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Intentions and Actions

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Manipulable objects have the potential to evoke mental representations of hand actions. Behavioural evidence favouring the view that this process happens automatically while passively viewing objects is critically examined. A case is made for the alternative proposal that objects may evoke action representations when observers concurrently operate with an intention to engage in a reach-and-grasp action. In addition, the nature of hand action representations was examined by considering two components of actions, hand selection and wrist orientation, and it is shown that the relationship between these dimensions is modulated by task context. When an action representation is evoked by a task-irrelevant object, these two dimensions are to a large extent independent of one another, but when an observer prepares an action for immediate production, these two action features are hierarchically integrated, with hand selection dominating the hierarchy.

Public Significance Statement

Knowledge about objects includes the actions we use when interacting with them. This work describes how action knowledge is recruited when people encounter objects and demonstrates differences between this action knowledge and what happens when a person prepares to perform an action. These different ways of organizing our thoughts about actions appear to be associated with different brain regions.

Keywords: action intention, action representations, correspondence effects, spatial codes

This article is based on the Donald O. Hebb Distinguished Contribution Award address that I presented at the 2018 meeting of the Canadian Society for Brain, Behaviour, and Cognitive Science. I am deeply grateful to the Society for selecting me as a recipient of this award. I am also thankful to the many colleagues and students with whom I have shared my research endeavors over the years. I particularly wish to acknowledge with deep appreciation my longstanding collaborator and colleague, Dr. Daniel Bub, whose insight and encouragement have been key factors in shaping my research program for the past 15 or so years. In honour of that collaboration, I have elected to review here some of the work that we have been doing together, highlighting a few of our earlier efforts and revealing some new discoveries as well.

I owe much gratitude to my collaborator, Daniel Bub, who was fully involved in all of the work described in this article. I also thank the students who contributed to the research that is included here and Marnie Jedynak, who facilitated the execution of all of the experimental work. This research was supported by Natural Sciences and Engineering Research Council of Canada Discovery Grants to Michael Masson and to Daniel Bub.

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A Transition

For most of my research career, my interests have targeted mental processes such as memory, word reading, language comprehension, and visual perception. For the most part, the mechanisms considered to underpin these activities are confined to the mental world, with little, if any, consideration given to the downstream effects of these computations. The consequences of mental processing often include some form of overt, adaptive behaviour, but in most theoretical accounts of cognition, any resulting action is tacked on as a separate module at the end of the processing chain (e.g., pushing the relevant button, emitting an utterance). Presumably, little thought need be given to the execution of actions, as they would simply follow as a necessary consequence of higher-order cognitive effort.

My constrained view of cognition was transformed one day nearly 20 years ago when my colleague, Daniel Bub, walked into my office and excitedly pointed to an article by Chao and Martin (2000) reporting neuroimaging evidence for the apparent activation of action representations related to graspable objects. This landmark paper set us off on a longstanding program of research (and many discussions and debates) aimed at understanding the relationship between cognitive processes and actions. For those seeking their own epiphany regarding the important connection between thought and action, I highly recommend the 2011 TED presentation by Daniel Wolpert (Wolpert, 2011; but you might wish to check the biological facts on his story about the sea squirt).

The work that I have chosen to include in this review has its origins in one of the first lines of investigation that we chose to open. In particular, we became interested in the question of whether simply viewing pictured manipulable objects truly could lead to the activation of associated mental representations of actions. I will describe our early efforts to resolve this question and will show how the issue remains an active one to this day. I will then explain our view regarding the important role played by action intentions in drawing out action representations while viewing objects, including considerations of action outcomes. In the last part of this review, I will discuss the issue of the relationship between components of action and how this relationship changes depending on the nature of the overriding action intention. There is some intriguing evidence from others indicating fundamental differences in the neural substrates that are associated with these different relationships.

Objects and Affordances

What usually spurs us to action? Quite commonly, the impetus to act includes manipulable objects—those with which we can interact using our hands. They can be used to accomplish some specific goal related to the object's purpose, or we might simply be interested in moving an object to a new location or transferring it to another person. In any case, the action we apply to an object is heavily dependent on our prior experience with that object, and we draw on memory for earlier interactions to guide the details of our current actions, such as completing a reach and grasp. Moreover, we claim that even pictures of objects are capable of eliciting action representations, at least under the right circumstances. As soon as that claim is made, however, we encounter what I call the *Magritte Challenge,* after the Belgian artist René Magritte. His classic painting of a pipe is accompanied by the phrase "*ceci n'est pas une pipe*" (this is not a pipe), meaning that a pictorial rendering is not the same thing as a real object. This observation readily translates into the criticism that a picture of an object is not likely to fool the visuomotor system into thinking that it is in the presence of an actual, manipulable version of the object.

But is this criticism valid? Fortunately, a recent study by Squires, Macdonald, Culham, and Snow (2016) has provided evidence that pictures of objects are as capable as real objects of evoking their associated action representations. Subjects were instructed either to move or to demonstrate how to use a target object that was placed in front of them. But before the target was presented, a priming stimulus was shown to the subjects. The prime was either a photograph of an object or a real object, and it either matched the upcoming target object (e.g., a spatula was presented as a prime and then as a target) or was a different object. Liquid crystal goggles were used to occlude the subject's vision while prime and target stimuli were placed and removed in front of the subject. The prime was valid on 60% of trials, providing subjects motivation for attending to it. The key issue was whether photographs of objects would be as effective as real object primes at priming the subject's motor interaction with the target object. When the task was simply to move the object by grasping its handle, lifting it, and placing it in a new location, neither type of prime was effective. This outcome probably was due to the fact that all of the objects had the same general shape and the same handle type, so moving any of those objects would involve very much the same action. For use actions, however, both photograph and object primes generated reliable and equally strong priming effects. The similarity in the priming effects for the two modalities supports the view that pictures of objects have at least some capacity to evoke related action representations.

Because we are considering action representations that something as abstract as a photograph of an object can elicit, these representations cannot be considered to be affordances in the sense that Gibson (1979) intended. In his view, real, three-dimensional objects naturally afford particular actions by virtue of their shape and position in space and by virtue of the constraints on the human form and its possible movements. No appeal to conceptual knowledge need be invoked to explain the notion that a flat horizontal surface of the correct width and height affords the act of sitting.

