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One hand, two objects: Emergence of affordance in contexts

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Abstract

Studies on affordances typically focus on single objects. We investigated whether affordances are modulated by the context, defined by the relation between 2 objects and a hand. Participants were presented with pictures displaying 2 manipulable objects linked by a functional (knife-butter), a spatial (knife-coffee mug), or by no relation. They responded by pressing a key whether the objects were related or not. To determine if observing other's actions and understanding their goals would facilitate judgments, a hand was: a. displayed near the objects; b. grasping an object to use it; c. grasping an object to manipulate/move it; d. no hand was displayed. RTs were faster when objects were functionally rather than spatially related. Manipulation postures were the slowest in the functional context and functional postures were inhibited in the spatial context, probably due to mismatch between the inferred goal and the context. The absence of this interaction with foot responses instead of hands in Experiment 2 suggests that effects are due to motor simulation rather than to associations between context and hand-postures.

Introduction

The ability to act appropriately with objects, to respond to objects' affordances, and to flexibly adapt our actions to the current situation is an important building block of human capability to interact with the environment. While affordances have been intensively studied, the mechanisms according to which their activation is modulated by the context, and particularly by the context in which actions of others are displayed, are poorly understood.

About 30 years ago, Gibson (1979) used the term "affordance" to indicate properties the environment provides to acting organisms which are relevant for an organism's goals. According to Gibson, affordances are variable and relational, as they emerge from the interaction between objects, organisms and the environment. For example, a chair affords sitting for human adults but not for other organisms such as elephant or mosquito, nor for human infants. Today, the contribution given by Gibson is widely recognized, though the term "affordances" is used in a slightly different way than the Gibsonian's one. An example is given by Ellis and Tucker (2000) who proposed to use the term "microaffordances", to indicate the activation of action components (e.g., reaching and grasping components) suitable for interacting with specific objects. The continuity with the view of Gibson is obvious. However, in antithesis with Gibson's view, recognizing an object is necessary to activate its microaffordances; in addition, microaffordances would be represented in the brain, that is they are conceived of as the product of conjoining in the brain of specific visual and motor patterns.

In the last 10 years a lot of evidence on affordances has been provided. On the neural side, many brain imaging studies have shown that observing an object activates possible actions to perform with it (affordances) (for a review, see Martin, 2007). Specifically, activation of parietal and premotor cortex has been linked to perception of tools' affordances (e.g., Jeannerod et al., 1995; Johnson-Frey, 2004).

On the behavioural side, many issues related to affordances have been investigated, particularly with compatibility paradigms (e.g., Tucker and Ellis, 1998; 2001; Borghi et al., 2007; Bub et al, 2008; Caligiore et al., 2010; Gianelli et al., 2008; Girardi et al., 2010; Riggio et al, 2008; Tipper et al., 2006; Yoon and Humphreys, 2007). A typical way to study activation of affordances is to verify whether an object characteristic related to action, such as object size, has an impact on a task (e.g., categorization task) for which size is not relevant. If this is the case, this would mean that affordances related to object's size and graspability are automatically activated (in this case the term "automatically" means "independently from the task"). For example, Tucker and Ellis (2001) found that mimicking a precision or a power grip to decide whether an object is an artefact (e.g., hammer, nail) or a natural object (e.g. apple, cherry) was influenced by the object size, which was not relevant to the categorization task. A compatibility effect was found, that is small objects (e.g., nail) were responded to faster with precision grip than with power grip responses, whereas the opposite was true for larger objects (e.g., bottle). The authors interpret their results claiming that observing the object automatically activates its affordances.

This evidence, though compelling, has one limitation we have considered in this work. In the majority of current studies objects (which are typically images and, less frequently, real objects) are often considered independently from the context in which they are embedded. This is striking, given the great relevance of contexts for object recognition and categorization. We perceive the world in scenes: perceiving objects embedded in a context facilitates object recognition (Bar, 2004) and it is not surprising that humans have the peculiar ability to be very fast in categorizing scenes (Thorpe et al., 1996). Furthermore, studies on categorization have shown that presenting objects in scenes facilitates categorization, particularly of superordinate level categories (e.g., musical instruments) (Murphy and Wisniewsky, 1989; see also Borghi et al., 2005).

In spite of the relevance of contexts for a variety of processes, only a few studies have accessed to what extent the activation of affordances is modulated by the context. To our knowledge there are only a few exceptions. For example, Pezzulo et al. (2010) investigated how expert and novice climbers remembered routes of different difficulty on a climbing wall. To perform the task climbers had to take into account the relationship between each hold (affordance) and the context given by the presence of other holds on the climbing wall in order to simulate how they could grasp the holds with the hands and use them as support for the feet. More directly relevant to the present work is the study by Yoon et al. (2010), who focused on affordances elicited by pairs of objects that appear in the same scene and are positioned for action, such as a frying pan and a spatula. The authors found an effect they called "paired object affordance effect": the time taken by right-handed participants to respond whether the two objects were used together was faster when the active object (e.g., the spatula) was to the right of the other object.

The aim of our work is to verify the effects of different kinds of contexts on activation of object affordances for tools. The context is suggested by the presence of a second object, which can be either spatially or functionally related to the tool. The active object and the second object are presented either alone, with a hand in potential interaction with them, or with a hand in effective interaction with them.

Specifically, in our study we address 3 issues pertaining the relationship between affordances evoked by the active object and the context in which it is embedded. They concern the behavioural effects of the relation between the 2 displayed objects, of the eventual presence of a hand near the object, and of the kind of interaction between the hand (when present) and the object. We will introduce these issues below.

1) Spatial vs. functional relations between objects. Our work aims to verify whether the activation of affordances of the active object is modulated by the presence of a second object, thematically related to the first, either through a spatial or a functional relation (Borghi and Caramelli, 2003; Kalénine et al., 2009; Estes et al., in press; Lin and Murphy, 2001; Yoon and Humphreys, 2007). The notion of thematic relation is common in categorization literature. A given object may be categorized taxonomically, as a member of a given category (e.g., both elephants and foxes are animals), or thematically, as part of the same context or action (e.g., trees and houses, dogs and bones are linked by a thematic relation). Thematic relations between objects are known to be the preferential mode of categorization in young children (Lucariello et al., 1992), but are still easily available in older children and adults (Borghi and Caramelli, 2003; Lin and Murphy, 2001). Here we consider two different kinds of thematic relations: we consider two objects are spatially related when they typically appear in the same context but are not directly used together; we classify them as functionally related when the two objects not only appear in the same context, but are also typically used together. For example, we have often experience of knives in the same context as coffee mugs – they are typically found in the kitchen, possibly on the table - , but the two objects are only spatially and not functionally related. Instead, a knife is not only spatially but also functionally related to a stick of butter.

