

On the Cognitive Control of Hand Actions for Lifting and Using an Object

by

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B.Sc. University of Victoria, 2015

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Supervisory Committee

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Abstract

Recent evidence suggests that when performing reach-and-grasp actions on day-to-day objects, lift-actions are faster to execute relative to use-actions, and that a “use-on-lift” interference occurs and produces switch costs when changing actions from using to then lifting (Jax & Buxbaum, 2010; Osiurak & Badets, 2016). Such findings result from paradigms that include the sudden appearance of objects, requiring participants to react quickly to the features of the object, independent of the functionality of the objects. Because of the importance this topic has to day-to-day interactions with objects, the following four experiments were executed with objects continuously visible to participants. When imitating images of hand actions on objects, participants showed no differences in the initiation time of use- and lift-actions, suggesting that no systematic differences exist between these two actions. Using this as a baseline, we compared a more generative approach, as when actions are instructed by auditory sentences. In this case, we see that switching actions is difficult, switching objects is even more difficult, and that use-actions are modestly faster than lift-actions; the reverse of what previous research shows. In a third experiment modelled after the paradigm used in studies producing rapid lift- and slowed use-actions, we showed that use-actions are actually *facilitating* lift-actions. Further, we demonstrate that having a use-action goal in mind provides the knowledge required to perform a lift-action, and that use-actions are again faster than lift-actions. These results are a critical addition to the task-switching literature on the cognitive control of motor processes associated with hand actions as distinctions are made between non-naturalistic and realistic settings relevant to day-to-day interactions with objects. We show that use-actions facilitate lift-actions and that, in realistic settings, both use- and lift-actions require access to stored knowledge.

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Dedication

This work is dedicated to the incredible people in my life who provided their unwavering support as I stumbled towards the finish line. Supervisors and lab managers, friends, family, colleagues, and my cat: thank you!

In the wise words of Christopher Robin:

"You are braver than you believe, stronger than you seem, and smarter than you think."

On the Cognitive Control of Hand Actions for Lifting and Using an Object

One of the defining features of human nature is our cognitive flexibility. Central to this ability is the ease with which we can switch between tasks. For instance, while preparing breakfast we might use a knife to chop fruit before switching actions to lift a spoon and stir sugar into our coffee. Presumably, the ability to make this switch depends (to some degree) on mechanisms of cognitive control. Indeed, research has demonstrated that there are complex cognitive processes at work in our ability to flexibly transition from one task to another (Allport, Styles, and Hsieh, 1994). In the above example, switching takes place between different manual actions; a great deal of task-switching has to do with the control of actions performed by means of our hands. This thesis will shed further light on the mechanisms that underlie the cognitive control of reach-and-grasp actions applied to everyday familiar objects.

Switching Between Use- and Lift- Actions

Grasp actions vary depending on whether we wish to use or lift an object. To use an object according to its proper function, manual actions are often directed at structural features that are not the most salient (e.g., depressing the keys of a cellphone to make a call). These actions are guided by stored knowledge, also referred to as “manipulation knowledge,” of how we typically use an object (Osiurak and Badets, 2016). The grasp for lifting rather than using an object can be generated directly from its global shape. At least in principle, lift-actions can be accomplished without prior knowledge of actions linked to an object’s identity. Dexterous actions include the ability to switch efficiently between use- and lift-actions. Nevertheless, despite the apparent ease with which we transition from one kind of grasp action to another, some evidence indicates that lift-actions are produced more rapidly than use-actions on the same

objects (Osiurak and Badets, 2016; Jax and Buxbaum, 2010). In addition, switch costs are induced by use-actions on subsequent lift-actions; the time to produce a lift-action is considerably delayed shortly after participants carry out a block of use-actions on the same set of objects (Jax and Buxbaum, 2010).

These results appear compatible with a widely held distinction between two cortical systems for producing grasp actions to visual objects (Johnson-Frey, 2004; Pisella, Binkofski, Lasek, Toni, & Rossetti, 2006). A left-lateralized system in the inferior parietal lobe has access to stored motor representations governing the use of familiar objects. A bilateral system, localized in the superior parietal lobe and intraparietal sulci, generates actions based only on the structural properties of an object. This route is active when the goal is to lift and transport an object from one location to another. A lift-action is automatically triggered by the overall structure of an object and is generated more rapidly than a use-action (Cant, Westwood, Valyear, & Goodale, 2005; Garofeanu, Kroliczak, Goodale, & Humphrey, 2004).

For a variety of objects, the dual routes to action yield discrepant motor representations; for example, we usually recruit a power grasp to lift a stapler but rely on an open palm to use the same object. This discrepancy can induce competing motor representations. Assume that the two routes operate independently: a rapidly triggered lift-action would compete with and delay the intended production of a use-action. Furthermore, switching between use- and lift-actions can yield additional interference effects. Two possible explanations have been proposed for “use-on-lift” interference. The representation of a use-action might remain active long after it has been generated to a particular object. A subsequent lift-action would then be delayed if the same object continued to evoke the prior (and competing) use-action. Alternatively, repeated production of

use-actions may induce a task set that entails an overall bias towards using rather than lifting objects. If the task set persists, the motor system will trigger a use-action that interferes with the production of a lift-action.

The ideas just described have been conceived as a general blueprint for our everyday interactions with manipulable objects. Thus, according to Jax and Buxbaum (2010), “...the intention to act on an object triggers a race-like competition between functional and structural responses during action selection” (page 354). In what follows, the claim that lift- and use-actions compete when we freely interact with graspable objects under normal viewing conditions will be challenged on both theoretical and methodological grounds. The issues to be raised will motivate a series of experiments designed to further elucidate the cost of switching between different actions. No support emerged for the idea that the production of a use-action generates motor representations that subsequently delay the production of a lift-action. Nonetheless, under certain task conditions, costs were observed when a switch is required between actions to the same or a different object. The nature of these switch costs provides insight into the control of grasp actions carried out on a set of familiar objects under normal viewing conditions.

