Grasping the pain: Motor resonance with dangerous affordances

Filomena Anelli [a,*]**, Anna M. Borghi** [a,b,*]**, Roberto Nicoletti** [a]

[a] University of Bologna, Italy

[b] Istituto di Scienze e Tecnologie della Cognizione, CNR, Roma, Italy

* Corresponding authors:
Anna M. Borghi
address: Dipartimento di Psicologia, viale Berti Pichat, 4 – 40127 Bologna, Italy.
phone: +39 051 2091838 or +39 06 49936279, fax: +39 051 243086
mail: annamaria.borghi@unibo.it

Filomena Anelli
address: Dipartimento di Discipline della Comunicazione, via Azzo Gardino, 23 – 40122 Bologna, Italy.
phone: +39 051 2092218, fax: +39 051 2092215
mail: filomena.anelli@unibo.it

Abstract

Two experiments, one on school-aged children and one on adults, explored the mechanisms underlying responses to an image prime (hand vs. control object) followed by graspable objects that were, in certain cases, dangerous. Participants were presented with different primes (a male hand, a female hand and a robotic grasping-hand; a male and a female static-hand; a control stimulus) and objects representing two risk levels (neutral and dangerous). The task required that a natural/artifact categorization task be performed by pressing different keys. In both adults and children graspable objects activated a facilitating motor response, while dangerous objects evoked aversive affordances, generating an interference-effect. Both children and adults were sensitive to the distinction between biological and non-biological hands, however detailed resonant mechanisms related to the hand-prime gender emerged only in adults. Implications for how the concept of "dangerous object" develops and the relationship between resonant mechanisms and perception of danger are discussed.

Keywords: empathy; dangerous objects; motor resonance; affordances.

1. Introduction

In order to survive, humans need to be able to discriminate between objects that pose a potential risk or threat (from now on "dangerous objects") and objects that can be approached without any risk (from now on "neutral objects"). Information about an object's potential risks might conflict with the motor actions that are activated while observing that object.

Since Gibson's seminal paper (1979), many behavioural and neuroscience studies have shown that observing objects, and particularly tools, activates affordances, evoking motor responses. In the last decade research has shed new light on the role played by affordances. Behavioural experiments have shown that objects evoke specific action components (i.e. micro-affordance, Ellis & Tucker, 2000), such as a specific grip. For example, when observing an apple or a bottle, participants were facilitated by having to mimic a power grip rather than a precision one (Tucker & Ellis, 2001).

More crucial to our aim here is how studies with a priming paradigm have shown that when the target-object is preceded by a hand prime displaying a congruent grip, categorization responses are facilitated. Borghi and colleagues (Borghi, Bonfiglioli, Lugli, Ricciardelli, Rubichi, & Nicoletti, 2007) found a compatibility effect between the prime-hand pose (precision vs. power) and the grip required to grasp the target-object (precision vs. power), in those cases where the experiment was preceded by a motor training phase. Vainio and colleagues (Vainio, Symes, Ellis, Tucker, & Ottoboni, 2008) replicated and expanded on the experiment by using a dynamic hand prime (i.e., video-clips rather than static images); their results confirmed previous findings. These studies highlighted how motor information emerges when a hand is observed while it is in a position of potentially interacting with an object, leading to a facilitation effect (for a review, see Borghi & Cimatti, 2010).

Having established that observing graspable objects evokes a motor response, particularly when preceded by an action prime, we posed the question: what happens when a hand is seen interacting with dangerous objects? Different transcranial magnetic stimulation (TMS) studies on empathy for pain have investigated passive responses by subjects who were made to watch images of pain being inflicted on others (e.g., Avenanti, Bueti, Galati, & Aglioti, 2005; Avenanti, Minio-Paluello, Bufalari, & Aglioti, 2006). The results of such research showed that, after watching a needle inserted deep into a model hand, a selective inhibition was registered. Indeed, the significant motor evoked potential (MEP) amplitude decreases were specific not only for the observed body part (i.e. for the hand and not for the foot), but for the particular muscle, compared to a non-bodily object (tomato) or to a tactile stimulation (innocuous cotton bud control). Thus, having to witness pain being inflicted on others led to a specific corticospinal inhibition, similar to the way in which pain was directly-experienced (e.g., Farina, Tinazzi, Le Pera, & Valeriani, 2003; Le Pera, Graven-Nielsen, Valeriani, Oliviero, Di Lazzaro, Tonali, & Arendt-Nielsen, 2001); this suggested a resonant activation of pain representations in the onlooker's sensorimotor system. Not only neural, but also behavioral evidence (Morrison, Poliakov, Gordon, & Downing, 2007) has demonstrated a specific influence on overt motor responses when pain is observed. More specifically, observing a video of a needle penetrating a hand accelerated withdrawal movements (key releases) and slowed approach movements (key presses); this difference was not present when participants observed a cotton bud touching a hand or when it was a sponge, rather than a hand, being penetrated or touched by either a needle or cotton bud.

It is necessary to explicate our use of the term "empathy." Following Morrison and colleagues (2007), we distinguish between pain empathy and pain recognition. "We regard pain empathy as a compassionate affective state which the observer experiences on behalf of the sufferer, and which may result in prosocial actions. Pain recognition [is] a basic appraisal of the pain-related nature of the sufferer's situation. Although pain recognition may be necessary for empathy, it is not sufficient for it, and may occur independently of empathy in day-to-day contexts. Nevertheless, pain recognition may involve affective evaluation and motor response modulation" (Morrison et al. 2007; page 415). Previous studies have upheld this distinction by concerning themselves with how

observing pain influences motor responses, and were thus interested in pain recognition rather than empathy. It is important to clarify that by adopting the term "empathy" we intend to refer to phenomena of emotional contagion, not to the cognitive aspects of empathy. Nummenmaa et al. (Nummenmaa, Hirvonen, Parkkola, & Hietanen, 2008) did a good job of shedding light on how simulating others' emotional states can represent a special case of empathy, i.e. emotional empathy, which differs from cognitive empathy. Indeed, emotional empathy (or emotional contagion) involves the mirror neuron system to a greater extent than what occurs in cases of cognitive empathy, and it is at the basis of the motor resonance evoked in the observer.

In short, previous studies provided clear evidence, both in the way of behavioural responses and underlying neural mechanisms, of pain recognition and emotional contagion (viz. empathy). However, to our knowledge these studies have investigated only cases in which pain was passively induced by an object (e.g., the needle), and in which there was a direct interaction between the painful object and the hand.

Our study chose to focus on the resonant mechanisms elicited when a hand is observed while in preparation for an action relative to a graspable, dangerous object and when the interaction between the hand prime and the object is not direct but rather a potential end result.

A contiguous line of research is relevant to the issue addressed in this study. Recent works have provided evidence of a motor resonance effect triggered by the observation of others' actions. A variety of brain imaging results have shown that the greater the similarity between the observed motor program and the motor program that the participants are able to execute, the greater the extent to which the mirror neuron system was activated. Neuroimaging and behavioural studies using expert dancers provided a good example (Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006 ; Calvo-Merino, Ehrenberg, Leung, & Haggard, 2010). Calvo-Merino and colleagues showed that neural activity in premotor and parietal areas was stronger when dancers viewed moves from their own motor repertoire compared to opposite-gender moves that they knew but did not perform.

To our knowledge, the only study in which motor resonance was investigated while observing different kinds of hands interacting with painful stimuli is a recent TMS work (Avenanti, Sirigu, & Aglioti, 2010) that explored emphatic brain responses in white and black participants while observing the pain of ingroup or outgroup members. Witnessing pain being inflicted on ingroup members led to an immediate resonance (i.e. an inhibition of the onlookers' corticospinal system) while responses to outgroup members' stimulations were not automatic.

