modulation of brain-based inhibitory control processes, it can also result from modulation of motor control processes (D'Ostilio and Garraux, 2012). That is, individuals may not-act because they inhibit an action that would have otherwise occurred or because they never begin to execute the action in the first place (i.e., an inhibition of an initiated action versus a lack of action initiation). Thus, demonstrating behavioral inhibition via an absence of action is not the same as demonstrating engagement of inhibitory control processes because it is possible that the absence of action represents a failure to initiate the action rather than an inhibition of the action. Fortunately, an event-related potential (ERP) component called the P3 can reflect engagement of brain-level inhibitory control processes that may not be observable at the level of behavior. Specifically, when participants successfully inhibit a behavior (e.g., a "no-go" response during a go/no-go task), larger P3 amplitude over frontal-central-parietal brain sites approximately 300–550 ms after the onset of a stimulus indicates greater engagement of inhibitory control processes (Smith, Johnstone, & Barry, 2007).

Therefore, to determine whether inhibitory control processes can be unconsciously and unintentionally engaged by stimuli that have never been consciously associated with task-specific behavioral responses, we conducted two experiments in which participants were subliminally primed with general action/inaction concepts during a go/no-go task, and we analyzed P3 amplitude on no-go (inhibition-related) trials as a function of prime to assess engagement of inhibitory control processes. If P3 amplitude is modulated in response to these stimuli, it would be a critical discovery because previous research has only demonstrated unconscious inhibitory control *after* conscious thought has been used to (a) form stimulus-inhibition associations and (b) form intentions to execute those associations. In contrast, we seek to demonstrate that engagement of inhibitory control processes can occur without using conscious thought to associate stimuli with inhibitory responses or to form intentions to modulate inhibitory control.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty participants were recruited via an online ad for research participants. Participants were paid a minimum of $10 and could earn up to $30 by exceeding target performance standards provided during the task. The age of participants ranged from 19 to 28 ($M = 21.2$ years, $SD = 2.5$). Thirty percent of respondents were female. The race/ethnicity of the sample was 50% Asian, 45% Caucasian/White, and 5% Black/African-American. All participants were native English speakers, had normal or corrected-to-normal vision, were right-handed, were not currently taking any psychoactive medications, and had refrained from caffeine and tobacco use for at least 1 h prior to the experiment.

2.1.2. Procedure

Participants completed a go/no-go task consisting of one calibration block and two experimental blocks. Each block contained 300 trials, half of which were go trials and half of which were no-go trials, presented in random order. Each trial consisted of the following: a pre-mask of &&&&&& (16.7 ms), a subliminal prime (33.4 ms), a post-mask of &&&&&& (50.1 ms), a target (variable time, see below), and a blank inter-trial interval (650–850 ms, randomly jittered). The targets were the letters X and Y, and the participants' task was to respond by pressing a button on a response box with their right index finger every time they saw an X (a go trial), but not to respond when they saw a Y (a no-go trial). The go target was always X, and the no-go target was always Y. Responses were only recorded if they occurred while a target was on screen. For the present purposes, we analyzed correct rejection trials – i.e., trials on which a Y was presented and participants correctly withheld a response. We focused exclusively on these trials because the P3 ERP response indicates engagement of inhibitory control mechanisms when participants are engaged in inhibitory control behaviors (i.e., when they are correctly not-responding to a no-go stimulus), but the P3 does not necessarily indicate these same processes under other conditions, such as when participants execute a motor response during a go trial (Smith et al., 2007).

2.1.3. Subliminal primes

The pre-mask, prime, and post-mask that occurred during each trial subjectively appeared to be a single, brief flash that preceded the target stimulus. As a cover story for this flash, participants were told that the flash was intended to draw their attention to the upcoming trial and to "prepare your visual system to efficiently process the target stimulus." During a funnel debriefing no participant reported awareness of the primes, no participant reported being suspicious that the flashes were anything other than an attention-grabbing device, and no participant could identify any of the prime words when asked to guess what the prime stimuli might have been. Thus, it appears that the primes did in fact remain subliminal (in Experiment 2, we use more sensitive prime awareness tasks). During the two experimental blocks, we introduced a within-subjects manipulation of the primes. For each participant, one-third of trials used primes that were general action words (*go*, *run*, *move*, *hit*, *start*), one-third of trials used primes that were general inaction words (*still*, *sit*, *rest*, *calm*, *stop*), and one-third of trials used primes that were controls (scrambled action and inaction prime words – e.g., *rnu*). Therefore, the experiment was a fully within-subjects design, such that each subject was exposed to action, inaction, and control primes during both experimental blocks. The only primes presented during the calibration block were control primes. The action and inaction prime word lists do not differ in usage frequency, $t(8) = .54$, $p = .60$ (Davies, 2009) and they have been used in previous research on motivation for general action and inaction (Albarracin et al., 2008; Albarracin et al., 2011; Hepler, Wang, & Albarracin, 2012b; Hepler et al., 2012a).