In contrast to Gibson's (1979) view of affordances, the action representations discussed here generally refer to previously experienced actions that are associated with particular objects. For example, a stapler affords the familiar action of pressing its top surface with the palm of a hand to cause a staple to be pushed through some pages of paper, fastening them together. There is deep conceptual knowledge here in addition to the motor actions, such as where on the upper surface of the stapler the hand should be placed to gain the correct leverage and that the distal goal is that of organizing a sheaf of paper.

Evoking Action Representations

We are now ready to turn to the question of the circumstances under which pictured objects (or real ones for that matter) are capable of activating an observer's mental representations of actions. As mentioned earlier, there is neuroimaging evidence to suggest that passively viewing pictures of manipulable objects activates regions of premotor cortex where representations of action are likely to be coded (e.g., Chao, Haxby, & Martin, 1999; Chao & Martin, 2000). The apparent tendency for passive viewing of objects to evoke action affordances is not, however, a safe conclusion. Gerlach, Law, and Paulson (2002) reported that activation of premotor cortex by viewing manipulable objects (e.g., clothing, fruit, and vegetables) relative to nonmanipulable objects occurred when subjects categorised items as natural or manmade but not when observers were required to make discriminations between real objects and nonobjects. The finding that particular tasks, such as categorisation, make use of motor-based knowledge, but other tasks do not, places an important limit on the proposal that passively viewed objects can elicit action representations associated with the corresponding real objects.

A further caveat regarding neuroimaging evidence for the ability of manipulable objects to selectively activate motor-related cortical regions is that the processes supported by those regions are not perfectly understood. For example, Mahon and Hickok (2016) reviewed evidence indicating that motor areas of the brain that are implicated when viewing manipulable objects versus other object types may reflect category-specific constraints that have their origin in a broader, nonvisual semantic network that is connected to visuomotor pathways. Moreover, Liu, Banich, Jacobson, and Tanabe (2004) and others (e.g., Fan, Flombaum, McCandliss, Thomas, & Posner, 2003) have shown that cortical regions associated with elevated activity when viewing objects, such as posterior parietal and dorsal premotor areas, are also especially active when subjects perform a Simon task that involves sensitivity to the spatial correspondence between the location of a visual stimulus (e.g., left or right of fixation) and the effector making a response (e.g., left or right hand). These findings suggest that selective activation generated by manipulable objects may be associated with spatial processing rather than motor representations. A full review of neuroimaging work on the relation between object perception and activation of motor-related cortical regions is beyond the scope of this article, but the studies cited here serve to indicate that the evidence on this issue is not entirely clear.

In addition to neuroimaging evidence, there is behavioural evidence that has been adduced to support the hypothesis that objects can automatically evoke action representations. A frequently cited example of this evidence is a study by Tucker and Ellis (1998) in which subjects made keypress responses to classify photographs of handled objects as upright or inverted. In each image, the object's handle pointed to the left or to the right. Response times were shorter when the response hand was on the same side of space as the object's handle, what I will call an *alignment effect*.

Although this result is consistent with the idea that handled objects can evoke limb-specific action representations (e.g., pick up a teapot with the left hand if the handle faces to the left), there is another interpretation that must be considered. The alignment in this task is between the spatial location of an object's handle and the spatial location of the response hand. The response time benefit of this alignment might be due to the spatial correspondence between the stimulus and response in this task, rather than to the activation of an object-relevant affordance, which leads to a more efficient response. As an example of how spatial correspondence effects can arise, consider a situation in which an arrow pointing left or right is presented instead of a handled object. If subjects make keypress responses to classify, say, the colour of the arrow, they are faster if the response hand is on the same side of space as the direction in which the arrow points (e.g., Pellicano, Lugli, Baroni, & Nicoletti, 2009; Proctor, Yamaguchi, Zhang, & Vu, 2009). This result clearly has nothing do to with object affordances but instead is a product of a correspondence between where in space attention has been directed by a visual stimulus and the location of the response device (key) with which the observer must interact to complete the assigned task.

Tucker and Ellis (1998) were sensitive to the possibility that their alignment effect could have been the result of a form of spatial correspondence, and to test this idea, they repeated the experiment with subjects making responses using the index and middle fingers of one hand. This task also requires responses to be mapped to left and right spatial locations, so if spatial correspondence is the basis for the alignment effect, then this version of the experiment should replicate that effect. But Tucker and Ellis found no reliable alignment effect with this new response mode. They argued that their alignment effect was a product of genuine action affordances being evoked by the pictured objects.

There are, however, some flaws regarding the results reported by Tucker and Ellis (1998) using the within-hand response method. First, when they used the mode rather than the mean as the measure of central tendency when analysing response times, a small alignment effect emerged. Second when subjects responded using two separate hands, the response key locations were widely separated (30 cm), but in the within-hand task, the keys were separated by a much shorter distance (2.5 cm). This confound might contribute to the observed size of the alignment effect, as increased spatial separation of response locations could make the correspondence between those locations and the location of the object's handle more salient.

In addition to these concerns about the interpretation of the alignment effect reported by Tucker and Ellis (1998), our early efforts to reproduce this effect were uniformly unsuccessful. For example, in one of our unpublished replication attempts, we had subjects make right- and left-hand keypress responses to classify pictured objects as upright or inverted, just as in the Tucker and Ellis experiment. Examples of stimuli are shown in Figure 1A. Our response time results showed no indication of an alignment effect (Figure 1B), despite relatively good measurement precision (small confidence intervals). In the research from our lab that is reported here, error rates typically were very low and never indicated the