On the behavioural side, evidence for motor resonance during the observation of different kinds of hands (e.g., in different poses, in different perspectives, or belonging to different populations) has been found with priming paradigms. Bruzzo and colleagues (Bruzzo, Borghi, & Ghirlanda, 2008) demonstrated that the similarity between the hand primes being observed and the participants' own hands facilitated judgments on action plausibility: specifically, responses were faster when participants wore a glove and observed gloved hands, and when they observed hands in their own perspective rather than in an allocentric perspective. Liuzza and colleagues (Liuzza, Setti, & Borghi, 2012) recently investigated motor resonance in children. Children were required to judge the weight of an object primed by a child or an adult hand in an action-pose (grasp) or in a non action-pose (fist). Their responses were faster when the object was preceded by a grasping hand and when the prime-hand was that of a child. In a similar vein, Ranzini and colleagues (Ranzini, Borghi, & Nicoletti, 2011) investigated action- and object-related motor cueing effects, by means of a hand-cued line bisection task in which human and robotics hands were displayed. In a finding that holds particular relevance to our study, they saw a stronger lateralization effect with biological stimuli (rather than non-biological), indicating a more marked motor resonance effect when the hand was human and not robotic.

In sum: Avenanti and colleagues (Avenanti et al., 2005; 2006; 2010) have provided evidence of a resonant mechanism while observing different kinds of hands interacting with painful stimuli. However, pain was passively induced by the object (the needle), and participants could observe the

direct interaction between the hand and the needle. In our study we intend to explore resonant mechanisms with a priming paradigm, during active action preparation, when the hand and the object do not interact. Thus, the present work is investigating at a functional level the mechanisms involved during observation of a prime given by a hand or by a control object followed by objects that might be dangerous or provoke pain. To the best of our knowledge, no previous study has investigated active responses to dangerous stimuli and the effects of social variables such as gender and age of participants on this kind of task. In addition, even if the study by Liuzza and colleagues (Liuzza et al., 2012) confirmed the existence of motor resonance in children, to our knowledge nobody has yet explored how motor resonance develops from childhood to adult age.

To investigate this complex issue we used a priming paradigm (Figure 1), presenting children (Experiment 1) and adults (Experiment 2) with different kinds of primes followed by different kinds of objects. We presented 5 different kinds of hands: 4 human hands and a robotic hand. The human hands were orthogonally organized as follows: there were 2 male hands and 2 female hands, of which 2 hands were in a position of grasping and 2 were in a non-grasping or "static" pose. The robotic hand was included to verify whether there was a difference between responses to human hands and to non-human hands (i.e., between biological and non-biological primes). In addition to these 5 hands-primes, a control stimulus was presented, in the form of an easily recognizable object of low visual complexity, i.e. a brick, in order to check whether the presentation of any kind of prime might influence the participants' response. These specific primes were selected in order to manipulate the gender of the observed prime-hand (male vs. female) and to suggest a potential action or not (grasping vs. static hand).

The presentation of the prime was followed by the appearance of a target-object. Overall, we selected 16 target-objects. In order to manipulate the object typology and the object category, the objects were orthogonally organized as follows: we used 8 neutral and 8 dangerous objects, of which 8 objects were artifacts and 8 natural objects.

The aim of our study is twofold. First, we intend to establish how humans develop general responses to objects as well as sensitivity to fine object characteristics (i.e. object typology and object category). Specifically, we are interested in understanding how human beings perceive and process both dangerous and neutral objects in different ways. We did not distinguish between risk for pain and threat, since we were interested in motor resonance while observing objects or entities that can potentially provoke pain, independently of their being active or passive. Indeed, even for animals it would be difficult to distinguish between those animals that represent an active threat and those that are potentially dangerous but typically more passive: for example, would a scorpion be considered an active threat or as merely acting in self defense? We hypothesize that all graspable objects activate a facilitating motor response; however, in the case of dangerous objects the response might be blocked, generating an interference effect. If this is the case then observing dangerous and potentially painful objects might evoke aversive affordances, in line with the results of Morrison and colleagues (Morrison et al., 2007). As to the developmental trajectory of this effect, we predict that the capability to distinguish object typology (i.e. between dangerous and not dangerous objects) emerges quite early on in development, as it is crucial from an adaptive point of view, whereas the capability to select different motor responses based on subtle differences related to the object category (i.e. between artifact and natural objects), for example the activation of functional information related to artifacts, emerges later.

Second, we aim to investigate how motor resonance develops, and hypothesize that, with age, participants become progressively more careful to details of the hands as well as to the motor program that the hand evokes. If a general motor resonance phenomenon occurs, then we should find a difference between responses to the biological primes (i.e., human hands) and the non-biological primes (i.e., a robotic hand and a brick). Moreover, if this motor resonance effect is sensitive to subtle aspects, then we should find:

1. a gender-dependent motor resonance: male participants should resonate more with male hand-primes, and female participants with female hand-primes;

2. a sensitivity to the relationship between the hand pose and the action: we should find a difference in responding to the grasping compared to the static hand pose.

The decision to employ a priming paradigm allows us to investigate the timing of these two different mechanisms, one possibly related to the activation of the mirror neuron system, triggered by the observation of the hand, and the other to the canonical neuron system, activated by the presence of the objects (Liuzza et al., 2012). There are two possible explanations. The first is that observing the hand prime induces preparation for an action, possibly through the mediation of the mirror neuron system, and then later the appearance of the object triggers either a facilitating or a blocking mechanism. This leads to the prediction that the greater the motor resonance induced by the observed prime, the greater the facilitation effect will be. The second is that the prime, together with the object that follows, activates a specific motor program. This leads to the prediction that the greater the similarity between the prime and the participant's own hand, the slower the responses to dangerous objects will be. This is to say, the greater the extent to which we identify with an individual who is interacting with a potentially dangerous object, the greater the attention we pay to dangerous objects.

2. Experiment 1

The aim of the first experiment is twofold. First, we intend to investigate whether school-age children are sensitive to differences in the level of risk posed by an object (i.e. neutral vs. dangerous objects) and in the object category (i.e. artifacts vs. natural objects). Specifically, we predict an interference effect, i.e. slower response times when subjects are presented with images involving dangerous objects.

Second, we are interested in exploring whether and to what extent children resonate while observing a hand priming an object. If observing a hand prime evokes motor resonance, then responses should differ when observing a biological prime (i.e. a human hand) compared to a non-biological one (i.e. a robotic hand and a control prime). In addition, if children are sensitive to any detailed aspect of the action they observe, they should respond differently when observing grasping hands compared to static hands, and when observing hands of their own gender compared to hands of another gender. If the motor resonance effect induced by the prime is modulated by the presented object, then we should find that greater similarity between the prime and the children's own hand causes interference when the prime is followed by a dangerous object and facilitation when followed by a neutral object.

In order to test these hypotheses, we conducted an experiment in which participants were required to observe primes and distinguish between artifacts and natural target-objects, with the object's risk level being irrelevant to the task.

2.1. Participants

Thirty participants (16 males and 14 females) with a mean age of 8.2 (range: 6 - 10) years took part in Experiment 1. All subjects were right-handed and had normal or corrected-to-be-normal vision. All were naive as to the purpose of the experiment, though parents had given their informed consent.

2.2. Apparatus and stimuli

Participants sat in front of a 17-inc. colour monitor (the eye-to-screen distance was approximately 50 cm). E-Prime 2.0 software was used for presenting stimuli and collecting responses.

The experimental stimuli (see Table 1) consisted of sixteen colour pictures of living and non-living objects preceded by a prime (Figure 1). All the objects would be normally grasped with a power grip. There were four categories (dangerous-natural objects, dangerous-artifacts, neutral-natural objects, neutral-artifacts), with four objects for each. Each target-object was preceded by one of six primes: a grasping hand of a man, a grasping hand of a woman, a grasping hand of a

robot, a static hand of a man, a static hand of a woman, a control stimulus (brick): we expected the grasping hand to trigger a potential action in the observer, and the static hand to result in less motor activation.