2.1.4. Performance calibration

The calibration block always preceded the two experimental blocks. During calibration, we identified the shortest target duration that elicited a 75% overall accuracy rate for each participant (overall accuracy = (hits + correct rejections)/(total number of trials); i.e., (responses to X + non-responses to Y)/(total number of trials)). The calibration trials were similar to the experimental trials with two exceptions. First, all primes during this block were control primes (i.e., no action or inaction prime words were presented). Second, the target presentation time varied from 300 ms to 525 ms in 25 ms increments. Participants received 30 trials at each increment, and all trials within an increment were presented sequentially. However, the increment order was determined randomly, such that participants may have received 30 trials at a presentation speed of 400 ms followed by 30 trials at another randomly determined presentation speed (e.g., 325 ms, 500 ms, etc.). Randomization of the increment order occurred separately for each participant. For each participant, we identified the shortest presentation time that elicited an overall accuracy rate as close to 75% as possible ($M_{\text{time}} = 370$ ms, $SD_{\text{time}} = 17$ ms; $M_{\text{accuracy}} = 75\%$, $SD_{\text{accuracy}} = 9\%$). This value was used as the target presentation speed in the experimental blocks to standardize task difficulty across participants. After the calibration block (and before the experimental blocks), participants were told that we would use their initial performance to make the upcoming experimental blocks moderately difficult, so that the blocks would be of medium difficulty rather than being too easy or too hard. Additionally, we incentivized good performance by offering to pay participants an extra $10 for each experimental block in which they exceeded a 75% overall accuracy rate. Participants were informed immediately after each experimental block of what their overall accuracy rate was for that block and if they earned the bonus money for that block.

2.1.5. EEG recording and preprocessing

After completing the calibration block, participants were equipped with electroencephalogram (EEG) recording equipment so that we could record continuous EEG while they completed the experimental blocks. Participants were fitted with an EEG cap, 32 scalp electrodes, and 5 external electrodes (left and right mastoids, left and right canthi, and below the left eye) using the BioSemi Active Two system. EEG data were digitized at 1024 Hz. After recording, data were re-referenced offline to the average of the mastoids and filtered with a 0.1–30 Hz bandpass filter. Data were epoched −200 ms to +800 ms relative to the onset of the targets (X and Y), with the 100 ms preceding prime onset used as baseline. Artifacts were rejected in a semiautonomous manner, with a criterion of ±75 μV change over any 200 ms window within an epoch; any epoch with such an artifact was excluded from analyses.

3. Results and discussion

3.1. Primary analysis: P3 amplitude

We analyzed P3 amplitude during the time window of 300–550 ms post-stimulus because previous research has identified that the P3 typically occurs near this time window for no-go trials in similar go/no-go tasks (e.g., Hughes et al., 2009; Smith et al., 2007); further, visual inspection of the grand average waveforms confirmed that the P3 did in fact occur during this time window in the present experiment (see Fig. 1). A three (Prime: Action, Control, Inaction) × three (Electrode: Fz, Cz, Pz) fully within-subjects repeated measures analysis of variance (ANOVA) on mean P3 amplitude during no-go trials revealed a main effect of prime, $F(2,38) = 3.98$, $p = .03$, a main effect of electrode, $F(2,38) = 21.40$, $p < .001$, and no prime-by-electrode interaction, $F(4,76) = .69$, $p = .91$. Follow-up tests for the main effect of electrode revealed that P3 amplitude was significantly larger at Cz ($M = 7.27, SD = 4.91$) than both Fz ($M = 5.37, SD = 5.13$), $t(19) = 3.53$, $p = .002$ and Pz ($M = 5.87, SD = 4.15$), $t(19) = 2.43$, $p = .03$. Fz and Pz did not differ from each other, $t(19) = -.50$, $p = .62$. This centrally-maximal P3 topography is consistent with previous research on the inhibition-related P3 component, and thus serves as a form of manipulation check because it indicates that the presently observed P3 effect is similar in form to previously validated inhibition-related P3 effects (e.g., Hughes et al., 2009; Smith et al., 2007). Critically, follow-up tests for the main effect of prime revealed that inaction primes ($M = 6.74, SD = 4.59$) resulted in a significantly larger P3 amplitude than action primes ($M = 5.68, SD = 4.20$), $t(19) = 2.70$, $p = .01$, and neither prime differed from control ($M = 6.09, SD = 4.60$), $ts(19) < 1.6$, $ps > .14$. Modulation