2) Presence of a hand near the objects. Previous studies using a categorization task (Borghi et al., 2007; Vainio et al., 2008; see also Fischer et al., 2008) provide evidence of a compatibility effect between the posture of a hand-prime (displaying either a power or a precision grip) and the grip (power vs. precision) required to grasp a target-object (see also studies on predictions we form based on observation of objects grasping, e.g., Becchio et al., 2012). However, the two aforementioned studies do not fully disentangle the effects given by the observation of the object and of the hand in potential interaction with it. Indeed, it is possible that the activation of different neural areas underlies observation of objects alone or of hands potentially interacting with objects. Studies on the premotor cortex in monkeys have demonstrated the existence of two different classes of visuomotor neurons, canonical and mirror neurons. Canonical neurons (Murata et al., 1997; Raos et al., 1996) discharge during interaction with graspable objects and also during simple object presentation; mirror neurons, instead, discharge both during action execution and during observation of a conspecific interacting with an object (Di Pellegrino et al., 1992), but do not fire in response to a simple object presentation. Further neuroimaging studies have confirmed the existence of canonical and mirror neuron systems in humans (for a review see Rizzolatti & Craighero, 2004; Rizzolatti & Sinigaglia, 2010). Borghi et al. (2007) and Vainio et al. (2008) argued that it is possible for 2 different mechanisms, one related to canonical

(affordances) and the other to the mirror neuron systems (motor resonance while observing others acting with objects), to be responsible for the effects found. Liuzza et al. (2012), using a weight decision task (light vs. heavy), showed that when a grasping hand prime preceded the object, participants responded slower to heavy than to light objects, while no difference was found when no hand prime was present. This confirms that two different mechanisms might be at play. This is similar to what has been proposed in the perceptuomotor domain in considering living versus non-living action affordance effects (Bennett, Thomas, Jervis, Castiello, 1998; Castiello, 2005). The present study allows us to disentangle the contribution played by these two different mechanisms without using a priming paradigm but presenting the hand together with the object. Indeed, in one condition subjects saw the two objects alone, without any hand: in this condition we hypothesize that only the Canonical neuron system would be activated. In a further condition, a hand was displayed close to both objects but not interacting with them (Still-Hand): this condition was aimed to verify whether the simple presence of a hand, even if not in a prehensile posture, produced a facilitation in processing action relations between objects. Since the Mirror Neuron System is typically activated when the action goal is present, it is possible that an action simulation occurs only when the hand is presented with a prehensile posture. If a mirroring mechanism is responsible of this simulation, then the simulation should occur only with manual responses (Experiment 1), not with foot responses (Experiment 2), due to an effector-specific motor resonance mechanism (Paulus et al., 2009). However, given the behavioural nature of our study, these proposals cannot be conclusive claims on the underlying neural mechanisms.

3) Relations between hand and object: manipulation vs. function. Psychological (Jax and Buxbaum, 2010; Costantini et al., 2011; Pellicano et al., 2010) and neuropsychological studies provide support for two different ways of interacting with objects (Buxbaum et al., 2003; Jeannerod et al., 1994), which have been termed by Bub et al. (2008) as volumetric and functional. Volumetric gestures are associated with the overall shape and weight properties of objects and concern the hand posture used to grasp an object to lift or move it, rather than to use it for its defined purpose. Functional gestures, on the other hand, involve specific manipulation of objects in accordance with their proper conventional use. Recent studies by Buxbaum have focused on the so called “conflict objects”, that is objects that evoke different actions (and different ways to manipulate them) depending on the action goal (Jax and Buxbaum, 2010). In addition, Buxbaum and Kalenine (2010) have recently proposed that two different circuits underlying different affordances might be activated, one based on the object structure (dorso-dorsal stream), and another related to object function (dorso-ventral stream; Rizzolatti and Matelli, 2003) (see also Young, 2006, and Borghi and Riggio, 2009, for a similar proposal of different kinds of affordances, more related to manipulation vs. to use; see also

Pellicano, Thill, Ziemke & Binkofski, 2011). In our study the hand can interact with the object in a manipulative vs. functional way (Manipulation-hand vs. Function-hand). Thus observing an action suggests two different underlying goals. Consider for example grasping a fork in order to place it somewhere else; the fork does not necessarily have to be grasped by the handle. Instead, if a fork is grasped for use, then it has to be held by the handle with a very specific grip (Creem and Proffitt, 2001). If a specific motor program is activated when the hand interacts with the objects, and if by observing an action with an object we infer the underlying goals of the agent, we expect a different effect depending on whether the hand is presented in a functional interaction with the object or in a manipulative interaction with it.

Based on these 3 issues concerning the relationship between affordances and the context in which objects are embedded, our predictions are the following:

1. If the activation of the affordances of the active object (possibly mediated by the activation of the Canonical Neuron System) is sensitive to the context given by the presence of a second object, then participants should respond faster and more accurately to the functional than to the spatial context, given that the functional context allows using the two objects together, while the spatial context does not allow a combined action with the two objects.

2. If observing a hand together with an object activates a simulated interaction with it (possibly through the mediation of the Mirror Neuron System), then participants should respond faster and more accurately when a hand is presented than when no hand is displayed, particularly if the hand is in a grasping posture.

3. If the activation of affordances is sensitive to fine-grained contextual information, then we should find an interaction between kind of context and kind of posture, due to a mismatch between the inferred action goal and the context. Thus, manipulation postures should be processed slower in the functional than in the spatial context; functional postures, instead, should lead to slower responses in the spatial than in the functional context.

Experiment 1

Experiment 1 was aimed to verify the aforementioned predictions; participants were required to respond by pressing two keys on the keyboard.

Method

Participants

Sixty-two participants volunteered for participation in the experiment (24 males; mean age = 28.18). All were right handed by self-report and had normal or corrected-to-normal vision. All were naive as to the purposes of the experiment.