A rating was carried out in order to check whether the target objects were perceived as constituting different levels of risk. Forty-three raters were asked to evaluate the degree of risk for pain represented by each object on a five-point Likert scale (with 1 = not dangerous/neutral object and 5 = extremely dangerous object). Response means were entered into a within-subject 2 x 2 ANOVA with the following factors: *Typology* (neutral and dangerous) and *Category* (artifact and natural). The analysis revealed the main effect of *Typology*, $F (1, 12) = 95.3$, $MSE = 0.24$, $p < .001$. This result demonstrated that the sixteen objects differed with respect to risk-for-pain levels, and it also showed that there was no difference between artifacts and natural objects.

Even if participants were children, we decided to use adult hand primes since gender information can be detected more clearly with adult hands. In fact, one of the aims of our work is to study the "gender-related resonance effect," while we are not interested in investigating the "age-related resonance effect" (Liuzza et al., 2012).

(Figure 1 about here)

2.3. Procedure

Participants were required to decide as quickly as possible whether the target-stimulus was an artifact or a natural object by pressing one of two designed keys. Half of the participants were required to make a right-hand key-response if the target was an artifact and a left-hand key-response if it was natural, whereas the opposite hand-to-category arrangement was applied to the other half.

The experiment consisted of one practice block of 24 trials and one experimental block of 96 trials. Each trial began with a fixation point (+) displayed for 500 ms in the center of the screen. Then, a prime was shown for 200 ms, followed by a white screen (SOA) for 50 ms. Then, a target object was shown and remained on the center of the screen until a response had been made or 2000 ms had elapsed. Both prime and target objects were centered on the screen. Their average size was 307 x 323 pixel. Participants received feedback on reaction time (RT) after pressing the right or the wrong key (the reaction time value or "Error," respectively). The next trial began after the feedback disappeared. Overall the experiment lasted about 15 minutes.

2.4. Results

Reaction times (RTs) for incorrect responses and RTs of more than two standard deviations from each participant's overall mean were excluded from the analysis. Error trials were excluded from further analyses (6 %). The correct RTs were entered into a mixed 2 x 2 x 2 x 6 ANOVA, with *Participant Gender* (male and female) as between participants factor, and *Object Typology* (neutral and dangerous), *Category* (artifact and natural), and *Prime* (grasping hand of an adult male, grasping hand of an adult female, grasping hand of a robot, static hand of an adult male, static hand of an adult female, control stimulus) as within participants factors. Newman-Keuls post-hoc tests were also conducted on significant interactions.

In the ANOVA, the analysis revealed two main effects: *Object Typology* [$F (1, 28) = 12.6$, $MSE = 6707$, $p\eta2 = 0.31$, $p < .01$], and *Prime* [$F (5, 140) = 2.8$, $MSE = 8673$, $p\eta2 = 0.09$, $p = .02$]. Responses were faster when the object was neutral and slower when the stimuli were dangerous (744 vs. 765 ms, respectively), (Figure 2). The second main effect showed that participants responded faster to the stimuli preceded by a human hand prime (i.e. a biological hand, 745 ms) and slower to the stimuli preceded by a robot hand and control stimulus (i.e. a non-biological hand, 773 ms). As revealed by the post-hoc test, response times were faster when the prime was the grasping hand of a woman ($M = 748$ ms) than the grasping hand of a robot ($M = 774$ ms, $p = .03$) or the control stimulus ($M = 771$ ms, $p < .05$), and when the prime was the grasping hand of a man ($M = 746$ ms) than the grasping hand of a robot ($p = .02$) or the control stimulus ($p = .04$). Moreover, the

responses were faster when the object was preceded by the static hand of a woman (M = 745 ms) than the grasping hand of a robot (p = .02) or the control stimulus (p = .03), and when the prime was the static hand of a man (M = 743 ms) than the grasping hand of a robot (p = .01) or the control stimulus (p = .02), (Figure 3).

There were no other significant main effects or interactions. However, the interaction *Object Typology* and *Category* was marginally significant [F (1, 28) = 3.7, *MSE* = 37521, $p\eta2$ = 0.11, p = .07] and it suggested that responses to neutral objects were modulated according to the category of the stimuli (i.e., responses to natural objects were faster than those to artifacts, M = 733 vs. 754 ms, respectively), while in the case of dangerous objects a difference between natural and artifact objects (M = 769 vs. 762 ms, respectively) was not present.

In order to verify if a correlation was present between object dangerousness and biological primes, we calculated for each subject an interference index (produced by dangerous objects over neutral objects) and three facilitation indices (produced by biological primes over non biological ones). The interference index was computed by subtracting neutral objects RTs to dangerous objects RTs, while the facilitation indices were calculated subtracting 1) the grasping hand of a robot RTs, 2) the control stimulus RTs, and 3) the non-biological primes RTs (i.e. the average of the robot hand and of the control stimulus RTs) to biological hands RTs. In the analyses there were no significant correlations between the interference index and the facilitation index of grasping hand of a robot and biological hands (r = -.04, p = .81), nor between the interference index and the facilitation index of control stimulus and biological hands (r = .21, p = .26), or between the interference index and the facilitation index of non-biological primes and biological hands (r = .12, p = .53).

(Figures 2 and 3 about here)

2.5. Discussion

Results revealed that children were sensitive to the distinction between dangerous and neutral objects, as response times were slower with the first than with the second. However, no difference was found between artifacts and natural objects, although data suggest that this distinction did begin to emerge.

In addition, we found evidence of a motor resonance effect, since children responded faster when primed with a human hand (rather than a non-biological prime). One could explain the advantage of the human hand over the non-biological stimuli as a sort of oddball effect, as there were twice as many human primes. However, we tend to exclude this explanation. Indeed, each single prime was presented the same number of times (4 presentations in the practice block and 16 presentations in the experimental block). If we assume that participants were sensitive to the frequency of the presentation of hand primes, then we should expect an advantage of the robotic hand over the brick (since all primes except the brick were hands), but there was no such advantage. Even if children were sensitive to the distinction between biological and non-biological primes, they did not seem to be sensitive to subtle aspects of the action they observed, since there was no effect of gender congruency and since response times did not vary with different hand poses (grasping vs. static hand).

Furthermore, it is worth making note of the fact that the two mechanisms, the motor resonance evoked by the prime and the motor response induced by observing the object, seem to be independent. Indeed, with the biological prime we consistently found a facilitation.-This testifies to the fact that probably there is an overall facilitation effect induced by observation of the hand action, and that interference occurs rather late, i.e. upon object presentation.

3. Experiment 2

In order to verify whether participants develop a finer sensitivity to objects and action characteristics with age, we followed the same procedure that we used in Experiment 1 but with young adults.

3.1. Participants

Twenty undergraduate students from the University of Bologna (10 males and 10 females) with a mean age of 23.5 (range: 19 − 32) years took part in Experiment 2 for course credits. All subjects were right-handed and had normal or corrected-to-normal vision. All were naive as to the purpose of the experiment and gave written informed consent.

3.2. Apparatus, stimuli, and procedure

The apparatus, stimuli, and procedure were the same used in Experiment 1.

3.3. Results

Reaction times (RTs) for incorrect responses and RTs more than two standard deviations from each participant's overall mean were excluded from the analysis. Error trials were excluded from further analyses (4 %). The correct RTs were entered into a mixed 2 x 2 x 2 x 6 ANOVA, with the same factors as those of Experiment 1. Newman-Keuls post-hoc tests were also conducted on significant interactions.

In the ANOVA, the analysis revealed the main effects of *Object Typology* [F (1, 18) = 9.3, MSE = 3263, $p\eta_2$ = 0.34, $p < .01$]. As in the previous experiment, responses were faster when the object was neutral and slower when the stimuli were dangerous (500 vs. 515 ms, respectively), (Figure 4).

