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Effects of paired-object affordance in search tasks across the adult lifespan

Melanie Wulff*, Alexandra Stainton, Pia Rotshtein

School of Psychology, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

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ABSTRACT

The study investigated the processes underlying the retrieval of action information about functional object pairs, focusing on the contribution of procedural and semantic knowledge. We further assessed whether the retrieval of action knowledge is affected by task demands and age. The contribution of procedural knowledge was examined by the way objects were selected, specifically whether active objects were selected before passive objects. The contribution of semantic knowledge was examined by manipulating the relation between targets and distracters. A touchscreen-based search task was used testing young, middle-aged, and elderly participants. Participants had to select by touching two targets among distracters using two search tasks. In an explicit action search task, participants had to select two objects which afforded a mutual action (e.g., functional pair: hammer–nail). Implicit affordance perception was tested using a visual color-matching search task; participants had to select two objects with the same colored frame. In both tasks, half of the colored targets also afforded an action. Overall, middle-aged participants performed better than young and elderly participants, specifically in the action task. Across participants in the action task, accuracy was increased when the distracters were semantically unrelated to the functional pair, while the opposite pattern was observed in the color task. This effect was enhanced with increased age. In the action task all participants utilized procedural knowledge, i.e., selected the active object before the passive object. This result supports the dual-route account from vision to action. Semantic knowledge contributed to both the action and the color task, but procedural knowledge associated with the direct route was primarily retrieved when the task was action-relevant. Across the adulthood lifespan, the data show inverted U-shaped effects of age on the retrieval of action knowledge. Age also linearly increased the involvement of the indirect (semantic) route and the integration of information of the direct and the indirect routes in selection processes.

1. Introduction

The processing of visual scenes is influenced by many factors. Gibson (1979) first outlined the concept of affordance, proposing that objects are not only perceived in terms of their visual properties but also in terms of what they afford (e.g., a knife affords cutting). Several studies have demonstrated that affordance processes are activated automatically when we view an object, regardless of the viewer's intention to act upon it (e.g., Grezes & Decety, 2002). Affordance effects can also be observed when two objects engage in a functional interaction: one object acting upon the other to produce an action (e.g., a bottle pouring into a glass; Gibson, 1979). Accumulating evidence demonstrates that attention and perception is facilitated when a functional relation between objects exists (e.g., Borghi, Flumini, Natraj, & Wheaton, 2012; Green & Hummel, 2006; Humphreys, Wulff, Yoon, & Riddoch, 2010; Laverick et al., 2015; Riddoch, Humphreys, Edwards, Baker, & Willson, 2003; Roberts & Humphreys, 2011; Wulff & Humphreys, 2013, 2015; Wulff, Laverick, Humphreys, Wing, & Rotshtein, 2015; Xu, Humphreys, & Heinke, 2015). It has been argued that affordance facilitates perception through the direct route from vision to action without accessing semantic knowledge. However, the interplay between procedural and semantic knowledge when retrieving action knowledge is still debated. In the present study, we examined the contribution of procedural and semantic knowledge to action retrieval using two different search tasks. We also explored whether this interaction would change across the adulthood lifespan.

The dual-route account from vision to action (Riddoch, Humphreys, & Price, 1989) assumes that action retrieval is mediated by two routes: A direct route based on the structural

* Corresponding author.
E-mail address: drmelaniewulff@gmail.com (M. Wulff).

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properties of objects (affordances) which automatically activates action and motor procedures (i.e., procedural knowledge; e.g., how to grasp a knife and how to use a knife with a fork) bypassing semantic knowledge. The direct route is assumed to be mediated by the dorsal (occipito-parietal) visual pathway mediating object-related actions (Goodale & Milner, 1992; Ungerleider & Mishkin, 1982). The dorsal visual stream route has been further subdivided into a dorso-dorsal and a ventro-dorsal stream (Rizzolatti & Matelli, 2003). The dorso-dorsal stream connects area V6 with areas V6A and MIP of the superior parietal lobule, while the ventro-dorsal stream connects the inferior parietal lobule with superior medial temporal (MT/MST) and ventral pre-motor cortices (Rizzolatti & Matelli, 2003). It is assumed that the link between affordance perception and motor procedures depicting the way we interact with objects is mediated by the ventro-dorsal rather than the dorso-dorsal stream associated with the on-line control of action (Binkofski & Buxbaum, 2013; Buxbaum & Kalenine, 2010; Rizzolatti & Matelli, 2003). A second indirect route enables retrieval of semantic knowledge by accessing previous knowledge about the object (e.g., knowledge on when and for what a knife is used for). This knowledge is stored as part of the semantic memory system (e.g., a knife as many other kitchen items is used in the context of food such as eating and preparing food; for a simulation of the dual-route model, see Yoon, Heinke, & Humphreys, 2002). The indirect semantic route is associated with the ventral (occipito-temporal) visual pathway for recognizing objects (Goodale & Milner, 1992) which terminates in the anterior temporal lobe where conceptual knowledge is believed to be represented.

