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Unconscious manipulation of free choice in humans ☆

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Abstract

Previous research has shown that subliminally presented stimuli accelerate or delay responses afforded by supraliminally presented stimuli. Our experiments extend these findings by showing that unconscious stimuli even affect free choices between responses. Thus, actions that are phenomenally experienced as freely chosen are influenced without the actor becoming aware of the manipulation. However, the unconscious influence is limited to a response bias, as participants chose the primed response only in up to 60% of the trials. LRP data in free choice trials indicate that the prime was not ineffective in trials in which participants chose the non-primed response as then it delayed performance of the incongruently primed response.

Keywords: Subliminal priming; Free choice; Unconscious cognition; LRP

1. Introduction

It is a lively debated issue, whether or not stimuli we are not aware of might influence our behavior. A famous example of such an unconscious effect on behavior that has almost become part of folk psychology is the so-called "drink coke/eat popcorn"-study by James Vicary, an advertising expert, in the late 1950s (Pratkanis, 1992). He claimed to have inserted the words "drink coke" or "eat popcorn" for about 1/3 ms every 5 s into films his "participants" saw at a movie theater. Allegedly, over the course of 6 weeks a substantial increase in soft drink and popcorn consumption ensued. The "study," however, was never reported in a scientific journal and although several attempts were made, the findings could never be replicated. Some years later, Vicary himself confessed in an interview that he had made up the whole story to revive his failing advertising business (Pratkanis, 1992). Despite this, the "drink coke/eat popcorn"-study continues to haunt public opinion like other urban myths.

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2. Subliminal priming

In the scientific community a lively debate about the standards for the investigation of unconscious manipulation has evolved (cf. Holender, 1986; Reingold & Merikle, 1993; Shanks & John, 1994). Recently, the method of subliminal priming has become an often used and well-established method to investigate the influence of unconsciously seen stimuli (Damian, 2001; Dehaene et al., 1998; Dell' Acqua & Grainger, 1999; Greenwald, Draine, & Abrams, 1996; Klotz & Neumann, 1999; Kunde, Kiesel, & Hoffmann, 2003; Neumann & Klotz, 1994). In subliminal priming experiments, participants usually perform a forced choice reaction time task with two response alternatives according to a supraliminally presented target. Prior to the target another stimulus, the so-called prime, is presented subliminally. Reaction times are decreased if the prime affords the same response as the target stimulus to which participants respond (congruent prime). In contrast, reaction times are increased if the prime is incongruent, i.e., if it affords another response than the target. To ensure that prime presentation is indeed subliminal, presentation time is very short, say 29 ms, and additionally the primes are masked so that the retinal afterimage is erased. Furthermore, the visibility of the primes is tested in an additional discrimination task often performed at the end of the experiment.

So far there is compelling evidence that subliminal primes affect target-elicited response production. The present study was conducted to extend current findings by investigating whether unconscious stimuli may also affect response selection from scratch (i.e., in the absence of a response-eliciting target stimulus). There is already some evidence in the literature that let us expect that subliminal primes may influence human's free choices. First, when participants perform a forced choice task, the prime congruency effect is quite often mirrored in the error rates, that means error rates are higher for incongruent compared to congruent primes (e.g., Damian, 2001; Kunde et al., 2003). Subliminal primes may cause participants to perform the prime-associated response that is incorrect in case of incongruent primes. Further on, Klapp and Hinkley (2002, Exp. 5, see also Klapp & Haas, 2005) reported priming effects in free choice trials. However, in this study the visibility of the primes was not checked (as in the studies of Klapp & Haas, 2005) and in another experiment with similar prime presentation, participants were able to identify the prime above chance-level leading to the suspicion that priming has not been subliminal.

The most compelling evidence for a biasing impact of subliminal stimuli for freely chosen actions so far comes from a study by Schlaghecken and Eimer (2004). In this study, double arrows (e.g., ≫) were subliminally presented and masked by random line patterns. In instructed trials, a target (e.g., ≫) followed and afforded a prescribed response. In other trials, a free choice signal was presented (<>) and it was up to the participants which response to carry out.

Participants responded faster to prime-congruent targets than to prime-incongruent targets in instructed trials, and they preferred prime-congruent over prime-incongruent responses in free choice trials when the stimulus onset asynchrony (SOA) between primes and target was short (16 ms). By contrast responding to prime-*incongruent* targets was faster and prime-*incongruent* responses were preferred when the SOA was long (166 ms).