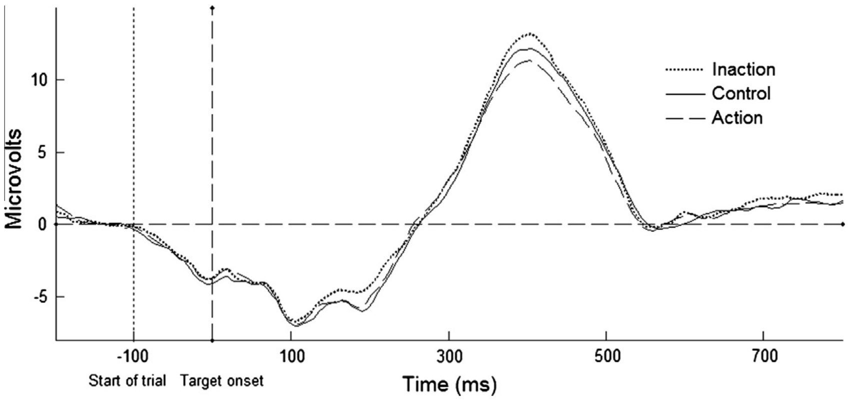

Fig. 1. Grand average waveforms at electrode Cz to correct no-go trials in Experiment 1. *Notes*: waveforms at Fz and Pz show the same pattern.

of the P3 in this context demonstrates that inhibitory control processes can be engaged unconsciously and unintentionally (a) by stimuli that have never been consciously associated with task-specific inhibitory responses and (b) in the absence of participants' intentions to modulate inhibitory control as a consequence of the prime stimuli.

3.2. Supplemental analysis: behavioral results

A one-factor (Prime: Action, Control, Inaction) repeated measures ANOVA on the proportion of correct no-go trials was not significant, $F(2,38) = .00$, $p = .99$. As discussed, behavioral inhibition and activity of inhibitory control processes are not synonymous. Specifically, behavioral inhibition can result from modulation of inhibitory control processes or from modulation of motor control processes (D'Ostilio and Garraux, 2012). As a result, behavioral inhibition is multiply determined and does not have an unambiguous relation with the activity of inhibitory control processes. Further, specific neural responses will not always translate to behavioral responses because behavior is multiply determined and can be heavily influenced by task-specific response strategies (e.g., Locke & Latham, 1990). Participants in this experiment engaged in substantially more trials ($n = 900$) than participants in our previous go/no-go experiments involving action and inaction primes ($n = 180$; Hepler et al., 2012a,b). It is possible that the extensive experience gained in this task resulted in participants developing response strategies that overrode the neural inhibition effects downstream. In support of this possibility, evidence for a practice effect emerged, such that participants' overall accuracy during the experimental blocks ($M = 84\%$, $SD = 10\%$) was substantially improved compared to their accuracy for trials of the same presentation speed completed during the initial calibration block ($M = 75\%$, $SD = 9\%$), $t(19) = 3.33$, $p = .004$ (also note that these blocks were incentivized, whereas the calibration block was not). In sum, the present results demonstrated unconscious activation of inhibitory control processes despite a lack of behavioral inhibition.