There were no other significant main effects or interactions. However, the main effect of *Prime* [F (5, 90) = 1.7, MSE = 2136, $p\eta_2$ = 0.09, $p = .12$] and the interaction *Prime* x *Participant Gender* [F (5, 90) = 1.9, MSE = 2136, $p\eta_2$ = 0.10, $p = .08$] were marginally significant. In line with the aim of investigating the gender-related resonance effect, we performed analyses separated by levels of *Participant Gender*. The main effect of *Prime* was significant as far as the males group was concerned [F (5, 45) = 3.6, MSE = 2080, $p\eta_2$ = 0.28, $p < .01$]. As revealed by the post-hoc test, participants responded faster when the prime was the grasping hand of a man (M = 473 ms) than with all other primes. More specifically, responses to the male grasping hand were faster than responses to the female grasping hand (M = 501 ms, $p < .01$), robotic grasping hand (M = 512 ms, $p < .01$), male static hand (M = 506 ms, $p = .01$), female static hand(M = 506 ms, $p = .02$), and control stimulus (M = 504 ms, $p = .01$), (Figure 5). The main effect of *Prime* was not significant for the females group [F (5, 45) = 7.5, MSE = 2191, $p\eta_2$ = 0.03, $p = .93$], but there was a significant interaction between *Object Typology* and *Category* [F (1, 9) = 7.5, MSE = 941, $p\eta_2$ = 0.46, $p = .02$]. The post-hoc test showed that responses to neutral objects were faster when they were natural and slower when they were artifacts (M = 498 vs. 518 ms, respectively, $p < .01$), while there was no difference between natural objects and artifacts when the objects were dangerous (523 vs. 520 ms, respectively, $p > .05$), (Figure 6).

We verified if a correlation was present between object dangerousness and biological prime, calculating for each subject the same indices as those of Experiment 1. A positive correlation was observed between the interference index and the facilitation index of grasping hand of a robot and biological hands (r = .69, $p < .01$). The positive correlation between the interference index and the facilitation index of non-biological primes and biological hands (r = .42, p = .06) was marginally significant, while the correlation between the interference index and the facilitation index of control stimulus and biological hands (r = -.20, p = .40) was not significant.

Moreover, we estimated if a correlation was present between object dangerousness and gender-congruency, considering the interference index produced by dangerous objects and calculating two gender-congruency indices. To obtain these indices we subtracted the male grasping hand RTs to the female grasping hand RTs for the females group, and subtracted the female grasping hand RTs to the male grasping hand RTs for the males group. Neither the correlation between the interference index and the female gender-congruency index (r = .36, p = .30) nor the correlation between the interference index and the male gender-congruency index (r = -.42, p = .22) were significant.

(Figures 4, 5, and 6 about here)

3.4. Comparison between Experiments 1 and 2

The correct RTs were entered into a mixed 2 x 2 x 2 x 2 x 6 ANOVA, with Age (children and adults) and Participant Gender (male and female) as between participants factors, and Object Typology (neutral and dangerous), Category (artifact and natural), and Prime (grasping hand of a male adult, grasping hand of a female adult, grasping hand of a robot, static hand of a male adult, static hand of a female adult, control stimulus) as within participants factors.

The analysis revealed the main effect of Age [F (1, 46) = 28.12, *MSe* = 624540, $p\eta_2$ = 0.38, $p <$ .001]. Given that the RTs of children were much slower than adults' RTs (754 vs. 508 ms, respectively), and also due to the different dimensions of the two samples, we decided to perform separate analyses for each age (reported in the Results section of each experiment), to avoid the occurrence of false interactions.

3.5. Discussion

In keeping with what found with children, adults responded more slowly to dangerous objects than to neutral ones, probably due to an interference or a blocking mechanism. Our data do not allow us to sort out which of two explanations is the most accurate. Indeed, it is possible that even dangerous objects evoke affordances, but responses to them are slowed down due to the presence of a late occurring blocking mechanism. Alternatively, it is possible that dangerous objects, even if they are potentially graspable, do not invite reaching/grasping, but rather evoke aversive affordances, since their danger is perceived from very early processing phases. Literature on approach-avoidance effects (e.g., Chen & Bargh, 1999; Freina, Baroni, Borghi, & Nicoletti, 2009; van Dantzig, Pecher, & Zwaan, 2008) has shown that positively connoted words evoke approaching movements, while the opposite is true for negative connoted words (see also studies on affective Simon effect, e.g. De Houwer, Crombez, Baeyens, & Hermans, 2001). However, in these studies emotional stimuli were put in relation to the subjects' self, as participants simulated attracting them to themselves if they were positively connoted and rejecting them if they were negative (see Lugli, Baroni, Gianelli, Borghi, & Nicoletti, in press, for introducing another addressee of approach/avoidance movements beyond the self), while in the present study participants observe the hands of others in potential interaction with objects. Previous TMS data have shown that observing pain (e.g., watching a syringe needle inserted in somebody else's hand) inhibited hand muscles through the cortical motor system (e.g., Avenanti et al., 2005). However, in our study the effect of the object might occur independently of the effect driven by the action observation. It is worth noticing that the positive correlation we found in adults between the interference index produced by dangerous objects and the facilitation obtained with biological hands over robotic hands, suggests that the two effects are at least partially related. Indeed, the correlations indicate that, the higher the motor resonance evoked by biological hands, the stronger the inhibition obtained with dangerous objects. To this end the results by Morrison and colleagues (Morrison, Tipper, Fenton-Adams, & Back, 2012) are relevant, showing with fMRI that the inferior postcentral gyrus was activated with dangerous objects, irrespective of whether a grasping or a withdrawal action relative to the object is observed. Only data on time course would allow us to more precisely determine the cause of the delay when the object is a dangerous one and to clearly determine whether affordances or aversive affordances are activated. Further observations on the mechanisms underlying inhibition will be introduced in the general discussion.

Interestingly, we discovered that adults are aware also of the distinctions between object categories. Specifically, females responded faster to natural objects than to artifacts. This result is in line with the literature (Borghi et al., 2007; Vainio et al., 2008; Anelli, Nicoletti, & Borghi, 2010) and probably depends on the activation of both manipulation and functional information with artifacts, while with natural objects only manipulation is activated. The results of our experiment build on the findings of similar research, demonstrating that participants respond differently to the

two object typologies only when they dealt with neutral objects, while with dangerous objects the perception of danger overcame more detailed categorical distinctions. It remains to be explained why females responded differently to natural objects and artifacts, while males did not. Notice, however, that in males we found evidence of a resonant mechanism, as they responded faster to the male hand prime than to the female and non-biological primes. In an important finding, the fact that they responded more quickly to the grasping hand of a man proves their sensitivity to the different motor program conveyed by the hand. This sensitivity to hand pose was not present in children, nor was it present in women. Whereas all were equally responsive to object risk level, females responded differently to object categories, while males responded differently to hand poses, revealing sensitivity to detailed aspects of action. One can speculate that this pattern has an evolutionary basis. If we consider our ancestors, it is well known that males were primarily hunters, while women had to select plants and vegetables to promote agriculture.