Recently, however, the functional mediation of priming effects with this particular stimulus material has become an issue of controversial debate. In particular it has been suggested that the untypical reversal of congruency effects with longer SOAs (superior performance in incongruent rather than congruent trials) might reflect interactions between prime-related and mask-related perceptual processes that are specific to the type of stimuli employed (Lleras & Enns, 2004; Verleger, Jaskowski, Aydemir, van der Lubbe, & Groen, 2004). Given the suspected special status of priming effects with this paradigm it seems warranted to clarify if the biasing impact of subliminal stimuli on 'freely' chosen responses holds for other types of stimulus material and masking procedure as well. Our first purpose was to obtain a positive bias on free choices with a rather long SOA between prime and target of 100 ms, which usually leads to negative priming effects for the stimulus material of Schlaghecken and Eimer (2004, see Schlaghecken & Eimer, 2002). This purpose was pursued in Experiment 1. To anticipate the main result, we indeed found such a positive bias effect. In Experiment 2 we confirmed the impact of subliminal primes on free choices by replicating the biasing effect in behavioral data and by demonstrating their impact on event-related brain potentials (ERP).

3. Experiment 1

Participants performed a simple choice reaction task, pressing one of two possible keys on each trial in response to one of two possible targets—the digits '4' and '6.' Unbeknownst to the participants, before each target one of these digits was presented as a subliminal prime (see Fig. 1). Apart from the "fixed" trials with a predetermined stimulus–response mapping, there were "free choice" trials. In these, a third stimulus—the digit '0'—was presented instead of the usual response signals. Participants were instructed to freely and randomly choose one of the two responses when the '0' appeared. Subliminal primes were also presented on these "free choice" trials. As described above, subliminal primes are assumed to trigger motor activation. If the current activation level of the response alternatives influences participants' choice, then participants should prefer the primed response, as this response has been pre-activated by the subliminal prime.

3.1. Method

3.1.1. Participants

Twenty volunteers (aged 17–29, mean 21.6, 14 women and 6 men) took part in an individual session of approximately 45 min. Participants took part either in fulfillment of course requirements or in exchange for pay. All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

3.1.2. Apparatus and stimuli

An IBM-compatible computer (Pentium III with 166 MHz) with a 17-in. VGA-Display was used for stimulus presentation and response sampling. Stimulus presentation was synchronized with the vertical retraces of a 70-Hz monitor, resulting in a vertical refresh rate of approximately 14.3 ms. Responses were executed with the index fingers of both hands and collected with an external keyboard with three response keys (1.7 cm width, distance 0.2 cm). The middle response key was not used.

The numbers 4 and 6 served as primes. As targets the numbers 4 and 6 indicated that a left or right response was required, the 0 served as free-choice signal. The mask consisted of 6 randomly chosen letters (all letters, except "I," were used). All characters were presented in Triplexfont in white on dark-grey background; a character extended approximately 1cm in height and 0.8 cm in width.

A trial started with the presentation of a random letter mask for 5 refresh cycles of the display, that is for 71 ms. Then a prime was presented for 2 refresh cycles, i.e., for 29 ms. After the prime another random letter mask was presented again for 71 ms. The target was presented for 200 ms immediately after the post mask. Participants could respond within a time window of 5000 ms after target onset. After response execution a fixed time interval of 2000 ms elapsed in which possible errors were indicated by a beep sound and the German word for "wrong."

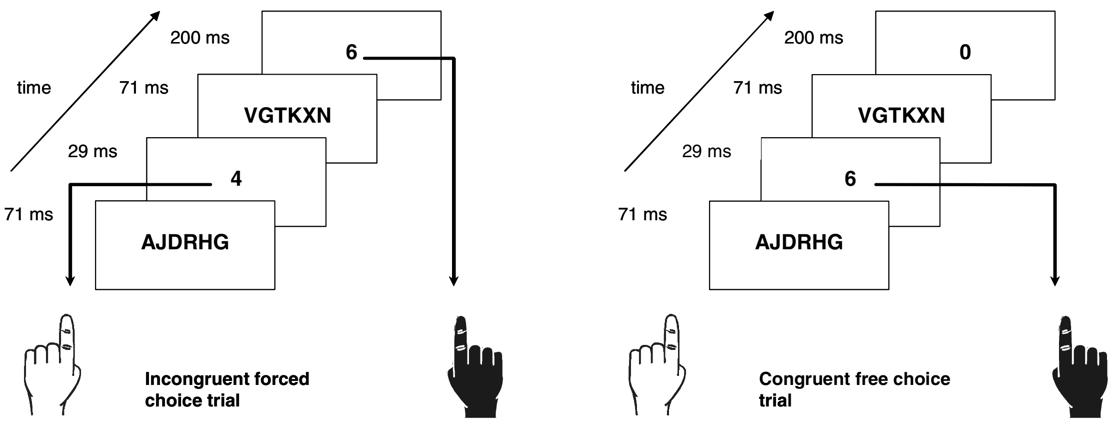

Fig. 1. Experimental Task. The left side shows an incongruent forced choice trial, in which the prime would afford a different response than the target. The right side shows a congruent free choice trial in which the selected response was congruent to the presented prime.