4. Experiment 2

Experiment 2 was designed with three primary objectives. First, due to the novel nature of these results, it is important to provide a replication. Second, although the action and inaction prime conditions differed from each other in Experiment 1, neither differed from control. Although this does not change the interpretation of the data for the present purposes because a difference between

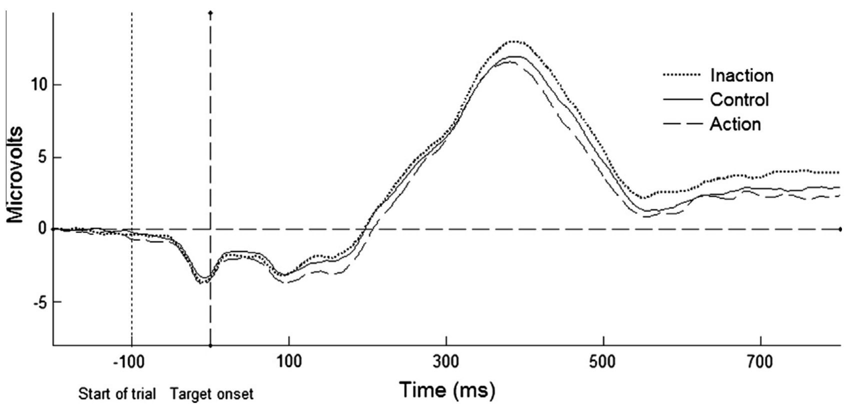

Fig. 2. Grand average waveforms at electrode Cz to correct no-go trials in Experiment 2. *Notes*: waveforms at Fz and Pz show the same pattern.

any set of conditions supports the hypothesis that inhibitory control mechanisms can be modulated unconsciously, it would nevertheless be useful to know whether this effect results from inaction primes facilitating inhibition, action primes reducing inhibition, or both. To this end, we doubled the number of trials in Experiment 2 to increase the power to detect differences between action, inaction, and control primes. Third, because the subliminal status of the primes is a critical aspect of the present hypothesis, it is important to provide thorough evidence that the primes did in fact remain subliminal. In Experiment 1, we used a funnel debriefing to assess prime awareness because this is a common and face valid assessment of prime awareness (Bargh & Chartrand, 2000). In Experiment 2, we supplemented the funnel debriefing with two tasks. The first was a prime recognition task in which participants were presented with a list of prime words and distractors and were asked to identify which words in the list were presented during the go/no-go task. The second was a prime detection task in which participants were presented with 200 trials that contained a subliminal prime followed by a choice-set of two words, one of which was the subliminal prime that was presented on that trial. Participants' task was to select the prime from the choice-set. Therefore, the prime recognition task served as a more sensitive measure of prime awareness, whereas the prime detection task assessed participants' ability to consciously perceive the subliminal primes when they were deliberately trying to perceive them. To examine whether the priming effects were primarily driven by a few participants who could have and/or did consciously perceive the subliminal primes, data were analyzed with and without participants who scored high on these two tasks.

5. Method

5.1. Participants

Twenty participants were recruited via an online ad for research participants. Participants were paid a minimum of $10 and could earn up to $40 by exceeding target performance standards provided during the task. The age of participants ranged from 18 to 27 (M = 21.0 years, SD = 2.2). Fifty percent of respondents were female. The race/ethnicity of the sample was 55% Caucasian/White, 30% Asian, 10% Black/African-American, and 5% other. All participants were native English speakers, had normal or corrected-to-normal vision, were right-handed, were not currently taking any psychoactive medications, and had refrained from caffeine and tobacco use for at least 1 h prior to the experiment.

5.2. Procedure

The procedure was identical to Experiment 1 with the following exceptions. First, participants completed four experimental go/no-go blocks rather than two, thus doubling the number of trials per participant. Second, participants were offered $5 rather than $10 for each experimental block in which they exceeded a 75% overall accuracy. Third, after the funnel debriefing, participants completed a prime recognition task followed by a prime detection task. All other aspects of the procedure remained the same.

5.3. Performance calibration

As in Experiment 1, we identified the shortest target presentation time that elicited an overall accuracy rate as close to 75% as possible based on participants' performance during the calibration block (M_{time} = 375 ms, SD_{time} = 28 ms; $M_{accuracy}$ = 75%, $SD_{accuracy}$ = 8%). This value was used as the target presentation speed in the experimental blocks to standardize task difficulty across participants.

