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Title:

Motor inhibition to dangerous objects: Electrophysiological evidence for task-dependent aversive affordances

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ABSTRACT

Previous work suggests that perception of an object automatically facilitates actions related to object grasping and manipulation. Recently, the notion of automaticity has been challenged by behavioral studies suggesting that dangerous objects elicit aversive affordances that interfere with encoding of an object's motor properties; however, related electrophysiological studies have provided little support for these claims. We sought EEG evidence that would support the operation of an inhibitory mechanism that interferes with the motor encoding of dangerous objects and we investigated whether such mechanism would be modulated by the perceived distance of an object and the goal of a given task. Electroencephalograms were recorded by 24 participants who passively perceived dangerous and neutral objects in their peripersonal, boundary or extrapersonal space and performed either a reachability judgment task or a categorization task. Our results showed that greater attention, reflected in the visual P1 potential, was drawn by dangerous and reachable objects. Crucially, a frontal N2 potential, associated with motor inhibition, was larger for dangerous objects only when participants performed a reachability judgment task. Furthermore, a larger parietal P3b potential for dangerous objects indicated the greater difficulty in linking a dangerous object to the appropriate response, especially when it was located in the participants' extrapersonal space. Taken together, our results show that perception of dangerous objects elicits aversive affordances in a task-dependent

way and provides evidence for the operation of a neural mechanism that does not code affordances of dangerous objects automatically, but rather on the basis of contextual information.

INTRODUCTION

A well-established concept in object perception research, is that the passive observation of graspable objects can potentiate the possible actions that we can perform with them (Grafton et al., 1997; Grèzes et al., 2003; Rice et al., 2007; Tucker & Ellis, 1998, 2001; Ellis & Tucker, 2000). This phenomenon is related to the concept of 'affordances' (Gibson, 1977) which has been a topic of great interest in literature and has been a matter of theoretical debate (for a recent review, see Osiurak et al., 2017). Here, we will refer to the term 'affordances' to indicate the action possibilities offered to an individual from the environment, and more specifically when an individual perceives a graspable object (Chemero, 2003; Borghi & Riggio, 2015). Actions can be 'afforded' or potentiated when certain object features are compatible with the motor capacities of the perceiver (Ellis & Tucker, 2000; Tucker & Ellis, 2004). For example, it has been shown that motor responses are facilitated when the object size is congruent with the shape of the hand grip (Ellis & Tucker, 2000) or when the handle is spatially compatible with the side of the responding hand (Riggio et al., 2008; Symes et al., 2005), even if the size and the handle position are not relevant to a given task. In recent years the view that affordances are always activated automatically, independently from the task or context, has been challenged (for reviews, see van Elk et al., 2014; Borghi, 2019; Ellis, 2018). Much evidence has been provided, showing that activation of affordances is task- and context- dependent and may rely on the goals and intentions of the perceiver. Affordances are not activated in tasks that involve only processing of superficial object features, such as color (e.g. Tipper et al., 2006; Pellicano et al., 2010). Furthermore, their activation is influenced by the context, for example by the presence of other objects (e.g. Borghi et al., 2012; Xu et al., 2015; Yoon et al., 2010), by the scene in which they are embedded (e.g. Kalénine et al., 2014) and by the distance between the object and the agent (Costantini et al., 2010; Ellis et al., 2013). For example, evidence shows that affordances are activated only or to a larger extent when they are placed in a person's reachable space (Costantini et al., 2011; Cardellicchio et al., 2011; Kalénine et al., 2016; Rowe et al., 2017; Previc, 1998).

The reachable space, also called 'peripersonal' space for action, is particularly relevant for our interactions with the environment, as it represents the private area surrounding the body (Rizzolatti et al., 1997; Holmes & Spence, 2004) and delineates the immediate dimension in which we can directly act upon objects (di Pellegrino & Ladavas, 2015). By contrast, the space that is beyond this boundary, also known as 'extrapersonal' space, represents the area that cannot be reached directly (Previc, 1998; Holmes & Spence, 2004). Objects that are placed in the margin of the peripersonal space rapidly attract attention, especially if they represent a threat to the individual's safety (Graziano & Cook, 2006). Indeed, it has been demonstrated that dangerous stimuli are detected faster and prioritized in visual selection compared to neutral ones (Ohman et al., 2001; Schmidt et al., 2014, Blanchette, 2006; Smith et al., 2003; Zhao, 2016). When a dangerous object is detected in the environment, individuals need to act quickly, preparing the body to a defensive reaction, typically indicated as a flight or fight (Pichon et al., 2012; Brown et al., 1969).

The urgency to act in response to threats increases when the dangerous stimuli are physically closer (Pichon et al., 2012). However, according to 'the threat-signal hypothesis' (Cole et al., 2013), dangerous objects may also lead to a perceptual bias, and appear to be physically closer compared to non-threatening ones. Similarly, threatening faces are perceived as closer in space than disgusting or neutral ones (Cole et al., 2013). Coello et al. (2012) showed that when an individual makes reachability judgements, a dangerous object is perceived closer when the threatening part is oriented towards the participants, compared to when it is oriented away from them.

