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Priming effects under correct change detection and change blindness

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ABSTRACT

In three experiments, we investigated the priming effects induced by an image change on a successive animate/inanimate decision task. We studied both perceptual (Experiments 1 and 2) and conceptual (Experiment 3) priming effects, under correct change detection and change blindness (CB). Under correct change detection, we found larger positive priming effects on congruent trials for probes representing animate entities than for probes representing artifactual objects. Under CB, we found performance impairment relative to a "no-change" baseline condition. This inhibition effect induced by CB was modulated by the semantic congruency between the changed item and the probe in the case of probe images, but not for probe words. We discuss our results in the context of the literature on the negative priming effect.

1. Introduction

Observers often fail to notice substantial changes in a visual scene, when such changes coincide with other events that disrupts the motion signal normally associated with the changes (Simons & Rensink, 2005).[1] In the present investigation, we will consider the priming effects that are induced by detected changes and by undetected changes.

1.1. Change blindness

Change blindness (CB) has been studied with two different approaches: the "one-shot" task and the "flicker task" (for a review, see Jensen, Yao, Street, & Simons, 2011). In the "one-shot" task, participants are shown an original display, a blank, and then the changed display (Simons, 1996). In the "flicker task", an original and changed image alternate back and forth, separated by a brief blank screen (Rensink, O'Regan, & Clark, 1997).

The extent to which observers show CB depends on several factors. The likelihood of CB is higher if the pre-change items are represented in memory with low fidelity (Hollingworth & Henderson, 2002), for objects that are not of central interest within a scene (Rensink et al., 1997), for items that had not been foveated (Henderson & Hollingworth, 1999), under conditions of high perceptual load (Lavie, 2006), and when fewer resources are available for encoding (McCarley et al., 2004). CB can occur with artificial stimuli and in the real world (Simons & Levin, 1998).

Several mechanisms have been proposed to explain why changes to images can go undetected. CB can reflect a representation failure (the post-change stimulus could disrupt access to the pre-change stimulus), a comparison failure (the pre-change representation might not have been encoded into memory, or the comparison between the pre-change and the post-change stimulus is not possible), or both (*e.g.*, Hollingworth, 2003; Rensink et al., 1997; Noë, Pessoa, & Thompson, 2000).

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[1] Failures of awareness have also been studied with other paradigms, such as the attentional blink (Raymond, Shapiro, & Arnell, 1992), repetition blindness (Kanwisher, 1987), and object masking (Boynton & Kandel, 1957).

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1.2. Priming under change blindness

An important research question is to determine what information, if any, is preserved under CB. The failure to consciously perceive a change, in fact, does not necessarily imply the absence of processing and encoding of the changes to an object or scene. Information from a stimulus change (hereafter called the "prime") might persist, even though it is not consciously available, and it might affect the processing of the subsequent stimulus (hereafter the "probe"). In order to address this question, researchers have asked whether an unattended scene or stimulus change is capable of priming.

Under correct change detection focused attention is given to the part of the visual scene being changed; the change is encoded in memory, and the pre-change information is compared to the post-change information. In these circumstances, *positive compatibility effects* (PCE) are observed, that is, response facilitation in compatible trials (*i.e.*, prime-probe pairs requiring the same response) and response hindering in incompatible trials (*i.e.*, prime-probe pairs requiring different responses) (*e.g.*, Silverman & Mack, 2006; Yeh & Yang, 2009).

But does stimulus information persist under CB? And is such information capable of priming? And, if priming is observed, do these priming effects involve access to abstract semantic representations, or do they occur at a more peripheral structural/perceptual processing level? The evidence for answering these questions is not conclusive. In the present research, we will examine these questions by considering the possible effects of an unperceived change on an immediately successive semantic categorization task.

1.3. Three hypotheses

Priming effects under CB are well documented when an image change is followed by a perceptual task (Fernandez-Duque & Thornton, 2000; Fernandez-Duque & Thornton, 2003; Laloyaux, Devue, Doyena, David, & Cleeremans, 2008; Laloyaux, Destrebecqz, & Cleeremans, 2006; Thornton & Fernandez-Duque, 2000). What has been less studied is whether CB can elicit priming effects on performance in a semantic task performed immediately after the image change (*e.g.*, word-picture matching, picture categorization, word categorization).[2] Three hypotheses can be derived from the literature.

1. The more extreme hypothesis is that, under CB, semantic priming does not occur at all: "in the face of change blindness, the change itself is not represented and can exert no influence on behavior" (Mitroff, Simons, & Franconeri, 2002, p. 814).
2. A second hypothesis is that non-perceived changes can still produce positive compatibility effects (PCE) on an immediately successive semantic response (*i.e.*, performance benefits on compatible prime-probe pairs and performance costs on incompatible prime-probe pairs).
3. A third hypothesis is that non-perceived changes produce negative compatibility effects (NCE) on an immediately successive semantic response (*i.e.*, performance costs on compatible prime-probe pairs).

Even though it is counter-intuitive, the third hypothesis is supported by several lines of evidence. Evidence of negative priming for ignored objects comes from the study of briefly-presented natural scenes. For example, in an experiment by VanRullen and Koch (2003) observers were asked to recall the objects within a visual scene that was shown for 250 ms and then masked. In a word-picture go/no-go matching task performed immediately after, VanRullen and Koch found that the objects that had been previously explicitly recognized elicited a positive priming effect, whereas the "ignored" objects (those that did not enter visual awareness) elicited a reliable negative priming effect (see also Gordon, 2006).

Support for the third hypothesis also comes from the masked priming literature, where it has been shown that the sign of the priming effect depends on the visibility of the prime (Eimer & Schlaghecken, 2003; Sumner, 2007; Sumner, Tsai, Yu, & Nachev, 2006). For example, Frings and Wentura (2005) asked participants to perform a naming task for a probe word preceded by a masked prime. They found a PCE in participants who were aware of the prime and a NCE in participants who were unaware of the prime.

A neural habituation priming model has been proposed to explain the change from positive to negative priming in masked priming experiments (Huber, 2008; Huber, Shiffrin, Quach, & Lyle, 2002; Huber, Shiffrin, Lyle, & Quach, 2002; Rieth & Huber, 2010; Weidemann, Huber, & Shiffrin, 2005). In their ROUSE model, Huber and collaborators argued that prime and probe stimuli give rise to noisy representations that are subject to source confusion. In order to recognize the probe, participants must "discount" from the decision about the probe the feature activity that is associated with the prime. The positive priming effects arise from the fact that the prime-related activity is not completely removed from decision about the probe (facilitation). But, under some circumstances, the prime-related activity is overestimated and the discounting mechanism introduces a bias against the features in the prime, producing a performance cost for probe stimuli that have the same features as the prime stimuli. This over-discounting of the activation of the features of the prime thus results in a

[2] There is a long-standing debate about the amount of processing of sensory input that occurs before conscious perception (*e.g.*, Hannula, Simons, & Cohen, 2005). Early-selection models postulate that semantic content is available only after attention selection and, therefore, it is necessarily associated with awareness (*e.g.*, Broadbent, 1987). According to such models, therefore, the processing of unattended information may only be limited to the earliest stages of perceptual analysis.