Theoretical Challenge

The goal of a use-action is typically couched in abstract terms. The action occurs in order to carry out the predetermined function of a tool or utensil, an object property inherently dependent on stored knowledge. By contrast, the intention behind a lift-action is usually defined more concretely. We produce these actions “...simply to grasp and move the object from one location to another” (Osiurak and Badets, 2016; page 538). The preconception that lift-actions deal merely with the spatial transport of an object readily accommodates the view that such

actions operate independently of long-term motor representations. To grasp and move an object between locations, it is assumed, requires only that the motor system "...encodes current constraints on action imposed by the body and environment, maintains information for milliseconds to seconds, and may operate independent of long-term conceptual information" (Jax and Buxbaum, 2010; page 351). In fact, though, a variety of distal goals can be satisfied by the lifting of an object. We may reach for and lift an object to rapidly snatch it away from a child, for example, if we perceive the object to be dangerous. We can lift and hand the object to someone else; we can lift and transport the object to a new location. Finally, we may grasp and move an object closer to ourselves because we intend to use it.

There is clear evidence that not all these ways of lifting an object takes place without access to stored knowledge. Osiurak, Roche, Ramone, and Chainay (2013) have reported that lift-actions are generated more slowly than use-actions when the goal of lifting is to hand the object to another person. The authors suggest that a "lift-to-give" action is determined not only by perceptual information like the object's position and size, but also requires access to long-term knowledge of an object's weight and other non-visual attributes. Additional results confirm that stored motor representations are available for grasp actions directed at lifting as well as using an object.

Auditory words denoting manipulable objects rapidly elicit grasp postures associated with their structural properties (Bub and Masson, 2012). Grasps linked to an object's functional properties are activated more strongly, but the fact that the posture for lifting as well as using an object is evoked within a few hundred milliseconds from word onset indicates that shape-based motor representations are directly linked to an object's conceptual attributes. Additional evidence

lends further support to the claim that lift-actions are influenced by stored knowledge. Gentilucci (2002) has shown that habitual interactions with objects exert an influence on the kinematics of a grasp action. Herbort and Butz (2011) found that habitual actions determine the grasp chosen to rotate an object, overriding the posture more directly afforded by the intended goal of the movement.

To summarize thus far, reasons exist to doubt the notion that lift-actions in general are determined only by the perceived form of an object without any reliance on stored motor representations. Given this scepticism, how do we rationalize previous evidence consistent with the idea that lift-actions are generated on-line to the structural properties of an object, while use-actions depend on slower access to stored (functional) knowledge?

Methodological Issues

The relevant evidence has been obtained as follows: familiar objects were displayed one at a time to participants whose vision was initially occluded by LCD goggles. Shortly after a warning tone, the goggles cleared to reveal a single object on a platform. Depending on the instructions, a given block of trials required either lift or use grasp actions. Irrespective of task order, lift-actions were generated more rapidly than use-actions (Osiurak, Roche, Ramone, and Chainay, 2013; Jax and Buxbaum, 2010). Furthermore, the production of use-actions interfered with the subsequent production of discrepant lift-actions on the same objects (Jax and Buxbaum 2010).

How general are these findings? That is, how well do they apply to everyday situations, when we interact with objects that are continuously visible? Consider in more detail the task of retrieving a grasp action to lift or use an object that appears suddenly after a brief interval of occluded vision. A use-action is determined by functional knowledge of an object, which

performance depends on its identity. A lift-action under the same viewing conditions, however, can occur in two ways. The object might again be identified, and the action determined by shape and weight properties retrieved from memory. Alternatively, the abrupt manifestation of an object can trigger a lift-action determined by visual information directly perceived. There is substantial evidence that immediate visuomotor control is mediated by dorsal systems that operate without reliance on object identity, a route involved in producing fast grasp responses to unknown objects (Jeannerod and Jacob, 2005; Rossetti, Pisella and Vighetto, 2003). The triggering of this route will yield the rapid production of a grasp action that occurs without access to long-term motor representations.

The conditions that elicit this kind of motor response are unusual. As noted by Rossetti, Pisella and Vighetto (2003) they require fast, immediate visuomotor transformations without supervision by conceptual levels of representation, precisely those invited when (i) an object appears suddenly; (ii) instructions are to produce a rapid grasp action and (iii) the task context discourages any higher-level constraints on motor intentions. Jax and Buxbaum (2010) instructed participants to enact lift-grasps by placing their dominant hand on the object as if to hand it to another person. Given that no actual transport of the object was required, it seems unlikely that action plans were guided by this intention. Directly relevant to this conjecture is the result obtained by Osiurak, Roche, Ramone, and Chainay (2013). These authors displayed objects with handles (e.g. a spatula) and, via the same method of presentation involving LCD goggles, also observed that lift grasps were faster than use grasps when participants were instructed to merely place their hand on each object as if to lift or use it, without subsequent movement. As already

noted, lift-actions became slower than use-actions when the transport task required that the object was actually given to another person.

According to Osiurak et al. (2013), the “lift-to-give” task demanded access to higher-level information such as the objects’ weight and even the position and size of the recipient’s hand. However, a more general inference emerges that is consistent with the idea that competition between lift and use-actions occurs only under rather special circumstances. To reiterate, the sudden appearance of an object may trigger a rapid visuomotor transformation determined by its shape, without any contribution from higher-level knowledge. When task demands enable the production of a grasp based on this immediate reaction, movement will be more rapid than actions determined by the object’s identity. Moreover, a block of trials that requires consistent retrieval of use-actions also entails persistent attention to object identity. The bias to generate actions determined by the identity of an object may remain active in switching to a block of lift-actions. Higher-level representations will continue to affect the production of lift-actions, pre-empting the contribution of the fast visuomotor route.