3.1.3. Design and procedure

First, participants were instructed to perform a left response when the digit 4 was presented, a right response when the digit 6 was presented, and to freely and randomly choose the response when the digit 0 was presented. Additionally, participants were asked to perform each response roughly equally often and not to follow a fixed scheme (like alternating between left and right or 3 times left and 3 times right) or to just press the same response button as in the previous trial. Furthermore, they were asked to decide only upon target presentation (and not before) which response to perform.

Participants performed two practice blocks of 100 trials to get familiarized with the stimulus–response mapping of the fixed response trials. In these practice blocks, 80 trials were fixed response trials in which the targets 4 or 6 were preceded equally often by incongruent (4–6 or 6–4) or congruent (4–4, 6–6) primes. Twenty trials were free choice trials in which either the digit 4 or the digit 6 preceded the target 0. Then six experimental blocks followed with 40 fixed-response-trials (each prime–target combination was presented 10 times) and 60 free choice trials with equal presentation of 4 or 6 as prime.

After the experiment, participants performed a detection task to test whether they were able to consciously perceive the primes. Participants were fully informed about the precise structure of the prime stimuli and were then presented with 128 trials identical to the experimental trials. Now half of the trials contained the primes 4 or 6 whereas the other half contained the neutral prime 0. Participants were to discriminate between neutral and non-neutral primes by pressing the 1 or the 0 key of the number keyboard. When they indicated to have seen a prime, they were additionally asked to identify it by pressing the corresponding key on the number keyboard.

3.2. Results

3.2.1. Prime visibility

Participants' discrimination performance for neutral vs. non-neutral primes was $d' = .25$ (the mean hit rate was 57.6%, false alarm rate 48.1%) and deviated from zero, $t(19) = 3.83$, $p < .001$. However, the d' measurement in the signal detection task did neither correlate with the amount of the priming effect in the fixed choice trials (effect on RTs: $r = .12$, $p = .61$, effect on errors: $r = .09$, $p = .71$) nor with the amount of the priming effect in the free choice trials ($r = .25$, $p = .29$) indicating that the priming effect is not related to the degree participants are able to detect the primes.

3.2.2. Response priming in fixed trials

Mean RTs and error rates for incongruent and congruent fixed choice trials are shown in Table 1. T tests revealed that participants responded slower and more error-prone in incongruent compared to congruent trials (RTs: $t(19) = 6.23$, $p < .001$, error rates: $t(19) = 4.61$, $p < .001$).

Table 1
RTs and error rates depending on prime–target-congruity

		Experiment 1		Experiment 2		Experiment 2	
		RTs (ms)	Percentages errors (%)	Behavior group		EEG group	
				RTs (ms)	Percentages errors (%)	RTs (ms)	Percentages errors (%)
Forced choices	Incongruent	426	12.8	407	9.2	387	10.9
	Congruent	404	7.5	389	5.9	364	5.7
	Congruity effect	22	5.4	18	3.3	23	5.2
Free choices	Incongruent	400	—	408	—	413	—
	Congruent	393	—	396	—	380	—
	Congruity effect	7[a]	—	12	—	33	—

[a] Non-significant difference.

3.2.3. Response priming in free choice trials

The impact of the primes on the freely chosen responses is shown in Fig. 2. In the free choice trials, participants selected the primed response in 54.5% of all trials, i.e., more often than the non-primed response, $t(19) = 4.53$, $p < .001$. RTs for primed and non-primed responses (shown in Table 1) differ only descriptively ($t(19) = 1.62$, $p = .12$).

3.3. Discussion

The results of Experiment 1 first replicate the standard finding of subliminal priming experiments. Participants respond slower and more error-prone in incongruent compared to congruent trials. Hence, our setting is suitable to generate a priming effect and it seems therefore apt to study the transfer of priming to freely chosen actions.

In the free choice trials, participants indeed selected the prime-related response more often. Thus, our results show that subliminally presented stimuli do have the power to bias responses in a prime-congruent direction. But the observed effect seems to be rather small. Participants chose the primed response in 54.5% of the trials. There could be different reasons for the moderate size of the effect. Either the prime impact might be consistently present but too small to affect overt responding in many cases, or the primes might strongly impact response choice but they do so only in a small proportion of trials.