4. General discussion

Results clearly demonstrate that both children and adults, males and females, are sensitive to the difference between dangerous and neutral objects. Dangerous objects produce an interference, as demonstrated by the slower RTs required to process dangerous objects. Even if our data do not allow us to come down on the side of any one of the accounts discussed in the previous section, it is possible to make some speculations concerning the different underlying neural mechanisms involved during processing of dangerous, as opposed to neutral, stimuli. Studies on the emotional Stroop effect (e.g., Algom, Chajut, & Lev, 2004) reveal that response times are generally slowed down with emotional stimuli. The slowdown of responses can be attributed to an inhibition effect provoked by a selective attention mechanism, as typically characterizes the Stroop effect. Alternatively, it has been proposed that with emotional stimuli a generic slowdown brought about by the threatening character of the stimuli is present (Algom et al., 2004). This explanation is compatible with our data. However, the mechanism underlying the slowdown in response times with dangerous stimuli could also be understood in terms of the mechanisms highlighted by Caligiore and colleagues (Caligiore, Borghi, Parisi, Ellis, Cangelosi, & Baldassarre, 2012) in their research on treating cognitive conflict. Their TRoPICAL model (see also Caligiore, Borghi, Parisi, & Baldassarre, 2010) is able to account for negative compatibility effects in cases where participants are asked to respond to target-objects while refraining from responding to distractors. The model shows that the dorsal and ventral pathways process information related to both the target-object and the distractor. This model can be used to account for our data as well. Indeed, Caligiore et al. (2012) have shown that the prefrontal cortex (PFC) plays a double role, exerting both an inhibitory and an excitatory control (Knight, Staines, Swickc, & Chaocet, 1999; Munakata, Herd, Chatham, Depue, Banich, & O'Reilly, 2011). In Caligiore et al. (2012), this inhibitory control allows the model to refrain from executing the actions suggested by the distractors; similarly, since PFC can receive inputs from the emotional circuits, in our case it may allow participants to inhibit the tendency to respond to affordances in the case of dangerous objects. A further possibility (see for example Egner, Etkin, Gale, & Hirsch, 2008; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006) is that two different, separable circuits underlie cognitive and emotional conflict: a lateral PFC system resolving conflict not related to emotional stimuli, and a rostral anterior cingulate system devoted to resolving emotional conflict and associated with a top-down inhibition of the amygdala when emotional distractors were present. However, as argued recently by Munakata et al. (2011) the PFC would have an impact on inhibition related to emotional stimuli as well. Indeed, the authors showed that PFC, specialized in abstract goal-derived information, is at the basis of different forms of inhibition: a form of global inhibition involving cortical and subcortical regions, among which those related to fear processing, and a form of indirect competitive inhibition in neocortical and subcortical regions.

A second noteworthy result lies in demonstrating that children are not equally sensitive to differences in object categories (natural vs. artifacts), an ability that is nascent in children but only

appears clearly in the adult-female group. This pattern suggests a specific developmental trajectory. Even if the task requires that artifacts and natural objects be distinguished, participants of all ages respond differently to dangerous and neutral objects, with more subtle differences, such as those related to object category, emerging later in life.

A third result, the effect of primes points to the existence of a resonant mechanism that is already developed in children and which becomes progressively more fine-tuned with age. Indeed, children already resonate more to the human hand than to the non-biological primes. The simplicity of the brick leads us to exclude the possibility that faster response times were due to the lower visual complexity of the human hand prime. Crucially, the human hand prime differed not only from the brick, but also from the robotic hand. Therefore the effect can be due to a higher motor resonance when the hand resembles our own. While a higher resonance with biological, as opposed to non-biological, stimuli is already present in children, their responses did not indicate a sensitivity to gender differences. Results reveal that adults become more sensitive to subtle aspects of the biological stimuli. Indeed, male participants respond faster to hands of their own gender, characterized by a specific pose, the grasping one. Why women did not exhibit this gender-dependent motor resonance nor a sensitivity to static rather than grasping poses can be matter of further investigation. It could depend on the effect of gender stereotyping, which leads men and women to respond quicker to male hands, or on the greater attention that women paid to object characteristics, rather than actions.

Our study is, to our knowledge, the first that investigates the development of sensitivity to dangerous vs. neutral objects and to others' actions relative to dangerous objects. We advance a few hypotheses concerning the mechanisms underlying the principal effects we observed (i.e. facilitation where the prime stimuli might produce resonance, interference with dangerous objects).

Our results indicate that observing a hand in a given pose induces participants to prepare for an action, probably as a result of mediation unfolding in the mirror neuron system. This action is prepared for more quickly when the effector being observed is similar to one's own. Results show that some important changes occur during development: while children rely only on the distinction between biological hands and other prime stimuli, adults become aware of gender and postural differences in biological hands. The resonant effects we found are in line with the ideomotor theories, in particular with the Theory of Event Coding (TEC; Prinz, 1997; Hommel, Muesseler, Aschersleben, & Prinz, 2001), according to which perceived events and actions are represented by the same "event codes", and rely on the same representational code. For this reason, the greater the similarity between the observed and the performed action, the greater the facilitation in motor responses. Once the motor response is prepared, however, it has to be adapted to a specific object. Responses are fast and straightforward when neutral objects are presented. When dangerous objects are displayed, instead, longer response times are required, and this points to the intervention of a blocking mechanism. Given that in our results there was no interaction between prime and objects one is led to conclude that two different neural systems are involved, in an independent fashion: one that is possibly mediated by the mirror neuron system and triggered by the action observation, with the other possibly mediated by the canonical neuron system being triggered by the objects displayed (Rizzolatti & Craighero, 2004). The strength of this conclusion is mitigated by the correlations between the interference produced by dangerous objects and the facilitation of biological over robotic hands we found with adults, suggesting that the higher the motor resonance evoked, the stronger the inhibition obtained with dangerous objects. The absence of integration in children and of the interaction in adults could be due to the specific paradigm we used, i.e. priming. Indeed, in a recent study by Morrison et al. (2012), there is evidence of integration between action and object information. In both an imaging (fMRI) study and a tactile detection experiment, participants observed hands in a grasping or withdrawing pose relative to noxious vs. neutral objects, and were required to evaluate whether object and action were appropriate to one another. Results showed that distinct sensorimotor regions were activated with specific responses to different stimuli characteristics (i.e., kind of object, kind of action, and action-object interaction). In particular,

viewing grasping actions toward dangerous objects activates the postcentral sensorimotor cortex that integrates both object and action information to process the sensory outcomes of observed hand–object interaction. Overall, somatosensory cortices/IPL seem to anticipate the consequences of observed hand-object interaction with noxious objects, as the painful grasp condition is activated to a greater extent compared to all other conditions.

To conclude, results of the present study corroborate and widely extend previous ones, showing resonant mechanisms when interacting with dangerous objects. Further studies are necessary in order to continue to investigate this complex issue and to better understand the neural mechanisms underlying the reported behavioral effects.

References

Algom, D., Chajut, E., & Lev, S. (2004). A rational look at the emotional Stroop phenomenon: A generic slowdown, not a Stroop effect. *Journal of Experimental Psychology: General, 133*, 323-338.

Anelli, F., Nicoletti, R., & Borghi, A. M. (2010). Categorization and action: What about object consistence? *Acta Psychologica, 133*, 203-211.

Avenanti, A., Bueti, D., Galati, G., & Aglioti, S. M. (2005). Transcranial magnetic stimulation highlights the sensorimotor side of empathy for pain. *Nature Neuroscience, 8,* 955-960.

Avenanti, A., Minio-Paluello, I., Bufalari, I., & Aglioti, S. M. (2006). Stimulus-driven modulation of motor-evoked potentials during observation of others' pain. *Neuroimage, 32,* 316-324.

Avenanti, A., Sirigu, A., & Aglioti, S. M.. (2010). Racial bias reduces empathic sensorimotor resonance with other-race pain. *Current Biology, 20,* 1018-1022.

Borghi, A. M., Bonfiglioli, C., Lugli, L., Ricciardelli, P., Rubichi, S., & Nicoletti, R. (2007). Are visual stimuli sufficient to evoke motor information? Studies with hand primes. *Neuroscience Letters, 411,* 17-21.

Borghi, A. M., & Cimatti, F. (2010). Embodied cognition and beyond: Acting and sensing the body. *Neuropsychologia, 48*, 763-773.

Bruzzo, A., Borghi, A. M., & Ghirlanda, S. (2008). Hand-object interaction in perspective. *Neuroscience Letters, 441,* 61-65.

Caligiore, D., Borghi, A. M., Parisi, D. & Baldassarre, G. (2010). TRoPICALS: A computational embodied neuroscience model of experiments on compatibility effects. *Psychological Review, 117,* 1188-1228.