It is believed that reachability judgments are made in relation to the action possibilities that an object offers and that they involve the mental representation of the actual reaching action and the anticipated sensory and spatial consequences (Delevoye-Turrell et al., 2010). This suggests that the shift of attention towards action-related features of an object may be critical to trigger the activation of affordances (Hommel et al., 2001; Sevos et al., 2016). Interestingly, whereas neuroimaging (Makin et al., 2007; Gentile et al., 2011; Bartolo et al., 2014; Delevoye-Turrell,et al., 2010) and electrophysiological (EEG) (Sambo & Foster, 2008; Goslin et al., 2012; Valdés-Conroy et al., 2014) investigations have suggested that the display of reachable objects can automatically activate motor brain networks, other studies have challenged the notion of automaticity, showing that task goals and hand postures may have a critical modulatory influence on sensorimotor representations (Thill et al., 2013). Bub & Masson (2010) showed that the compatibility effect (i.e. faster responses when the handle is aligned with the hand) emerges only when participants were required to make a reach and grasp response, but not when the task required a key press. Witt et al. (2005) demonstrated that when participants held a tool with the intention to use it, the perceived boundary of the peripersonal space was expanded. However, when participants did not intend to reach an object, the extent of the perceived boundary of the peripersonal space was the same, with or without holding a tool. Wamain et al. (2016)

demonstrated that EEG activity over motor areas was modulated by the location of the object only when the participant was asked to make a reachability judgment, but not when performing an object discrimination task. Furthermore, it has been shown that prefrontal areas associated to top-down control can contribute to updating the neural representations of objects and contexts suitable for controlling movements so as to best pursue the person's goals (Hamilton & Grafton, 1993; Fogassi et al., 2005). More specifically, reciprocal fronto-parietal and fronto-temporal connections (Fuster, 2008; Chelazzi et al., 1993) are critically involved in the top-down affordance processing control according to environmental contexts and attentional resources availability (Colby and Goldberg, 1999; Knudsen, 2007).

To summarize, previous research suggests that objects placed in the peripersonal space can rapidly attract our attention, and that the perception of proximity might be amplified when the object is dangerous, because it represents an immediate threat to our safety. However, the processing of object motor-related information and the activation of affordances does not occur automatically when objects are reachable, but it depends on a given the task goal, for example when participants have to estimate the reachability, but not when they have to judge other object features (i.e. categorize the object). Behavioral studies on the perception of dangerous objects showed that, whereas neutral stimuli facilitate actions, eliciting faster responses, dangerous objects generate an 'interference' effect that slows down the motor response, which occurs independently of the task (e.g. categorization vs. bisection) or the display of an hand prime (Anelli et al., 2012; 2013a). In addition, Anelli et al. (2013b) investigated whether the dynamic presentation of neutral and dangerous stimuli (objects moving toward or away from the observer) would modulate the behavioral response. The results showed that responses were slower when dangerous objects moved toward the participants, suggesting that perception of dangerous objects may evoke aversive affordances, reflected in response inhibition. However, recent EEG studies seem to indicate that this is not the case. Liu et al. (2017; 2018a; 2018b) investigated the event-related potentials (ERPs) in response to dangerous objects combining a motor priming paradigm (Anelli et al., 2012) with a Go/NoGo task. Results showed that dangerous objects elicited a larger parietal P3 (P3b) potential compared to neutral ones in the Go but not in the NoGo trials, which was interpreted as an indication of recruitment of additional attentional resources when perceiving dangerous objects (Israel et al., 1980). In a later study, Cao et al. (2020) modified the perceptual salience of two stimuli in a similar motor priming paradigm combined with a shape categorization task and found a larger frontal P3 (P3a) for dangerous objects compared to safe objects, but only for objects with relatively small perceptual salience. Interestingly, the frontal N2 potential, typically associated with motor inhibition (Falkenstein et al., 1999; Smith et al., 2007) was similar in response to dangerous and neutral stimuli, providing no evidence that dangerous objects are automatically encoded in motor terms and elicit aversive affordances. However, all EEG studies on processing of dangerous objects (Liu et al., 2017; 2018a; 2018b; Cao et al., 2020) have been limited to stimuli with low ecological validity (e.g. round vs. rectangular saw blades) and a narrow range of cognitive tasks (Go/NoGo and shape categorization tasks).

The aim of the present study was to investigate the processing of dangerous objects with a larger set of graspable stimuli and to clarify whether the location of the object and the goal of the task modulate the encoding of the object's motor properties. In order to test our hypotheses, we used a paradigm similar to Wamain et al. (2016) to design a controlled EEG experiment including a large set of graspable stimuli. Stimuli were rated through an online questionnaire by an independent sample of participants and then divided in two categories (dangerous vs neutral). A pre-experiment session was conducted prior to the main experiment in order to determine the extent of the perceived peripersonal space for each participant. In the main experiment, the selected dangerous and neutral objects were presented in three different spaces (peripersonal, boundary and extrapersonal) according to the subjective perceived maximum reachable point. Participants were asked to perform a reachability judgment task and a categorization task. We predicted that the dangerous objects would elicit distinct ERPs, which would be differently modulated by the location of the objects and by the goal of the perceptual task.

More specifically, we hypothesized that the participants would pay more attention to dangerous objects especially when they are located within their peripersonal space. We predicted that this would be reflected in an enlarged amplitude of the occipital P1 potential, which is considered an index of attentional processes toward relevant stimuli attributes (Johannes et al., 1995; Hillyard & Anllo-Vento, 1998; Hermann & Knight, 2001). In addition, we hypothesized that a reaching action towards the object would be inhibited when the participants judge the reachability of an object (Delevoye-Turrell et al., 2010), more so in the case of a dangerous object. Consequently, we predicted a larger amplitude of the frontal N2 potential in reachability judgments of dangerous objects, possibly when they are located close to the observer. Moreover, we predicted that activation of the link connecting the displayed object to the appropriate action towards it should be reflected in the amplitude of the parietal P3b potential (Verleger, 2020), which should be larger when the participants perceive a dangerous object (Cao et al., 2020).