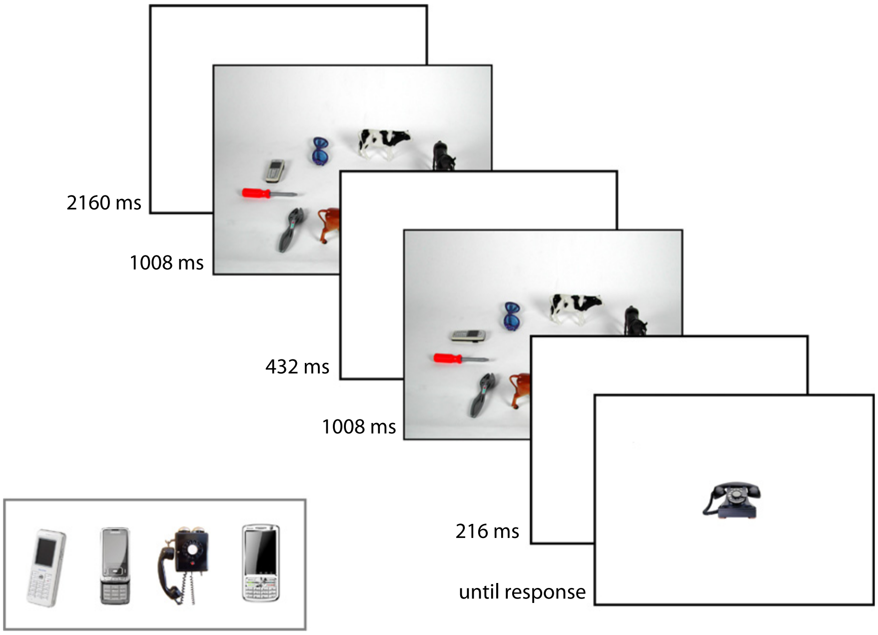

Fig. 1. Sequence of events within a trial. Two visual displays (each consisting of a circular arrangement of eight objects) were presented for 1008 ms each, separated by a 432-ms empty screen. The presentation of the two displays was followed by the presentation of a probe image (Experiments 1 and 2) or a probe word (Experiment 3). The probe image used in Experiment 1 was physically identical to one of the unchanged objects, or to the pre-change or post-change object. The probe image used in Experiment 2 was similar – not physically identical – to one of the eight items of the changing scene (an example is shown in the Figure). The inset in the bottom left of the figure shows other alternative four images that were used in different trials of Experiment 2 for the probe image of a telephone. In Experiment 3, the probe was a word.

NCE (see also Carr & Dagenbach, 1990).[3] This model has been developed to explain priming effects obtained using clearly visible primes, but similar mechanisms could also act to produce a change from positive to negative priming under CB (Barbot & Kouider, 2012).

1.4. Aims of the present study

In the present investigation, we studied the priming effects that were elicited by the changed item under correct change detection and under detection failure. In Experiment 1, immediately after the presentation of a two-image sequence which contained an image change in a proportion of trials, participants were asked to decide if the item shown in an individually presented picture was an animate entity or an artifactual object. After performing this picture categorization task (PCT) under time pressure (Fig. 1), participants were asked to rate their confidence about whether they had seen the change. In Experiment 2, the structure of each trial was identical, except that the probe item was perceptually similar (but not identical) to one of the items presented in the two-image sequence. In Experiment 3, the animate–inanimate decision task concerned an individually presented word (not a picture).

In change-detection trials, we expected PCEs. The open question concerns the direction of the priming effects under CB.

2. General methods

2.1. Apparatus

Stimuli were presented and responses collected using a custom script written with the PsychToolbox extension (Brainard, 1997; Pelli, 1997) of MATLAB (Mathworks, Massachusetts) on a 486-based PC-compatible computer connected to a 17-in. video monitor operating at 72 Hz.

2.2. Stimuli

The stimulus sequence is shown in Fig. 1. On each trial, three images were presented. All displays measured 768 × 1024 pixel and were centered in the middle of the monitor without a visible border. The typical viewing distance was 60 cm. After

[3] An advantage of this model is that it is based on neurophysiological mechanisms, such as synaptic depression, that are well-understood (Huber & O'Reilly, 2003). While producing a performance cost under certain circumstances, habituation processes are generally beneficial for our perception, serving to reduce source confusion from recent stimulations (Huber, 2008; in a different domain, see also Caudek, Domini, & Di Luca, 2002; Domini, Caudek, & Skirko, 2003; Domini, Vuong, & Caudek, 2002; Treue, Andersen, Ando, & Hildreth, 1995).

a fixation cross on a white background (2160 ms), a first display was presented for 1008 ms and consisted of a circular arrangement of eight (four animate and four inanimate) real objects (*e.g.*, mug) and toy models (*e.g.*, motorcycle, tiger) photographed from an angle of 45^0.

After a blank of 432 ms, a second display appeared for 1008 ms. On "change-trials", one of the eight items in the second image changed its orientation (Experiments 1 and 2: a 90° rotation about a vertical axis; Experiment 3: either a 90° rotation about a vertical axis or a 180° flip). Because the type of change did not alter the priming effects, it was not further analyzed. In each pair of images, the spatial arrangement of the items was randomized. Half of the time the changed item was an animate entity and half of the time it was an artifactual object. The change could take place at any item location with equal probability. On the remaining ("no-change") trials, the first and the second displays were identical. Each pair of images was shown only once to each participant.

After a blank of 216 ms following the second display, a probe image was presented on the screen until the participant made his or her response. The probe image was the picture of one of the eight items that had been shown in the previous two images (Experiment 1), or a picture that was perceptually similar (but not identical) to one of the items presented in the previous two images (Experiment 2), or a word describing one of the eight items (Experiment 3).

In all experiments, the probe (image or word) was located in the center of the screen – never in spatial correspondence to the previously shown changed item. This was done in order to control for the location-based negative priming effect. Several studies, in fact, found that participants are slower to respond to a target when the target is located in the same spatial position, where a previously ignored stimulus had been located (*e.g.*, Tipper, Brehaut, & Driver, 1990).

2.3. Procedure

At the beginning of each session, the general structure of each trial was explained to the participants and, after a practice phase (20 trials), participants completed the experimental session divided into "blocks" of trials, with a short break between blocks. The presentation order of trials was randomized. Each trial was initiated by the participants by pressing the spacebar. Participants were instructed to fixate the centre of the screen throughout the experiment, but to stay alert for a possible change of orientation of one of the eight items.

In all experiments, participants performed a dual-task. In Experiments 1 and 2, participants performed an animate-inanimate Picture Categorization Task (PCT) followed by a Change Detection Task (CDT). In the PCT, participants were requested to make a speeded decision by pressing one of two keys on the keyboard. In the CDT, which was performed immediately after the PCT, participants were asked to report whether or not they had detected a change from the first to the second display. The CDT was performed with no time pressure. In Experiment 3, participants performed an animate-inanimate Word Categorization Task (WCT) followed by a CDT. No feedback was provided on either judgment.

In the CDT of Experiment 1, we asked participants to rate their confidence about whether they had seen the change on a 7-point scale (from 1 = "I am absolutely certain that no change has happened" to 7 = "I am absolutely certain that a change has happened"). To give participants a sense of how to use the scale, the experimenter explained that a score of seven indicated that they had actually seen the change and a score of one indicated that they were "completely confident" that no change has occurred. In Experiments 2 and 3, participants were only asked to produce a binary (yes/no) detection response (*e.g.*, Fernandez-Duque & Thornton, 2000, 2003).

2.4. Data analysis

2.4.1. Picture categorization task

Because the distribution of the reaction times (RTs) was skewed, a reciprocal transformation (*i.e.*, $-1/\mathrm{RT}$) was performed to approximate normality. A visual inspection of the quantile–quantile plot of the transformed RTs for each participant showed no clear departure from normality. We multiplied reciprocal scores by -1 to maintain the direction of effects compatible for untransformed and reciprocal RTs (this transformation converts speed into "rate of slowing").

Choice of items in the pictures was randomized, as was the choice of items for the probes. Because we used only a limited amount of items, randomization cannot exclude that some items had more influence than others. Some items might be more salient than others and some more easy to classify than others. We dealt with this problem by analyzing the transformed RTs with mixed-effects multiple regression models with participants and items (probe pictures or words) as crossed random effects.[4] In the following, we discuss only those fixed effects that reached significance at the 5%-level in a backwards stepwise

[4] In linear regression, a dependent variable (y) is described by means of a weighted sum of all predictors in the model plus normally distributed noise. For a single predictor (x), we have: $y_i = \alpha + \beta x_i + \varepsilon_i, \varepsilon \sim \mathcal{N}(0, \sigma^2_\varepsilon)$. One shortcoming of the ordinary linear model is that it is not robust to violations of the conditional independence assumption that arise whenever observations fall into groups (*e.g.*, multiple measures of the same participant in a repeated-measure experiment). Linear mixed models are an extension to linear regression and can be used to analyze grouped data. Multilevel modeling accounts for the grouping structure of the data by allowing the regression coefficients to vary by group (indexed by j). For example, the random-slope, random-intercept model can be written as $y_i = \alpha_{j[i]} + \beta_{j[i]} x_i + \varepsilon_i$, for $j = \ldots, J$, where $\alpha_j \sim \mathcal{N}(\mu_\alpha, \sigma^2_\alpha)$ and $\beta_j \sim \mathcal{N}(\mu_\beta, \sigma^2_\beta)$ are random variables with means μ_α, μ_β and standard deviations σ_α, σ_β estimated from the data (Gelman & Hill, 2007). The grouped structure is accounted for by adjusting the overall intercept and slope (*fixed effects*) of the model to reflect the group-specific intercepts and slopes (*random effects*). In a typical priming experiment, participants are not the only random effect, because there are multiple observations for the same item (which are inherently related and hence not independent). An important advantage of linear mixed models is the possibility to specify crossed (or partially crossed) random effects for participants and items. In this respect, mixed models can replace the by-subjects (F1) and by-items (F2) ANOVAs (Baayen, Davidson, & Bates, 2008; Clark, 1973; Forster & Dickinson, 1976; Raaijmakers, Schrijnemakers, & Gremmen, 1999). For an introduction to linear mixed models see, for instance, Baayen (2008), Gelman and Hill (2007), or Pinheiro and Bates (2000).

model selection procedure. We removed outliers from the data of each experiment (*i.e.*, points that fell outside the range of −2.5 to 2.5 units of SD of the residual error of the model). Once outliers were removed, the models were refitted.