Materials

A special care was taken in selecting the materials. 24 everyday manipulable objects were chosen. Every target-object was presented in 3 different pictures, paired with 3 different artefacts; thus we obtained a total of 72 pictures displaying pairs of objects, in which the active member of the pair was located on the right. For example, a picture displayed scissors (the active member of the pair) located on the right with respect to a sheet of paper. All images were presented in an egocentric position (Bruzzo et al., 2008). In each pair the target-object was composed by a part graspable for object use and a manipulable part: for example, when we use a fork to eat we typically hold it by the handle (Function hand), but not by grasping it by its teeth (Manipulative hand). There were 3 kinds of pairs depending on the relation existing between the 2 objects. This relation could be: 1. functional, when objects are both typically located in the same context and are used together (e.g., knife - butter); 2. spatial, when objects typically occur in the same context but are not used together (e.g., fork - spatula); 3. no relation, when the two objects are unrelated (e.g., knife - nail, scissors - bottle).

Before the experimental study, a separate group of subjects evaluated the pictures (without the hand) for familiarity. After asking participants to evaluate items familiarity, one item ("potato-peeler") was eliminated. This lead to the removal of 3 pictures. Thus we obtained 69 object pairs that were selected to be used for the experiment. The pictures, presented in 4 different random orders, were rated by an independent groups of 20 subjects for visual complexity, using a 7-point-scale (7 very complex, 1 not complex at all), and were invited to use not just the poles but also the intermediate values of the scale. The analyses on visual complexity of the single objects revealed that there was no difference between the Functional ($M = 2.59$), the Spatial ($M = 2.60$) and the No Relation Context ($M = 2.76$), $F(1, 42) = 0.43$, $MSe = 0.47$, $p = .65$. (Consider that in some cases the same object was used in different pairs).

For the experimental stimuli, the frame size was 730 pixels wide and 548 pixels high. Four (4) pictures of each pair were taken, as each pair was presented in 4 different conditions. In one condition only the objects were displayed (No-Hand condition), whereas in further 3 conditions a hand was presented as well. The hand was always presented in an egocentric perspective, since it has been shown that processing is faster when the hand and the participant's perspective match (Bruzzo et al., 2008; Vogt et al., 2003), on the right side of the picture. The hand could simply be displayed near the object (Still-Hand condition), or it could interact with the object in a posture relevant for using it, for example grasping the fork handle (Function-Hand condition), or in a posture apt to manipulate the object, for example holding the fork teeth (Manipulation-Hand condition). Note that in our study the hand configuration is exactly the same for both functional and manipulative postures, but realized in a way that the manipulative posture simply does not afford tool-object interaction (see the Method section's Figure 1, in which from the right top corner are displayed Function-Hand, Manipulation-Hand and Still-Hand conditions) but some other manipulation movements (e.g. turning the object around, rotating or relocating it etc.). We think that creating identical physical hand postures for both manipulative and functional interactions makes it possible to measure more clearly what is the extent of the context's influence on affordances activation. Furthermore, at a methodological level, reducing the visual difference between two basilar experimental conditions keeps them more controlled and comparable. The list of the selected materials can be found at the following link: http://laral.istc.cnr.it/borghi/Materials-Borghi-Flumini-Natraj-Wheaton.htm.

Insert Figure 1 about here

Design and procedure

Participants sat 50 cm from the computer screen, with their right and left hands placed over the "3" and the "9" key on the keyboard. Each trial began with a fixation point (+) that remained on the screen for 500 ms. Then one of the photographs was displayed at the centre of the screen and remained on the screen until a response was made. Participants read the following instructions: "In the center of the screen a little cross will appear, followed by a picture showing two objects and sometimes a hand. You are required to decide if the two objects are usually seen/used together or not. If the two objects are usually seen/used together (e.g. a flowerpot and flowers) press the 9 key with your right hand, if the two objects are not usually seen/used together press the 3 key with your left hand. Please respond as quickly and as accurately as you can. The experiment lasts approximately 15 minutes. Press a key to start." We decided to ask participants to simply decide whether the objects were linked by some sort of relationship, and not by a functional relation, since we wanted to avoid rendering the aims of the study too transparent for participants. Indeed, our aim was to simply assess what differentially drove the strength of the association, whether context, hand, or both.

Since participants were required to decide whether the two objects were functionally or spatially related, or not, a "yes" response should occur in 2/3 of the trials, while a "no" response would occur in 1/3 of all trials. They had to respond "yes" with their dominant hand. Participants were instructed to respond as quickly and as accurately as possible and received feedback for both correct and incorrect responses. Each pair was presented once for each of the four hand conditions. Overall, the experiment consisted of one practice block of 12 trials and one experimental block of 276 trials.

Data analysis and results

We performed separate analyses on the “yes” trials (i.e. trials requiring a “yes” response with the right hand, characterized by functional or spatial relations between the two objects) and the “no” trials (i.e. trials implying a “no” response with the left hand, characterized by the absence of relation between the two objects).

From the ”yes”-trials 12.79% of the trials were removed as errors. The low number of errors reveals that the task was easy to perform. Reaction times (RTs) more than 2 standard deviations from each participant's mean were excluded from the analysis; this trimming method lead to the removal of 2.06% of the data. Errors and correct RTs were entered into a 2 x 4 within-subject ANOVA with the factors Context (Functional, Spatial) and Hand (No-Hand, Still-Hand, Manipulation-Hand, Function-Hand). Where permissible, interaction effects were evaluated with Newman-Keuls test ($p < .05$).

The ANOVA on errors demonstrated reliable main effects of both Context and Hand. The Spatial context (M = 3.78) elicited more errors than the Functional (M = 2.30) context, $F(1, 61) = 69.80$, MSe = 3.89, $p <.001$. The factor Hand, $F(3, 183) = 4.14$, MSe = 2.09, $p <.01$ was significant due to the fact that the Functional-Hand (M = 2.73) elicited less errors than both the No-Hand (M = 3.18) and Still-Hand condition (M = 3.33).

The ANOVA on RTs demonstrated reliable main effects of both the factors Context and Hand; the interaction was significant as well. The Spatial context reaction time (M = 803 ms) was longer in duration than the Functional (M = 767 ms) context, $F(1, 61) = 56.28$, MSe = 2947.82, $p <.001$. The factor Hand, $F(3, 183) = 14.41$, MSe = 1544.72, $p <.001$ was also significant. Post-hoc analysis revealed that it was due to the fact that the No-Hand (M = 769 ms) was significantly faster than all other conditions, and to the fact that Manipulation-Hand (M = 802 ms) was significantly slower than all other conditions. The Context x Hand interaction, $F(3, 183) = 2.78$, MSe = 1424.95, $p <.042$, depicted in Figure 2, reveals that with the Spatial Context RTs in the No-Hand condition (M = 787 ms) are faster than Manipulation-Hand (M = 814 ms) and Function-Hand (M = 812 ms) , probably due to the lower visual complexity of the first. To testify the sensitivity to the combination between the hand posture and the context, with the Functional context RTs in the Function-Hand condition (M = 760 ms) are slower than in the Still-Hand condition (M = 752 ms) . However, with the Functional context, Manipulation (M = 789 ms) is slower than all other conditions (Newman-Keuls test $p < .05$).