METHODS

Participants

Twenty-four healthy right-handed participants (16 female and 8 male; age range = 18-28; mean age = 21.46 years, *SD* = 2.9 years) took part in the experiment. The sample size was chosen according to previous EEG investigations (Liu et al., 2017; Cao et al., 2020). All participants had normal or corrected to normal visual acuity. The experiment was approved by the University of Stirling Ethics Committee and all participants provided their written informed consent.

Stimuli

Stimuli consisted of 16 color pictures of non-living objects, half of which would be normally grasped with a precision grip and the other half with a power grip (Table 1). There were two categories (dangerous/neutral) with 8 objects each. The objects were rated by an independent group of 104 participants on a five point Likert scale (Likert, 1932) according to harmfulness (danger/neutral), harmfulness to people (if used towards other people), knowledge (familiarity), dangerousness to grasp, visual complexity and belonging to the category of artifacts or natural objects (typicality). Paired sample t-tests revealed significant differences for harmfulness [$t(7) = 8.73$, $p < .001$], for harmfulness to people [$t(7) = 9.453$, $p < .001$] and dangerousness to grasp [$t(7) = 11.789$, $p < .001$], but no difference for familiarity, visual complexity or typicality. In addition, 8 pictures of plants selected online were used for the categorization task.

Table 1: Objects used in the main experiment.

	Precision grip	***Power grip***
Neutral objects	Pencil Dental mirror Car keys Battery	Ping-Pong racket Kettle Flask Bulb
Dangerous objects	Syringe Scalpel Fishing hook Firecracker	Pruning saw Gun Dagger Axe

All objects were processed with Gimp 2.0 in order to remove the background and presented at two different orientations (i.e. graspable part to the left or to the right, Figure 1). Each object was linearly scaled and shaded to enhance the 3D perception. They were presented in their original shape and placed in different locations, according to individual perceived peripersonal space, in the middle of a table with a black background. The images were projected on an 86" projection screen using a projector in a dark room. The visual scene consisted of an image 180 cm x 150 cm. All stimuli were presented at -35 cm, -30 cm, -25 cm (peripersonal space), -5 cm, 0, +5 cm (boundary space), + 25 cm, +30 cm, +35 cm (extrapersonal space) of the perceived maximum reachable space.

[FIGURE 1 ABOUT HERE]

Procedure

Determination of perceived maximum reachable space.

A pre-experiment session was used to determine the extent of the perceived maximum reachable space. Three different objects (a ball, a bowling pin, and a glass) were presented on the table. Each object was linearly scaled and shaded to enhance the 3D perception. The images were projected via E-prime 3.0 on an 86" projection screen using a projector in the same dark room of the main experiment. The visual scene consisted of an image 180 cm x 150 cm. The locations of the objects randomly varied between 5 cm from the edge of the table and 145 cm in steps of 5 cm (29 locations). Each object was shown 10 times in each location, which resulted in a total of 348 trials. Participants were comfortably seated on a chair 100 cm away from the screen and asked to judge whether the object was reachable/not reachable from their position without moving or stretching the arm or the shoulder. Each image remained on the screen until a verbal response was provided. Answers were provided vocally and recorded by the experimenter. The boundary of perceived maximum reachable space was determined using a maximum likelihood method based on the second-order derivatives (quasi-newton method) to obtain the logit regression model that best fitted the participants reachable/unreachable space using the equation: $y = e\ (\alpha + \beta X)/(1 + e\ (\alpha + \beta X)$, in which y was the participant's response, X was the distance of the stimulus, and (α / β) was the critical value of X corresponding to the transition between reachable/unreachable stimuli, thus expressing the perceived maximum reachable space (Wamain et al., 2016). The individual perceived maximal reachable space was used to select the location of the objects presented in the main experiment. The length of the participants' right arm and maximal reachable actual point (i.e. maximal point reachable on a table with the right finger) was measured.

Main experiment

In the main experiment, participants were firstly informed that they would have to perform two different tasks: a Reachability Judgment task (RJT) and a Discrimination - Categorization task (DCT). Figure 2 illustrates the sequence of two trials for both RJT and the DCT. For both tasks, objects were presented centrally at different locations for 1000ms; the inter-stimulus interval randomly varied between 1500-1900 ms (Proverbio et al., 2012; Wamain et al., 2016). The combination of category (neutral/dangerous) and location (9 locations, 3 for each space - peripersonal, boundary and extrapersonal) was randomly selected for each trial. After the display of the object, a question ('Reachable?' for RJT, 'Natural?' for the DCT) appeared in 20% of the trials for each block (catch trials). Participants were asked to respond as fast as possible by pressing a foot-pedal either with the left or with the right foot. Questions remained on the screen until the answer was provided. In the RJT participants indicated whether the object was reachable or not reachable from their position without moving or stretching the arm or their shoulder. Participants performed a total of 432 trials divided in 4 experimental blocks. In the DCT participants were shown also images of the plants and they were asked to indicate whether the object was natural or not. Participants performed a total of 504 trials divided in 6 experimental blocks; Trials in which the plants appeared (72 trials in total) were excluded from the analysis. In each task, there were 72 trials per space for neutral objects and 72 trials per space for dangerous objects. The order of the two tasks and the side of the response (left/right) was counterbalanced across participants.