Following Baayen and Milin (2010), we included three control predictors in order to remove autocorrelational structure from the residual errors: the trial number (Trial) in a subject's experimental block (rescaled to Z-scores to bring its magnitude in line with that of other predictors), the Block, and the response latency at the preceding trial (Previous RT).

The variable Condition was represented in the mixed-effect models with dummy coded contrasts. In Experiment 1, the contrasts were C_1, C_2, C_3, and C_4. In the dummy variable coding, the no-change trials represented the baseline condition (coded as 0) against which the other levels of Condition (*e.g.*, ID1, ID2, SC, and DC) were compared (coded as 1). In Experiment 2, we compared the ID and DC conditions to the baseline with the contrasts C_1 and C_2. In Experiment 3, we compared the ID, SC, and DC conditions to the baseline with three contrasts (C_1, C_2, and C_3, respectively). Throughout the paper, the parameter β_i indicates the fixed-effect estimate associated to the contrast C_i, which compares an experimental condition to the baseline (or, alternatively, two experimental conditions). The parameter estimates of the fixed effects can be interpreted as the amount of priming after controlling for (partialing out) the effects of the other variables in the model. In the following, we will report the partial effects on the transformed $-1/\mathrm{RT}$ scale and we will back-transform these partial effects on the original RT scale.

We evaluated significance by computing the deviance statistic (minus 2 times the log-likelihood; change in deviance is distributed as chi-square, with degrees of freedom equal to the number of parameters deleted from the model) and by the size of the fixed effects coefficients. For a large dataset (as in the present case), an absolute *t*-value exceeding 2 is an excellent indicator of significance (see Baayen et al., 2008).[5]

2.4.2. Word categorization task

We analyzed the impact of the image change on the word categorization latency with a linear mixed-effect model with participant and word as crossed random-effect factors. We added the lexical characteristics associated with each word (number of letters, number of syllables, and frequency) to the control predictors (Trial, Block, PreviousRT) used in Experiments 1 and 2. The frequency measure was log-transformed and scaled (centered and divided by the standard deviation).

2.4.3. Change detection task

A cumulative link mixed model with participants and items as random effects was used to model the rating scale data of the CDT (Experiment 1). When employing a probit link function, this is equivalent to fitting the data with the equal-variance Gaussian signal detection model (see Devinck & Knoblauch, 2012). We performed the fits to the rating data using the `clmm` function in the package `ordinal` in the software R (Christensen, 2012; R Development Core Team, 2012). In Experiments 2 and 3, we computed the discriminability measure d' from the binary detection responses using a generalized linear mixed-effects model with a probit link function (Wright & London, 2009; Wright, Horry, & Skagerberg, 2009).

3. Experiment 1

Picture probes were used to measure the priming effects produced by an immediately previous image change. The picture probes were selected from the pre-change or post-change displays. Five different type of probes were used: ID1 = image of a pre-change item; ID2 = image of a post-change item; SC = image of an unchanged item in the same category as the changed item (*e.g.*, horse-lion); DC = image of an unchanged item in a different category as the changed item (*e.g.*, horse-scissors).

3.1. Participants

A total of 35 undergraduate students (22 females and 13 males) aged from 18 to 26 years from the University of Trento participated in the experiment. All participants were naïve to the purpose of the study and had normal or corrected-to-normal vision.

3.2. Procedure

Each participant performed 640 trials divided in five blocks of 128 trials each. 160 (25%) were no-change trials. In 240 trials the changed item was an animate entity and in 240 trials the changed item was an artifactual object. The probe was the picture of one of the items that had been shown in the previous two images.

The probe depicted a pre-change item (ID1), a post-change item (ID2), or a non-changing item (SC, DC). There were 120 trials for each ID1, ID2, SC, and DC condition; in 60 trials the changed item was an animate entity and in 60 trials the changed item was an artifactual object. The animate items were: crab (56), pig (44), turtle (40), bull (36), cow (24), tiger (20), horse (12), and lion (8). The inanimate items were: screwdriver (64), pincers (56), googles (52), cellular phone (48), and scissors

[5] The degrees of freedom for *t*-values are not known exactly for a linear mixed-effects model. Given the large number of observations in each of our experiments, however, the *t* distribution converges, for all practical purposes, to the standard normal distribution. The 2-SE criterion, therefore, is close to the conventional two-tailed 5% level of significance (*e.g.*, Kliegl, Masson, & Richter, 2010). In alternative, *p*-values can be estimated by the Monte Carlo Markov chain (MCMC) method, or with the *t*-test for fixed effects using the difference between the number of observations and the number of fixed effects as the upper bound for the degrees of freedom (for a discussion, see Baayen, 2008; Baayen et al., 2008; Pinheiro & Bates, 2000).

(20). The numbers in parenthesis indicate, for each participant, the number of "change" trials for that item throughout the experiment.

In 80 no-change trials, the probe was an animate entity and, in the remaining 80 trials, the probe was an inanimate object. In no-change trials, each item was used as the probe with the following frequencies: 23 (screwdriver), 15 (googles), 15 (cellular phone), 15 (scissors), 15 (turtle), 14 (cow), 13 (pig), 12 (pincers), 10 (crab), 9 (tiger), 9 (lion), 7 (bull), and 3 (horse).

3.3. Results

Trials with incorrect responses in the PCT were discarded from statistical analysis (2%).

3.3.1. Response time latencies in the PCT

We expected qualitatively different priming effects in the PCT depending on the awareness of change.

3.3.1.1. Minimum awareness of change. Fig. 2 displays the mean untransformed RTs and -1/RTs as a function of probe Category (animate, inanimate) and Condition (ID1, ID2, SC, DC) in the "change" trials in which participants responded "I am absolutely certain that no change has happened" (24% of change trials). The baseline (BA) corresponds to the no-change trials in which participants responded "I am absolutely certain that no change has happened."

There is no interaction between Category and Condition, $\chi^2_4 = 3.17,\ p = .53$, nor an effect of Category, $\chi^2_1 = 0.01$.[6] There are statistically significant inhibition effects in the SC (β_3 = 0.04, 28 ms, t = 2.94) and DC (β_4 = 0.05, 29 ms, t = 3.07) conditions relative to the baseline (BA) condition. The average response times in the ID1 (t = 0.78) and ID2 (t = 0.59) conditions do not differ significantly from baseline. On average, response times are faster in the congruent conditions (ID1, ID2, SC) than in the incongruent condition (DC), β = – 0.030, 11 ms, t = 2.31. Mean response times in the change trials (ID1, ID2, SC, DC) are slower than those for the no-change trials (BA), β = 0.029, 35 ms, t = 3.26. Standard and transformed RTs afford the same interpretation.

3.3.1.2. Maximum awareness of change. Now let us examine the change trials in which participants responded "I am absolutely certain that a change has happened.". Performance in the ID1, ID2, SC, and DC conditions was compared with baseline (no-change) trials in which participants responded "I am absolutely certain that no change has happened.". The pattern of means reveals both facilitation and inhibition effects (Fig. 3). Standard and transformed RTs afford the same interpretation.