Insert Figure 2 about here

From the "no"-trials 21.35% of the trials were removed as errors. We used the same trimming method as for "yes"-trials: this method lead to the removal of 3.02% of the data. Errors and correct RTs were entered into a one-way within-subjects ANOVA with the 4 levels factor Hand (No-Hand, Still-Hand, Manipulation-Hand, Function-Hand).

The ANOVA on errors did not show any reliable main effect, $F(3, 183) = 0.22$, $MSe = 2.63$, $p = .87$.

In the ANOVA on RTs, instead, we found a reliable main effect of the Hand factor, $F(3, 183) = 12.74$, $MSe = 2329.46$, $p < .001$, due to the fact that Manipulation-Hand ($M = 967$ ms) was significantly slower than all other conditions. Function-Hand ($M = 927$ ms), No-Hand ($M = 916$ ms) and Still-Hand ($M = 929$ ms) did not significantly differ.

Discussion

Based on our first hypothesis, as predicted, participants were more accurate and faster with the Functional context than with the Spatial context, suggesting that seeing functional pairs of objects heightens activity of the motor system. As to our second hypothesis, the presence of a hand did affect RTs. More crucially, related to the third hypothesis, the interaction we found indicate that manipulation postures were processed slower in the Functional than in the Spatial context. At the same time, the functional postures, which were processed rather fast in the Functional context, were slower in the Spatial context.

This result can be explained in two different ways. This interaction can be simply the product of an association between the context and a specific hand posture. Alternatively, our results might be interpreted in terms of activation of a motor simulation. Participants would have more difficulties in simulating a manipulative action when the context implies using the object rather than simply manipulating it. Similarly, because in the Spatial context no functional use of the object is allowed, it is possible that the motor system continues to try to make sense of the scene, leading to longer RTs with the functional posture. It is therefore possible that in the Function-hand condition not only effector-independent action information is activated, but that the perception of a functional grip evokes an effector-specific simulation. Experiment 2 was aimed at ruling out the first purely associative interpretation of the interaction: for this reason we had participants using foot instead of hand responses.

Experiment 2

The aim of Experiment 2 was to demonstrate that the interaction found in Experiment 1 was due to a motor simulation, related to a specific effector (the hand). Indeed, it could be argued that Manipulation-Hand posture was slower in the Functional context and Function-Hand posture was slower in the Spatial context because of the lower association degree between a given context and a given posture. Experiment 2 was aimed at ruling out this explanation. It was identical to Experiment 1, but responses were provided with the foot instead than with the hand. We predicted that, with a different effector, no grasping motor simulation would occur, thus the Context x Hand interaction effect should not be present. As to the hand, our results do not allow us to determine definitively whether the lowest RTs obtained with the No-Hand condition are due to the lower visual complexity or to the concurrent activation of two different mechanisms. Experiment 2 can help us in solving this issue, as the response effector is the foot instead of the hand.

Method

Participants

Sixty-two participants volunteered for participation in the experiment (20 males; mean age = 23.53). All were right handed by self-report and had normal or corrected-to-normal vision. All were naive as to the purposes of the experiment.

Materials

The same materials as in Experiment 1 were used; the frame size of the stimuli was 730 pixels wide and 548 pixels high.

Design and procedure

Participants sat 50 cm from the computer screen, with their right and left feet placed over two pedals high 9 cm and wide 7.6 cm, placed 13.5 cm far from each other and at 20.5 cm from the frontal legs of the chair in which they sat. The procedure was exactly the same as in Experiment 1. The only difference was that participants were required to use foot responses: they had to respond “yes” with their right foot; “no” responses were 1/3 of the overall trials as in Experiment 1.

Data analysis and results

As in Experiment 1, we split the data collected in two different groups depending on the required response (“yes” right foot responses vs. “no” left foot responses), and performed separate analysis on them.

From ”yes”-trials 8.97% of the trials were removed as errors. Reaction times (RTs) more than 2 standard deviations from each participant's mean were excluded from the analysis; this trimming method leads to the removal of 2.10% of the data. Errors and correct RTs were entered into a 2 x 4 within-subject ANOVA with the factors Context (Functional vs. Spatial) and Hand (No-Hand, Still-Hand, Manipulation-Hand

and Function-Hand). Where permissible, interaction effects were evaluated with Newman-Keuls test ($p < .05$).

The ANOVA on errors demonstrated reliable main effects of both the factors Context and Hand; the interaction was significant as well. As in Experiment 1, the Spatial context (M = 3) elicited more errors than the Functional (M = 1.83) context, $F(1, 61) = 65.22$, MSe = 2.58, $p < .000001$. The factor Hand was significant too, $F(3, 183) = 4.80$, MSe = 1.67, $p < .01$, due to the fact that Function-Hand (M = 2.09) elicited less errors than all other conditions, differing significantly from Manipulation-Hand (M = 2.42) and Still-Hand (M = 2.71), and almost significantly from No-Hand (M = 2.45) (Newman-Keuls $p = .07$). The Context x Hand interaction, $F(3, 183) = 6.30$, MSe = 1.62, $p < .001$, revealed that, while within the Spatial Context there were no significant differences between the 4 Hand conditions, in the Functional context the Still-Hand condition (M = 2.43) elicited significantly more errors than the Manipulation-Hand (M = 1.61) and Function-Hand (M = 1.24) conditions, but not differing from the No-Hand condition (M = 2.04) as well (Newman-Keuls $p = .09$).

The ANOVA on RTs demonstrated reliable main effects of both the factors Context and Hand, but as predicted their interaction was not significant. RTs were slower in the Spatial context (M = 856 ms) than the Functional context (M = 800 ms), $F(1, 61) = 91.92$, MSe = 176.48, $p < .0000001$. The factor Hand, $F(3, 183) = 29.42$, MSe = 1943.38, $p < .0000001$, was also significant, due to the fact that Manipulation-Hand (M = 859 ms) was significantly slower than all other conditions. The Context x Hand interaction was not significant, $F(3, 183) = 0.80$, MSe = 1784.62, $p = .49$.