In summary, grasp actions to lift and transport an object may not typically be generated by fast visuomotor transformations that operate without access to long-term knowledge, and interference effects between lift- and use-actions may not be observed in everyday contexts where objects are continually visible. Take, for example, the usual interaction with objects arrayed on a table. Imagine only three such objects; a spray-can, a cell phone and a pencil. Assume these objects are all clearly visible and close together, and that a grasp action is produced to one object, followed by another action carried out on the same or a different object (use the cellphone), and so on. Because each of the three possible targets remains constantly in

view, the task requires the programming of various grasp actions to objects that have already been identified. The question of interest is the following: what switch-costs, if any, occur under these conditions, and what light do they shed on the nature of lift- and use-actions?

Experiment I

In Experiment I, participants were cued on each trial to carry out grasp actions on physical objects by means of an image depicting either a use- or lift-action (see Figure 1). In accordance with everyday experience, objects were continuously visible throughout the duration of the experiment. Reaction times were recorded to evaluate the presence of switch costs. Because responses were cued by pictures of lift- and use-actions, any switch-costs will depend on procedures that are more imitative than generative. Additional costs incurred when actions are triggered less concretely in subsequent experiments can be evaluated relative to this baseline (see Jax and Buxbaum, 2010 for a similar control condition).

Participants: Thirty-two English-speaking students were recruited from undergraduate psychology classes at the University of Victoria. Participants were given extra credit as an incentive to engage in the study.

Materials: Hand actions for use- and lift-grasps were selected and matched to three specific objects: a cellphone, spray-can, and pencil. Each object was associated with one use-and one lift-grasp, affording six possible hand actions in total. Digital photographs were made with each of the three objects posed with a male human hand demonstrating each of the six corresponding actions (see Figure 1).

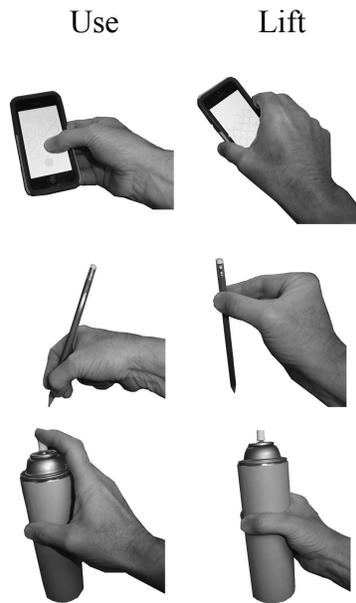


Figure 1. Using and lifting grasps for Experiment I.

Images were modified so that the background matched that of the computer monitor. Two different versions of the images of the hands with the objects were created; one with the images oriented for right-handed participants and the other oriented for left-handed participants. Images demonstrated to participants to either “lift” or “use” one of the three objects. Sixteen images were made in total: half of which demonstrated use-actions and half of which demonstrated lift-actions. Images were presented at random with equal frequency. Each trial consisted of images with four possible combinations: switch in action class, switch in object, switch in action class and object, or no switch (see Figure 2). Each participant experienced 64 images x 4 blocks for a total of 256 images. Participants practiced with 32 images: eight randomly chosen from the 12 in each of the four conditions. Image presentation was initiated with a button press and responses were recorded on the response apparatus designed with a curved metal base to hold three-dimensional graspable objects. Correctness of participant responses were recorded by the experimenter using a Macintosh computer keyboard and the following codes: c=correct, a=incorrect action, o=incorrect object, b=incorrect action and object, s=spoil. The task of the

current experiment was to view the images on the screen and mimic the action shown on the response apparatus.

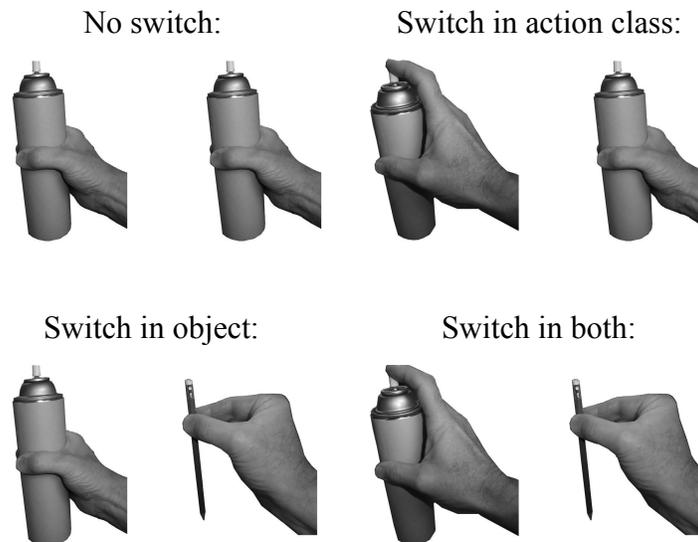


Figure 2. Example conditions for Experiment I.

Procedure: Experiment I was run using a G3 Macintosh computer with two colour 18" monitors. Participants were tested individually in a quiet room and sat approximately 50 cm in front of one of the monitors. Both the response apparatus and the button box were placed in front of the participant and within reach. Right-handed participants rested their hands on the button furthest to their right while left-handed participants rested their hands on the button furthest to their left. The experimenter faced the other monitor so as to view the actions the participant saw on the other monitor. This allowed the experimenter to record the accuracy of participant responses. Each of the three-dimensional forms on the response apparatus were designed to represent the corresponding objects – cellphone, spray-can, and pencil – and the position of each was counterbalanced across all participants. Although the experimental images contained real objects the elements on the response apparatus were stylized prototypes (see Figure 3).

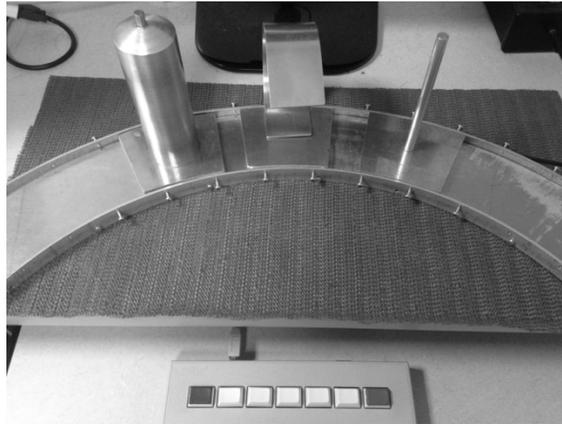


Figure 3. Response apparatus with response elements for Experiment I.