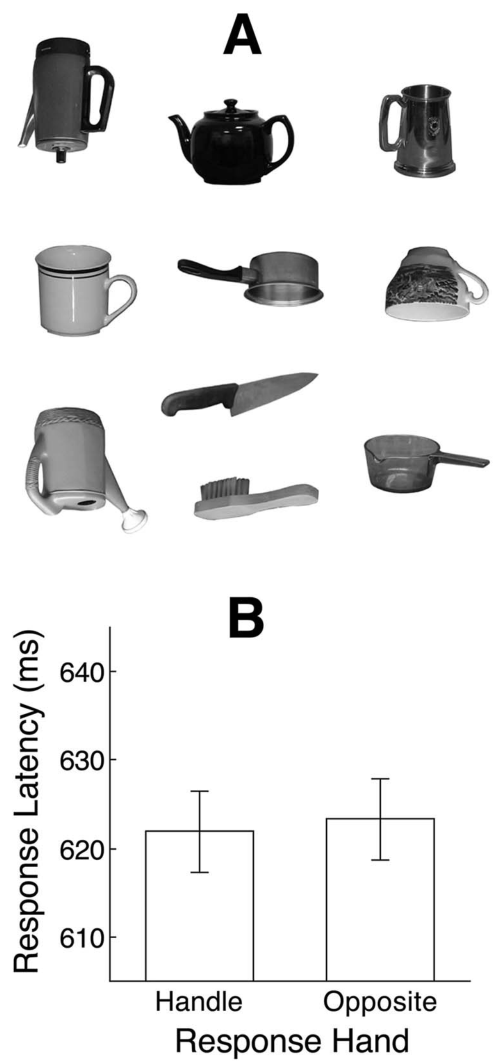

Figure 1. (A) Examples of handled objects used in an experiment requiring subjects to classify objects as upright or inverted. (B) Mean response time as a function of alignment between response hand and object's handle. Error bars are 95% within-subject confidence intervals (Loftus & Masson, 1994; Masson & Loftus, 2003).

potential for speed–accuracy trade-offs. Consequently, in this article, I report only response time data.

These results led us to be skeptical about the idea that passive viewing of objects would automatically evoke associated action representations. We therefore speculated that affordances might be elicited if subjects were operating in a context in which motor intentions were active. In support of this possibility, Riddoch, Edwards, Humphreys, West, and Heafield (1998) reported that in a neurological case of anarchic hand syndrome, a condition in which patients have a tendency to carry out hand actions without being able to clearly express a corresponding intention. Riddoch et al. showed that for their patient, a hand action associated with an object could be involuntarily evoked but only when a reach-and-grasp action intention was active. They had their subject respond to a handled mug placed at the far left or right side of a table, with its handle oriented either to the left or to the right. The subject was instructed either to touch the mug or to grasp it by its handle. The response hand was to be the one on the same side as the mug. When under the grasp instruction, the subject frequently grasped the mug using the incorrect hand when its handle was oriented toward that side of space (e.g., mug placed on the right side of the table with its handle pointing to the left). This erroneous response was consistent with the limb-specific grasp one would likely apply to the object when oriented in that way, but it was not the correct action given the instructions that were in effect. These errors, however, were much less common when the task was simply to point to the mug, but not grasp it. This result suggests that a grasp action intention can help elicit action representations associated with a viewed object.

We directly tested this idea by having healthy subjects make a reach-and-grasp response to classify the colour in which an object appeared (Bub & Masson, 2010). Subjects were briefly shown a grayscale image of a handled object (beer mug or frying pan), which then changed colour (green or blue). One hand was assigned one of the colours and the other hand was assigned the other colour, and a response was made by moving the relevant hand to a response element placed in front of the subject. This metallic element was designed to accommodate the required grasp response and had a weak electrical current passing through it. Contact by the subject's hand broke the circuit, allowing us to measure the time at which the reach-and-grasp response was completed. Figure 2 shows examples of the events on a trial and the response elements that were used.

To make contact with our previous failure to replicate the alignment effect with keypress responses, we tested a separate group of subjects who classified object colour by making keypresses rather than grasp responses. The mean response time for each of these two response mode conditions is shown in Figure 3. It is clear that whereas the keypress response requirement failed to generate a handle alignment effect, a strong effect was present when subjects were required to grasp a response element to indicate their decisions. These results strongly support our contention that eliciting action affordances from objects can be supported by inducing some form of action intention that involves a grasp response. Note that in this experiment, subjects always made a grasp response that was compatible with the orientation of the object's handle. I will address in a later section of this article the important question of whether this compatibility is necessary for an alignment effect to emerge.

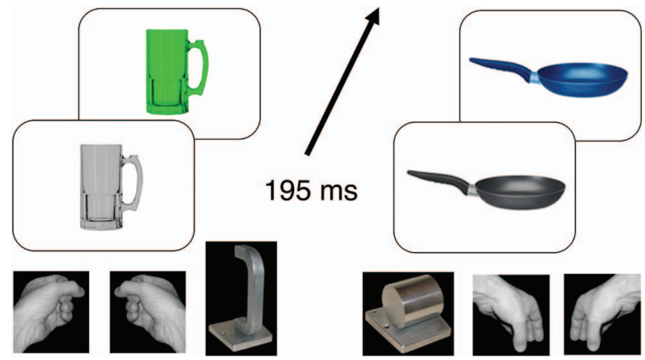

Figure 2. Trial events in the colour classification task using handled objects. Subjects either made a reach-and-grasp response with the left or right hand or they made a keypress response. The object first appeared in grayscale for 195 ms, then changed to either a blue or green colour (the online version of this article shows this figure in colour; the upper version of the beer mug is green and the upper version of the frying pan is blue). The pictured hands show the type of grasp required to make the response, and the response element used in each case is also shown. One group of subjects made vertical grasps to a beer mug, and the other group made horizontal grasps to a frying pan. Two other groups made keypress responses to one or the other of these objects. See the online article for the color version of this figure.

Insidious Spatial Correspondence Effects

Our proposal regarding the central role played by action intentions has been challenged by a recent demonstration of a robust handle alignment effect produced with keypress responses. Pappas (2014) obtained this result using an upright/inverted judgment task like the one used by Tucker and Ellis (1998), but his stimulus set consisted of just one object: a frying pan. Also like Tucker and Ellis, Pappas showed that the alignment effect obtained when responses were made using two hands was much reduced when subjects responded using two fingers of the same hand. This outcome was taken as evidence against the possibility that the alignment effect resulted from some form of spatial correspondence effect rather than from activation of a limb-specific action representation. Once again, however, Pappas used a wide key separation for the two-hand response mode and of necessity a small key separation for the one-hand mode. I have already pointed out the potential problem with this confound. But we are still left with the question of how the alignment effect emerged in the Pappas study when we have consistently failed to generate one using keypress responses.