The significant Condition × Category interaction ($\chi^2_4 = 135,\ p = .001$) indicates the presence of larger priming effects for animate probes than for inanimate probes. For animate probes, there are significant facilitation effects in the ID1 (β_1 = – 0.38, 176 ms, t = 4.84), ID2 (β_2 = – 0.44, 176 ms, t = 6.01), and SC (β_3 = – 0.18, 91 ms, t = 3.44) conditions relative to the baseline (no-change) condition. There is also a significant inhibition effect in the DC condition (β_4 = 0.175, 120 ms, t = 5.26) relative to baseline. On average, response times are faster in the ID2 condition than in the ID1 condition (β = – 0.06, 20 ms, t = 2.13). Congruent prime-probe pairings (ID1, ID2, SC) resulted in significantly faster response times than incongruent prime-probe pairings (DC), β_1 = – 0.38, 176 ms, t = 7.92. For inanimate probes, there are significant facilitation effects in the ID1 (β_1 = – 0.22, 117 ms, t = 2.78) and ID2 (β_2 = – 0.19, 104 ms, t = 2.63) conditions relative to baseline. Also in this case, congruent prime-probe pairings resulted in significantly faster response times than incongruent prime-probe pairings, β_1 = – 0.18, 93 ms, t = 3.35.

3.3.1.3. Priming effects with intermediate levels of awareness of change. Table 1 shows the mean response latencies as a function of Category, level of Awareness, and Condition. For the trials in which participants responded "2", "3", … or "6" when rating their confidence as to whether they had seen the change, we computed the priming effects for each level of awareness (*i.e.*, the difference scores between the mean latencies in no-change trials and the response latencies in change trials). These priming effects were then analyzed as a function of Congruency [congruent (ID1, ID2, SC) versus incongruent (DC) prime-probe pairing], Awareness of the change (levels 2, …, 6), and probe Category (animate, inanimate). Neither the three-way interaction nor any of the two-way interactions are statistically significant, $\chi^2_{13} = 21.65,\ p = .061$. There is no significant effect of Category, $\chi^2_1 = 1.07,\ p = .302$. There is a significant effect of Congruency: Average response times tend to be longer (29 ms) for incongruent (DC) than for congruent (ID1, ID2, SC) trials, $\chi^2_1 = 13.91,\ p = .001$. As shown in Fig. 4, the statistically significant effect of Awareness indicates that priming tends to be positive if participants rate their awareness of change as "6" and negative otherwise, $\chi^2_4 = 11.59,\ p = .021$.

[6] To gain an insight to the importance of accounting for the effects of items, we fitted a simpler (random intercept, random slope) model to the present data with Condition as the only fixed effect and with participants and items as crossed random effects. A likelihood ratio test can be performed to evaluate whether including a random effect parameter is justified (Baayen et al., 2008). This likelihood ratio test can be done by fitting a model with and without one variance component and by comparing the quality of the fits. The likelihood ratio test statistic is asymptotically distributed as χ^2 with degrees of freedom equal to the number of parameters deleted from the model. In the present case, deleting the parameter for items random effect significantly decreased the fit of the model, $\chi^2_1 = 22.1,\ p = .001$. χ^2 has 1° of freedom because the random effect for items is represented in the model by a single random variable defined as a normal variate with zero mean. A further information of the relative importance of the estimated parameters is given by the variance component parameters of the random effects. These variance components comprise the estimated standard deviations (*i.e.*, square roots of variance estimates) of the items' and participants' means and of participants-related effects of Condition. The estimate variance components are: $\sigma_{\text{subj int}} = 0.350,\ \sigma_{\text{item}} = 0.035,\ \sigma_{\text{subj:}C_1} = 0.053,\ \sigma_{\text{subj:}C_2} = 0.039,\ \sigma_{\text{subj:}C_3} = 0.064,\ \sigma_{\text{subj:}C_4} = 0.044$, and σ_{residual} = 0.406. This model is mentioned for exemplification purposes only. The mixed-effects models that had been used for the statistical tests reported in the paper are more complex and their motivation is described in Section 2.4.

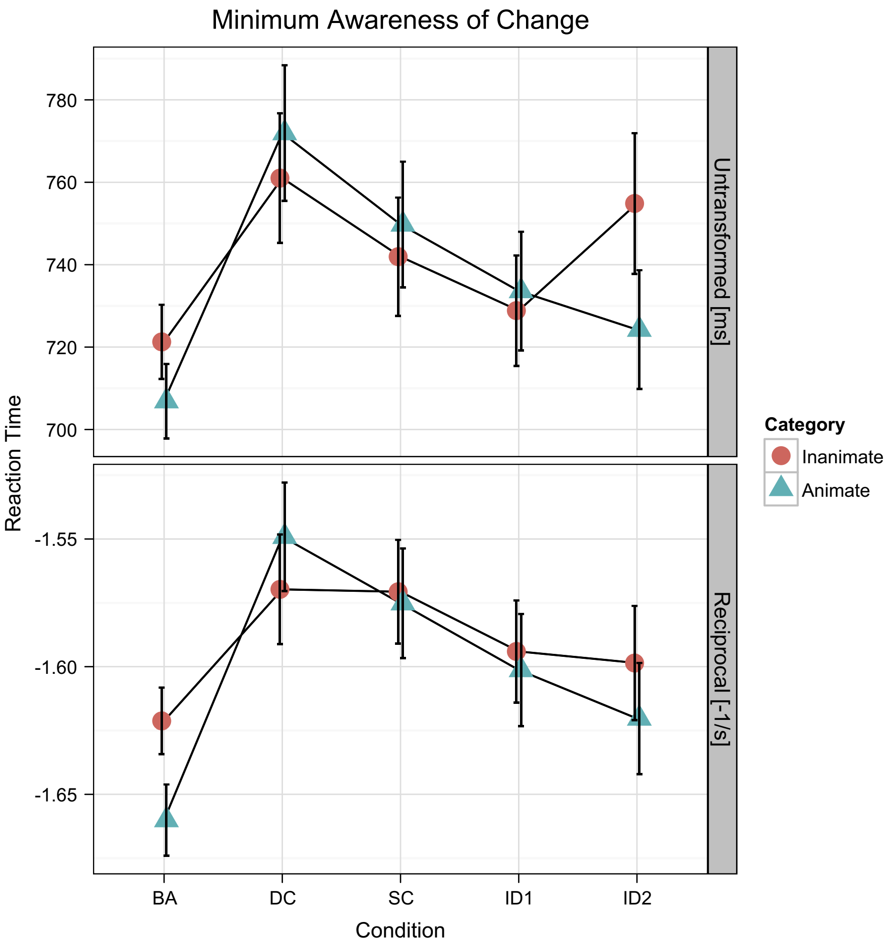

Fig. 2. Experiment 1. Condition [Baseline (BA), Different Category (DC), Same Category (SC), Identity 1 (ID1), and Identity 2 (ID2)] by Probe Category (inanimate, animate) interaction for untransformed RT (top row) and reciprocal RT (*i.e.*, −1/RT, bottom row). The figure depicts the mean response time latencies for the change trials in which participants responded "I am absolutely certain that no change has happened.". The baseline corresponds to the no-change trials in which participants responded "I am absolutely certain that no change has happened." Error bars represent standard errors for cell means.

3.3.2. Change detection

By assigning the value of 1 to the responses indicating the maximum level of awareness of change and 0 otherwise, the average individual hit and false-alarm rates are 0.31 ($SE = 0.02$) and 0.02 ($SE = 0.003$), respectively. According to this classification, participants responded correctly in 98% of no-change trials and in 31% of change trials. For animate probes, d' is equal to 1.25, $SE = 0.55$, $z = 2.25$, $p = .024$. For inanimate probes, d' is equal to 0.97, $SE = 0.36$, $z = 2.70$, $p = .007$.

3.4. Discussion

Under change detection, there are positive compatibility effects: For animate probes, reaction times are faster on congruent trials than on baseline trials; reaction times are slower on incongruent trials than on baseline trials. The PCEs are more pronounced for animate probes than for inanimate probes (Bermeitinger, Wentura, & Frings, 2008). For image changes of animate items, response times are faster when the probe is the post-change item rather than the pre-change item (Silverman & Mack, 2006; Yeh & Yang, 2009). Under CB, instead, there are inhibition effects: Response times are longer in the DC and SC conditions than in the (no-change) baseline condition. Response times in the ID1 and ID2 conditions do not differ significantly from baseline.