Participants were trained to think of each element as the corresponding object in the image and to associate each of the three-dimensional forms with the correct corresponding lift-and use-grasps. Trials began with the participant resting their dominant hand on the appropriate button on the button box. When a fixation cross appeared on the monitor participants pressed down on the button and the fixation cross disappeared. Following a 250ms interval the image was presented and participants lifted their dominant hand off the button to make a speeded reach-and-grasp movement to grasp the element on the response apparatus. Participants practiced with 32 images and the experimenter used this time to correct any grasping behaviour, if necessary. After the training phase, participants were told that the remainder of the experiment would include five breaks and that it was important to respond as quickly and accurately as possible. Participants responded to 48 pairs of images x 4 blocks for a total of 256 images randomized across all trials. For Experiment I, the dependent variable of interest was reaction time, measured from the moment the participant lifted their dominant hand from the button box to make contact with the response apparatus. Independent variables included the experimental conditions: No Change (repeat same action on same object), Action Change (action class change on same object), Object Change (same action class on a different object), Both Change (both action class and

object change). The experiment concluded with a short debrief and participants were shown a table of their results for each condition.

Results

Errors and spoils were uncommon, with a mean error rate of 0.3%. Because the majority of participants made few or no errors we do not report these results. Reaction time displayed in Figure 4 is a function of action class (use and lift actions) and condition (No Change, Action Change, Object Change, and Both Change). Error bars are 95% within-subject confidence intervals computed separately for each action class. These data were submitted to a two-way within-subject analysis of variance (ANOVA) revealing a main effect of condition $F(3, 93) = 4.667$, $MSE = 496.7$, $p = 0.0044$, such that the No Change condition was faster than the Action Change, Object Change, and Both Change conditions combined, $F(1, 31) = 6.638$, $MSE = 821$, $p = 0.015$.

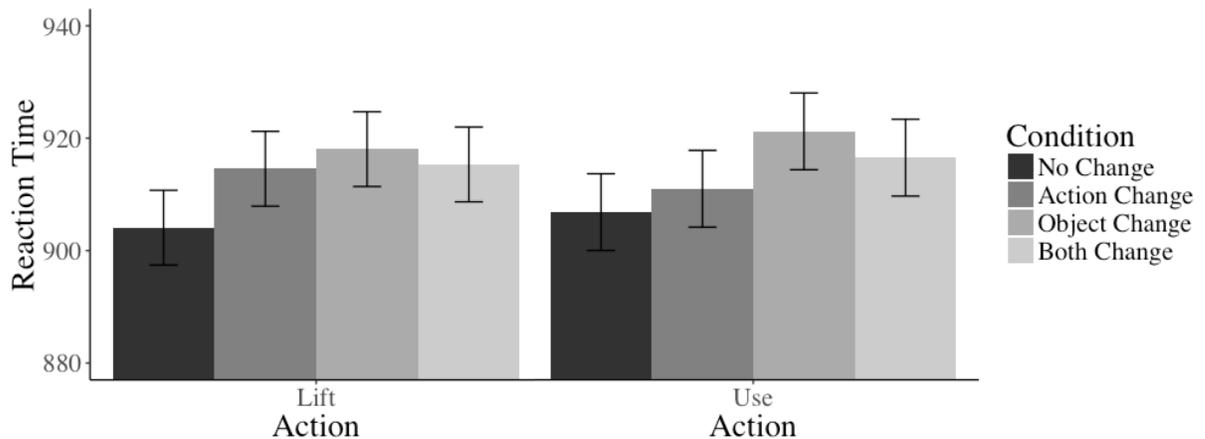


Figure 4. Reaction time as a function of condition and action.

Discussion

Experiment I did not produce differences in the speed of use- and lift-actions. Rather, these results suggest that when participants imitate the actions demonstrated pictorially, use and lift-actions are equally rapid. This outcome provides a baseline against which to compare our subsequent experiments. Jax and Buxbaum (2010) conducted a similar control study with images and also found no systematic differences in the initiation times to hand postures depicting lift- and use-actions. In the following experiment we turn to a situation more closely tailored to everyday life, that of responding to an imperative sentence that demands a use- or lift-action. The task involved in carrying out such actions on a set of objects allows us to evaluate switch costs incurred when generating actions to short sentences like “use the cell phone” or “lift the spray-can”. Objects are visible throughout, and a switch can occur either if an alternate grasp action is invoked to the same object (e.g. “lift the cellphone” directly after “use the cellphone), or the switch implicates a different object. The possibility of use-on-lift interference effects can be tested in two contexts. First, when the switch between actions occurs in response to the same object. The continued activation, for example, of a use-action associated with a cellphone would interfere with the subsequent production of a lift-action to the same object. Second, the action class (use or lift) could be maintained in switching to another object (e.g. “use the spray-can” followed by “use the pencil”). If a task set exists for using or lifting in general, then switch costs should be less pronounced when action class is maintained, relative to switch costs that encompass both action class and object.

Experiment II

In Experiment II participants executed speeded reach-and-grasp responses in the same manner as Experiment I but responded to imperative sentences in place of images.

Participants: Thirty-two English-speaking students who did not take part in Experiment I were recruited from undergraduate psychology classes at the University of Victoria. Participants were given extra credit as an incentive to engage in the study.

Methods: The same hand actions associated with use and lift grasps were implemented as in Experiment I. Sentences were recorded by a female speaker whose first language was English and manipulated to run 1s each. Sentences instructed participants to either "lift" or "use" one of the three objects. Sixteen sentences were recorded in total – half of which described use grasps and half of which described lift grasps. Sentences were presented with equal frequency and always stated the action first ("lift" and "use") and the object second ("the cellphone," "the spray-can," "the pencil"). Each trial consisted of two sentences with four possible combinations (see Figure 5).