To help understand the answer to this question, consider what turns out to be a crucial feature of the stimulus displays that Pappas (2014) used. The image of the frying pan was placed against a small gray background. The pan was positioned so that the set of pixels comprising its image were evenly divided between the two sides of the vertical midline of the background (see Figure 4A). I will refer to this as a *pixel-centred* display. Notice that over the course of a sequence of trials, with the object's handle appearing now on the right, now on the left, the handle's position changes substantially across trials. In contrast to this variation, the body of the frying pan remains near the centre of the background. We considered the possibility that this arrangement would draw atten-

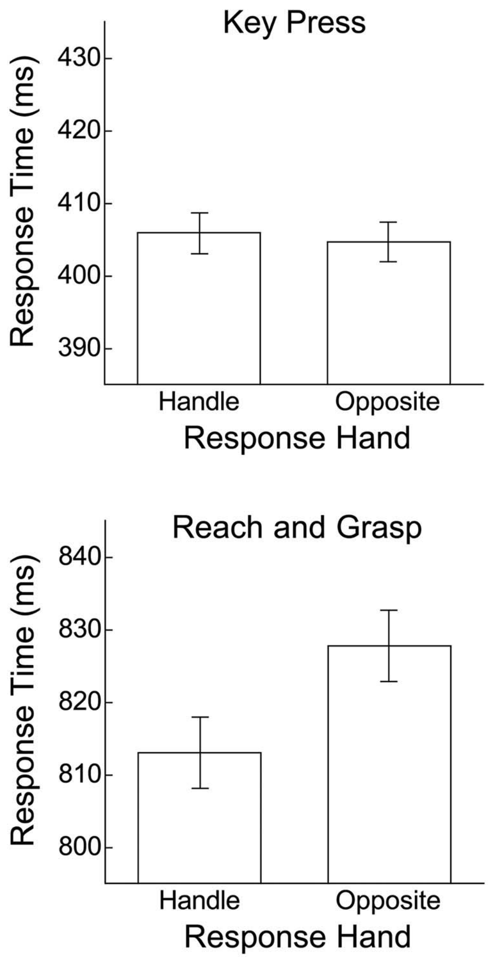

Figure 3. Mean response time for making keypress or reach-and-grasp responses to classify the colour of handled objects. The response hand was aligned either with the object's handle or with the opposite side of the object. Error bars are 95% within-subject confidence intervals. From "Grasping beer mugs: On the dynamics of alignment effects induced by handled objects," D. N. Bub & M. E. Masson, 2010, *Journal of Experimental Psychology: Human Perception and Performance, 36,* pp. 346–348. Copyright 2018 by the American Psychological Association. Adapted with permission.

tion to the horizontal displacement of the handle and consequently set the stage for a spatial correspondence between the handle's location and the location of the response hand.

The influence on visual attention suggested by this stimulus arrangement can easily be modified, simply by positioning the object against the background in a different way. In our work, we typically have used a *whole-object centred* display where each object is centred on the computer screen according to the horizontal and vertical extent of the object, regardless of the distribution of its constituent pixels. We incorporated this constraint with a gray background to produce a display similar to that shown in Figure 4B. Note that with this version of centring, not only does the handle vary its position from trial to trial, but the body of the frying pan, which carries the large majority of the object's mass, also varies its spatial position substantially across trials. This situation contrasts with the relatively stable position of the body in the case of pixel centring.

In a recent study, we compared these two methods of centring the image of a frying pan against its background, with the expectation that the nature of the alignment effect would be drastically influenced by this apparently trivial change (Bub, Masson, MacRae, & Marshall, 2018). Specifically, we expected to replicate the Pappas (2014) alignment effect when the frying pan was pixel centred, but under whole-object centring, we anticipated that the body of the pan, by virtue of its larger mass now shifting location across trials to a much greater extent than with pixel centring, would attract attention to itself and would become the anchor point for spatial correspondence between the visual display and the response location. The results of our experiments clearly showed this to be the case, with the alignment effect completely changing over from favouring the handle side of the object under pixel centring to favouring the body side under whole-object centring (see Figure 5). This result is consistent with a recent report by Proctor, Lien, and Thompson (2017).

To further support our claims about the important role of action intentions in eliciting genuine object-based affordances, we also tested the whole-object centred displays of a frying pan using a reach-and-grasp response rather than keypresses (Bub, Masson, & Kumar, 2018). Under these response requirements, the alignment effect again reversed, showing a clear advantage for responses made using the hand that was aligned with the object's handle (see Figure 5). We suggest that this alignment effect arises from a genuine object affordance. Even though visual attention may be induced to track the location of the object's body under whole-object centring, the action intention associated with grasping apparently is capable of overcoming that tendency, leading to sensitivity to the location of the object's handle—the graspable part. This series of studies highlights the importance of distinguishing between possible accounts of alignment effects. One can quite easily mistake an attentional effect based on spatial correspondence for evocation of a limb-specific action representation (see also Phillips & Ward, 2002).

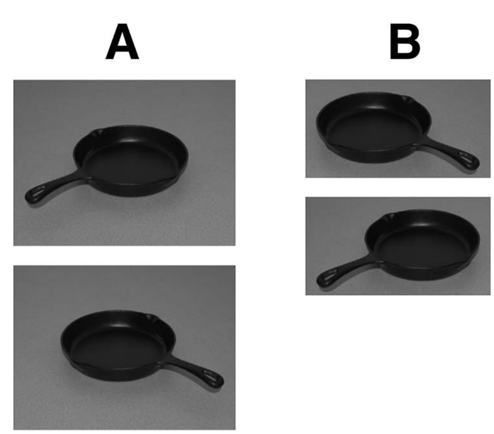

Figure 4. Examples of pixel-centred (A) and whole-object centred (B) displays of a handled object. These images were adapted from "Dissociating Simon and affordance compatibility effects: Silhouettes and photographs," by Z. Pappas, 2014, *Cognition, 133,* pp. 719. Copyright 2014 by Elsevier B. V. Adapted with permission.