[FIGURE 2 ABOUT HERE]

Data acquisition

Behavioral data

Behavioral data were recorded by the foot-pedal box on which participants had placed their feet.

Electrophysiological data

EEG data were continuously recorded continuously with Ag/AgCl electrodes from 64 scalp electrodes (Neuroscan system). The electrodes were positioned following the International 10-20 system. Vertical and horizontal eye movements were monitored using two pairs of electro-oculography (EOG) electrodes placed above and below the left eye and lateral to the external side of the eyes. EEG and EOG signals were amplified with a band-pass of 0–250 Hz.

Data Processing and Analysis

Electrophysiological data

EEG data analysis was performed using BrainVision Analyzer software (Brain Products GmbH, Gilching, Germany). Data were high-pass filtered at 0.05 Hz and low-pass filtered at 50 Hz. Data were re-referenced to the mean of the left and right mastoid electrodes. Ocular correction was performed using an infomax Independent Component Analysis. Data were segmented into epochs from 500ms before to 1500ms after the stimulus onset. Epochs contaminated by artifacts were rejected using an Automatic artifact rejection method. An epoch was rejected if the difference between the minimum and the maximum value of a single channel exceeded 100 µV. On average, 5.5% of epochs per condition was excluded from the analysis after artifact rejection. Data were baseline corrected (-200ms to 0) and then averaged across participants. The ERPs were identified by visual inspection of the grand average of the different conditions during the relevant time window. ERP amplitudes were quantified by pooling the activity of neighboring electrodes within the time periods of interest (for details, see Results).

Statistical analyses of EEG data were performed by 2x2x3 ANOVAs (Greenhouse-Geisser corrected) with factors Category (dangerous vs neutral), Task (DCT vs RJT) and Space (peripersonal vs boundary vs extrapersonal). Significant interactions were further investigated via post-hoc paired t-tests.

RESULTS

Behavioral Data

In the pre-experiment data, we found that the boundary of the perceived maximal reachable space (perceived reachable space = 49.0 ± 7.6cm) corresponded to a 19.9% overestimation of the actual reachable space (reachable space = 39.2 ± 5.7cm). Although participants were required to provide a response only in the 20% of trials (catch trials), 2x3 ANOVAs with factors Category (dangerous vs neutral) and Space (peripersonal vs boundary vs extrapersonal) repeated measures ANOVAs were conducted to assess differences between reaction times separately for the RTJ and the DCT. The Greenhouse-Geisser was used where the assumption of sphericity was violated and post-hoc paired sample t-tests were adjusted using Bonferroni correction. In the RTJ a main effect of Space ($F(1, 21) = 16.33$, $p < .001$, $\eta_p^2 = .438$) revealed that participants were slower in the judgment of the boundary space compared to the extrapersonal ($t(21) = -6.85$, $p < .001$) and to the peripersonal one ($t(21) = 3.817$, $p < 001$). In the DCT, the ANOVA did not reveal any significant main effects or interaction ($p > .05$). Generally, participants were slower for dangerous compared to neutral objects in both the RTJ (dangerous = 1069.0 ± 314; neutral = 996.8 ± 340) and the DCT (dangerous = 1093.7 ± 229.7; neutral = 1053.1±252.2) but the comparisons did not reach the statistical significance ($p > .05$).

Electrophysiological data

As expected, the inspection of the EEG data revealed that the onset of the stimuli elicited an occipital P1, a frontal N2 and a parietal P3b. We also identified a large frontal N400, which was also analyzed in order to have a complete picture of all the cognitive processes that are related to object affordances.

P1

The P1 was quantified as the mean amplitude of electrodes O1, O2 and Oz between 150 and 180ms after object onset. The ANOVA revealed a main effect of Category ($F(1, 23) = 8.61$, $p <.01$, $\eta_p^2 = .272$, Figure 3) showing that the P1 was larger for dangerous objects compared to neutral objects. Also, a main effect of Space ($F(1, 23) = 3.83$, $p <.05$, $\eta_p^2 = .143$) showed that the P1 was larger when objects were presented closer to the participant. Post hoc paired sample t-tests showed a statistically significant difference between boundary and extrapersonal space ($t(23) = 2.76$, $p < .05$) and a marginally significant difference peripersonal extrapersonal space ($t(23)=1.86$, $p = .075$). There were no other statistically significant main effects or interactions ($p > .05$).

[FIGURE 3 ABOUT HERE]

N2

The N2 was quantified as the mean amplitude of electrodes FPz, FP1, FP2, AF3, AF4, Fz, F1, F2 between 200ms and 260ms after object onset. A main effect of Category ($F(1, 23) = 5.69$, $p < .05$, $\eta_p^2 = .198$) showed that N2 was larger for dangerous compared to neutral objects. Moreover, there was a significant Category x Task interaction ($F(1, 23) = 6.83$, $p < .05$, $\eta_p^2 = .229$, Figure 4). Post hoc paired sample t-tests showed that the N2 was larger in the RJT for dangerous compared to neutral objects ($t(23) = -3.09$, $p < .01$) whereas there was no difference in the DCT, ($p = .503$). There were no other significant main effects or interactions ($p > .05$).

