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Short Communication

Conflict between object structural and functional affordances in peripersonal space

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A B S T R A C T

Recent studies indicate that competition between conflicting action representations slows down planning of object-directed actions. The present study aims to assess whether similar conflict effects exist during manipulable object perception. Twenty-six young adults performed reach-to-grasp and semantic judgements on conflictual objects (with competing structural and functional gestures) and non-conflictual objects (with similar structural and functional gestures) presented at difference distances in a 3D virtual environment. Results highlight a space-dependent conflict between structural and functional affordances. Perceptual judgments on conflictual objects were slower that perceptual judgments on non-conflictual objects, but only when objects were presented within reach. Findings demonstrate that competition between structural and functional affordances during object perception induces a processing cost, and further show that object position in space can bias affordance competition.

1. Introduction

Multiple action representations guide the execution of object-directed actions (Cooper & Shallice, 2006; Grafton & Hamilton, 2007; van Elk, van Schie, & Bekkering, 2014). In order to accomplish the desired outcome (e.g., drink), human agents need to select an object (e.g., cup), and derive the appropriate gesture (e.g., grasp handle). At each step, the cognitive system has to select the adequate action representation among several alternatives (Cisek, 2007). The resolution of the competition between several possible action candidates induces a processing cost and affects action execution. Consistent with this view, Jax and Buxbaum (2010, 2013) demonstrated that during action planning, structural and functional gesture representations associated to the same object interfere with one another. In healthy adults (Jax & Buxbaum, 2010), actions towards conflictual objects (with distinct structural and functional gestures, e.g., calculator) were more slowly initiated than actions towards non-conflictual objects (with similar structural and functional gestures, e.g., baseball). The cost observed for conflictual objects was even amplified in patients with ideomotor apraxia (Jax & Buxbaum, 2013), a deficit likely due to lesions of the supramarginal and inferior frontal gyri, two key regions for the resolution of action competition (Schubotz, Wurm, Wittmann, & von Cramon, 2014; Watson & Buxbaum, 2015). Together, recent studies indicate that conflict between action representations affects planning of object-directed actions. In contrast, the impact of competing action representations on object visual processing remains an open issue.

Important work has been done on the role of motor affordances in object perception. Although it is now clearly established that the perception of objects involves the retrieval of motor information through the activation of the visuomotor system (e.g., Chao & Martin, 2000; Ellis & Tucker, 2000), the content of the motor information evoked (i.e., the variety of affordances) has just started to receive some attention. Perceived objects reactivate many different action representations in a flexible way (Borghi & Riggio, 2015; Natraj, Pella, Borghi, & Wheaton, 2015; Thill, Caligiore, Borghi, Ziemke, & Baldassarre, 2013). In particular, perceived objects may evoke both structural and functional affordances (Bub, Masson, & Cree, 2008; Lee, Middleton, Mirman, Kalénine, & Buxbaum, 2013). Moreover, the relative importance of structural and functional gesture activation depends on visual context and action goals. For instance, Kalénine, Shapiro, Flumini, Borghi, and Buxbaum (2014) showed that semantic categorization of conflictual objects entailed stimulus-response compatibility effects with the functional gesture when the object was presented in a use context (e.g., calculator on desktop), but with the structural gesture when the object was presented in a move context (e.g., calculator

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in drawer). Yet the existence of conflict effects between functional and structural affordances during object perception has never been demonstrated.

If, as growing evidence suggests, affordance evocation is flexible and context-dependent, then conflict effects between functional and structural affordances should be sensitive to the relevance of structural and functional gestures for the current situation. A critical determinant of gesture evocation may be objet position in space. Space perception is not continuous and depends on individual motor capacities (Coello & Delevoye-Turrell, 2007; Costantini, Ambrosini, Sinigaglia, & Gallese, 2011). The perceived boundary of the action space delimitates individual peripersonal and extrapersonal spaces, where objects appear as reachable or not reachable, respectively. Critically, several studies have shown that the evocation of motor affordances during object perception is maximum in peripersonal space (Costantini, Ambrosini, Scorolli, & Borghi, 2011; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010; Ferri, Riggio, Gallese, & Costantini, 2011; Wamain, Gabrielli, & Coello, 2016; Yang & Beilock, 2011). In Costantini, Ambrosini, Scorolli, et al. (2011), participants had to judge the correctness of object-verb associations (e.g., bottle-pour). Objects could be presented in peri- and extra-personal spaces, and verbs could refer to structural actions, functional actions, or observation. An advantage for judgments involving action verbs compared to observation verbs was only observed when objects were presented in peripersonal space. This result indicates that structural and functional gestures are more (perhaps exclusively) activated when objects are presented in peripersonal space. Using immersive virtual reality technologies, Wamain et al. (2016) further showed that the greater activation of object motor affordances in peripersonal space was reflected at the neural level by an increased desynchronisation of Mu rhythm when objects were perceived as reachable. Notably, the neural modulation of affordance activation as a function of space was present when the perceptual task was relevant for action (i.e., reachability judgments), but not when the perceptual task focused on object surface properties (i.e., object versus non-object judgments). Together, research on action planning, object affordances and space perception suggests that the co-activation of structural and functional affordances during perception of conflictual objects may induce a processing cost. Nevertheless, such cost should be influenced by the position of the object in space and the relevance of the task for action. Perceptual judgments on conflictual objects should be slower than perceptual judgments on non-conflictual objects. The disadvantage of conflictual object processing should be greater in peripersonal space, and possibly more pronounced when the perceptual task orients attention towards the object properties that are relevant for action. These predictions were tested with the immersive virtual reality paradigm developed by Wamain et al. (2016).