In the General Discussion section we will propose an interpretation of these results, which cannot be accounted for by any of the three hypotheses presented in the Introduction. Here, we point out that these results cannot be explained by attention allocation. According to this possible alternative interpretation, on change detection trials the likelihood the critical (change) item has been attended is high, whereas for CB trials the likelihood the critical item is attended is low. This is because we have split the data on the basis of the awareness of the change and awareness is highly correlated with attention. On baseline trials, by chance, sometimes the critical item is attended, which makes it more likely to be attended than the critical item on

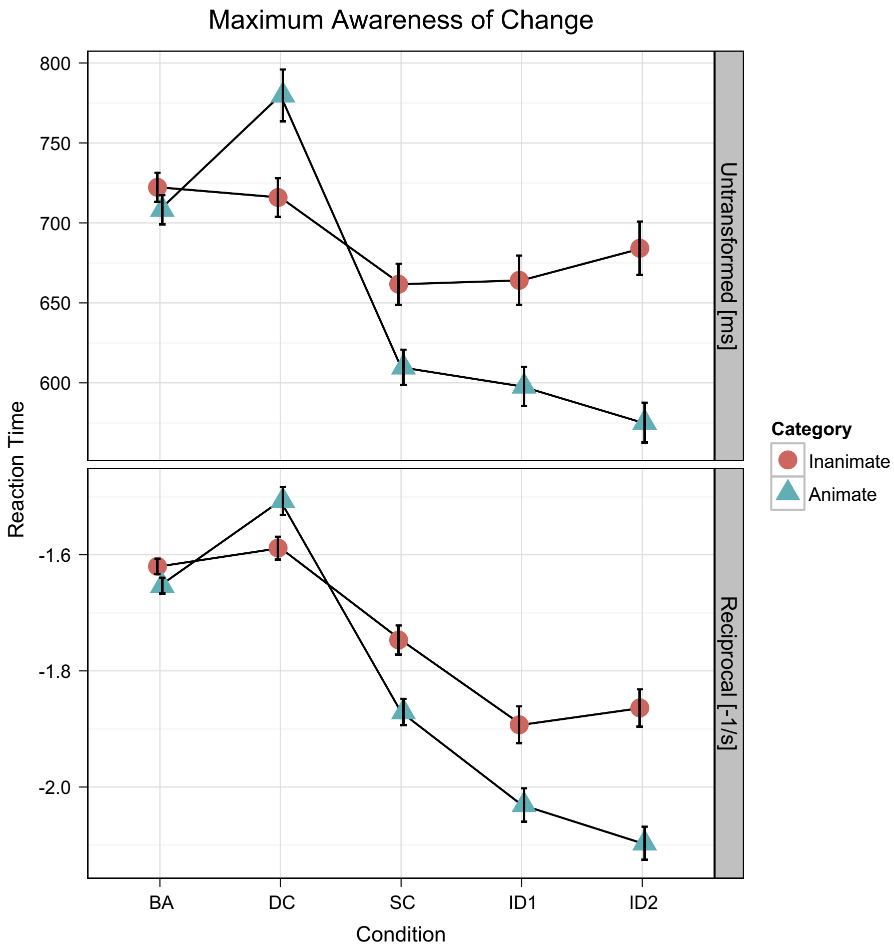

Fig. 3. Experiment 1. Condition [Baseline (BA), Different Category (DC), Same Category (SC), Identity 1 (ID1), and Identity 2 (ID2)] by Probe Category (inanimate, animate) interaction for untransformed RT (top row) and reciprocal RT (*i.e.*, −1/RT, bottom row). The figure depicts the mean response time latencies for the change trials in which participants responded "I am absolutely certain that a change has happened." The baseline corresponds to the no-change trials in which participants responded "I am absolutely certain that no change has happened." Error bars represent standard errors for cell means.

CB trials, yet less likely to be attended than the critical item on change detection trials. However, the "attention allocation" hypothesis does not explain why, under CB, participants are slower on DC trials relative to baseline trials. On DC trials, in fact, the target item is a non-changing item and it is unclear why failing to attend to the changed item on CB trials should lead to slower response of a probe that corresponds to a non-changed item. Moreover, there was no spatial cueing, because the probe was always presented in the center of the screen.

4. Experiment 2

In Experiment 2, the design of Experiment 1 was replicated, except that (1) the probe was a picture that was perceptually similar (but not identical) to one of the items presented in the previous two displays (see Fig. 1), (2) participants were asked to produce a binary (yes/no) detection response, and (3) only the extreme ID and DC conditions were used. The goal of the first manipulation was to determine whether the priming effects observed in Experiment 1 require an "exact" template-matching between the changed item and the probe. The goal of the second variation was to determine whether splitting the data into change detection and CB depending on a binary detection response would yield the same pattern of results as in Experiment 1 (for a discussion of the subjective measures of CB, see Busch, 2009).

4.1. Participants

A total of 20 undergraduate students (12 females and 8 males) aged from 18 to 24 years from Florence University participated in the experiment. All participants were naïve to the purpose of the study and none of them had participated in Experiment 1. All participants had normal or corrected-to-normal vision.

Table 1
Mean response latencies (ms) in the picture categorization task for the "change" trials of Experiment 1 as a function of probe Category (animate/inanimate), level of Awareness of the change (from 1 = "I am absolutely certain that no change has happened" to 7 = "I am absolutely certain that a change has happened"), and Condition [ID1: the probe depicts a pre-change item; ID2: the probe depicts a post-change item; SC: the probe item belongs to the same category as the changed object [*e.g.*, pig, turtle]; DC: the probe and the changed item belong to different categories (*e.g.*, pig, scissors)]. Standard errors are reported in parentheses. For each condition, the asterisks indicate significant differences to the minimum awareness condition.

Awareness	Condition			
	ID1	ID2	SC	DC
Animate				
1	734 (14)	724 (14)	749 (15)	772 (16)
2	756 (26)	743 (28)	828 (29)**	808 (25)
3	760 (28)**	804 (30)**	819 (40)**	776 (27)
4	857 (36)***	863 (41)***	802 (32)*	847 (28)*
5	833 (43)***	765 (34)*	793 (35)**	815 (34)*
6	688 (33)	715 (30)	699 (30)	754 (32)
7	598 (9.74)***	576 (12)***	611 (11)***	766 (16)
Inanimate				
1	729 (13)	755 (17)	742 (14)	761 (16)
2	755 (24)	781 (29)	796 (26)	823 (30)
3	765 (28)	737 (26)	785 (26)***	796 (36)
4	850 (57)***	787 (36)*	911 (38)***	839 (39)**
5	804 (42)**	807 (43)*	800 (32)*	819 (36)**
6	765 (33)*	743 (33)	740 (32)	758 (26)
7	668 (14)	687 (16)**	662 (13)	710 (12)

* $p < .05$.
** $p < .01$.
*** $p < .001$.

4.2. Procedure

Each participant performed 700 trials, 200 (29%) of which were "no-change" trials. The stimuli were similar to those used in Experiment 1, except that the probe images were not identical to the items used in the changing scene (see Fig. 1). For each of the eight items shown in the changing scene, five different probe images were created. In 250 trials, an item representing an animate entity changed its orientation; in 250 trials the change concerned an item representing an artifactual object. 50% of "change" trials were congruent (ID) trials (*e.g.*, changed item: horse; probe image: a different picture of a horse) and the remaining 50% were incongruent (DC) trials (*e.g.*, changed item: horse; probe image: hammer). The artifactual objects were: pincer, cellular phone, screwdriver, scissors, and google. The animate entities were: cow, pig, leon, bull, and tiger. Each of these items changed its orientation in 50 trials. In 25 of these trials, the probe was an artifactual object and in the remaining 25 trials it was an animate entity. In the no-change trials, the probe was selected 20 times from each of the 10 possible items used in the experiment. In no-change trials, a probe image was randomly chosen with equal probability among the possible animate or inanimate probe images.

4.3. Results

Trials with incorrect responses in the PCT were discarded from statistical analysis (less than 1%).

4.3.1. Response time latencies in the PCT

The pattern of means in the different experimental conditions is shown in Fig. 5.

4.3.1.1. Change blindness. When considering the change trials in which participants failed to report a change (which are denoted by the circles in Fig. 5 for the DC and ID conditions), neither the effect of Category ($\chi_1^2 = 1.06, p = .30$) nor the Category $\times$ Condition interaction ($\chi_1^2 = 1.16, p = .28$) are statistically significant. On average, in "change" trials (ID, DC) response times are slower than in no-change trials, $\beta = 0.028$, 10 ms, $t = 3.30$. As in Experiment 1, response times are faster in the congruent (ID) condition than in the incongruent (DC) condition, $\beta = -0.029$, 13 ms, $t = 2.60$.