Caligiore, D., Borghi, A. M., Parisi, D., Ellis, R., Cangelosi, A., & Baldassarre, G. (2012). How affordances associated with a distractor object affect compatibility effects: A study with the computational model TRoPICALS. *Psychological Research.*

Calvo-Merino, B., Grèzes, J., Glaser, D. E., Passingham, R. E., & Haggard, P. (2006). Seeing or doing? Influence of visual and motor familiarity in action observation. *Current Biology, 16,* 1905–1910.

Calvo-Merino, B., Ehrenberg, S., Leung, D., & Haggard, P. (2010). Experts see it all: Configural effects in action observation. *Psychological Research, 74,* 400-406.

Chen, M., & Bargh, J. A. (1999). Consequences of automatic evaluation: Immediate behavioral predispositions to approach or avoid the stimulus. *Personality and Social Psychology Bulletin, 25,* 215-224.

De Houwer, J., Cromber, G., Baeyens, F., & Herman, D. (2001). On the generality of the affective Simon effect. *Cognition and Emotion, 15,* 189-206.

Egner, T., Etkin, A., Gale, S., & Hirsch, J. (2008). Dissociable neural systems resolve conflict from emotional versus nonemotional distracters. *Cerebral Cortex 18,* 1475-1484.

Ellis, R., & Tucker, M. (2000). Micro-affordance: the potentiation of components of action by seen objects. *British Journal of Psychology, 91,* 451-471.

Etkin, A., Egner, T., Peraza, D. M., Kandel, E. R., & Hirsch, J. (2006). Resolving emotional conflict: A role for the rostral anterior cingulate cortex in modulating activity in the amygdala. *Neuron, 51,* 871-882.

Farina, S., Tinazzi, M., Le Pera, D., & Valeriani, M. (2003). Pain-related modulation of the human motor cortex. *Neurological Research, 25,* 130–142.

Freina, L., Baroni, G., Borghi, A. M., & Nicoletti, R. (2009).Emotive concept-nouns and motor social context and stimuli valence responses: Attraction or repulsion? *Memory and Cognition, 37,* 493-499.

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston: Houghton Mifflin.

Hommel, B., Muesseler, J., Aschersleben, G., & Prinz, W. (2001). The Theory of Event Coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24,* 849-878.

Knight, R. T., Staines, W. R., Swickc, D., & Chaoc, L. L. (1999). Prefrontal cortex regulates inhibition and excitation in distributed neural networks. *Acta Psychologica, 101,* 159–178.

Le Pera, D., Graven-Nielsen, T., Valeriani, M., Oliviero, A., Di Lazzaro, V., Tonali, P. A., & Arendt-Nielsen, L. (2001). Inhibition of motor system excitability at cortical and spinal level by tonic muscle pain. *Clinical Neurophysiology, 112,* 1633-1641.

Liuzza, M.T., Setti, A., & Borghi, A. M. (2012). Kids observing other kids' hands: Visuomotor priming in children. *Consciousness & Cognition, 21,* 383-392.

Lugli, L., Baroni, G., Gianelli, C., Borghi, A. M., & Nicoletti, R. (in press). Self, others, objects: How this triadic interaction modulates our behaviour. *Memory and Cognition.*

Morrison, I., Poliakov, E., Gordon, L., & Downing, P. (2007). Response-specific effects of pain observation on motor behavior. *Cognition, 104,* 407-416.

Morrison, I., Tipper, S. P., Fenton-Adams, W. L., & Bach, P. (in press). Feeling others' painful actions: The sensorimotor integration of pain and action information. *Human Brain Mapping.*

Munakata, Y., Herd, S. A., Chatham, C. H., Depue, B. E., Banich, M. T., & O'Reilly, R. C. (2011). A unified framework for inhibitory control. *Trends in Cognitive Sciences, 15(10),* 453-459.

Nummenmaa, L., Hirvonen, J., Parkkola, R., & Hietanen, J. K. (2008). Is emotional contagion special? An fMRI study on neural systems for affective and cognitive empathy. *Neuroimage, 43,* 571-80.

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology, 9,* 129-154.

Ranzini, M. Borghi, A. M., & Nicoletti, R. (2011). With hands I do not centre! Action- and object-related effects of hand-cueing in the line bisection. *Neuropsychologia, 49,* 2918-2928.

Rizzolatti. G., & Craighero, L. (2004). The mirror neuron system. *Annual Review of Neuroscience, 27,* 169-92.

Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition, 8,* 769-800.

Vainio, L., Symes, E., Ellis, R., Tucker, M., & Ottoboni, G. (2008). On the relations between action planning, object identification, and motor representations of observed actions and objects. *Cognition, 108,* 444-465.

Van Dantzig, S., Pecher, D., & Zwaan, R. A. (2008). Approach and avoidance as action effect. *The Quarterly Journal of Experimental Psychology, 61*(9), 1298-1306.