[FIGURE 4 ABOUT HERE]

P3b

The P3b was quantified as the mean amplitude of electrodes Pz, POz, P1, P2, PO3 and PO4 between 315ms and 375ms after object onset. A main effect of the Category ($F(1, 23) = 36.82$, $p < .001$, $\eta_p^2 = .616$) revealed that the P3b was significantly larger for dangerous compared to neutral objects. In addition there was a significant Category x Space interaction ($F(1, 23) = 3.53$, $p < .05$, $\eta_p^2 = .133$, Figure 5), because the difference in P3b amplitude between dangerous and neutral objects was significantly larger in the peripersonal space compared to the difference in the boundary ($t(23) = 2.80$, $p < .01$) and marginally significant to the difference in the extrapersonal space ($t(23) = 2.05$, $p = .051$).

The main effect of Space ($F(1,23) = 17.53$, $p < .001$, $\eta_p^2 = .433$) indicated that the amplitude of the P3b was inversely related to perceived reachable space. More specifically, the P3b was smaller in the peripersonal space compared to the boundary ($t(23) = -4.60$, $p < .001$) or to the extrapersonal space ($t(23) = -4.28$, $p <.001$), but not in the boundary compared to the extrapersonal space ($t(23) = -1.87$, $p = .074$). Furthermore, a significant Task x Space interaction ($F(1, 23) = 3.69$, $p < .05$, $\eta_p^2 = .138$) indicated that the P3b was larger in the DCT compared to the RJT when the object was placed in the peripersonal space ($t(23) = -2.18$, $p < .05$), but not in the boundary ($p = .121$) or in the extrapersonal space ($p = .727$). There were no other significant main effects or interactions ($p > .05$).

[FIGURE 5 ABOUT HERE]

N400

The N400 was quantified as the mean amplitude of electrodes FPz, FP1, FP2, AF3, AF4, Fz, F1, F2 between 450ms and 510ms after the onset of the object. The ANOVA revealed a main effect of Space ($F(1, 23) = 6.82$, $p < .05$, $\eta_p^2 = .229$) showing that the N400 decreased with the perceived reachable space. The N400 was larger when the object was placed in the peripersonal space compared to the boundary ($t(23) = 2.52$, $p < .05$) or to the extrapersonal space ($t(23) = -2.70$, $p < .05$) and in the boundary compared to the extrapersonal space ($t(23) = -2.27$, $p < .05$). There were no other significant main effects or interactions ($p > .05$).

DISCUSSION

We employed high-density electroencephalography to investigate the cognitive mechanisms associated with the processing of dangerous and neutral objects in relation to their perceived distance from a passive observer. Our results show that the participants paid more attention to objects that were presented closer to them, especially to dangerous ones. Importantly, our results demonstrate that affordances of dangerous objects were task-dependent and were coded around 200ms after object onset. Furthermore, we found evidence for higher processing demands that link the perception of dangerous objects to the representation of the relevant actions compared to neutral objects, especially when they are perceived in one's peripersonal space.

Our first hypothesis was that object location and dangerousness would modulate attentional processes. We focused our analysis on the occipital P1 potential, which is considered an index of early visual attentional processes (Johannes et al., 1995; Hillyard & Anllo-Vento, 1998; Hermann & Knight, 2001). The P1 was larger for objects that were presented within the observer's peripersonal space and for dangerous objects compared to neutral ones, regardless of the task. Previous studies showed that graspable objects located in the peripersonal space automatically activate attentional mechanisms that facilitate a potential interaction with proximal objects (Gallivan et al., 2009; Spence & Paris, 2010; Valdés-Conroy et al., 2014; Anderson et al., 2002). However, in addition to object location, attention may be driven by other object characteristics, such as visually or functionally salient features (Pellicano et al., 2010; Kourtis & Vingerhoets, 2015) and its perceived threat value. Stimuli that pose a threat to ourselves or others are detected faster than neutral stimuli (Ohman et al., 2001; Blanchette, 2006; Smith et al., 2003; Zhao, 2016) and prime our attention in order to enhance body responsiveness and preparation of defensive mechanisms, typically referred to as flight or fight reactions (Pichon et al., 2012; Brown et al., 1969). Accordingly, the modulation of the P1 shows that automatic allocation of attention depends on the proximity as well as the perceived dangerousness of an object regardless of the task performed.

Our second hypothesis was that a reaching action towards the object would be inhibited when the participants judge the reachability of a dangerous object. We investigated the amplitude modulation of the N2 potential, a fronto-central negativity, which is typically considered as an index of action inhibition (Munro et al., 2007; Bokura et al., 2002; Schmajuk et al., 2006; Kok et al., 2004; Pliszka et al., 2000; Huster et al., 2013). Our analysis showed that the N2 was larger in relation to the display of dangerous objects compared to neutral ones, but it was unaffected by the proximity of the objects. This finding is in line with the notion that perception of dangerous objects may evoke aversive affordances (Anelli et al., 2012; 2013a; 2013b). Importantly, this difference was significant only when participants made a reachability judgement, but not when they categorized the objects. This suggests the operation of a fast inhibitory mechanism (i.e. ~200ms after object onset) that depends on the perceived dangerousness of an object. The onset of such inhibitory mechanism is consistent with previous findings (Proverbio et al., 2011; 2012; 2013; Rowe et al., 2017). In addition, the present study demonstrates for the first time that coding of object affordances for dangerous objects is not a fully automatic process, but it rather depends on contextual information. This result is similar with data on affordances evoked by neutral objects in context obtained by a large number of behavioral (reviews in van Elk et al., 2014; Borghi & Riggio, 2015) and neurophysiological and brain imaging studies (Fogassi et al., 2005 and Thill et al. 2013 for a review).