Insert Figure 3 about here

We removed as errors 18.04% of the trials from the “no” response trials. Using the same trimming method as before, 3.83% of the data were eliminated. Errors and correct RTs were entered into a one-way ANOVA with the 4 levels factor Hand (No-Hand, Still-Hand, Manipulation-Hand, Function-Hand) manipulated within-participants.

The ANOVA on errors demonstrated the reliable main effect of the factor Hand, $F(3, 183) = 3.26$, MSe = 2.55, $p < .05$: Manipulation-Hand (M = 4.61) elicited more errors than Function-Hand (M = 3.79) and No-Hand (M = 3.94), but not of Still-Hand (M = 4.26) (Newman-Keuls $p = .22$).

The main effect of Hand was significant also in the ANOVA on RTs, $F(3, 183) = 24.80$, MSe = 2026.69, $p < .000001$, due to the fact that Manipulation-Hand (M = 1022 ms) was significantly slower and that No-Hand (M = 954 ms) was significantly faster than all the other conditions; the difference between Function-Hand (M = 985 ms) and Still-Hand (M = 972 ms) did not reach significance (Newman-Keuls $p = .13$).

Discussion

The sensitivity to the difference between Spatial and Functional context found in Experiment 1 was confirmed. As to the role played by the displayed hand, the fact that we did not find an advantage of the No-Hand condition, as in Experiment 1, confirms that the result is not due to the lower visual complexity but to the activation of two mechanisms, one related to observation of others interacting with objects, the other to observation of objects evoking actions. More crucially for us, the absence of an interaction between Context x Hand for foot response rules out one of the possible interpretations of the interaction found in Experiment 1. Given that this interaction was present with the hand but not with the foot responses, we can argue that our main result is not due to the association between a given context and a given hand posture. Rather, it suggests that the interaction is due to a motor simulation, which is related to the effector involved (and it might activate grasping

Comparison between the two experiments

To better understand the differences between the two experiments, we performed a 2 x 2 x 4 ANOVA for the "yes" responses. The factor Experiment (Manual responses vs. Foot responses) was manipulated between subjects, while the already used Context (Functional, Spatial) and Hand (No-Hand, Still-Hand, Manipulation-Hand, Function-Hand) factors were manipulated within subjects. Where permissible, interaction effects were evaluated with Newman-Keuls test ($p < .05$).

The ANOVA on errors demonstrated reliable main effects of Experiment, Context and Hand. The first effect was due to the fact that Manual responses (M = 3.04) elicited more errors than the Foot ones (M = 2.42), $F(1, 122) = 10.29$, MSe = 9.48, $p <.01$. The Spatial context (M = 3.39) yelded more errors than the Functional (M = 2.07) context, $F(1, 122) = 69.80$, MSe = 134.05, $p <.0001$. The factor Hand, $F(3, 366) = 7.34$, MSe = 1.89, $p <.0001$ was significant as with the Function-Hand (M = 2.41) errors were less than in all other conditions. The interaction Context x Hand, $F(3, 366) = 7.48$, MSe = 1.80, $p <.0001$, was significant due to the fact that, with the Functional context Manipulation and Function Hand had an advantage over the other two conditions, while with the Thematic context the four hand conditions did not differ.

In the ANOVA on RTs all main effects were reliable. RTs with Foot responses (M = 827 ms) were longer in duration than RTs with Manual responses (M = 785 ms), $F(1, 122) = 5.35$, MSe = 84864.67, $p <.05$. The factor Context, $F(1, 122) = 205.87$, MSe = 2562.33, $p <.0001$, was significant as RTs with the Functional Context (M = 783 ms) were faster than RTs with the Spatial (M = 829 ms) one. The factor Hand was also significant, $F(3, 366) = 41.06$, MSe = 1744.04, $p <.0001$, due to the fact that the Function-Hand was significantly faster and that Manipulation-Hand was significantly slower than all other conditions. The interaction between Experiment x Context, $F(1, 122) = 8.81$, $MSe = 2562.33$, $p < .01$, was significant due to the combined effect of the advantage in both experiments of the Spatial Context over the Functional Context, and of the Manual over the Foot responses. The other significant interaction, the Experiment x Hand one, $F(3, 366) = 4.49$, $MSe = 1744.04$, $p < .01$, showed that, while with the Manual responses the Manipulation-Hand factor was slower compared to all others and the No-Hand factor was the fastest one, with the Foot responses only the Manipulation-Hand condition differed from the others as it was the slowest one. The Context x Hand interaction just approached significance, $F(3, 366) = 2.18$, $MSe = 1822.69$, $p = .091$.

General Discussion

Our results allow us to address the three principal issues advanced in the introduction.

First, they indicate that the relations existing between objects have a strong effect on the responses. Our results suggest that positioning the objects for action facilitated the responses. As predicted, in both experiments participants were more accurate and faster with the Functional context compared to the Spatial context. In this respect, referring to work by Yoon et al. (2010) might be useful. Yoon et al. (2010) presented pairs of objects and submitted participants to two different tasks, an action decision task (they had to decide whether two objects were typically used together) and a contextual decision task (they had to decide whether both objects were for example kitchen items). They propose that responses to Task 1 depend on the time necessary to access action knowledge, whereas responses to Task 2 are dependent on the time necessary to access semantic knowledge. In our experiment, participants were required to decide whether the two objects were related or not, and the kind of relation linking the two objects could be either spatial (the two objects are typically located in the same place, e.g. in an office or in a kitchen) or functional (the two objects are typically used together).

The finding that responses were faster with functional contexts suggests that action knowledge is available earlier and accessed faster than knowledge of objects' common location. In addition, the advantage of functional over the spatial context in both experiments might suggest that the first evoked a lateralized compatibility effect for the right effector, either hand or foot, since in both experiments the "yes" response was associated with a movement of a right effector.

One could argue that this might depend on the differences in semantic association between functionally and spatially related objects. This is certainly possible, and merits further investigation. In any case, we believe that the very fact that action relations between common objects lead to faster responses compared to spatial relations between common objects is in itself informative. A possible cause of this different accessibility can be found in the differences between functional and spatial relations. While functional relations between two objects are normally clear and, in some cases, even socially established (e.g., in Western societies you need to use a fork or spoon to bring food to the mouth), spatial relations are more subject to individual differences and less conventionalized (e.g., some people keep their scissors with their cutlery, others in their office desk). This higher variability might explain why participants needed longer and produced more errors to verify a potential spatial relation than a functional relation between two objects.