Figure 1. Design of the experiments. In the two experiments, participants were required to perform a natural/artifact categorization task by pressing one of two designed keys. Each trial started with a fixation point (+) displayed for 500 ms in the center of the screen. Then a prime was displayed for 200 ms, followed by a white screen (SOA) for 50 ms. The target object appeared and remained on the screen until a response had been made or 2000 ms had elapsed. Finally a feedback message on reaction time (RT) was shown for 2000 ms.
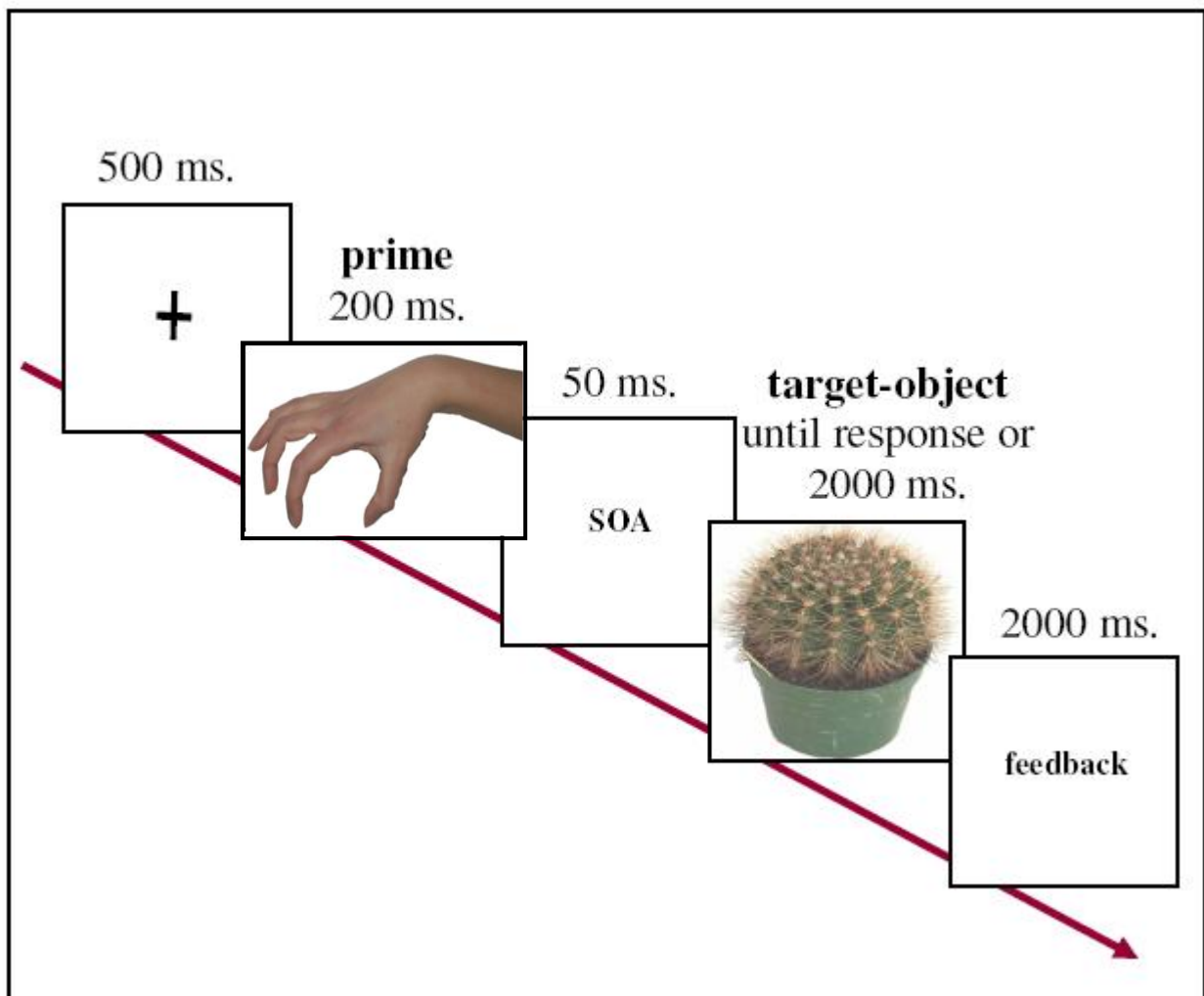
Figure 2. Significant *Object Typology* effect for RTs in Experiment 1, values are in ms and bars are SEM. Participants responded faster to neutral objects than to dangerous objects.
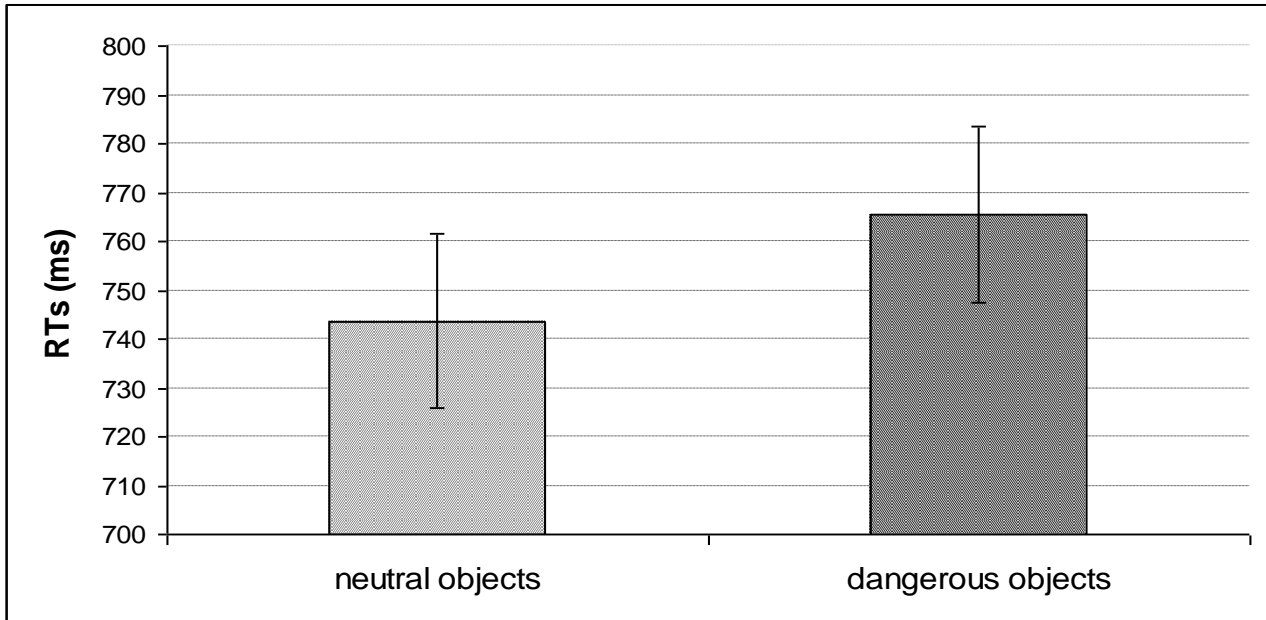
Figure 3. Significant *Prime* effect for RTs in Experiment 1, values are in ms and bars are SEM. Participants responded faster when the objects were preceded by a human hand prime (i.e. a biological hand) and slower when the objects were preceded by a robot hand and by a control stimulus (i.e. a non-biological hand).
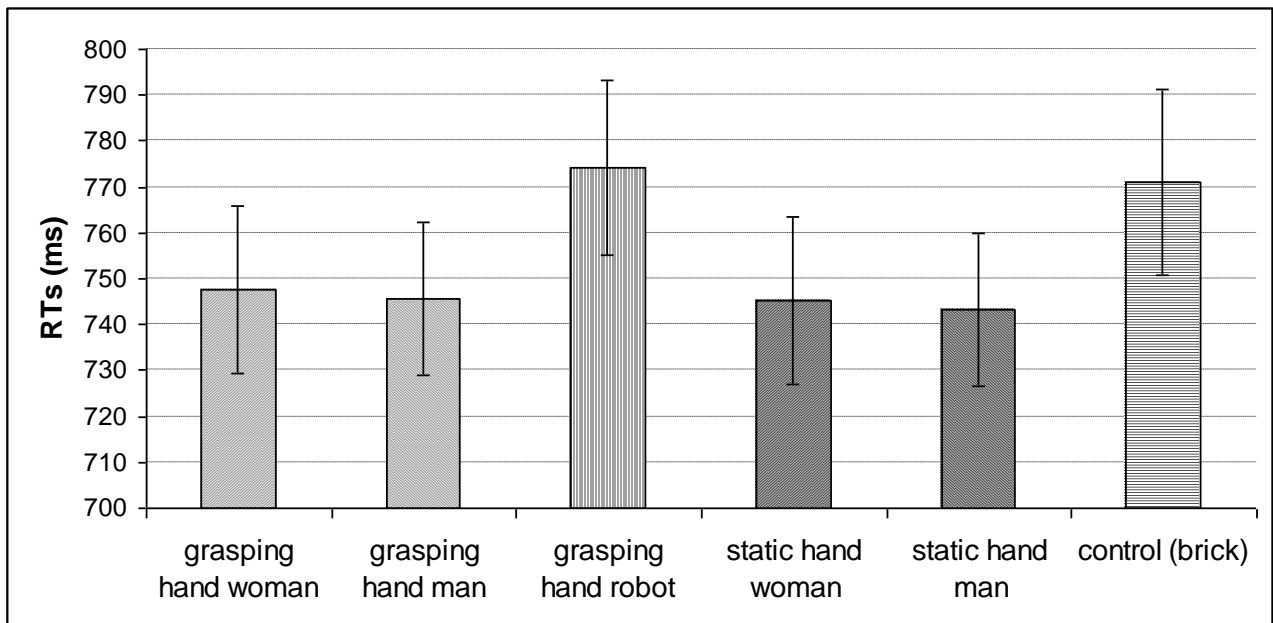