Previous EEG research on object affordances, showed that N2 may reflect the strength of the perception-action coupling (Wokke et al., 2016), is larger in response to the observation of tools compared to non-tools (Proverbio et al., 2011; 2012; 2013), and depends on the type of the grip (i.e. precision v. power) that a person uses in order to handle an object (Rowe et al. 2017).

Furthermore, Proverbio et al. (2011) suggested that the N2 that is elicited by the observation of tools is partially generated by the left premotor cortex and left somatosensory cortex, which is consistent with the operation of a left-lateralized ‘praxis’ network that codes object-directed movements (e.g. Vingerhoets et al., 2012). This further corroborates our hypothesis that the N2 in the present study reflects task-dependent inhibition of the motor system, which is more pertinent in the presence of dangerous objects (Anelli et al., 2012; 2013a; 2013b). It should be noted that previous EEG investigations on object perception have not reported a significant effect of the object’s dangerousness on the N2 amplitude (Liu et al., 2017; 2018a; 2018b; Cao et al., 2020). We believe that the apparent discrepancy with the results of the present study may be attributed to differences in the experimental design. These studies involved the performance of motor priming tasks, in which a dangerous or a neutral/safe object was always preceded by the display of a hand. It is plausible that the N2 did not reflect only object processing, but it was possibly influenced by a motor resonance mechanism induced by the perception of the preceding hand (Anelli et al., 2013a). Nevertheless, further investigation is needed in order to clarify the source of this apparent discrepancy.

Our third hypothesis was that the activation of the link between a perceived object and the appropriate motor response will be affected by the dangerousness of the object. To verify this, we focused on the parietal P3b potential. The P3b in the present study was larger in relation to dangerous objects compared to neutral ones and this difference was greater when the objects were located within the observer’s peripersonal space. The P3b is an endogenous cognitive potential, the functional significance of which is still a matter of debate. It has been considered to reflect context updating (Donchin & Coles, 1988) and working memory processes (Polich, 2007), although it is likely that it is indirectly associated with working memory, reflecting reactivation of stimulus-response links (Verleger et al., 2017; Verleger 2020). In line with this account, which states that the P3b does not simply reflect stimulus processing mechanisms, other EEG studies suggest that it is related to response selection (Falkenstein et al. 1995; Koivisto & Revonsuo, 2003) and that its amplitude is enlarged by the difficulty of the task (Sawaki & Katayama, 2009; Waszak et al., 2005). Hence, our results suggest that the selection of the appropriate action toward an object is a more cognitively demanding process for dangerous objects compared to neutral objects, especially when they are located within reachable distance. Our results extend findings from previous EEG studies on perception of dangerous objects (Liu et al., 2017; 2018a; 2018b; Cao et al., 2020), highlighting the importance of the reachability of a dangerous object.

Moreover, the P3b was larger when the objects were located in the observer's extrapersonal space, suggesting the activation of a link between an object and the appropriate action was a more demanding process when the object was located outside the observer's reach. This is consistent with previous studies that showed that activation of actions related to a graspable object is largely affected by the proximity of the object to the perceiver (Cardellicchio et al., 2011; Costantini et al., 2010). We also found a significant interaction between task and space, because the P3b was smaller in the reachability judgment task only when the object was located in the peripersonal space. This shows that linking the perception of a proximal object to the appropriate action is easier in reachability judgements compared to categorization of the object, possibly because the proximity of the object facilitates action representation. Overall, our results agree with data supporting the key role of fronto-parietal and fronto-temporal connections in attention modulation and in the on-line control of visually guided movements (Andersen & Buneo, 2002; Buneo & Andersen, 2006; Colby & Goldberg, 1999; Knudsen, 2007) through the augmentation of the neural sensitivity related to the salient features of objects (Carrasco et al., 2000).

In addition to the modulation of the ERPs of main interest, we observed a frontal negativity peaking around 480ms after stimulus onset, the amplitude of which was inversely related to the distance between object and the observer. This negativity could be considered as the N400 potential which is considered as the brain's response to any type of meaningful stimulus (Kutas & Federmeier, 2011) in language, (Kutas & Hillyard, 1980; Johnson & Hamm, 2000), pictorial stimuli (Hamm et al., 2002), mathematics (Niedeggen et al., 1999), gestures (Wu & Coulson, 2011), action-outcome relationships (Bach et al., 2009) and mismatches between objects and selected actions (Sitnikova et al., 2003). The frontal distribution of the N400 in the present study is consistent with previous findings that showed that the action-related N400 has a more frontal focus compared to the language-related N400 (Amoruso et al., 2013). Previous work on object affordances suggests that recognition of action-related tool properties requires the recall of motor and semantic information, stored in a broad fronto-parietal visuomotor network (Natraj et al., 2013; 2018; Ramayya et al., 2010). Furthermore, Natraj et al. (2013) reported smaller N400-like amplitudes when pairs of objects were presented together with an interacting hand, which presumably constrained the action possibilities for the observer (Natraj et al., 2018). Taking everything into consideration, it is plausible that the decreased N400 in the present study when an object was located in the extrapersonal space reflects the limited action possibilities to interact with the object. This is in agreement with the view that activation of object affordances is not a purely automatic process, but rather depends on contextual information, such as the proximity of the object (van Elk et al., 2014; Borghi & Riggio, 2015).