To elaborate whether subliminal priming effects on mean RTs result from a general prime impact or are restricted to some trials, it might be helpful to consider the impact of the primes by means of EEG data. In forced choice settings, subliminal priming is assumed to work because the subliminally presented primes can activate their corresponding motor processes. This assumption receives support by "lateralized readiness potentials" (LRP). The LRP reflects relative differences in activation levels of left and right motor cortex. Prior to movement onset, the motor cortex contralateral to the response side becomes more active than the ipsilateral motor cortex. This is reflected in the LRP waveform by a negative-going shift occurring in the interval between stimulus onset and response onset. LRPs are thought to indicate response preparation processes (Coles, 1989). Recent studies (Dehaene et al., 1998; Eimer & Schlaghecken, 1998) have demonstrated that subliminal primes presented before the target stimulus trigger LRPs, indicating that the primes cause motor activation in the absence of conscious stimulus processing. As LRPs (like all event related potentials) are computed by averaging the obtained waveforms of many trials, an influence on LRPs is only visible if the prime triggers the response in the majority of trials. If primes triggered a response in only a small proportion of trials (let's say 8%, given the 54% prime-consistent response choices in Experiment 1) no prime-induced LRP would be observed, because averaging over all trials results in smaller ERP amplitudes due to smearing.

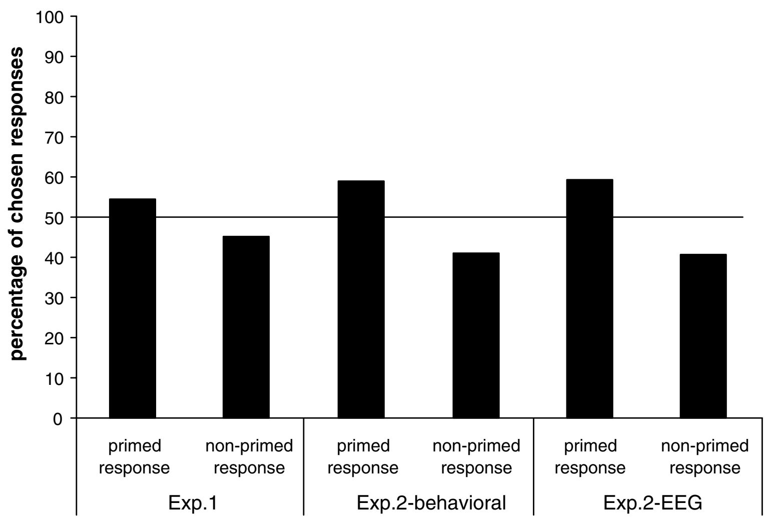

Fig. 2. Behavioral priming effect for the free choice trials.

4. Experiment 2

As prime stimuli, left- and right-pointing arrows were presented that were superimposed by metacontrast-targets (see Fig. 3). Here, masking results from the fact that the prime arrows exactly fit into the middle cutting of the target stimuli, rather than from the use of an extra pattern mask (e.g., Kunde, 2003; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003).

Participants were instructed to press the left or the right response key for left vs. right-pointing target arrows and to freely choose a response for the double-pointing target arrow. The choice of this stimulus material does also overcome a potential problem of the stimuli in Experiment 1. The free choice signal 0 was perceptually more similar to the target digit 6 than to the digit 4. Therefore the digit 0 might suggest the response assigned to the digit six in forced choice trials. Even though such an influence cannot explain the basic biasing effect, it would nevertheless work against our idea that the responses in the free-choice trials were not suggested by external stimulation. The double-pointing arrow used in Experiment 2 was perceptually as similar to a left pointing arrow as it was to a right pointing arrow and hence it did certainly not suggest any of the two response alternatives.

Furthermore, a different measure was used to test whether participants were able to see the primes. Now, exactly the same trials as in the experiment were presented and participants were asked to discriminate between the left- and the right-associated prime.

Data from two experimental groups were collected: for one group only behavioral data were collected (called the behavior group in the following) while for another group additionally EEG data were recorded (called EEG group).

4.1. Method

4.1.1. Participants

For the behavioral data recordings, 11 volunteers (aged 20–27, mean 22.1, 6 women and 5 men) took part in an individual session of approximately 60 min. 13 other volunteers (aged 19–26, mean 20.6, 7 women and 6 men) participated for the EEG data recording that lasted ca. 75 min. Participants took part either in fulfillment of course requirements or in exchange for pay. All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

4.1.2. Apparatus and stimuli

An IBM-compatible computer with a 17-in. VGA-Display was used for stimulus presentation and response sampling. Stimulus presentation was synchronized with the vertical retraces of a 70-Hz monitor, resulting in a vertical refresh rate of approximately 14.3 ms. The experiment was programmed using E-Prime (Schneider, Eschman, & Zuccolotto, 2002). Responses were executed with the index fingers of both hands. The “1” and “3” key of the number keyboard were used to collect responses.

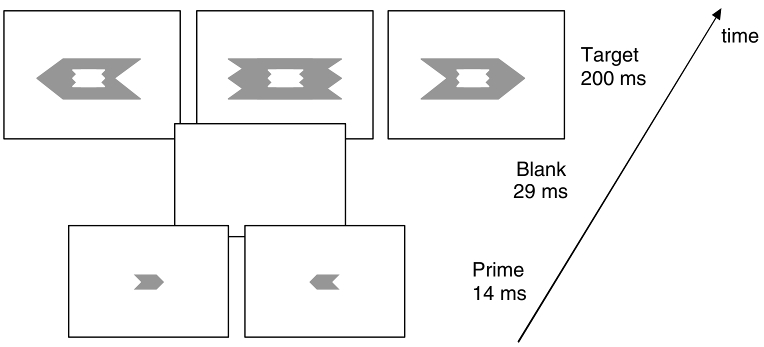

Fig. 3. Stimulus presentation in Experiment 2.