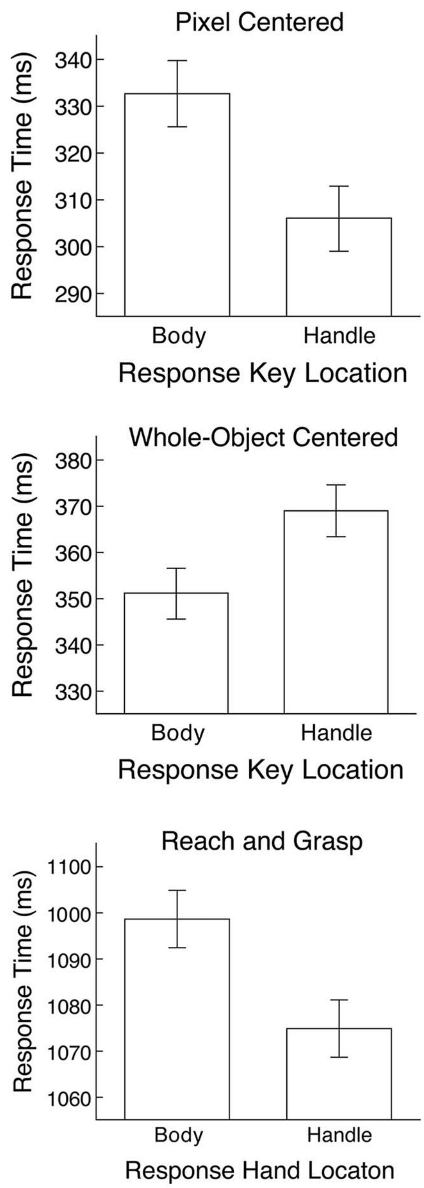

Figure 5. Mean response time for classifying photographs of a frying pan as upright or inverted. The two upper panels show keypress response times under two different stimulus placement conditions with response key location corresponding either to the handle of the object or to its body. The bottom panel shows reach-and-grasp response times under whole-object centring with response hand corresponding either to the handle of the object or to its body. Error bars are 95% within-subject confidence intervals. From "Spatial and motor codes induced by pictures of handled objects," D. N. Bub, M. E. J. Masson, C. MacRae, & G. Marshall, 2018, manuscript submitted for publication.

This lesson might profitably be applied to a recent demonstration purporting to show evidence that physical objects placed within reach have a greater potential to activate relevant motor representations than do photographs of those objects or even real objects placed out of reach (Gomez, Skiba, & Snow, 2018). The objects in this case were plastic spoons oriented with handles pointing left or right, with a centrally located target spoon flanked above and below by congruent or incongruent distractor spoons. Larger congruency effects were observed for reachable, actual objects. No evidence was reported, however, as to whether comparable results might be obtained had subjects responded with two fingers of one hand instead of making keypresses with left and right hands. The assumption that limb-specific action representations had been activated leads to the prediction that the effects should not be replicated when responding with two fingers of the same hand. Nor do we know whether similar results would obtain if a nonmanipulable object with a clear directional bias, such as an arrow, were used in place of spoons. These are important precautions to take before concluding that spatial correspondence effects reflect activation of action representations.

Dimensions of Action Representations

I now wish to move to a consideration of dimensions that characterise action representations and the nature of the relationship between these dimensions. Consider the object shown on the left of Figure 6. The sauce pan pictured there would naturally invite a right-hand grasp oriented horizontally. Indeed, the two dimensions of reach-and-grasp actions that we have examined extensively refer to hand selection (right, left) and orientation of the grasp (horizontal, vertical).

An additional dimension of interest is illustrated by the object shown on the right of Figure 6. Here we have a beer mug lying on its side with the handle on the object's dorsal surface. Imagine that you were asked to grasp this object by its handle using an overhand grasp. Even though most observers would be right-handed, it is very likely that people would opt to use their left hand to grasp this object. The reason for this preference is that observers are sensitive to action outcomes. In this case, an overhand left-handed grasp would allow one to comfortably rotate the left wrist in a counterclockwise direction to move the mug into its normal, upright position, ready for use. A right-handed grasp would require an awkward and possibly painful rotation of the wrist to bring the object into its upright position.

Rosenbaum, Vaughan, Barnes, and Jorgensen (1992) demonstrated that subjects exhibit this preference when choosing how to grasp a bar that had to be rotated into a target position and referred to it as an *end-state comfort effect*. Grasp selection of this kind indicates anticipation of how the grasping limb will need to be adjusted to complete the target movement. Our interest was in the possibility that action representations evoked by handled objects not only are affected by the current state of the object and its most likely graspable part but also by a consideration of the outcome of that action (e.g., a rotation that might be required to render the object ready for use). This aspect of action is dependent on rather

Figure 6. Images of handled objects. The sauce pan invites a right-handed grasp with a horizontal orientation. The beer mug invites a horizontal grasp given its current orientation, and consideration of the outcome of that action suggests that the left hand would be preferred.

deep conceptual knowledge, and if it helps to shape evoked action representations, that would suggest that the mechanism that imbues objects with the potential to elicit action representations is grounded at least to some extent in semantic knowledge about objects.

I would now like to make the case for how these action dimensions (hand selection, orientation, and sensitivity to action outcome) are represented. One method we have been using to do that involves asking observers to view a prime object whose handle is positioned to the left or right and is oriented either horizontally (e.g., sauce pan) or vertically (e.g., beer mug), then to make a cued hand action (Bub, Masson, MacRae, et al., 2018; Masson, Bub, & Breuer, 2011). Figure 7 illustrates the events for a typical trial, where the object prime appeared by itself briefly before a hand cue was superimposed, indicating the required action. No action was made to the object itself, although subjects were occasionally required to name the prime object at the end of a trial. Subjects performed the cued action by grasping a vertical or horizontal bar mounted on a response apparatus like the one used in the work reported above. The factors of interest consisted of the match or mismatch between the prime and the cued action on the two dimensions of hand selection and orientation. When the response hand was on the same side of space as the prime object's handle, as in the example in Figure 7, we called this the aligned condition. When the opposite hand was used, it was the not-aligned condition. If the cued action required the response hand and wrist to have the same orientation as the object's handle, this was considered the congruent condition. If the orientations differed, this was the incongruent condition. Besides using upright primes as indicated in Figure 7, we also used primes that were rotated 90 degrees, like the beer mug shown in Figure 6. The response hand was considered to be aligned, or *commensurate,* with the object's handle if, after grasping the handle, a supinated rotation from horizontal to vertical (as for the beer mug in Figure 6) or a pronated rotation from vertical to horizontal would place the object in its normal, upright position. If the selected response hand would require an awkward rotation in the opposite direction to bring the object to upright, this was considered an *incommensurate* hand selection. Orientation congruency was determined by the orienta-

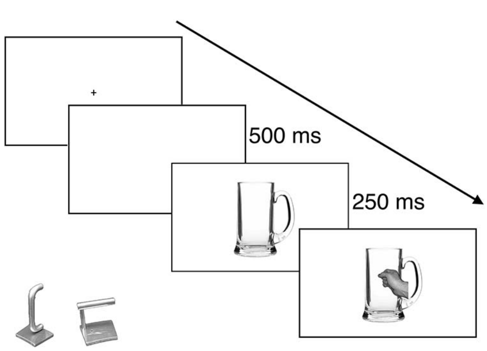

Figure 7. An illustration of trial events in the object priming study of Bub, Masson, and Kumar (2018). Subjects made reach-and-grasp responses cued by the picture of a hand by applying the indicated grasp to one of the response elements shown here. Vertical grasps were applied to the element on the left, and horizontal grasps were made using the element on the right.