4.3.1.2. Change awareness. When considering the trials in which participants reported a change that was present (denoted by the triangles in Fig. 5), there is a statistically significant Category $\times$ Condition interaction, $\chi_1^2 = 4.64,\ p = .031$. This interaction indicates that prime-probe congruency had a significant effect on animate probes (faster RTs in the ID condition than in the DC condition, $\beta = -0.083$, 32 ms, $t = 5.2$) but not on inanimate probes ($\beta = -0.018$, $t = 1.3$). For animate probes there is a significant facilitation effect relative to baseline in both ID ($\beta_1 = -0.13$, 50 ms, $t = 9.1$) and DC ($\beta_2 = -0.046$, 19 ms, $t = 2.90$) conditions. Also for inanimate probes there is a statistically significant facilitation effect relative to baseline in both the ID ($\beta = -0.045$, 15 ms, $t = 3.4$) and DC ($\beta = -0.027$, 9 ms, $t = 2.2$) conditions.

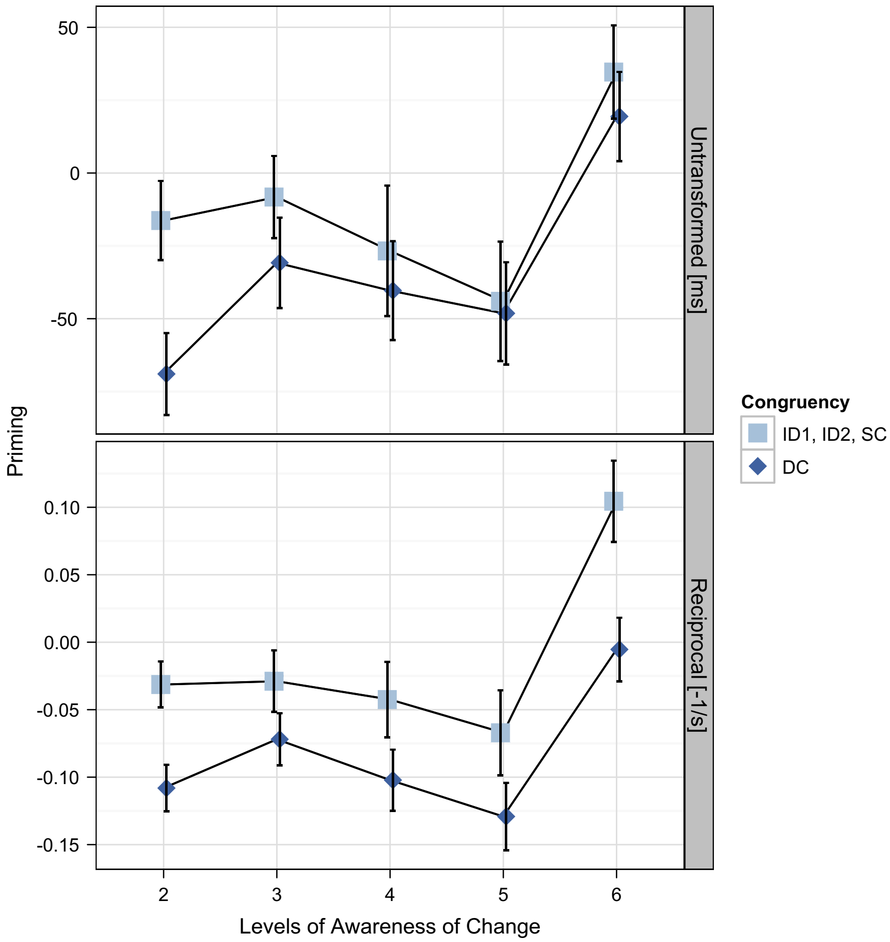

Fig. 4. Experiment 1. Priming effects as a function of Level of Awareness of the change and Congruency between prime and probe [congruent (ID1, ID2, SC) versus incongruent (DC)] for untransformed RT (top row) and reciprocal RT (*i.e.*, −1/RT, bottom row). From the figure are excluded the trials in which participants responded 1="I am absolutely certain that no change has happened" and 7="I am absolutely certain that a change has happened" (see Figs. 2 and 3). Positive values (*i.e.*, above zero on the ordinate) denote facilitation and negative values denote inhibition. Error bars represent standard errors for cell means.

4.3.2. Change detection

Overall d' is equal to 1.63, $SE = 0.44$, $z = 3.65$, $p = .0003$. The average individual hit and false-alarm rates are 0.559 ($SE = 0.033$) and 0.088 ($SE = 0.014$), respectively. Participants responded correctly in 91% of no-change trials and in 56% of change trials. For animate changed items, $d' = 1.89$, $SE = 0.29$, $z = 6.5$, $p = .0001$; for inanimate changed items, $d' = 1.37$, $SE = 0.43$, $z = 3.17$, $p = .0015$.

4.4. Discussion

Even if change awareness was based on dichotomous responses, in Experiment 2 we replicated the main results of Experiment 1, with some noteworthy differences between the two. Under correct detection, performance in the PCT was faster in congruent (ID) than in incongruent (DC) trials, at least for animate probes. Differently from Experiment 1, the response times for the DC condition were faster than the baseline condition. We do not have an explanation as to why different results were obtained in the two experiments in this respect. We can only point out that the absolute amount of facilitation and inhibition with respect to a baseline is difficult to measure because the prime in the "neutral" condition interacts with the probe and it leads to overestimate or underestimate the size of any one of these two effects (Jonides & Mack, 1984). In general, facilitation effects tend to be larger than inhibition effects (McNamara, 2005).

Under CB, we found larger inhibition effects in the DC condition than in the ID condition. Differently from Experiment 1, response times were slower in the ID condition than in the baseline. We should note, however, that the probe in the ID condition of Experiment 2 was not physically identical to either the pre-change or post-change item. By portraying a different exemplar from the same category of the changed item (*e.g.*, a different model of a phone), the ID condition of Experiment 2

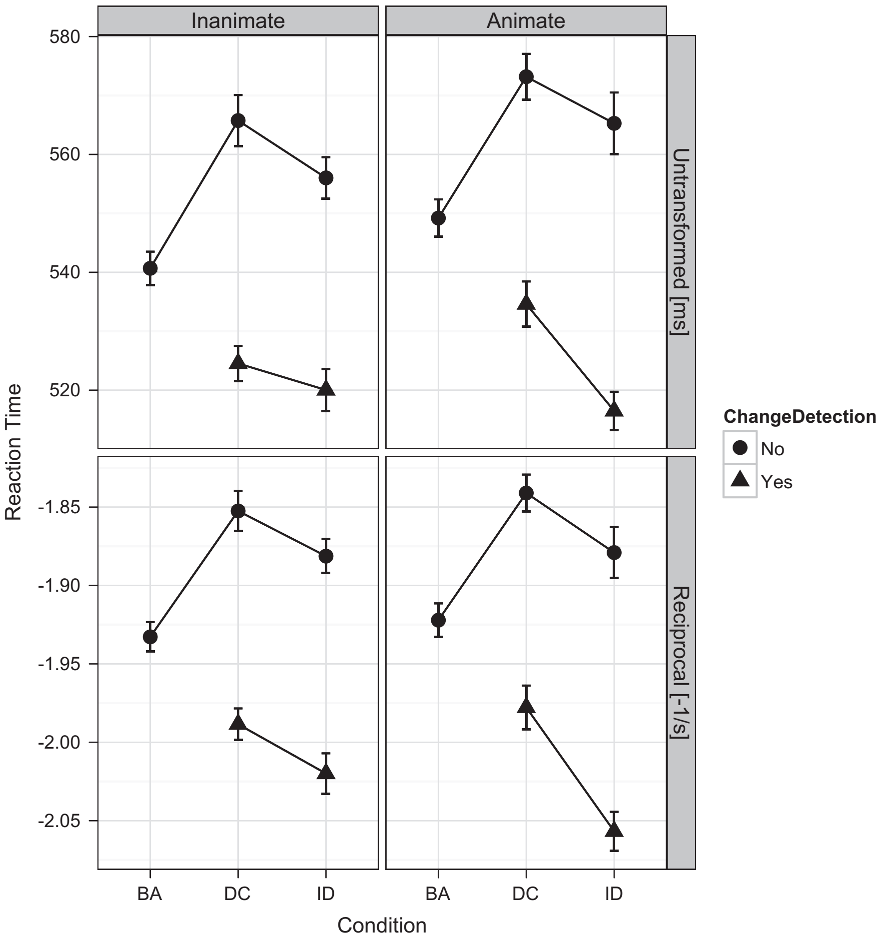

Fig. 5. Experiment 2. Each row shows the mean response latences in the PCT for the Condition [Baseline (BA), Different Category (DC), and Identity (ID)] by Change Detection interaction. Left column: inanimate probe; right column: animate probe. Effects are displayed for untransformed RT (top row) and reciprocal RT (*i.e.*, −1/RT, bottom row). Error bars represent standard errors for cell means.

was similar to the SC condition of Experiment 1. Therefore, the priming effects might had been due to the encoding of the changed-item category rather than the changed-item identity.