5.4. Prime recognition task

Immediately after the funnel debriefing, participants completed a prime recognition task in which they were presented with a sheet containing 100 words in alphabetical order. All ten prime words were included in the list along with 90 distractor words that included action and inaction words not used in the study (e.g., decide, slow) as well words unrelated to action and inaction (e.g., education, perfect, ticket). Participants were informed that some but not all of the words had been subliminally presented during the task, and they were asked to read through the list and place a checkmark next to any word they believed they recognized as being presented during the go/no-go task.

5.5. Prime detection task

After the prime recognition task, participants completed a prime detection task in which they were presented with 200 trials of the following: a pre-mask of &&&&&& (16.7 ms), a subliminal prime (33.4 ms), a post-mask of &&&&&& (50.1 ms), and a choice-set (remained on screen until participants made a button-press response). The subliminal prime was always one of the 10 prime words used in the main task – each prime appeared in 20 trials, and trials were presented in randomized order. The choice-set consisted of two words that appeared on the left and right sides of the computer screen. Each choice-set included the subliminal prime that was presented on that trial and one of the other primes from the same category (e.g., for a trial in which the subliminal prime was "move", one of the two words was "move" and the second was one of the other four action primes used in the go/no-go task). Each prime appeared with each potential distractor an equal number of times, and the prime word was presented on the left and right sides of the choice-set an equal number of times. Participants were told that this task assessed their ability to detect the subliminal primes when they were deliberately looking for them, and that they should press the left-most (right-most) button on the response box if they believed the word on the left (right) was the one presented as a subliminal prime on that trial. Choice-sets remained on screen until participants made a selection. To motivate correct responding, participants were offered $10 if they responded accurately to at least 90% of trials.

6. Results and discussion

6.1. Primary analysis: P3 amplitude

A three (Prime: Action, Control, Inaction) × three (Electrode: Fz, Cz, Pz) fully within-subjects repeated measures ANOVA on mean P3 amplitude between 300 and 550 ms post-stimulus during no-go trials revealed a main effect of prime, $F(2,38) = 10.92$, $p < .001$, a main effect of electrode, $F(2,38) = 3.61$, $p = .04$, and no prime-by-electrode interaction, $F(4,76) = .92$, $p = .46$. Follow-up tests for the main effect of electrode revealed that P3 amplitude was significantly larger at Cz ($M = 8.97$, $SD = 5.06$) than both Fz ($M = 7.70, SD = 4.75$), $t(19) = 2.82$, $p = .01$ and Pz ($M = 7.12, SD = 3.98$), $t(19) = 2.53$, $p = .02$. Fz and Pz did not differ from each other, $t(19) = .67$, $p = .51$. Follow-up tests for the main effect of prime revealed that inaction primes ($M = 8.57$, $SD = 4.64$) resulted in a significantly larger P3 amplitude than both action primes ($M = 7.31$, $SD = 4.08$), $t(19) = 3.93$, $p = .001$ and control primes ($M = 7.91$, $SD = 4.17$), $t(19) = 2.97$, $p = .008$. Further, action primes resulted in a significantly smaller P3 amplitude than control primes, $t(19) = -2.34$, $p = .03$ (see Fig. 2). Therefore, these results represent a successful replication of Experiment 1. Further, the prime results indicate that the effects of general action and inaction on inhibitory control are driven both by inaction increasing inhibitory control and by action decreasing inhibitory control relative to baseline levels.

6.2. Prime recognition and detection results

6.2.1. Funnel debriefing

During a funnel debriefing no participant reported awareness of the primes, no participant reported being suspicious that the flashes were anything other than an attention-grabbing device, and no participant could identify any of the prime words when asked to guess what the prime stimuli might have been.

6.2.2. Prime recognition results

During the prime recognition task, 13 participants stated that they could not recognize any of the words as having been presented during the main task. These participants were asked to take a second look through the list and to write "I do not recognize any words" at the bottom of the paper if they still did not recognize any of the words; none of these 13 participants recognized any words on their second look. Four participants placed checkmarks next to distractor words but not prime words (number of distractors selected: 1, 4, 5, 6). Three participants placed checkmarks next to distractors and primes: The first identified one prime and twelve distractors, the second identified one prime and six distractors, and the third identified four primes and seven distractors.