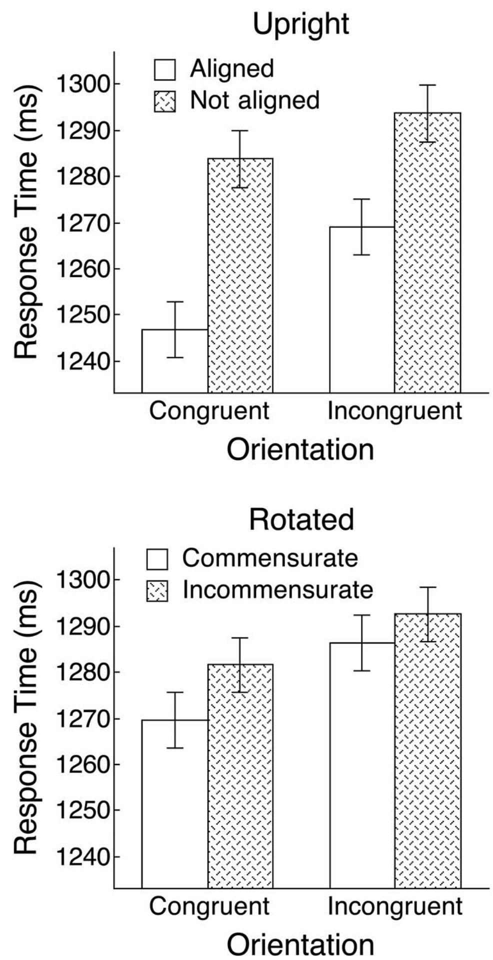

Figure 8. Mean response time for reach-and-grasp responses to hand cues in the presence of handled objects as primes. Alignment refers to the correspondence between the location of the object's handle and the response hand, and congruency refers to the match between the orientation of the object's handle and the grasp response. For rotated primes, commensurability refers to whether grasping the object with the indicated hand would allow the object to be rotated to upright with a comfortable wrist rotation. Error bars are 95% within-subject confidence intervals suitable for comparing means within each panel. From "Time course of motor affordances evoked by pictured objects and words," by D. N. Bub, M. E. J. Masson, & R. Kumar, 2018, *Journal of Experimental Psychology: Human Perception and Performance, 44,* p. 60. Copyright 2018 by the American Psychological Association. Adapted with permission.

tion of the object's handle and the response hand in the same way as with upright primes.

Response time was measured from the onset of the hand cue to completion of the grasp response (contact with the response element). Mean response times for the case in which primes were shown for 250 ms before the onset of the hand cue are shown in Figure 8. Considering first the results for upright primes, it is clear there was a benefit both for having the response hand aligned with the object's handle and for having the response oriented congruently with the handle. Moreover, the alignment effect was obtained regardless of whether the orientation was congruent between the prime and the action performed, although it was modulated some-what by congruency. Similarly, there was a congruency effect, regardless of whether the response hand was aligned with the object's handle. For rotated primes, a commensurability effect was apparent, but only when the orientation of the response hand was congruent with the orientation of the prime object's handle. This loss of the commensurability effect may be an issue of statistical power, given the effect is relatively small, even under the ideal circumstances of congruent orientation. In general, these results convincingly demonstrate that both the dimensions of hand selection and of orientation are components of action representations evoked by pictured objects. In addition, the anticipation of action outcome helps to shape the nature of these elicited action representations.

Distinguishing Types of Action Representation

The near independence of the hand selection and orientation dimensions seen in our work with action representations elicited by viewing object primes, which we have replicated multiple times (e.g., van Noordenne, 2017), does not fit very well with what is known about how action dimensions such as these are organized when an action is prepared for immediate execution. Brown, Friston, and Bestmann (2011) have obtained evidence showing that when subjects prepare an action for immediate production, action dimensions are integrated and become dependent on one another, unlike what we have demonstrated using object primes. To follow their account, consider an arrangement involving again two action dimensions, hand selection (left or right) and hand movement that requires bending the wrist (flex or extend). Based on results from the physiological literature (e.g., Kakei, Hoffman, & Strick, 1999, 2003; Soechting & Flanders, 1992), Brown et al. (2011) argued that when there is some input into the motor system that prescribes a particular action, such as flexing the left hand, that action intention would be coded in the premotor cortex in an extrinsic frame of reference, using independent encoding of dimensions. Just prior to execution of a movement, however, actions are coded in the motor cortex with an intrinsic coordinate system, encoding movement in terms of joint angles and relevant proprioceptive input. At this level of representation, movement dimensions are integrated together. These two representational possibilities make different predictions about how the relationship between a primed action and a target action should affect action execution. In particular, if a primed action is represented in the premotor cortex, in extrinsic coordinates with dimensions separately activated, then any dimensional overlap between a primed and target action should lead to more efficient action execution. If a primed action is represented at the level of the motor cortex, however, action dimensions would be integrated within intrinsic coordinates and only the specific action defined by the relevant values on each dimension would show a benefit.

Brown et al. (2011) tested these ideas by presenting a cue that specified one value on each dimension (hand and movement), for example, left-hand/flex. Shortly after the cue appeared, a target stimulus appeared, defining the action that was to be executed, again by specifying the dimensions of hand and movement. The cues were highly, but not perfectly, predictive of the target action, and so they likely induced subjects to prepare the action indicated by the cue in advance of the target stimulus. Brown et al. measured muscle activation using surface electromyographic electrodes.