2. Methods

2.1. Participants

Twenty-six young adults (mean age = 21; age range 19–26; 20 women) took part in the experiment. Data from one participant with response times greater than 3 standard deviations of the group mean were excluded from the analysis. The final sample included 25 participants. All were right-handed (handedness quotients 60–100%; mean 90%; Oldfield, 1971), and had normal or corrected-to-normal visual acuity. The protocol was approved by the Ethical Committee of the University and was in accordance with the declaration of Helsinki. All participants gave written informed consent and were not paid for their participation.

2.2. Stimuli

Three-dimensional images of 40 unimanual manipulable objects were selected from open source 3D object databases and converted into OpenGL compatible format. Objects were displayed in virtual scenes generated with MatLab 6.5 (MathWorks, Natiek, MA, USA) and Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). Among the 40 objects, 20 were conflictual (e.g., soap dispenser) and 20 were non-conflictual (e.g., plastic cup, see Fig. 1 bottom and Appendix A).

Conflictual and non-conflictual objects were selected from a pretest conducted on 9 right-handed participants who did not participate in the actual experiment. During pretest, 2D screen capture images of 3D objects were presented on a computer screen, and participants were asked to demonstrate how they would position their hand on the object in order to (1) move it and (2) use it (questions counterbalanced between participants). Hand postures were classified into 8 categories (open clench, closed clench, palm, pinch 2 fingers, pinch 3 fingers, poke, horizontal trigger, vertical trigger). Each object received a conflict index between 0 (highly conflictual) and 9 (highly non-conflictual) corresponding to the number of common hand postures provided between the move and use conditions. Conflictual and non-conflictual object categories had a mean index of 1.95 (SD = 1.85, range 0–5) and 7.8 (SD = 1.24, range 6–9), respectively. After hand posture production, participants were asked to tell in what room the object was typically found and to name it. Half of the final object set could be found in the kitchen.

2.3. 3D immersive virtual reality system

Visual scenes were presented on a 2 m $\times$ 4 m rear projection screen using a 3D stereoscopic projector (Christie Mirage 4K35) generating images at 120 Hz with a 4 K spatial resolution (3840 $\times$ 2060 pixels). Active 3D eyewear (Christie) was used for producing 3D images perception. Images were generated taking into account participants' height. For each stimulus, two different images were computed and displayed 8.33 ms alternatively to each eye. Normal fusion created the illusion of viewing a single object. Relative size and perspective cues as well as binocular disparity were used to induce a 3D perception of the visual scene and objects. The visual scene was composed of a wooden textured table inside a rectangular room with wooden textured roof and tile-layered walls (Fig. 1 top). Conflictual and non-conflictual objects were presented on the virtual table at various distances according to the vantage point of the participant. Distances were individually normalized as a function of the perceived boundary of the peripersonal space of each participant. Objects were displayed at −50%, −60%, −70% (peripersonal space), −10%, 0%, +10% (boundary), +50%, +60%, +70% (extrapersonal space) of this boundary.

2.4. Procedure

Participants were equipped with Active 3D eyewear and seated approximately 100 cm from the screen. Eye-floor distance and right arm length were measured. Participants were asked to respond to the different judgments on the stimuli with their left and right feet using a pedal response device. Reach-and-grasp and semantic judgments were performed in two separate blocks counterbalanced between subjects.[1] Prior to the two tasks, the boundary of peripersonal space was evaluated for each participant, and object stimuli were briefly presented for familiarization.

[1] We verified the presence of effects related to task order on reaction times and there were none, neither in isolation nor in interaction with other factors of interest.