5. Experiment 3

In Experiment 3, the design of Experiment 2 was replicated, except that the probe was a word. In these conditions, the priming effects do not depend on a perceptual match between prime (image change) and probe (word). As in Experiment 2, participants were asked to produce a binary (yes/no) detection response.

5.1. Participants

A total of 58 undergraduate students (34 females and 24 males) aged from 18 to 29 years from Florence University participated in the experiment. All participants were naïve to the purpose of the study and none of them had participated in Experiments 1 and 2. All participants had normal or corrected-to-normal vision.

5.2. Procedure

Each participant performed 396 trials: 120 (30%) no-change trials (BA) and 92 change trials in each of the ID, SC, and DC conditions. The changing scenes were similar to those used in the previous experiments. After a blank of 216 ms following the second display, a word was shown until the participant gave his response. In the ID, SC, and DC conditions, 46 trials displayed the change of an animate entity and 46 trials displayed the change of an inanimate object.

Probe words ranged in length from 4 to 11 letters (median = 7 letters). Twenty-five probe words were used, one for each of the possible animate and inanimate objects shown in the changing displays. The following probe words were used:

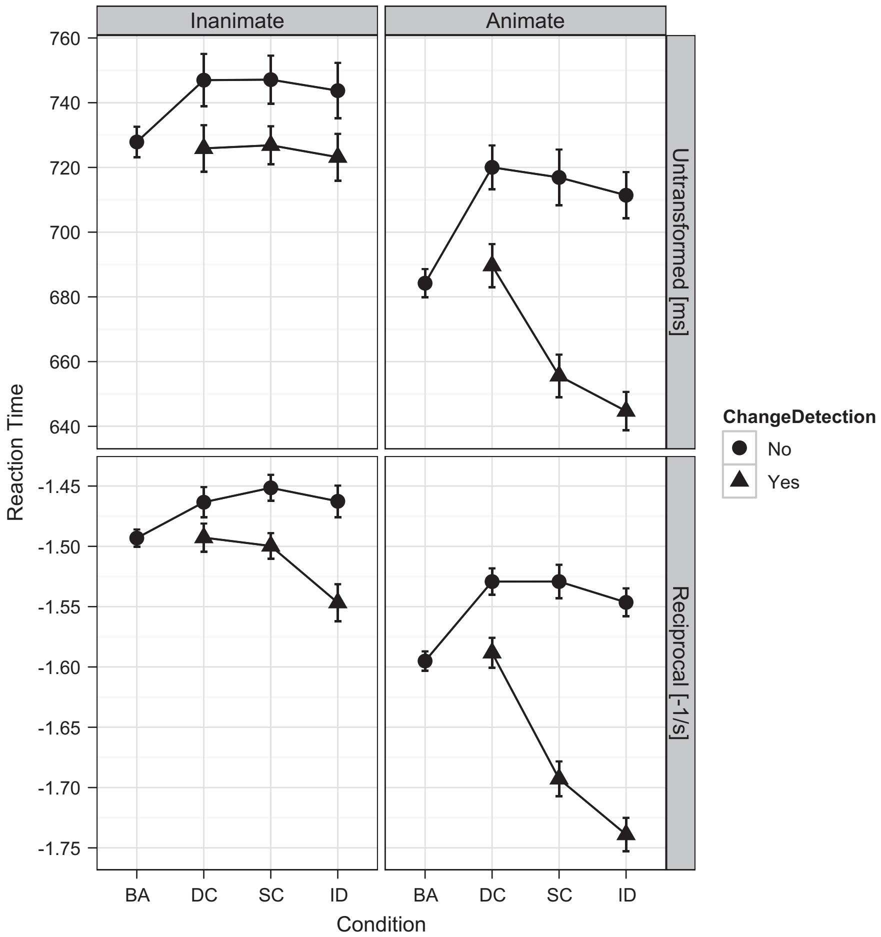

Fig. 6. Experiment 3. Each row shows the mean response latences in the WCT for the Condition [Baseline (BA), Different Category (DC), Same Category (SC), and Identity (ID)] by Change Detection interaction. Left column: inanimate probe; right column: animate probe. Effects are displayed for untransformed RT (top row) and reciprocal RT (*i.e.*, −1/RT, bottom row). Error bars represent standard errors for cell means.

"cavallo" (horse), "maiale" (pig), "toro" (bull), "ariete" (ram), mucca (cow), "lupo" (wolf), "bisonte" (bison), "capra" (goat), "asino" (donkey), "tartaruga" (tortoise), "granchio" (crab), "tigre" (tiger), "leone" (lion), "forbici" (scissors), "occhiali" (eyeglasses), "caffettiera" (coffee-maker), "tenaglie" (pincers), "cellulare" (cell phone), "motociclo" (motorcycle), "martello" (hammer), "tazzina" (cup), "accendino" (lighter), "orologio" (watch), "chiavi" (keys), "cacciavite" (screwdriver). Each word was used, on average, in 16 trials (minimum = 5, maximum = 29). In half of the trials the probe word denoted an animate entity and in the remaining half the probe word denoted an inanimate object.

In "change" trials, the animate and inanimate words were assigned with equal probability to the ID [*e.g.*, changed item: horse; probe word: "cavallo" (horse)], SC [*e.g.*, changed item: horse; probe word: "lupo" (wolf)], or DC [*e.g.*, changed item: horse; probe word: "forbici" (scissors)] conditions. In "no-change" trials, animate words were used in 50% of the trials and inanimate words were used in the remaining 50% of trials. The animate and inanimate words were selected randomly on each trial with this constraint.

5.3. Results

Trials with incorrect responses in the word categorization task were discarded from statistical analysis (1.5%).

5.3.1. Response time latencies in the WCT

The pattern of means in the different experimental conditions is shown in Fig. 6.

5.3.1.1. Change blindness. In "change" trials in which participants failed to report a change (denoted by the circles in Fig. 6), there are no statistically significant differences among the ID, SC, and DC conditions, $\chi^2_2 = 4.54,\ p = .10$. Mean response times are significantly longer for inanimate words than for animate words (β = 0.040, 49 ms, t = 2.30), also after "covarying out" the influence of number of letters, number of syllables, and frequency of use (*e.g.*, Rayner, 1998). On average, response times are significantly longer in the "change" trials (DC, SC, and ID conditions) than in the baseline (BA) condition (animate words: $\beta = 0.026$, 15 ms, $t = 3.4$; inanimate words: $\beta = 0.023$, 13 ms, $t = 2.8$).

5.3.1.2. Change awareness. When considering the trials in which participants reported a change that was present (denoted by the triangles in Fig. 6), response times for animate words are significantly faster in the ID ($\beta = -0.066$, 36 ms, $t = 3.3$) and SC ($\beta = -0.054$, 30 ms, $t = 2.7$) conditions than in the baseline condition. There are no significant differences between the DC condition and the baseline ($t = 1.5$). Response times are significantly faster in the congruent (ID, SC) conditions than in the incongruent (DC) condition ($\beta = -0.083$, 32 ms, $t = 5.67$). In the case of inanimate words, response times are significantly faster in the ID condition than in the baseline ($\beta = -0.028$, 16 ms, $t = 2.50$). There are no significant differences between the congruent (ID, SC) and incongruent (DC) conditions ($t = 0.47$).