We re-analyzed the data excluding the three participants who identified at least one prime word. The results were unchanged and revealed a main effect of prime, $F(2,32) = 7.89$, $p = .002$, a main effect of electrode, $F(2,32) = 3.64$, $p = .04$, and no prime-by-electrode interaction, $F(4,64) = .95$, $p = .44$. P3 amplitude was significantly larger at Cz ($M = 8.60$, $SD = 5.35$) than both Fz ($M = 7.38$, $SD = 4.90$), $t(16) = 2.36$, $p = .03$ and Pz ($M = 6.58$, $SD = 3.58$), $t(16) = 2.63$, $p = .02$. Fz and Pz did not differ from each other, $t(16) = .87$, $p = .40$. Inaction primes ($M = 8.13$, $SD = 4.71$) resulted in a significantly larger P3 amplitude than both action primes ($M = 6.93$, $SD = 4.09$), $t(16) = 3.27$, $p = .005$ and control primes ($M = 7.50$, $SD = 4.29$), $t(16) = 2.57$, $p = .02$. Action primes resulted in a smaller P3 amplitude than control primes, $t(16) = -2.03$, $p = .06$.

Further, the number of primes identified in the recognition task was uncorrelated with P3 amplitude in response to inaction primes ($r(20) = .04$, $p = .86$), control primes ($r(20) = .07$, $p = .77$), and action primes ($r(20) = .00$, $p = .99$). Therefore, the results of the prime recognition task support the conclusion that the subliminal primes did in fact remain outside of participants' awareness, and excluding participants who recognized even a single prime did not influence the experiment's results.

6.2.3. Prime detection results

Due to a programming error, responses were not recorded for trials that used "go" as the subliminal prime. This resulted in 180 analyzable trials for each participant. Accuracy rates for prime detection across the 180 trials ranged from 39% to 75%, with a mean of 52% ($SD = 11\%$), which is not significantly different from chance-level responding of 50%, $t(19) = .82$, $p = .42$.

Although these results indicate that participants could generally not identify the subliminal primes even when they were deliberately trying to do so, three participants had relatively high accuracy rates of 66%, 74%, and 75%. We re-analyzed the data excluding these three participants. The results were unchanged and revealed a main effect of prime, $F(2,32) = 7.77$, $p = .002$, a main effect of electrode, $F(2,32) = 3.53$, $p = .04$, and no prime-by-electrode interaction, $F(4,64) = 1.52$, $p = .21$. P3 amplitude was significantly larger at Cz ($M = 8.53$, $SD = 5.35$) than both Fz ($M = 7.27$, $SD = 4.94$), $t(16) = 2.41$, $p = .03$ and Pz ($M = 6.53$, $SD = 3.57$), $t(16) = 2.60$, $p = .02$. Fz and Pz did not differ from each other, $t(16) = .79$, $p = .44$. Inaction primes ($M = 7.97$, $SD = 4.69$) resulted in a significantly larger P3 amplitude than both action primes ($M = 6.84$, $SD = 4.12$), $t(16) = 3.24$, $p = .005$ and control primes ($M = 7.52, SD = 4.29$), $t(16) = 2.25$, $p = .04$. Action primes resulted in a smaller P3 amplitude than control primes, $t(16) = -2.29$, $p = .04$.

Next, we re-analyzed the data excluding any participant who had a relatively high accuracy rate in the prime detection task or who identified at least one prime word in the prime recognition task. Two participants had relatively high accuracy rates and identified at least one prime, and this analysis therefore excludes four participants (two participants identified by both tasks, one participant identified by the prime recognition task only, and one participant identified by the prime detection task only). The results were unchanged and revealed a main effect of prime,

$F(2,30) = 6.43$, $p = .005$, a main effect of electrode, $F(2,30) = 3.27$, $p = .05$, and no prime-by-electrode interaction, $F(4,60) = 1.22$, $p = .31$. P3 amplitude was significantly larger at Cz ($M = 8.56$, $SD = 5.52$) than both Fz ($M = 7.41$, $SD = 5.06$), $t(15) = 2.10$, $p = .05$ and Pz ($M = 6.52$, $SD = 3.69$), $t(15) = 2.50$, $p = .03$. Fz and Pz did not differ from each other, $t(15) = .91$, $p = .38$. Inaction primes ($M = 8.02$, $SD = 4.84$) resulted in a significantly larger P3 amplitude than both action primes ($M = 6.94$, $SD = 4.23$), $t(15) = 2.93$, $p = .01$ and control primes ($M = 7.53$, $SD = 4.43$), $t(15) = 2.30$, $p = .04$. Action primes resulted in a smaller P3 amplitude than control primes, $t(15) = -1.96$, $p = .07$.