A further, less plausible interpretation is that the possibility to interact with both objects is activated in all cases, independent from the relations linking them. However, when the objects are linked only by a spatial relation, this possibility is activated and then discarded; this would slow down response times. However, in future studies we will give consideration to the idea that spatially related objects might be useful for a single bimodal action goal (Swinnen, 2002; Swinnen & Wenderoth, 2004) which is beyond what was presented in the present stimuli (one hand grasping one object).

The evidence we found that observing functional objects together activates possible actions does not imply that this activation is always effector specific. Indeed the finding that we respond faster to objects linked by a functional than by a spatial relation could depend on their being typically acted upon together, and suggests that a simulated action is activated. However, the same effect was present in Experiment 1 and 2, with both hand and foot responses. A possible explanation is that the difference between functional and spatial context concerns the overall action goal, not the specific effector to use, and it is therefore present with both the hand and the foot responses. This interpretation is coherent with the idea that observing objects activate the canonical neuron system (Raos et al., 1996; Murata et al., 1997), but not the mirror one. In other words, objects might evoke the simulation of an action that does not imply the involvement of a specific effector (hand, foot). When, instead, the functional hand posture is observed, then the Mirror Neuron System is activated as well, and the action is programmed at a more detailed and fine-grained level, through the recruitment of a specific effector. This interpretation is compatible with recent evidence on action hierarchies and action chains. It has been suggested that actions can be comprehended at different levels: the overall action goal (e.g., preparing a coffee), which can be segmented in short-terms goal (e.g. grasping the coffee-pot), as well as the kinematic level describing the hand posture (e.g. opposing the thumb to the index to take a mug) (Hamilton and Grafton, 2007). Studies on action chains, both in monkeys (Fogassi et al., 2005) and in humans (Cattaneo et al., 2007; Iacoboni et al., 2005), have confirmed that actions have a goal-based hierarchical organization. In terms of the Theory of Event Coding (Hommel et al., 2001), we could say that the absence of an effector-specific effect confirms that actions are primarily coded in terms of their distal features, not of their proximal ones.

Our results do not allow us to clearly address the second issue we discussed in the introduction, i.e. the role played by the presence of a hand near the objects. Indeed, contrary to our expectations, in Experiment 1 we found that when no hand was displayed, RTs were faster than when the hand was present. A possible explanation is based on the higher visual complexity of the scenes in which the hand is presented together with the objects. However, if visual complexity were the determining factor, RTs in the No-Hand condition should always be faster than RTs in all conditions with a hand, regardless of Context, in both Experiment 1 and 2. This was not seen. An alternative explanation suggests the more complex mechanism mentioned above. Our results might reflect the contemporary activation of two different systems, one triggered by the observation of the objects in the context (affordances), the other triggered by the hand together with the object (mirror mechanism?). When only one mechanism is activated, as in the No-Hand condition, the responses are faster. Instead, when the hand interacts with the object, the concurrent activation of the two mechanisms slows down response times unless the context strongly activates action (as it happens in the Functional context). As to the Still-Hand condition, given that the fingers were flexed it is possible that it was perceived as slowly moving towards the object (Cangitano et al., 2001). To verify this we submitted a group of 14 participants a rating task.- They were required to determine using a 7 point scale whether the hand was moving or not. An ANOVA with the factor Relation manipulated within items. Results were significant, $F(1, 44) = 4.75$, $MSe = .2496$, $p < .05$, due to the fact that in the No-Relation context the hand was perceived less in motion as in the Functional relations. This suggests that, even if the hand displayed was in the same position, the context, and particularly the functional one, suggested implied motion of the hand toward the object.

As to the third issue, our results show that participants were not only sensitive to the kind of context (Spatial vs. Functional), but also to the adequacy of the hand posture to the kind of context. Importantly, the interaction between context and posture was significant in Experiment 1, when the response effectors were the hands, but not in Experiment 2, when participants provided foot responses; the effector dependency of the effect suggests possible involvement of motor simulation, not a simple association between contexts and hand postures. Specifically, in Experiment 1 in the Functional context observing a hand in the manipulative posture was inhibited, as the slowest RTs obtained with the Manipulation-Hand reveal. It is possible that object recognition was more difficult with the manipulation posture, as it occluded the object a bit. In order to rule out this hypothesis, we performed a rating task asking participants to determine using on a 7-point-scale how easily recognizable was the object. Fourteen participants were shown with the images of the objects; each image was presented with the hand both in the manipulative and the functional posture. and were asked to what extent was easy for them to recognize. The ANOVA with the within-items factor

Manipulation vs. Function did not reveal any difference, F (1, 22)= 0.58; MSe = .078; p = .045. This result strongly reduces the probability that the delay with manipulation posture is due to the fact that it occludes the object. Even if Manipulation-hand is the slowest posture in not related pairs and when responses are provided with the foot too, in Experiment 1 in the Spatial context there is no difference in RTs between manipulation and functional postures. This result clearly suggests that in the Spatial context functional postures were inhibited, while they were facilitated in the Functional context. We propose that, when a functional grip is perceived, the effector-specific functional knowledge about the object is retrieved. However, in the spatial context no clear functional use of the object is possible. Given that effector-specific information is activated, this provokes an interference with the hand response, but not with the foot response. The idea that a motor resonance mechanism is activated while observing a functional grip in interaction with an object is in line with recent findings on tool recognition and effector-dependency. Witt et al. (2010) have recently demonstrated, with a motor interference task (squeezing a rubber ball in one hand), that participants were faster in naming tools with the handle faced away from the ball than facing towards it. Paulus et al. (2009) manipulated the kind of motor interference (hand, foot, and attentional interference) during acquisition of functional knowledge of objects. They found an effector-specific interference during a subsequent object detection task: verbal learning of object function was impaired when a manual motor action was executed. Literature on selection for action is relevant to our results as well. For example, Tipper et al (1997) found with a kinematics study that, when two or more objects are presented in a scene, non-target objects evoke competing responses, slowing down the reach. Consistently, in our study the shortest RTs were found when the two objects were functionally compatible, thus the possibility for the non-target object to evoke a competing response was mimimized. Our results suggest that participants infer from the context the goal underlying the observed action (Gallese, 2009). In this respect, this behavioural study complements and extends results found with fMRI study by Iacoboni et al. (2005) with a single object. They presented participants with grasping hand actions without a context (e.g., a hand grasping a cup), context only (scene containing object) (e.g., a table with objects arranged as before or after having tea) and grasping hand actions performed in two different contexts, suggesting two different intentions, such as drinking from a cup or putting it away after tea. Results revealed that the context, beyond activating visual information, recruits the motor system as it prepares for situated action: observing both action and context videos activated the parieto-frontal circuit for grasping. Our results are compatible with the Predictive Coding model (Kilner et al., 2007) proposed to account how the mirror neuron system would interpret and predict actions. According to this model the observed kinematics of an action can be interpreted at different levels, which are hierarchically organized. At each level of this hierarchy the mismatch between the predicted and the observed activity might lead to a prediction error. As highlighted by the authors, the goal inferred while observing an action is matched with information (priors) received from the context. Similarly, in our study, it is possible that participants observe the functional posture and infer both the short-term goal (grasping the object) and the long-term goal (using it). However, even if the short-term goal doesn't conflict with the context, the long-term goal inferred by the kinematics of the functional posture doesn't match with the information provided by the Spatial context. This could explain why functional postures are interfered in the Spatial context when responses are provided with the hand.