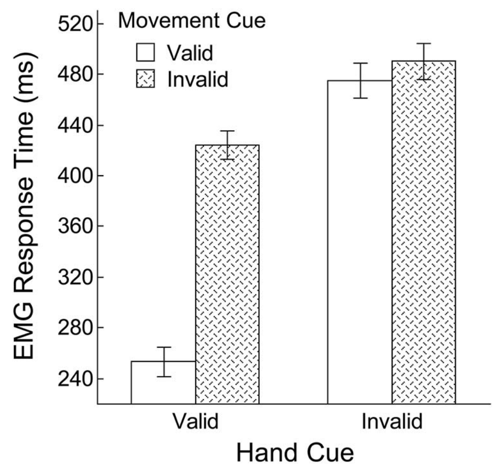

Figure 9. Mean response time in the Brown et al. (2011) study as a function of validity of the hand and movement cues. Error bars are one standard error of the mean. From "Active inference, attention, and motor preparation," by H. Brown, K. Friston, & S. Bestmann, 2011, *Frontiers in Psychology, 2,* p. 7. Copyright 2011 by the Authors. Adapted with permission.

Mean response time as a function of the validity of the two dimensions of the cue stimulus is shown in Figure 9. This pattern of response times clearly indicates a strong dependence between the two dimensions. Responses were faster when the hand dimension was validly cued, but particularly so when the movement cue was also valid. There were some savings even if the movement cue was invalid as long as the hand cue was valid. But if the hand cue was invalid, there was no benefit at all for having a valid movement cue. These results most closely resemble what would be expected if the action dimensions were integrated and represented within intrinsic coordinates in the motor cortex.

These results contrast sharply with the pattern of priming effects seen when subjects perform cued reach-and-grasp actions in the presence of a prime object (see Figure 8). Our conclusion is that there appear to be at least two different ways in which action representations might be coded. One format characterizes action representations that are evoked when subjects view manipulable objects in the context of making reach-and-grasp responses. The other is engaged when preparing immediately to execute a physical action. To reinforce this point, I will close by describing a very recent result from our lab (Lawless, 2018) in which we induced subjects to prepare to perform an action that was defined by hand selection and orientation, just as in our priming experiments. At the beginning of each trial, subjects were cued with a two-letter code specifying the response hand (L or R) and the hand/wrist orientation (H or V). After the subject signalled that he or she was ready to produce the action, there was a short delay, and then, on 20% of the trials, a cue was given and the subject executed that action as rapidly as possible. To ensure that subjects were genuinely preparing to execute the designated action, they were required to produce it within a short response time deadline. On the remaining trials, however, a different cue was delivered that consisted of a picture of a hand (left or right) in a power grasp (like the grasp one would use to grip the handle of a teapot) that was either horizontally or vertically oriented. On these trials, the subject's task was to abandon the originally planned action and execute the action dictated by the pictured hand. The hand cue shared one, both, or neither of the action dimensions with the originally prepared action. When we examined response time on these *switch* trials as a function of the overlap in action dimensions between the prepared and the executed action, we found exactly the same pattern of results as that reported by Brown et al. (2011). Namely, responses were faster if the same hand was involved in both the prepared and the executed action, with much greater benefit if the orientation was also preserved. If the new action required a change of response hand, then there was no benefit whatsoever for retaining the same orientation. This result was obtained in two separate experiments, leaving us firmly convinced of the difference in representations of actions that are prepared for immediate execution and of actions that are evoked by viewing manipulable objects. We characterise the integration implied by the results related to the representation of an impending action as a *hierarchical integration,* in the sense that the hand component of the hierarchy is at the top (changing hands eliminates any benefit), with the orientation dimension embedded below it.

Summary and Future Directions

In this overview of some of my collaborative work with Daniel Bub, I have argued that action representations can be elicited by viewing manipulable objects, at least when observers are operating under some form of action intention. I have also provided evidence that sensitivity to potential action outcomes helps to shape the particular action representations that objects may evoke. But it is necessary to be cautious when interpreting evidence for correspondence effects such as handle alignment (e.g., Pappas, 2014; Tucker & Ellis, 1998), because these results may be due to spatial correspondence effects that are grounded not in action representations but in principles governing the distribution of spatial attention. Finally, I presented evidence concerning two kinds of action representations, characterised by independent versus integrated coding of action dimensions and potentially associated with different cortical regions.

In the near future, we will be expanding our investigation of subtle influences of context on the kinematics of reach-and-grasp actions (e.g., Till, Masson, Bub, & Driessen, 2014). We are very interested in understanding how aspects of hand trajectory and shape are modulated by factors such as the presence of irrelevant objects or intentions to produce a future action that is compatible or conflicts with the current action. We have also developed a system to assess sensitivity to tactile stimulation that involves applying tactors to specific body locations, such as hands and feet, allowing us to detect modulation of sensitivity when subjects perform or even merely observe actions. Changes in sensitivity may reveal activation of limb-specific action representations. These methodologies hold great promise for generating further insights into the deep relationship between cognition and action.

Résumé

Les objets manipulables ont le potentiel de susciter des représentations mentales d'actions manuelles. Les preuves comportementales démontrant que ce processus se fait automatiquement lors de l'observation passive d'objets sont soumises à un examen critique. Une hypothèse alternative est mise de l'avant suggérant que les objets peuvent susciter des représentations d'action lorsque les observateurs agissent en même temps avec l'intention de s'engager dans une action d'atteinte et de saisie. En outre, la nature des représentations d'actions manuelles a été examinée en tenant compte de deux éléments d'action, le choix de main et l'orientation du poignet, et il est démontré que la relation entre ces dimensions est modulée par le contexte de la tâche. Lorsque la représentation de l'action est suscitée par un objet sans relation avec la tâche, ces deux dimensions sont, dans une large mesure, indépendantes l'une de l'autre, mais lorsqu'un observateur prépare une action en vue d'une production immédiate, ces deux caractéristiques d'action sont intégrées de façon hiérarchique, le choix de main dominant la hiérarchie.

Mots-clés : intention d'action, représentations d'action, effets de correspondance, codes spatiaux.

References

Brown, H., Friston, K., & Bestmann, S. (2011). Active inference, attention, and motor preparation. *Frontiers in Psychology, 2,* 218. http://dx.doi.org/10.3389/fpsyg.2011.00218

Bub, D. N., & Masson, M. E. J. (2010). Grasping beer mugs: On the dynamics of alignment effects induced by handled objects. *Journal of Experimental Psychology: Human Perception and Performance, 36,* 341–358. http://dx.doi.org/10.1037/a0017606

Bub, D. N., Masson, M. E. J., & Kumar, R. (2018). Time course of motor affordances evoked by pictured objects and words. *Journal of Experimental Psychology: Human Perception and Performance, 44,* 53–68. http://dx.doi.org/10.1037/xhp0000431

Bub, D. N., Masson, M. E. J., MacRae, C., & Marshall, G. (2018). *Spatial and motor codes induced by pictures of handled objects*. Manuscript submitted for publication.