If the ability to consciously perceive the primes was related to the influence of the primes on the P3 response, then P3 amplitude in response to inaction (action) primes should be positively (negatively) associated with accuracy rates in the prime detection task. However, accuracy rates in the prime detection task were uncorrelated with P3 amplitude in response to inaction primes ($r(20) = .19$, $p = .42$), control primes ($r(20) = .14$, $p = .54$), and action primes ($r(20) = .22$, $p = .36$). Therefore, the results of the prime detection task indicate that even when participants were deliberately trying to consciously perceive the subliminal primes, they could not do so. Further, individual differences in the ability to detect primes was unrelated to the primes' influence on the P3 response, and excluding participants with high prime detection rates did not influence the experiment's results. This further supports the conclusion that the subliminal primes in the main task did in fact remain outside of participants' awareness and that the effect of the primes on P3 occurred unconsciously.

These results suggest that the primes remained subliminal, but it is possible that participants perceived the prime detection task to be excessively difficult, thus causing them to reduce effort on the task. If so, an inability to perceive prime words may either be the result of the primes being truly subliminal or a lack of participant effort (Pratte & Rouder, 2009; cf. Finkbeiner, 2011). Several factors argue against this alternative explanation for the present results. First, the prime detection task was highly incentivized, and a full 25% of participants' payment depended on high accuracy rates in this task; therefore, participants should have had adequate motivation to succeed despite any perceptions of task difficulty. Second, if the priming effects observed during the task occurred because participants could consciously detect the prime words when they were not trying to do so and did not know that the primes existed, then it seems unreasonable to assume that participants' ability to detect the subliminal primes would be so poor that they would find the prime detection task excessively difficult and withdrawal all effort form the task. Finally, the prime detection task had a statistical power of .99 to detect an average prime detection rate of 60% or higher (i.e., participants scoring at least 10% above chance levels) and .65 to detect an average prime detection rate of 55% or higher (i.e., participants scoring at least 5% above chance levels). Therefore, unless participants perceived the task to be so difficult that they withdrew all effort from the very start of the task, the present research was sufficiently powered to detect minor deviations from chance level responding. Overall then, the results suggest that the primes remained subliminal and that the effect of the primes on P3 occurred unconsciously.

6.2.4. Supplemental analysis: behavioral results

A one-factor (Prime: Action, Control, Inaction) repeated measures ANOVA on the proportion of correct no-go trials was not significant, $F(2,38) = .87$, $p = .43$. Once again, evidence for a practice effect emerged, such that participants' overall accuracy during the experimental blocks ($M = 88\%$, $SD = 6\%$) was substantially improved compared to their accuracy during the calibration block trials of the same speed ($M = 75\%$, $SD = 8\%$), $t(19) = 6.42$, $p < .001$. Therefore, it seems plausible that participants may have developed influential response strategies over the course of the calibration block that rendered the influence of prime-induced inhibitory control activity on behavior relatively weak.

7. General discussion

This research represents a critical finding in the scientific study of consciousness because it demonstrates that inhibitory self-control mechanisms can operate unconsciously and unintentionally, without prior conscious input – that is, inhibition processes can be engaged by motivationally relevant stimuli that have never been consciously or unconsciously paired with specific, task-relevant responses. Although previous work has demonstrated similar effects on behavior (Hepler et al., 2012a,b), behavioral inhibition can occur as the result of multiple cognitive processes other than the engagement of inhibitory control mechanisms (D'Ostilio and Garraux, 2012; Locke & Latham, 1990). Thus, the present research is the first to demonstrate that inhibitory control mechanisms can be modulated completely outside of conscious control.