No switch:	Switch in action class:
“Use the pencil”	“Use the pencil”
“Use the pencil”	“Lift the pencil”
Switch in object:	Switch in both:
"Use the pencil”	“Use the pencil”
"Use the cellphone”	“Lift the cellphone”

Figure 5. Example conditions for Experiment II.

Each participant was tested on 64 sentences x 4 blocks for a total of 256 sentences. Participants practiced with 32 sentences – eight randomly chosen from the 12 in each of the four conditions. Sentences initiated with a button release and were recorded on the response apparatus designed with a curved metal base to hold three-dimensional "graspable" objects. Correctness of participant responses were recorded by the experimenter using a Macintosh computer keyboard and the following codes: c=correct, a=incorrect action, o=incorrect object, b=incorrect action and object, s=spoil. The task of the current experiment was to listen to sentences and mimic the action described on the response apparatus.

Procedure: Experiment II was run with a similar procedure to Experiment I with the following modifications: Trials began with the participant resting their dominant hand on the appropriate button on the button box. When a fixation cross appeared on the monitor participants pressed down on the button and the fixation cross disappeared. Following a 250ms interval the sentence was presented and participants lifted their dominant hand off the button to make a speeded reach-and-grasp movement to grasp the element on the response apparatus. Participants practiced with 32 sentences and the experimenter used this time to correct any grasping behaviour, if necessary. After the training phase, participants were told that the remainder of the experiment would include five breaks and that it was important to move as quickly and accurately as possible. Participants responded to 48 pairs of sentences x 4 blocks for a total of 256 sentences randomized across all trials. For Experiment II, the dependent variable of interest was reaction time, measured from the moment the participant lifted their dominant hand from the button box to make contact with the response apparatus. Independent variables included the

experimental conditions (Action Change, Object Change, Both Change, No Change) and the hand actions (use and lift).

Results

Errors and spoils were uncommon, with a mean error rate of 0.3%. Because the majority of participants made few or no errors we do not report these results. Reaction time displayed in Figure 5 is a function of action class (use- and lift-actions) and condition (Action Change, Object Change, Both Change, and No Change). Error bars are 95% within-subject confidence intervals computed separately for each action class. These data were submitted to a two-way within-subject analysis of variance (ANOVA) revealing a main effect of condition $F(3, 93) = 24.14$, $MSE = 2,145$, $p = 1.22e-11$ and a main effect of action $F(1, 31) = 5.522$, $MSE = 940$, $p = 0.0253$. Post-hoc pairwise comparisons indicate that use-actions are faster than lift-actions, $p = .0042$. Further, there was a significant differences between all conditions for both use and lift-actions except for the Both Change and Object Change conditions. The difference between these two conditions was not reliable, $F(1, 31) = 0.72$, $MSE = 510.9$, $p = 0.403$.

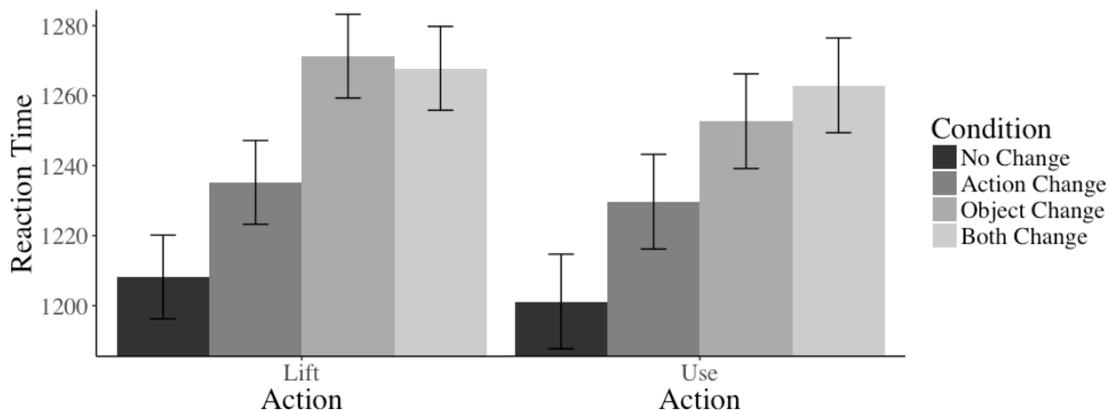


Figure 6. Reaction time as a function of condition and action.

Discussion

The main effect of action indicates that use-actions are faster than lift-actions. This evidence is consistent with previous research (Bub & Masson, 2012; Osiurak, Roche, Ramone, & Chainay, 2013). However, this result diverges from Jax and Buxbaum (2010) who show the reverse: lift-actions are faster than use-actions, and use-actions interfere with the subsequent production of lift-actions. Experiment II did not produce evidence for either of these assumptions. Rather, we find costs in switching to a different action on the same object, and a further cost induced when an action is applied to another object, as in the Both Change and Object Change conditions. There is no evidence for “use-on-lift” interference stemming from a task-set bias for use-actions, as an advantage would have been seen for the Object Change condition (e.g. “use the pencil” followed by “use the cellphone”) relative to the Both Change condition. In the former case, the action class (use or lift) is maintained. The fact that the switch cost was no different in this condition than in the Both Change condition (action class changes as well as object) provides no support for the notion that a generic task set exists for use-actions. Because our findings were not consistent with Jax and Buxbaum’s (2010), we turn to a blocked-task model similar to their design. However, in keeping with a naturalistic approach, objects were continuously visible throughout the duration of our experiment.

Experiment III

In Experiment III we sought to emulate the design implemented by Jax and Buxbaum (2010) in order to assess switch costs between blocks of use- and lift-actions. In this experiment, names of objects were used to cue speeded reach-and-grasp hand actions. Participants responded to objects that were continuously in view, and carried out use- or lift-actions over a block of trials.