To summarize, the present study demonstrates that visual perception of a dangerous graspable object requires the engagement of greater attentional resources compared to a neutral object. Importantly, we provide evidence that aversive affordances are coded ~200ms after the display of a dangerous object when a passive observer estimates the distance of the object on the basis of its perceived reachability. Furthermore, our results suggest that linking the perception of a dangerous object to the representation of the corresponding grasping action is a cognitively demanding process, especially when the object is located outside a person's peripersonal space. In conclusion, the present study provides strong electrophysiological evidence that challenges the notion of automaticity of object affordances, supporting the operation of a flexible mechanism that codes affordances of dangerous objects on the basis of contextual information.

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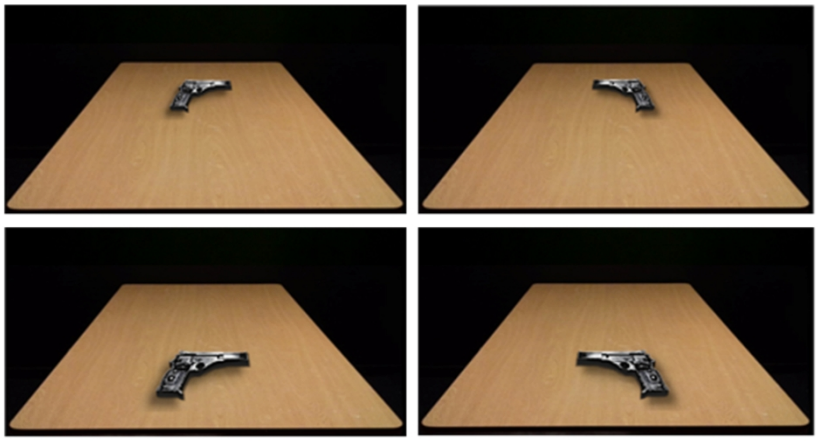

Figure 1. Representation of the visual scene and the orientations of a dangerous object placed in different locations seen by the participants in the main experiment.

339x171mm (96 x 96 DPI)

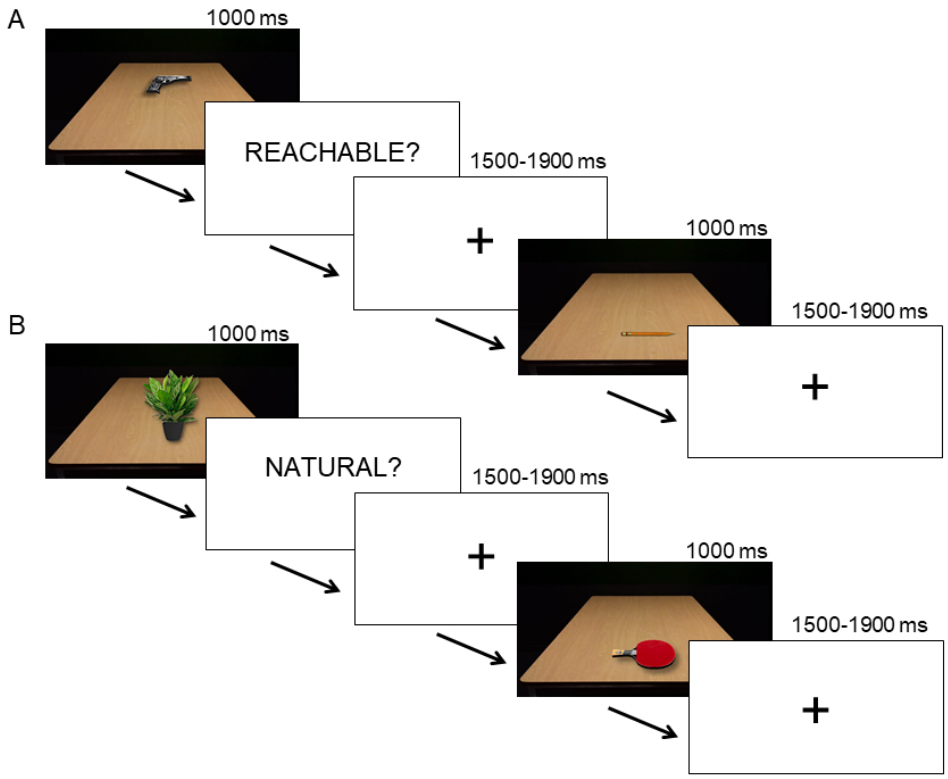

Figure 2. Schematic representation of a sequence of two trials in (A) the Reachability Judgment Task and (B) the Discrimination-Categorization Task.

232x190mm (96 x 96 DPI)