Left and right arrows, extending 1.2×0.6 cm, served as primes (see Fig. 3). Somewhat larger left and right arrows served as fixed choice targets and a double-pointing arrow as free-choice signal. The target signs extended 3.5×1.5 cm. The arrows were drawn in grey on a white background. To enhance perceptual masking, the outer contour of the prime stimuli touched the inner contour of the cutouts of the targets. Primes were presented for 1 refresh cycle of the display, i.e., 14 ms. After prime presentation a blank screen was displayed for 29 ms followed by the target that was presented for 200 ms. Participants could respond within a time window of 5000 ms after target onset. After response execution a fixed time interval of 2000 ms elapsed. In this interval possible errors were indicated by a beep sound and the German word for wrong.

4.1.3. Design and procedure

Design and procedure was similar to Experiment 1. Again, participants performed two practice blocks containing 100 trials. Then seven experimental blocks followed. Like in Experiment 1, the experimental blocks contained 40 fixed response trials and 60 free choice trials, resulting in 280 fixed choice and 420 free choice trials.

After the experiment participants were fully informed about the precise structure of the prime stimuli and were then presented with 120 trials similar to the experimental trials. The frequency of primes (left vs. right) and targets (left, right, or free choice) was equal, resulting in 20 trials for each prime–target-combination. Now participants were asked to indicate which prime was presented in each trial by pressing the "1" or "3" key of the number keyboard. Instruction stressed accuracy and did not demand fast responding.

4.1.4. EEG data recording

Electrophysiological recordings were obtained by recording EEG from 9 electrodes (Fz, C3, C3′, Cz, C4, C4′, P3, Pz, and P4) which were placed according to the enhanced International 10–20-system (Jasper, 1958) referenced to an electrode at the nose. The ground electrode was placed on the forebrain. Eye movement was monitored by two electrodes attached to the outer canthus of each eye (horizontal electrooculogram, EOG) and one electrode attached underneath the left eye (vertical EOG). Electrode resistance was kept below 5 kΩ. The sampling rate of the electroencephalogram (EEG) was 250 Hz. A bandpass filter of 0.16–70 Hz was used as well as an online notch filter.

4.1.5. EEG data analysis

The data analysis of the EEG-data was accomplished with the software Brain Vision Analyzer. EEG activity was segmented in epochs of 800 ms, starting 100 ms before the onset of the prime. Epochs containing eye movements were corrected using the regression procedure of Gratton, Coles, and Donchin (1983), which is implemented in the Brain Vision Analyzer Software. Segments with amplitudes exceeding ± 80 μV were regarded as artifact afflicted and therefore these segments were excluded from further analysis. At least 37 segments (mean 62) per conditions for the fixed trials and at least 46 segments (mean 101) per condition for the free choice trials were artifact-free.

EEG activity was averaged separately for error-free forced trials and for all free choice trials and each combination of the factors prime response congruency (congruent vs. incongruent) and response side (left vs. right). LRPs were computed separately for each participant and each experimental condition relative to a 100-ms baseline interval beginning 100 ms before prime onset. Because we were interested in premotor processes like the influence of primes on the decision between response alternatives, we chose to investigate the stimulus-locked LRP, where such premotor processes are most strongly apparent (see Mordkoff & Gianaros, 2000). LRPs were computed as the average of the C3′–C4′ difference potentials for trials with right-hand responses and the C4′–C3′ difference potentials for trials with left-hand responses (see Fig. 4; cf. Coles, 1989; Eimer, 1998). As a result of this procedure, negative deflections in the LRP waveforms indicate motor activation of the selected response side, whereas positive deflections indicate motor activation for the opposite response side.