Interestingly, the direction of the P3 effect in response to general action and inaction primes in the present experiments is opposite to the direction observed in previous research in response to specific go and no-go primes. For example, Smith et al. (2007) and Hughes et al. (2009) both observed larger P3 amplitudes on no-go trials after priming participants with a go cue and smaller P3 amplitudes after priming participants with a no-go cue. In contrast, we observed smaller amplitudes in response to action primes and larger amplitudes in response to inaction primes. A critical difference between the present research and these previous studies is the nature of the subliminal primes. Specifically, the primes in the present research were words representing the concepts of general action and general inaction, and they had no direct relation to the target stimuli to which participants were responding (i.e., X and Y) and had no learned associations with the task-specific responses (i.e., button press or button press inhibition). In contrast, the primes in previous research were the actual target stimuli themselves and had been associated with task-specific responses. For example, in Hughes et al. (2009), participants were instructed to respond to arrows pointing to the right (>>) but not arrows pointing to the left (<<). The subliminal primes used in that study were these same arrows, such that go primes were right pointing arrows (>>) and no-go primes were left pointing arrows (<<). It is possible that the difference in P3 effect resulted from either of these differences. For example, directly priming a no-go target that will be presented shortly thereafter may make it easier to visually or conceptually process that target, and this facilitation could ease the burden on subsequent inhibition-related processes, and vice versa when directly priming the go target on a no-go trial. Similarly, priming a cue that has been associated with a task-specific response (e.g., participants have learned that << means "do not press button" and >> means "press button") could directly and immediately prime the specific motor representation associated with that cue (Kühn & Brass, 2010), thus changing the demands placed of the inhibition system when the target stimulus is eventually perceived. In contrast, when participants are primed with general action or general inaction words that are not used as target stimuli and that have not been associated with task-specific responses, these same processes could not be engaged. These are necessarily speculative explanations for the observed difference in the direction of the P3 effect, and it could be fruitful for future research to explore why these different types of primes elicit seemingly opposing effects. Regardless, the present research demonstrates that inhibitory control mechanisms can be modulated completely outside of conscious control.

These results also help clarify how motivation for general action and inaction are able to influence an incredibly diverse array of psychological outcomes, including cognitive performance (e.g., memory, problem solving), motor behaviors (e.g., exercise, food consumption), and judgment processes (e.g., intention formation, political decisions) (Albarracin & Handley, 2011; Albarracin & Hart, 2011; Albarracin, Wang, & Leeper, 2009; Albarracin et al., 2008, 2011; Gendolla & Silvestrini, 2010; Hart & Albarracin, 2012; Hepler et al., 2012a; Hepler et al., 2012b; Laran, 2010; McCulloch, Li, Hong, & Albarracín, 2012; Noguchi, Handley, & Albarracín, 2011). Specifically, because general action motivation is associated with decreased inhibitory control, it should result in an increased probability of executing a response when that response is considered, and vice versa for general inaction motivation. This is the exact behavioral pattern observed in previous research with these motivations – general action motivation increases behavioral engagement regardless of whether behaviors are positive (e.g., exercise; Hepler et al., 2012a,b) or negative (e.g., over indulgence in food; Albarracin et al., 2008, 2009), whereas general inaction motivation decreases engagement. However, the dissociation in the present research between inhibitory control processes and behavioral responses also indicates that general action and inaction motivations will not always influence behavioral responses; identifying factors that moderate the influence these motivations on behavior is an exciting direction for future research.

8. Concluding remarks

It is important to note that demonstrating that consciousness is not necessary for a process is not the same as demonstrating that consciousness cannot be involved in that process (Baumeister & Masicampo, 2010). However, to understand the role of consciousness in behavioral control, scientists must discover what processes do and do not require consciousness. Although conscious thought can influence inhibitory control under certain conditions (e.g., Gallo et al., 2009), the present research is the first demonstration that inhibitory control processes can be modulated by stimuli even if those stimuli have never been consciously associated with task-specific responses. Consequently, it appears that conscious thought is not a necessary prerequisite for complete behavioral control (action initiation *and* inhibition).

Acknowledgements

We would like to thank members of the Social Action Lab, members of the Psychology of Religion, Agency, and Morality Lab, and members of the Champaign-Urbana Social Interaction Lab for helpful feedback on earlier versions of this manuscript. We would like to specially thank Molly Ireland, Mallory Stites, and Melanie Tannenbaum for insightful discussions and comments that advanced this research.

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