Participants: Forty-eight English-speaking students who did not participate in Experiment I or Experiment II were recruited from undergraduate psychology classes at the University of Victoria. Participants were given extra credit as an incentive to engage in the study.

Methods: Experiment III was run similarly to Experiment II with the exception that auditory words were used in place of auditory sentences and real objects were used in place of three-dimensional forms. Three new objects were added to the objects used in Experiment I and II – stapler, calculator, and lotion bottle. The addition of these objects afforded a total of 12 possible hand actions. Names of the objects were recorded in the same manner as Experiment II. The nature of each block (e.g. lifting or using the objects) was indicated by a sentence displayed on the screen stating "You will now use the objects" or "You will now lift the objects." Each trial within the block consisted of the name of an object presented to indicate which object to act upon (e.g. "cellphone," "spray-can," "pencil," "stapler," "lotion bottle," and "calculator"). Object names were presented at random equally as often within each block. Each participant was tested with 36 trials x 4 blocks for a total of 144 objects. Object names were initiated with a button press and liftoff time was measured as the participant performed the reach-and-grasp action. Correctness of responses were recorded by the experimenter using a Macintosh computer

keyboard and the following codes: c=correct, a=incorrect action, o=incorrect object, b=incorrect action and object, s=spoil. The task of the current experiment was to listen to the name of the object and perform the relevant reach-and-grasp action pertaining to the block (e.g. using or lifting the objects) on the objects mounted to the response element.

Procedure: Experiment III was run in a similar manner to Experiment I and II with some exceptions. In Experiment III, the response elements involved real objects – a cellphone, spray-can, pencil, stapler, calculator, and lotion bottle. Object order was counterbalanced across all participants. Participants were trained to associate each of the three-dimensional objects with the correct corresponding lift and use grasps. Trials began with a sentence on the screen indicating "You will now use the objects" or "You will now lift the objects." Two versions of the experiment were made to observe order effects of action blocks (e.g. use then lift or lift then use). Twenty-four participants completed one order of blocks: a lift block to a use block, across both cycles, and twenty-four separate participants completed a different order of blocks: a use block to a lift block, across both cycles (see Figure 6). Participants rested their dominant hand on the outer button of the button box and pressed down when a fixation cross appeared on the monitor. The fixation cross disappeared, followed by a 250ms delay, and then the presentation of the name of the object via headphones. Participants responded to the auditory cue by lifting their dominant hand from the button box to make a speeded reach-and-grasp movement to the correct object. Participants were told that the experiment included three breaks and to react as quickly and accurately as possible. For Experiment III the dependent variable was initiation time, measured from the moment the participant lifted their dominant hand from the button box. Independent variables included the order of blocks (use then lift or lift then use), action class

(use versus lift), and cycle. Experiment III concluded with a short debrief and a table of results summarizing average reaction time across both actions ("use" or "lift").

Cycle 1			Cycle 2	
Block 1	Block 2		Block 1	Block 2
Lift	Use	Break	Lift	Use
Use	Lift	Break	Use	Lift

Figure 7. Action sequences for between-subject cycles in Experiment III.

Results

Errors and spoils were uncommon, with a mean error rate of less than 0.5%. Because the majority of participants made few or no errors we do not report these results. Reaction time displayed in Figure 8a and 8b is a function of action class (use- and lift-actions) and block. Error bars are 95% between-subject confidence intervals computed separately for each block order. These data were submitted to an analysis of variance (ANOVA) with block order as a between-subject factor, and cycle and action as within-subject factors. There was a significant main effect for cycle, $F(1, 46) = 8.37$, $MSE = 5,856$, $p < 0.05$, an interaction effect between cycle and action, $F(1, 46) = 5.5$, $MSE = 1,927$, $p < 0.05$, and an interaction between block order, cycle, and action, $F(1, 46) = 9.53$, $MSE = 2,028$, $p < 0.05$. To examine the three-way interaction, separate analyses were conducted for the two cycles. In Cycle 1, there was a significant interaction between block order and action, $F(1, 46) = 10.07$, $MSE = 2,909$, $p < 0.05$. This interaction occurred because lift-actions were performed significantly faster than use-actions for the subjects who performed use-actions before lift-actions, $F(1, 23) = 7.38$, $MSE = 3,724$, $p < 0.05$. There was no significant difference between use- and lift-actions if lift-actions were performed first, $F(1, 23) = 2.77$, $MSE = 2,093$, $p > .05$. No effects were obtained in Cycle 2.

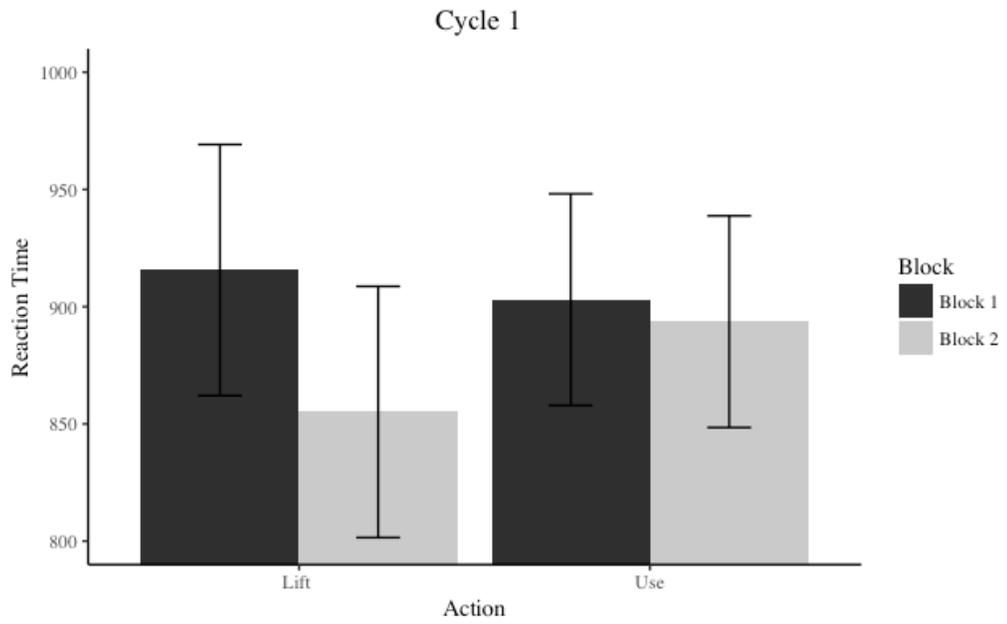


Figure 8a. Cycle 1 reaction times as a function of action class and block.