Chao, L. L., Haxby, J. V., & Martin, A. (1999). Attribute-based neural substrates in temporal cortex for perceiving and knowing about objects. *Nature Neuroscience, 2,* 913–919. http://dx.doi.org/10.1038/13217

Chao, L. L., & Martin, A. (2000). Representation of manipulable man-made objects in the dorsal stream. *NeuroImage, 12,* 478–484. http://dx.doi.org/10.1006/nimg.2000.0635

Fan, J., Flombaum, J. I., McCandliss, B. D., Thomas, K. M., & Posner, M. I. (2003). Cognitive and brain consequences of conflict. *NeuroImage, 18,* 42–57. http://dx.doi.org/10.1006/nimg.2002.1319

Gerlach, C., Law, I., & Paulson, O. B. (2002). When action turns into words. Activation of motor-based knowledge during categorization of manipulable objects. *Journal of Cognitive Neuroscience, 14,* 1230–1239. http://dx.doi.org/10.1162/089892902760807221

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

Gomez, M. A., Skiba, R. M., & Snow, J. C. (2018). Graspable objects grab attention more than images do. *Psychological Science, 29,* 206–218. http://dx.doi.org/10.1177/0956797617730599

Kakei, S., Hoffman, D. S., & Strick, P. L. (1999). Muscle and movement representations in the primary motor cortex. *Science, 285,* 2136–2139. http://dx.doi.org/10.1126/science.285.5436.2136

Kakei, S., Hoffman, D. S., & Strick, P. L. (2003). Sensorimotor transformations in cortical motor areas. *Neuroscience Research, 46,* 1–10. http://dx.doi.org/10.1016/S0168-0102(03)00031-2

Lawless, K. (2018). *From a planned action to a revised action: Revealing the structure of motor plans*. Unpublished Master of Science thesis, University of Victoria, Victoria, Canada.

Liu, X., Banich, M. T., Jacobson, B. L., & Tanabe, J. L. (2004). Common and distinct neural substrates of attentional control in an integrated

Simon and spatial Stroop task as assessed by event-related fMRI. *NeuroImage, 22,* 1097–1106. http://dx.doi.org/10.1016/j.neuroimage.2004.02.033

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review, 1,* 476–490. http://dx.doi.org/10.3758/BF03210951

Mahon, B. Z., & Hickok, G. (2016). Arguments about the nature of concepts: Symbols, embodiment, and beyond. *Psychonomic Bulletin & Review, 23,* 941–958. http://dx.doi.org/10.3758/s13423-016-1045-2

Masson, M. E. J., Bub, D. N., & Breuer, A. T. (2011). Priming of reach and grasp actions by handled objects. *Journal of Experimental Psychology: Human Perception and Performance, 37,* 1470–1484. http://dx.doi.org/10.1037/a0023509

Masson, M. E. J., & Loftus, G. R. (2003). Using confidence intervals for graphically based data interpretation. *Canadian Journal of Experimental Psychology, 57,* 203–220. http://dx.doi.org/10.1037/h0087426

Pappas, Z. (2014). Dissociating Simon and affordance compatibility effects: Silhouettes and photographs. *Cognition, 133,* 716–728. http://dx.doi.org/10.1016/j.cognition.2014.08.018

Pellicano, A., Lugli, L., Baroni, G., & Nicoletti, R. (2009). The Simon effect with conventional signals: A time-course analysis. *Experimental Psychology, 56,* 219–227. http://dx.doi.org/10.1027/1618-3169.56.4.219

Phillips, J. C., & Ward, R. (2002). S-R correspondence effects of irrelevant visual affordance: Time course and specificity of response activation. *Visual Cognition, 9,* 540–558. http://dx.doi.org/10.1080/13506280143000575

Proctor, R. W., Lien, M.-C., & Thompson, L. (2017). Do silhouettes and photographs produce fundamentally different object-based correspondence effects? *Cognition, 169,* 91–101. http://dx.doi.org/10.1016/j.cognition.2017.08.009

Proctor, R. W., Yamaguchi, M., Zhang, Y., & Vu, K.-P. L. (2009). Influence of visual stimulus mode on transfer of acquired spatial associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 434–445. http://dx.doi.org/10.1037/a0014529

Riddoch, M. J., Edwards, M. G., Humphreys, G. W., West, R., & Heafield, T. (1998). Visual affordances direct action: Neuropsychological evidence from manual interference. *Cognitive Neuropsychology, 15,* 645–683. http://dx.doi.org/10.1080/026432998381041

Rosenbaum, D. A., Vaughan, J., Barnes, H. J., & Jorgensen, M. J. (1992). Time course of movement planning: Selection of handgrips for object manipulation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 1058–1073. http://dx.doi.org/10.1037/0278-7393.18.5.1058

Soechting, J. F., & Flanders, M. (1992). Moving in three-dimensional space: Frames of reference, vectors, and coordinate systems. *Annual Review of Neuroscience, 15,* 167–191. http://dx.doi.org/10.1146/annurev.ne.15.030192.001123

Squires, S. D., Macdonald, S. N., Culham, J. C., & Snow, J. C. (2016). Priming tool actions: Are real objects more effective primes than pictures? *Experimental Brain Research, 234,* 963–976. http://dx.doi.org/10.1007/s00221-015-4518-z

Till, B. C., Masson, M. E. J., Bub, D. N., & Driessen, P. F. (2014). Embodied effects of conceptual knowledge continuously perturb the hand in flight. *Psychological Science, 25,* 1637–1648. http://dx.doi.org/10.1177/0956797614538842

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 830–846. http://dx.doi.org/10.1037/0096-1523.24.3.830

van Noordenne, M. H. J. (2017). *Compatibility effects evoked by pictures of graspable objects*. Unpublished Master of Science thesis, University of Victoria, Victoria, Canada.

Wolpert, D. (2011). *The real reason for brains*. Retrieved from https://www.ted.com/talks/daniel_wolpert_the_real_reason_for_brains

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