The hypothesis that action retrieval can be mediated by the direct route from vision to action is supported by neuropsychological data (for a review, see Humphreys & Riddoch, 2003). For example, patients with left occipito-temporal brain damage were able to make appropriate gestures to objects even though they were unable to name the objects (e.g., Riddoch & Humphreys, 1987; Yoon, Humphreys, & Riddoch, 2005; for a similar dissociation in semantic dementia patients, see Hodges, Bozeat, Lambon Ralph, Patterson, & Spatt, 2000; Hodges, Spatt, & Patterson, 1999). The opposite pattern is evident for patients with left parietal brain damage. These patients were able to access semantic knowledge but they were impaired when asked to interact with objects (Riddoch et al., 1989). This double dissociation confirms the existence of a direct route and challenges the traditional view that vision to action interacts only indirectly through semantic knowledge (Ochipa, Rothi, & Heilman, 1992).

Even though the above cited literature supports the direct route for procedural knowledge retrieval and the indirect route for semantic knowledge retrieval, there is evidence that the direct and the indirect route may both contribute to action retrieval. For example, using computational modelling (naming and action model; Yoon et al., 2002), it has been shown that damage to one route impaired ("blocked") action retrieval of the other route. This is supported by experimental data showing a strong linear relationship between semantic impairment and accuracy of object use (Silveri & Ciccarelli, 2009), specifically when using the same stimulus set in semantic dementia patients (Hodges et al., 2000). Neuroimaging evidence in healthy participants also suggests a link between action and semantic knowledge. For example, Mizelle, Kelly, and Wheaton (2013) showed that the indirect (semantic) route was involved in evaluating functional relations between objects, and thus linking action semantic and action procedural systems. Taken together, these above cited studies suggest a strong relationship between action and semantic knowledge (see also, Bozeat, Ralph, Patterson, & Hodges, 2002; Buxbaum, Schwartz, & Carew, 1997; Frey, 2007).

There is growing evidence that the interaction between the direct (affordance) route and the indirect semantic route also affects selection processes. Patients with right fronto-parietal brain damage and left-sided extinction, a disorder of spatial selective attention, were able to report more objects in their extinguished hemifield when the objects were presented in a way that afforded an action (a fork and knife facing each other) or not (a knife facing away from a fork; Humphreys et al., 2010; Riddoch et al., 2003, 2006; Wulff & Humphreys, 2013, 2015). Note that mere semantic associations between objects did not facilitate selective attention processes in these patients (Riddoch et al., 2003; for a similar result with healthy participants, see Adamo & Ferber, 2009). Similarly, healthy participants showed improved performance when the objects were functionally related compared to when they were unrelated (Adamo & Ferber, 2009; Borghi et al., 2012; Green & Hummel, 2006; McNair & Harris, 2014; Roberts & Humphreys, 2011).

An important action cue for interacting objects is the functional role of each object within an action pair (i.e., procedural knowledge). Riddoch et al. (2003) differentiated between the active and the passive object within a pair, with the active object (e.g., bottle) being the one which is typically gripped by the dominant hand and acts upon the passive object (e.g., glass) gripped by the non-dominant hand to produce the action (cf. Laverick et al., 2015). However, which hand is used to grasp the active object is influenced by the context in which the objects will be used (e.g., drinking vs. pouring). Studies with visual extinction patients (Riddoch et al., 2003; Wulff & Humphreys, 2013) and healthy participants demonstrated an attentional bias toward the active object (Laverick et al., 2015; McNair & Harris, 2014; Roberts & Humphreys, 2010; Tipper, Paul, & Hayes, 2006; Wulff et al., 2015). McNair and Harris (2014), for example, manipulated the temporal sequence of a tool (the active object) or its corresponding action recipient (the passive object) in an attentional blink paradigm. Reduced attentional blink occurred when the active object preceded the passive object but not when the temporal order was reversed. These results suggest that the active object has a higher attentional weight than the passive object in an action pair.

Wulff et al. (2015) and Laverick et al. (2015) investigated the contribution of semantic and procedural knowledge to the retrieval of action knowledge by manipulating these two factors orthogonally using real objects and static pictures of the same objects on a screen. In the real object task, participants performed a conceptual search, i.e., they had to select a pair of real objects affording a mutual action among distracters. In this task, search targets were identified based on the retrieval of action knowledge. The authors assessed the involvement of semantic processes in action decisions by manipulating the semantic relation between action pair and distracters. For example, for the action pair knife and fork, the semantically related distracters were cup and spatula and the unrelated distracters were pen and scissors (kitchen vs. office items, respectively). Procedural knowledge was assessed using the way/order objects were selected. Specifically, if objects were selected in a manner matching the execution of an action (e.g., selecting the active object first with the right hand) this would indicate an involvement of the direct (procedural) route in the retrieval of action knowledge. In the computerized version of the experiment, participants had to decide by button press whether two consecutively presented objects can interact with each other. Here the involvement of semantic knowledge was assessed by the time to reject a functional relation between two semantically related or unrelated objects. As with real objects, the involvement of procedural knowledge was tested by manipulating the order by which the active and passive objects were presented and the way objects were gripped. Facilitation of action decisions for active-before-passive objects or congruently gripped objects for action would indicate the involvement of procedural knowledge. In both studies (Laverick et al., 2015; Wulff et al.,