The LRP waveforms obtained for congruent and incongruent trials were analyzed within the interval between onset of the prime signal and 700 ms after this onset. To enable a statistical comparison of the

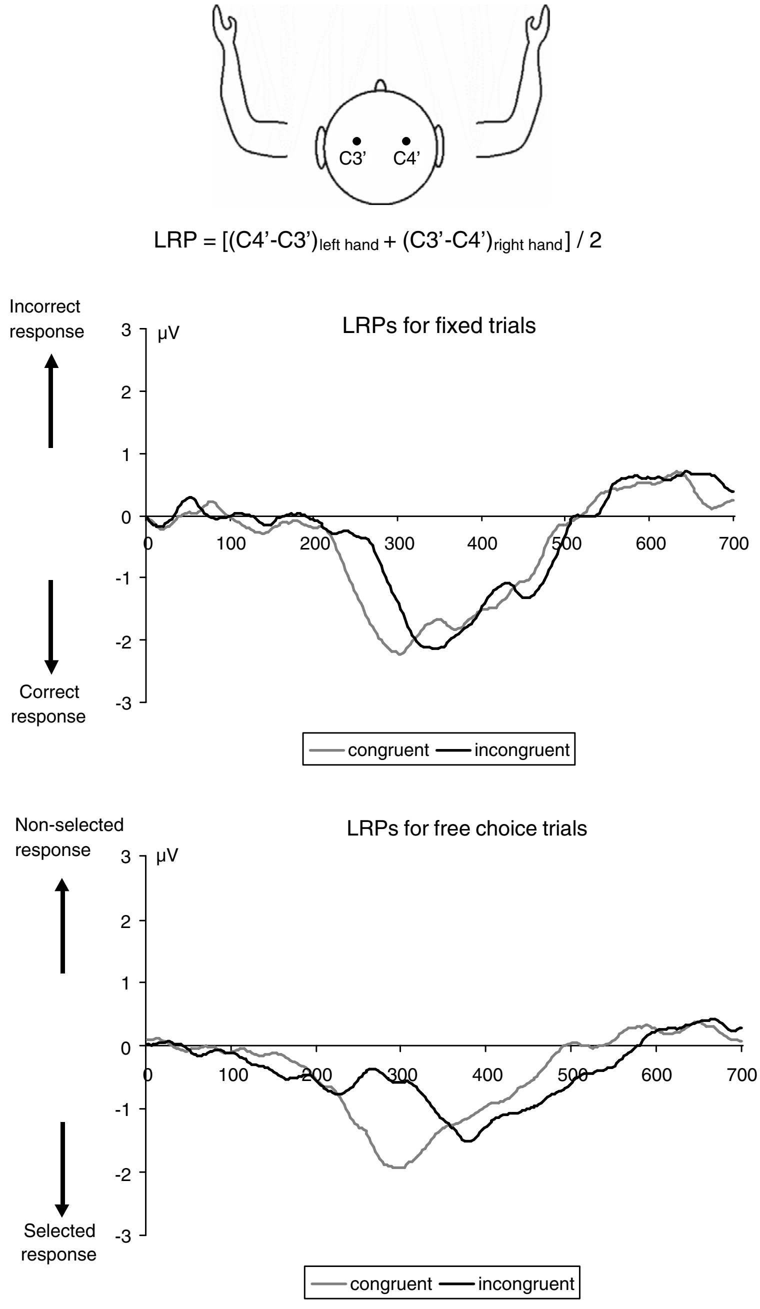

Fig. 4. LRP waveforms obtained for congruent and incongruent trials in forced and free choice trials.

LRP, the activation within consecutive 50 ms time windows is averaged. Separate ANOVAs for fixed and free choice trials were conducted on the LRP mean amplitude values (that were obtained within these 50 ms time windows) with the within-subject variables prime–response-congruency (congruent vs. incongruent) and time steps (fourteen 50 ms—steps). As recommended from Quintana and Maxwell (1994), with a Huynh–Feldt $\epsilon = 0.75$, the Huynh–Feldt correction (Huynh & Feldt, 1976) was applied, whereas with a Huynh–Feldt $\epsilon < 0.75$ the Greenhouse Geisser correction (Greenhouse & Geisser, 1954) was used.

4.2. Results

4.2.1. Prime visibility

In the behavior group the discrimination performance for left vs. right prime arrows was $d' = .22$ (the mean hit rate was 54.4%, false alarm rate 46.4%) and did not deviate from zero, $t(10) = 1.38$, $p > .19$. The d' measurement did neither correlate with the priming effect in the fixed trials (effect on RTs: $r = -.30$, $p = .38$; effect on errors: $r = .32$, $p = .33$) nor with the priming effect in the free choice trials ($r = .43$, $p = .19$).

In the EEG group the discrimination performance was $d' = .14$ (mean hit rate: 51.9%, mean false alarm rate: 46.5%) and did not deviate from zero ($t(12) = 1.60$, $p = .14$). Again the d' measurement did neither correlate with the priming effect in the fixed trials (effect on RTs: $r = -.15$, $p = .63$; effect on errors: $r = .46$, $p = .12$) nor with the priming effect in the free choice trials ($r = .44$, $p = .14$).

4.2.2. Response priming in fixed trials

Mean RTs and error rates for incongruent and congruent fixed choice trials for the behavior and the EEG group are presented in Table 1. *T* tests revealed that in both groups participants responded slower and more error-prone in incongruent compared to congruent trials (behavior group—RTs: $t(10) = 4.55$, $p < .001$, error rates: $t(10) = 2.48$, $p < .05$; EEG group—RTs: $t(12) = 3.11$, $p < .01$; error rates: $t(12) = 5.30$, $p < .001$).