5.3.2. Change detection performance

Overall d' is equal to 1.42, $SE = 0.085$, $z = 16.6$, $p = .001$. The average individual hit and false-alarm rates are 0.54 ($SE = 0.018$) and 0.134 ($SE = 0.013$), respectively. Overall, participants responded correctly in 87% of no-change trials and in 54% of change trials.

5.4. Discussion

When considering the change detection trials, the results of Experiment 3 replicate those of Experiments 1 and 2. There are facilitation effects in the ID condition [*e.g.*, changed item: horse; probe word: "cavallo" (horse)] relative to baseline, for both animate and inanimate probe words. There are also facilitation effects in the SC condition [*e.g.*, changed item: horse; probe word: "lupo" (wolf)] relative to baseline, for animate probe words. In the DC condition, we found no inhibition effects relative to baseline [*e.g.*, changed item: horse; probe word: "forbici" (scissors)] (see the discussion of Experiment 2).

Under CB, the results of Experiment 3 differ in one important aspect from those of Experiments 1 and 2. Even though the average response latencies in "change" trials are significantly longer than baseline, these inhibition effects are not modulated by the semantic relation (ID, SC, DC) between the changed item and the probe word.

6. General discussion

The aim of the present investigation was to determine whether and in which manner the changes between two images affect performance in an immediately successive picture categorization task (PCT) or word categorization task (WCT), under correct change detection and under CB. The main results are the following:

1. The awareness of an image change induced PCEs on an immediately successive animate/inanimate decision task. These priming effects were stronger in Experiment 1, where there was a perfect perceptual match between the changed item and the probe, but they were also observed in Experiment 3, where the probe was a word. The PCEs were stronger for probe images or words representing animate beings rather than inanimate objects.
2. Change trials in which participants reported being unaware of any change were associated with a performance cost relative to no-change trials.
3. The inhibition effects observed under CB were modulated by semantic relatedness when there was a perfect (Experiment 1) or partial (Experiment 2) perceptual match between the prime and the probe. These inhibition effects were not modulated by semantic relatedness when the prime was a picture and the probe was a word (Experiment 3).

Under correct detection, we found stronger facilitation effects in congruent trials for probe images and words representing animate entities rather than inanimate objects. This might be due to the fact that, in our stimuli, changes of animate entities were more easily detectable than changes of inanimate objects. An increased perceptual salience might cause greater priming effects. Alternatively, this result might be due to the fact that priming effects tend to be smaller for inanimate categories. Evidence supporting this second view comes from a study of Bermeitinger et al. (2008). They found larger priming effects for natural categories compared to artifactual categories even though, in their experiments, the words of the two categories were balanced with respect to word frequency, word length, association strength, or the number of category coordinates per category.[7]

The inhibition effects that we found under CB cannot be explained by attention selection. One might argue that lack of attention might drive both CB and slow RTs in CB trials relative to (no-change) baseline trials. According to this hypothesis, in trials in which the participant does not pay attention/look at the phone, for example, she will be less likely to detect the change and she will be slower at semantic categorization. In contrast, in trials in which she does look at the phone, she will be more likely to notice the change and she will be faster at categorizing the phone probe. More specifically, if the participant does not pay attention/look at the phone when the phone changes its orientation, then the probability that she will attend to

[7] Bermeitinger et al. (2008) list several lines of evidence suggesting the existence of processing differences between natural and artifactual categories. For example, in a living versus non-living decision task, living beings are processed faster than non-living objects (Allen, Goldstein, Madden, & Mitchell, 1997) and the same advantage has also been reported in a naming task (Laws, Leeson, & Gale, 2002). However, only one study prior to theirs reports an advantage for the animate category in a semantic priming paradigm (Moss, Ostrin, Tyler, & Marslen-Wilson, 1995).

an item belonging to the animate category will be 4/7 and the probability that she will attend to an item belonging to the artifact category will be 3/7. Therefore, if the inhibition effects were due to a lack of attention to the changed item, we should expect a performance advantage under CB for incompatible trials (prime-probe incongruence) over compatible trials. Instead, the opposite was found: In Experiments 1 and 2 (where the probe was an image rather than a word), we observed an advantage of compatible trials over incompatible trials. In Experiment 1, response times were faster in the combined congruent conditions (ID1, ID2, SC) than in the incongruent condition (DC). In Experiment 2, response times were faster in the congruent (ID) condition than in the incongruent (DC) condition.

A comparison of the results from all experiments suggests that the modulation of the inhibition effects under CB by prime-probe congruency (Experiments 1 and 2) can be attributed to processing that occurs at a structural (or featural) rather than semantic level of representation. In fact, such modulation disappears when the probe is a word (Experiment 3). Interestingly, the size of the inhibition effects was similar for animate and inanimate probes. Instead, the facilitation effects observed under correct detection were stronger for animate than for inanimate probes.

In CB experiments, the "prime" (changed item) is well above the sensory detection threshold and it remains invariant across experimental conditions. What varies from trial to trial is the participant's awareness of the change. The validity of the reports of subjective awareness of the changes in a visual scene can be questioned. In our experiments, however, such subjective measure of awareness, when combined with prime-probe congruency, was an effective predictor of the direction of the priming effects. In this regard, particularly interesting are the priming effects for the animate probes in the SC condition (*e.g.*, horse-lion) of Experiment 1. When participants reported being maximally aware of the change, we found a strong facilitation relative to the (no-change) baseline condition (Fig. 3). When participants reported the minimal awareness of the change, the priming effect was reversed and became a performance cost (Fig. 2). This reversal in the direction of priming can be contrasted with performance in the DC condition: In that case, the priming effects reflect a performance cost regardless of whether participants reported the maximum or minimum awareness of the change.

In three experiments, under CB we observed inhibition effects relative to the baseline condition in a PCT and in a WCT. These results rule out Hypotheses 1 and 2 described in the Introduction (no priming effects, PCEs). Moreover, these inhibition effects cannot be explained by classical negative priming (Tipper, 2001), which corresponds to the negative compatibility effect (Hypothesis 3).

While other interpretations are possible, we propose to explain our results as the sum of two processes. According to this proposal, the performance costs observed under CB are caused by (1) the inhibition of both animated and inanimate categories, due to the uncertainty in the identification of the changed item, and (2) a boosting of the properties of the changed item, of which participants are still unaware even after such an enhancement.

The performance cost for "change" trials relative to "no-change" trials, when participants reported not being aware of any change, might be a form of "cognitive aftereffect", as described by Huber (2008). According to Huber, the representations associated with the prime, which are activated at prime onset, must be removed from the decision process about the probe that is presented immediately after. Under some circumstances, this discounting mechanism produces an excessive amount of inhibition that results in a bias against the probe, if the probe shares a sufficient number of features with the prime. Huber's proposal can be adapted to the present case in the following manner. In CB trials, participants might "sense" the change, without being able to identify with certainty the changed item (Simons & Rensink, 2005; Rensink, 2004). Under the locational uncertainty about the changed item, the processing resources must be distributed evenly over the entire display, with parallel processing of all the items (*e.g.*, Musch & Klauer, 2001). In these circumstances, both animate and inanimate categories might become simultaneously activated. When the probe is presented immediately after the changing scene, the lingering activation of these two semantic categories must be inhibited, in order to reduce interference with the decision processes about the probe. This discounting mechanism may result in a performance cost for the processing of the probe, if the probe is to be categorized in terms of the two inhibited categories, with respect to a baseline condition in which the "prime" is absent.

Why are the inhibition effects modulated, under CB, by the congruency between prime and probe? Sumner, Tsai, Yu, and Nachev (2006) showed that the processing that follows the presentation of a weak stimulus may be affected by attention in two manners. (1) Attention may boost perceptual representations, making the stimulus more likely to be consciously perceived. (2) Attention may enhance unconscious sensory processes initiated by invisible stimuli, which still remain invisible after such enhancement. In the experiments of Sumner et al. attention was driven by spatial cues. Likewise, in our experiments, the unperceived change might act as a cue that enhances the processing of the changed item relative to the unchanged items. The modulation of the inhibition effects might thus depend on such "unconscious boosting".

In summary, our results suggest that an image change that does not reach awareness can nevertheless produce a trace of neural activity that interferes with successive semantic processing. This interference effect is modulated by the congruence between the changed item and the probe, but this modulation disappears if the prime bears no physical similarity to the probe.

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