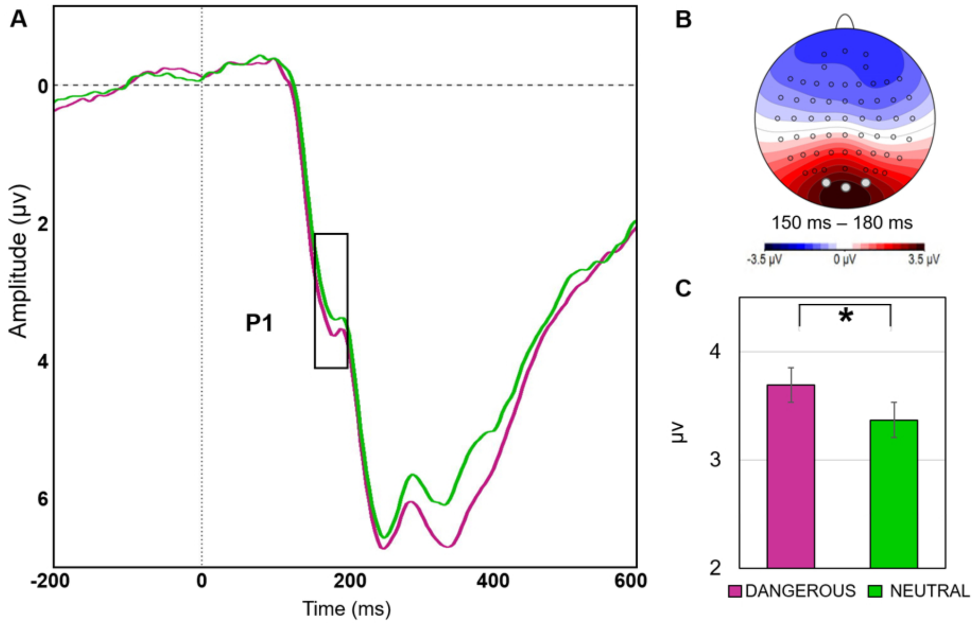

Figure 3. A) Grand average color-coded ERP waveforms. The rectangle indicates the period of interest for quantification of the P1 amplitude; time '0' indicates object onset. B) P1 voltage scalp topography. C) P1 amplitude as a function of Category. The asterisk indicates statistical significance.

249x162mm (96 x 96 DPI)

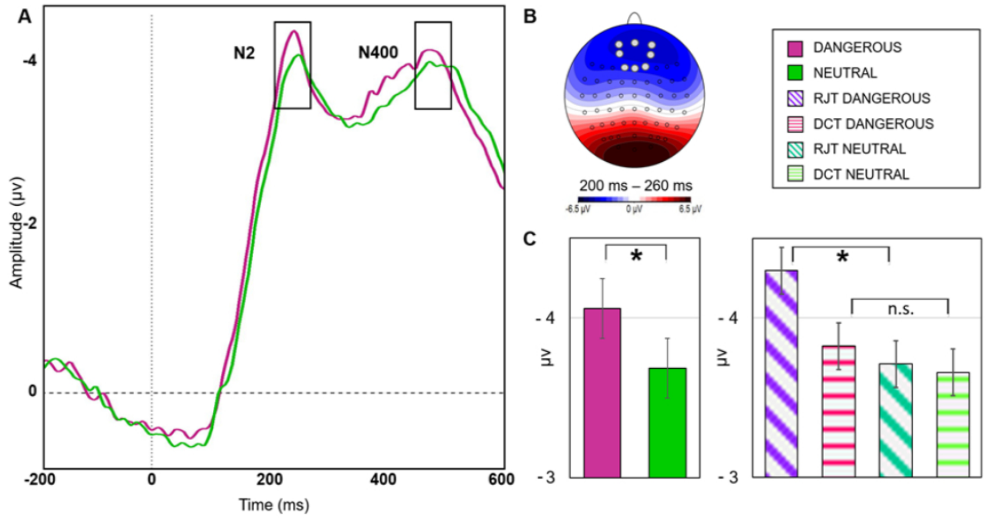

Figure 4. A) Grand average color-coded ERP waveforms. The rectangle indicates the period of interest for quantification of the N2 and N400 amplitudes; time '0' indicates object onset. B) N2 voltage scalp topography. C) N2 amplitude as a function of Category x Task. The asterisk indicates statistical significance whereas n.s. indicates non statistically significant difference.

300x162mm (96 x 96 DPI)

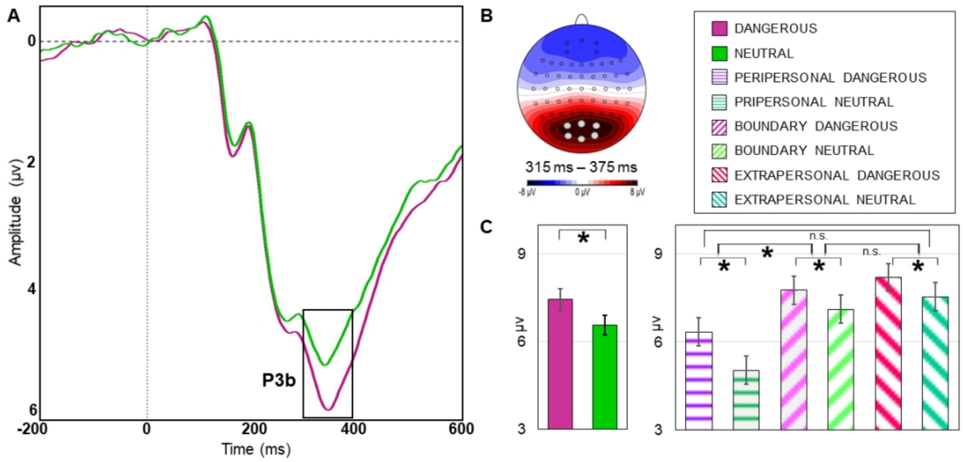

Figure 5. A) Grand average color-coded ERP waveforms. The rectangle indicates the period of interest for quantification of the P3b amplitude; time '0' indicates object onset. B) P3b voltage scalp topography. C) P3b amplitude as a function of Category and Category x Space. The asterisks indicate statistical significance whereas n.s. indicates non statistically significant difference.

338x164mm (96 x 96 DPI)