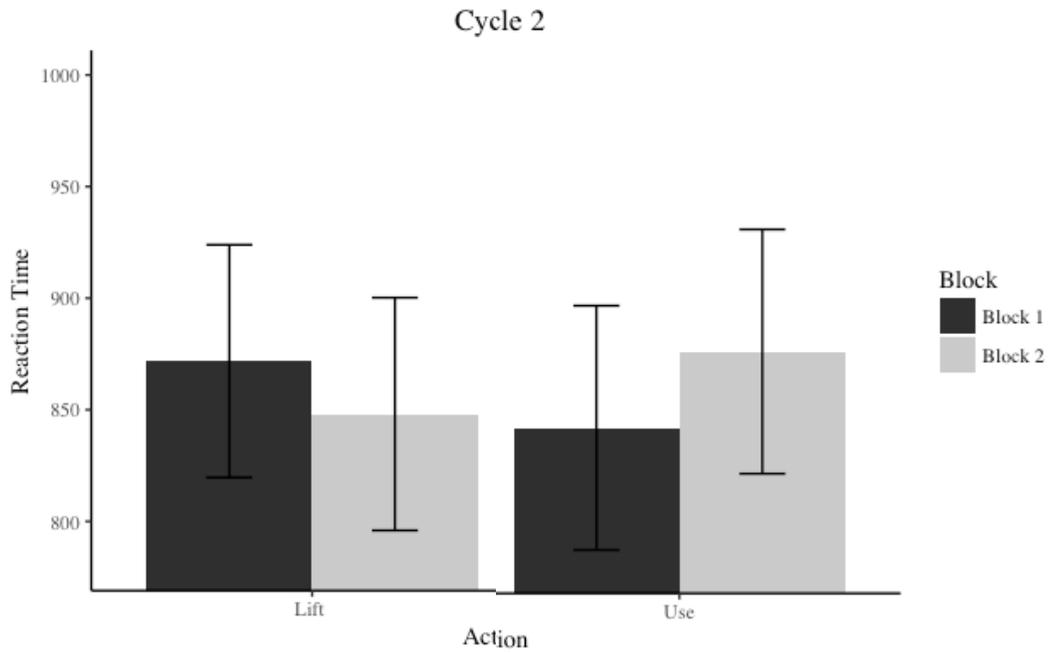


Figure 8b. Cycle 2 reaction times as a function of action class and block.

Discussion

Experiment III, which represents an attempt to replicate the Jax and Buxbaum (2010) study, failed to show either an overall advantage for lift-actions over use-actions, or a negative influence on producing lift-actions after having performed use-actions. Indeed, Experiment III obtained an effect that contradicts the latter result from Jax and Buxbaum. When lift-actions were performed after use-actions, the lift-actions were performed more quickly than the use-actions. For subjects who experienced the actions in the reverse order, no difference between use- and lift-actions was found. It can be concluded, then, that lift-actions actually benefited from having subjects execute use-actions first. The only other noteworthy effect in Experiment III was that a general practice effect was obtained, with faster responses in Cycle 2 than in Cycle 1.

Experiment IV

In Experiment IV we introduced an additional task that required participants to prepare an action as a distal goal, while a prior action was cued via an image on the screen. Imperative sentences generated a future-oriented goal action, and images of grasp postures on objects were used to cue interim use- and lift-action production on manipulable objects.

Participants: Thirty-two English-speaking students who did not participate in Experiment I, II, or III were recruited from undergraduate psychology classes at the University of Victoria. Participants were given extra credit as an incentive to engage in the study.

Methods: Similar to the previous experiments, hand actions for use- and lift-grasps were selected and matched to objects; specifically, a calculator, stapler, lotion bottle, spray-can, cellphone, and pencil. Imperative sentences were recorded similarly to those used to Experiment II wherein participants were instructed to either "lift" or "use" the objects. Twelve sentences were recorded in total: half describing use-actions and half describing lift-actions. Further, hand actions for use- and lift-grasps were selected and matched to the objects mentioned above. Digital photographs were composed similarly to Experiment I such that a male hand was superimposed demonstrating each of the corresponding gestures. Images were modified such that the background matched that of the computer monitor. Two different versions of the hands with the images were created: one oriented for right-handed participants and one oriented for left-handed participants. Sentences were presented first (e.g. "lift the cellphone") followed by a pause and then an image of an object. Each trial consisted of one audio sentence and one pictorial depiction of the object with three possible combinations: switch in action class, switch in object, and switch in both action class and object. Sentences and objects were randomized across trials.

Each participant was tested on 30 trials x 6 blocks to total 180 trials. Participants practiced with 18 pairs of sentences and images to total 36 trials. Breaks occurred after each 30 trial block. Audio sentences and images were initiated with a button release and liftoff time was recorded as participants moved to respond. Correctness of participant response was recorded by the experimenter using a Macintosh computer keyboard and c=correct, a=incorrect action, o=incorrect object, b=incorrect action and object, s=spoil. The task of the current experiment was to listen to sentences and mimic the action described on the response apparatus.