This result confirms what to our knowledge has not yet been found in a behavioural study, i.e. that functional information is more accessible than manipulation information, and that the activation of both functional and manipulation information is modulated by an action goal, which in this case is made explicit through the context. This result is in line with evidence by Van Elk et al. (2008) who demonstrated that objects presented in a location associated to the action goal were recognized earlier than objects in another location (e.g., cup at eye). This result bolsters previous findings showing that both manipulation and function are activated, and that a competition between the two takes place (Jax and Buxbaum, 2010). This competition is rather easily solved when the context disambiguates the situation. Given that typically we interact with objects in a functional way, the competition is more easily solved when the object's function has to be taken into account.

Overall, our study shows that affordances activation is modulated by the context. Other objects in a scene as well as cues related to action/interaction with objects, such as a hand, influence RTs. It remains an open issue, to be investigated in further research, whether and how the two mechanisms interact, one triggered simply by observation of objects and another by observation of others in potential interaction with objects. Brain imaging studies are required, in order to investigate whether two different neural circuits underline object manipulation and object use. Further studies are needed, in order to understand the precise time course of activation of motor information associated to one object, to two objects and to the hand. In relation to context, there is evidence of ventral stream activation to images of man-made artefacts shown in incorrect contexts (Mizelle and Wheaton, 2010a, 2010b, 2011) and further investigation into this mechanism is presently underway.

The finding that affordance activation is modulated by the context might have important theoretical implications and might contribute to the ongoing debate on automaticity of activation of affordances. Indeed, it is unclear from current evidence and it is still hotly debated in the literature whether the object affordances are activated in an automatic way or whether they are modulated by the task and by the context (e.g., Creem-Regehr and Lee, 2005; Buxbaum and Kalenine, 2010).

As clarified before, the automaticity of activation is often inferred from the fact that, even if the task requires processing a given aspect of an object (for example assigning it to a given a category, or deciding its colour, etc.), affordances related to other aspects (e.g. grip, orientation) are activated. Studies so far have shown that affordances might be activated independently of the task – for example, affordances related to object grasping might be activated in a categorization task. However, very recent evidence has indicated that the kind of task modulates the activation of affordances: for example, Pellicano et al. (2010) and Tipper et al. (2006) have shown that affordance effects are not present with tasks implying simple perceptual processing of the stimuli, such as colour discrimination tasks, whereas they emerge when the task implies deeper processing, as in categorization and decision on objects shape. Initial neuroimaging evidence further suggests that ventral stream areas for awareness of correct versus incorrect contexts of man-made artefacts are not active when subjects are not seeking functional relationships between objects (Mizelle and Wheaton, 2010a). This evidence suggests that activation of affordances might be less automatic and more dependent on the task and situation than previously thought. Our evidence bolsters these results, showing that not only the task, but also the context modulates activation of affordances, and that our cognitive systems responds flexibly to changing contexts. In other terms, we side with the "affordance competition hypothesis" (Cisek, 2007), according to which a competition between different available action opportunities is activated. In our study we demonstrated that context and relations between objects, as well as the presence of the hand of someone suggesting a specific action goal, can orient this competition.

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Figure captions

Figure 1. Stimuli and procedure. Right side: Objects with a Spatial relation (scissors-stapler), with No relation (scissors-bottle), and with a Functional relation (scissors-sheet). Left side: Hand in a functional posture, in a manipulative posture, and hand close to the objects.

Figure 2. Experiment 1. Interaction between the Context and the Hand posture: Response Times.

Figure 3. Experiment 2. Interaction between the Context and the Hand posture: Response Times.