4.2.3. Response priming in free choice trials

Fig. 2 shows the impact of the primes on the freely chosen responses. In free choice trials, participants of the behavior group selected the primed response in 58.9% of all trials, $t(10) = 6.16$, $p < .001$. Participants of the EEG group selected the primed response in 59.2% of all trials, $t(12) = 5.94$, $p < .001$.

RTs for the primed and non-primed responses are listed in Table 1. RTs for non-primed responses are increased compared to primed responses (behavior group: $t(10) = 2.56$, $p < .05$, EEG group: $t(12) = 4.84$, $p < .001$).

4.2.4. LRP for fixed trials

The first graph of Fig. 4 shows the LRP waveforms for error-free congruent and incongruent prime–response combinations for fixed trials. A difference between the two prime conditions is seen 230–320 ms after prime onset. Within this interval, the LRP for congruent prime–response pairs already reveals an activation of the response that is performed in this trial, whereas for incongruent prime–response pairs the negative shift starts roughly 40 ms later.

These observations are substantiated by a significant interaction between the factors prime response congruency (congruent vs. incongruent) and time steps (fourteen 50 ms—steps), $F(13, 156) = 4.74$. $p < .01$, $MSE = 2.19$. Two-tailed paired *t* tests show that the LRPs of both conditions differ in the intervals 200–300 ms after prime onset, $ts(12) > 2.27$, $p < .05$; the LRP for congruent prime–response pairs is more negative than the LRP for incongruent prime–response pairs. Another difference between congruent and incongruent conditions is observed in the last time interval ranging from 650 to 700 ms; here the LRP for incongruent primes is more positive than for congruent primes, $t,(12) = 2.20$, $p < .05$. The remaining time windows show no significant differences between congruent and incongruent prime–response pairs, $ts(12) < 1.4$, $ps > .20$.

Additional analyses were conducted to test whether the LRP in a given time window significantly differs from zero (two-tailed paired *t* test are reported). For congruent trials the LRP is marginally smaller than zero in the time interval 200–250 ms, $t(12) = 1.92$, $p < .08$, and significantly smaller than zero in the time intervals 250–500 ms, $ts(12) > 2.4$, $p < .05$. In the time intervals ranging from 550 ms to 650 ms the LRP is larger than zero, $ts(12) > 2.5$, $ps < .05$. For incongruent trials the LRP is smaller than zero in the time intervals 250–500 ms, $ts > 2.4$, $ps < .05$, and it is larger then zero in the time intervals 550–700 ms, $ts > 2.3$, $ps < .05$.

4.2.5. LRP for free choice trials

The second graph of Fig. 4 shows the LRP waveforms for congruent and incongruent prime–response combinations for free choice trials. A first slight difference between the two prime conditions is seen 100–200 ms after prime onset. Within this interval, the LRP for incongruent prime–response pairs is more negative than for congruent prime–response pairs. A second difference is seen 240–350 ms after prime onset: the LRP for congruent prime–response pairs is more negative than the LRP for incongruent prime–response pairs, i.e., it shows more activation of the response that is performed in this trial. This pattern is reversed in the time windows from 350 to 600 ms as there the LRP for incongruent prime–response pairs is more negative than the LRP for congruent prime–response pairs.

These observations are substantiated by a significant interaction between the factors prime–response-congruency (congruent vs. incongruent) and time steps (fourteen 50 ms—steps), $F(13, 156) = 7.14$. $p < .001$, $MSE = 5.39$. Two-tailed paired t tests confirm that the LRP for congruent compared to incongruent prime–response pairs is more negative in the intervals 250–350 ms, $t(12) > 2.4$, $p < .05$. In the time interval 450–500 ms the LRP for incongruent compared to congruent prime–response pairs is more negative, $t(12) = 2.31$, $p < .05$. This difference is marginally significant in the consecutive time window 500–550 ms, $t(12) = 1.95$, $p < .08$. The remaining time windows show no significant differences for congruent or incongruent prime–response pairs, $ts(12) < 1.6$, $ps > .14$.

Additional analyses were conducted to test whether the LRP in a given time window significantly differs from zero. For congruent trials the LRPs are significantly smaller than zero in the time intervals ranging from 200 to 450 ms, $ts(12) > 3.5$, $ps < .01$. For incongruent trials the LRP is smaller than zero in the time interval 100–500 ms, $ts(12) = 2.2$, $p < .05$.

4.3. Discussion

The subliminally presented prime arrows influence performance in the fixed as well as in the free choice trials. In the fixed trials participants respond faster and more accurately in congruent compared to incongruent trials, reflecting the typical priming effect. In the free choice trials participants select the prime-associated response in 59% of the trials. Thus, it is evident that subliminally presented primes influence free choices between two response alternatives.