Figure 4. Significant *Object Typology* effect for RTs in Experiment 2, values are in ms and bars are SEM. Participants responded faster to neutral objects than to dangerous objects.
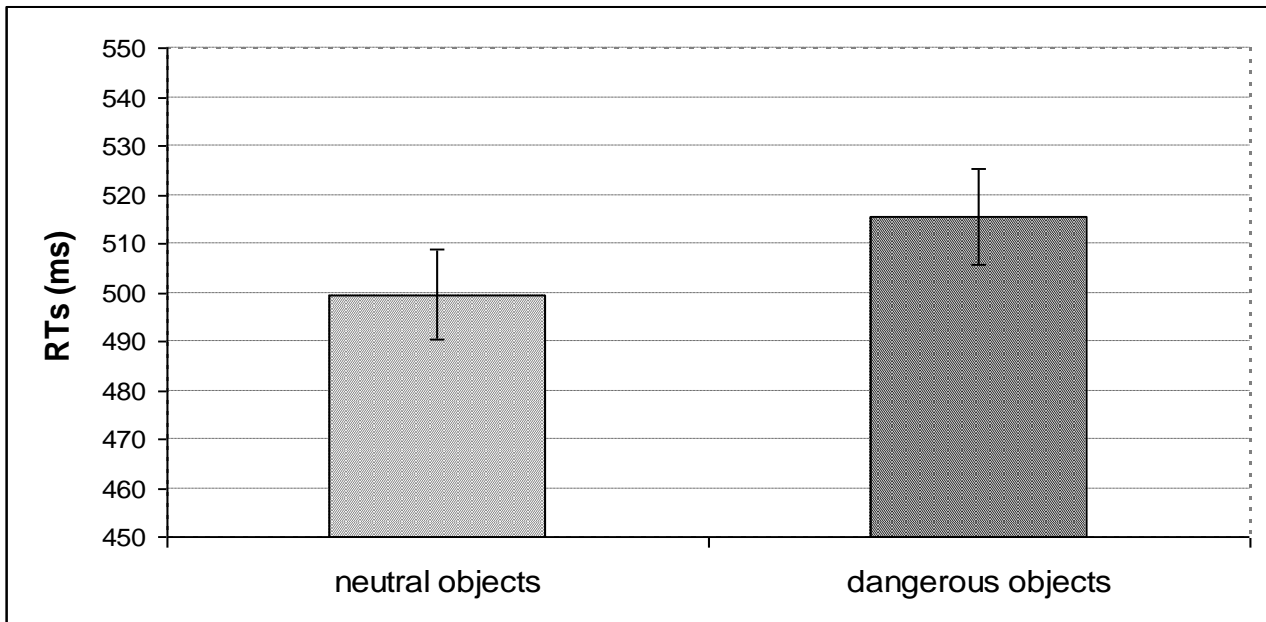
Figure 5. Significant *Prime* effect for RTs (males group) in Experiment 2, values are in ms and bars are SEM. Male participants responded faster when the objects were preceded by the grasping hand of a man and slower when the objects were preceded by all other primes.
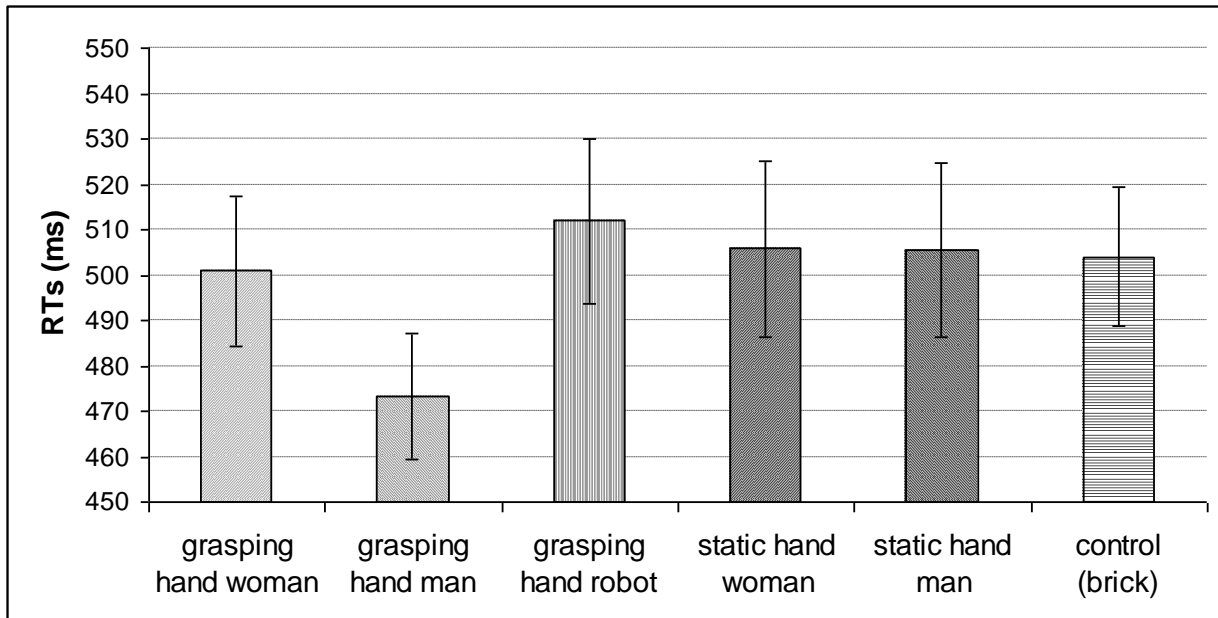
Figure 6. Significant *Object Typology* and *Category* interaction for RTs (females group) in Experiment 2, values are in ms and bars are SEM. Female participants responded faster to neutral objects when they were natural compared to when they were artifacts, while when the objects were dangerous no difference emerged between natural objects and artifacts.
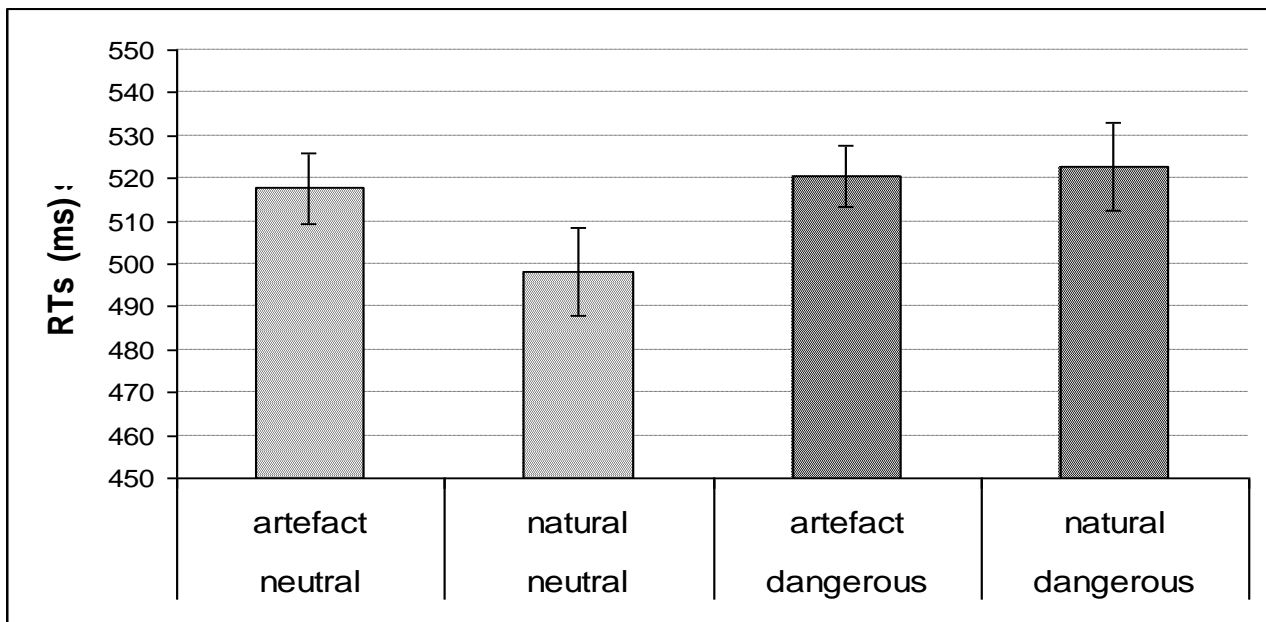
Table 1. Experimental stimuli (6 primes and 16 objects).

Prime: Control Stimulus	Prime: Grasping hand of a robot
Prime: Grasping hand of a male	Prime: Grasping hand of a female
Prime: Static hand of a male	Prime: Static hand of a female
Objects	
Bulb	Broken bulb
Glass	Broken glass

Tomato	Cactus
Cat	Scorpio
Chick	Husk
Plant	Porcupine
Spoon	Knife

Lighted out match	Lighted match