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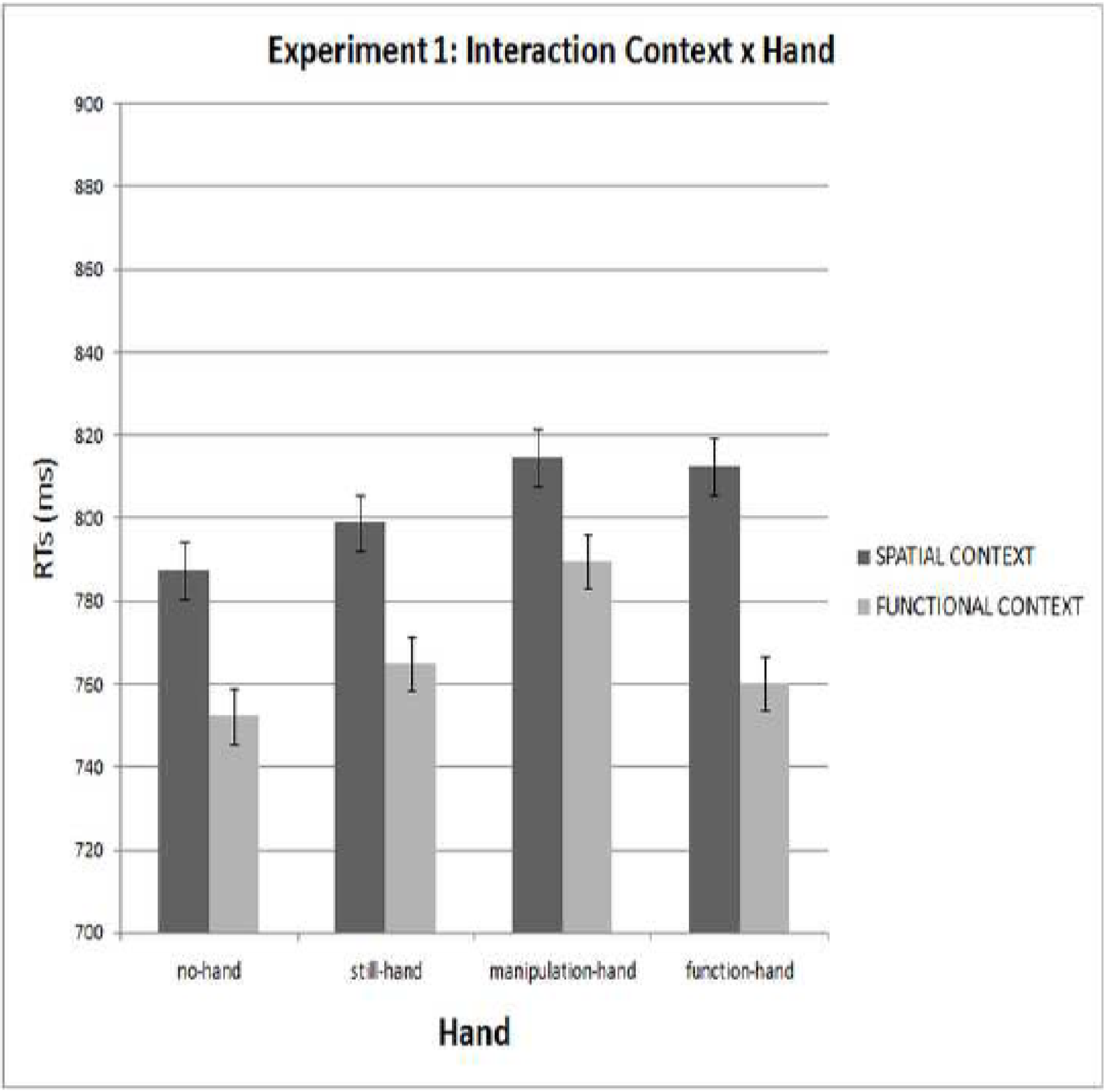
Experiment 1: Interaction Context x Hand
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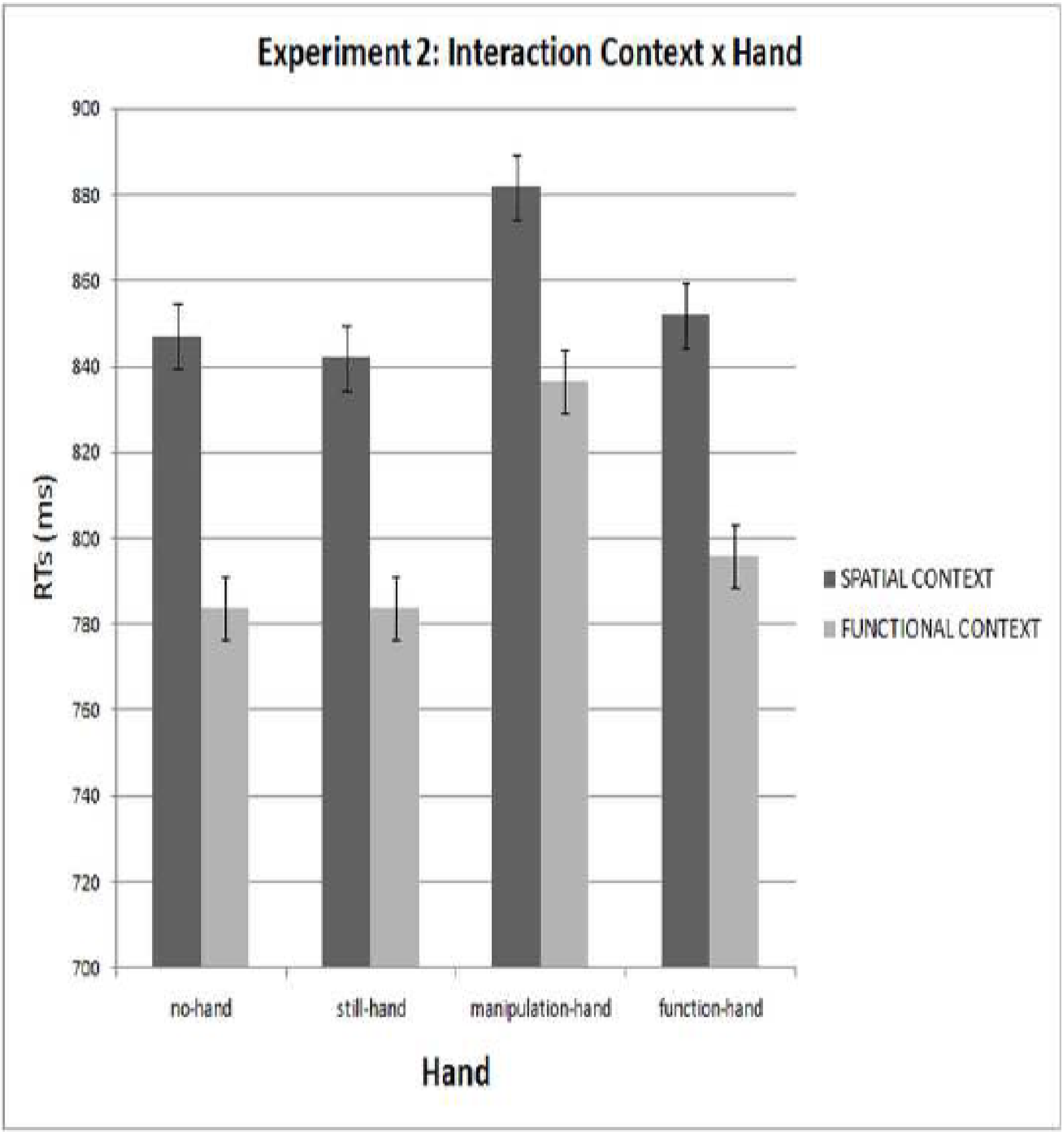
FUNCTIONAL CONTEXT


Experiment 2: Interaction Context x Hand
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function-hand
Hand
SPATIAL CONTEXT
FUNCTIONAL CONTEXT