LRPs within fixed trials reveal an earlier negative deflection in congruent compared to incongruent trials, reflecting that the whole LRP waveform is shifted to the right along the x-axis (i.e., the time) for incongruent prime–target pairs. Thus, the LRP nicely resembles that participants respond slower in incongruent compared to congruent trials. But in contrast to recent findings of Dehaene et al. (1998) or Eimer and Schlaghecken (1998), LRPs in our study do not reflect a mere prime-induced motor activation. Especially in incongruent trials, there is no positive LRP deflection that would indicate incorrect response activation by the incongruent prime. The different results are probably due to different time relations between prime and target. In our experimental setting, the prime target SOA amounted only to 43 ms, whereas in the mentioned studies it was ca. 100 ms. If the target is presented shortly after the prime, the motor activation caused by the target presumably overrides prime-induced motor activation. But for free choice trials, this is extraneous as there is no direct target-induced motor activation in these cases.

When considering the LRPs in free choice trials, there is an early negative deflection in trials with incongruent prime–response pairs. The impact of the primes on the free choices is not visible in the LRPs as otherwise there should be an early deflection according to the presented primes, i.e., a positive deflection in incongruent trials. Thus, we conclude that the prime-induced response activation occurs only in some trials and is not visible in the LRPs due to the averaging procedure. In contrast, in opposition to the presented prime, the motor response that will be performed in this trial is activated only 100 ms after prime onset. Compared to congruent trials, the negative deflection in incongruent trials is weakened in the time windows 250–350 ms. It seems that in incongruent trials participants choose which response to perform rather early, probably before the prime had induced any motor activation. Then the incongruent prime delays the motor activation of the response that has been chosen. If this holds true, incongruent prime–response pairs should not only be decelerated in average but the ratio between incongruent and congruent trials should differ depending on response speed. An additional analysis of the priming effect in free choice trials separately for RT quintiles indicated that this is indeed the case: participants chose the primed response in 65.5% of the 20% fastest responses, in 65.7% in the 20–40% quintile, in 60.8% in the 40–60% quintile, in 51.0% in the 60–80% quintile, and in 50.2% in the 80–100% quintile (for the behavior group the primed response was chosen in 60.8, 68.8, 60.0, 51.0, and 51.9% in the respective quintiles). Thus, for long RTs the same number of congruent and incongruent prime–response pairs is observed presumably as for incongruent prime–response pairs the primes delay performance of the chosen response.

Therefore, we assume that subliminal primes affect performance in free choice trials in a twofold manner. First, the prime may influence the free choice between two responses, that is, it induces that participants more often perform the primed response. Second, even in trials in which the ultimately selected response is in opposition to the prime, the prime nevertheless delays responding.

5. General discussion

Our results clearly show that subliminally presented stimuli do have the power to influence behavioral choices. Therefore, we conclude that participants' free decisions were influenced by external stimulation participants were not aware of.

However, it is remarkable that there are still numerous trials (45% in Experiment 1 and 41% in Experiment 2) in which participants selected the non-primed response. The question why subliminal priming on free choices does not work in so many trials remains open. One possible explanation could be that participants mostly select their response before prime-onset. It might be possible, that participants quite often already decide which response they will perform in the next free choice trial depending on their decision in the current free choice trial (e.g., "now I choose a left response, but in the next free choice trial I will press the right response button"). Thus, the prime has a minor chance to influence the free choice as the decision which response to make has already taken place. Nevertheless, the prime is not ineffective in these trials as it delays the execution of the already selected response.

Alternatively, one may speculate that the processes that take place when freely choosing a response are very fast in a lot of trials—too fast to allow the prime-induced motor activation to influence them. Then all the primes can do is accelerate or delay response activation of the already chosen responses in these trials.

A third alternative might be that processes to freely choose between response alternatives differ qualitatively from those processes that are needed to select a response in a fixed choice setting. There is in fact a growing body of evidence showing that stimulus-oriented and goal-oriented actions differ fundamentally in terms of the cognitive processes and of brain areas involved (Keller et al., in press; Waszak et al., 2005). Along this line of research one can speculate that endogenous response choice processes are less easily influenced by subliminal primes than exogenously induced response selection processes. Possibly, stimulus processing (and hence prime processing as well) is turned off relatively abruptly as soon as it becomes apparent that external stimuli provide no cue as to carry out one action or the other. Further experiments are needed to address this idea in more detail.

To conclude, we have shown that subliminal primes influence free choices between two response alternatives in two Experiments using different stimulus material and masking procedures. Thus, the effect of subliminal primes on free choices seems to be robust and replicable. It remains an open question whether the nature of this prime induced impact on response selection in free choice trials differs from the impact primes have in forced choice trials.

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