Procedure: Experiment IV was run using a G3 Macintosh computer with two colour 18" monitors. Participants were tested individually in a quiet room and sat approximately 50 cm in front of one of the monitors. Both the response apparatus and the button box were placed in front of the participant and within reach. Right-handed participants rested their hands on the button furthest to their right while left-handed participants rested their hands on the button furthest to their left. The experimenter faced the other monitor so as to view the actions the participant saw. This allowed the experimenter to record the correctness of participant responses. Each of the ten objects were mounted on the response apparatus directly in front of the participant. Experimental images of a male human hand grasping real objects were direct comparisons to the objects used throughout the experiment. Participants were trained on how to properly perform the corresponding use and volumetric grasps on the objects. Trials began with the participant resting his or her dominant hand on the appropriate button on the button box. When a fixation cross appeared on the monitor participants pressed down on the button and the fixation cross disappeared. Following a 250ms interval the imperative auditory sentence was presented, followed by an image. Participants lifted their dominant hand from the button to make a speeded

reach-and-grasp movement depicted in the image. Participants returned their hand to the button-box and proceeded to perform the action in the sentence once an orange dot appeared on the screen. Participants first completed a practice trial and the experimenter used this time to correct any problems responses, if necessary. Participants were then told that the remainder of the experiment would include five breaks and that it was important to move as quickly and accurately as possible. Participants responded to 30 trials x 6 blocks for a total 180 trials. Images and sentences were randomized across all trials. For this experiment, the dependent variable of interest was reaction time, measured from the moment the participant lifted their dominant hand from the button box. Independent variables include the experimental conditions (Action Change, Object Change, Both Change) and action class (use and lift). The experiment concluded with a short debrief and participants were shown a table of their results for each of the conditions.

Results

Errors and spoils were uncommon, with a mean error rate of 0.5%. Because the majority of participants made few or no errors we do not report these results. Reaction time displayed in Figure 8 is a function of action class (use- and lift-actions) and condition (Action Change, Object Change, and Both Change). Error bars represent within-subject variability. These data were submitted to a two-way within-subject analysis of variance (ANOVA) revealing a main effect of action $F(1, 30) = 9.267$, $MSE = 1,771$, $p = 0.00482$ and condition $F(2, 60) = 3.454$, $MSE = 2,207$, $p = 0.038$. Post-hoc pairwise comparisons indicate that use-actions are faster than lift-actions, $p = 0.0031$. In addition, a test of the action-sequence hypothesis was carried out by comparing reaction times in Action Change and Both Change conditions for use- and lift-actions. The assumption is that producing a lift-action in the context of an intended use-action conforms to the

normal sequence of lifting then using an object. In contrast, planning to lift an object does not bring forward actions consistent with its prior use (we do not first use and then lift an object). An analysis including only the Action Change and Both Change conditions found a significant interaction between action type and condition ($F(1,30) = 4.57$, $MSE = 1,770$, $p < 0.05$). As indicated in Figure 9, there is no difference between Action and Both Change conditions for use-actions ($F < 1.0$), whereas for lift-actions, the Both Change condition is substantially slower than the Action Change ($F(1,30) = 6.85$, $MSE = 3,108$, $p < 0.05$). Thus, when a use-action is planned, lifting the same object is carried out more readily than lifting another object. In contrast, planning to lift an object allows for a use-action that occurs rapidly for the same or some other object.

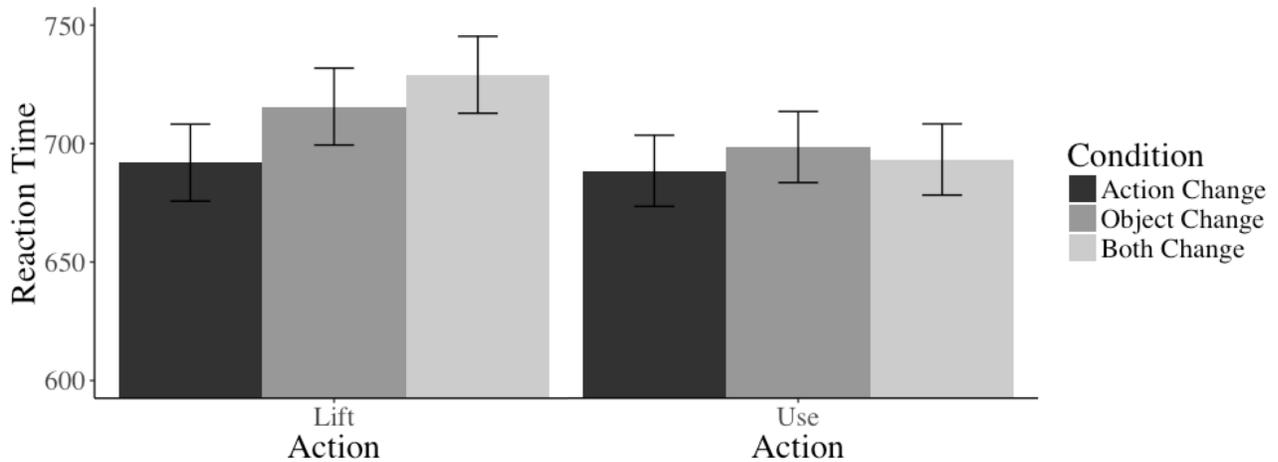


Figure 9. Reaction time as a function of condition and action order.

Discussion

Experiment IV was a hybrid of our first two experiments: participants imitate images in pictures but also generate actions from imperative sentences. Because we find a main effect of action and condition (not consistent with Experiment I), we can conclude that image

representations are changed when participant hold an imperative sentence in working memory. The results from this experiment are compelling for several reasons. First, the lift-use sequence on the same object (Action Change) is more rapid relative to the other two conditions (Both Change and Object Change). This result is sensible given the normal sequence of actions we engage in when interacting with day-to-day objects: lifting then using an object. In the Action Change condition for lift-actions, the end goal is to perform a use-action on the same object. This planned use-action allows for the identification of the object and a prior lift grasp to be programmed. Thus, the rapid lift-use sequence is not due to lift-on-use overlap but rather the result of object identification. Further, the Object Change and Both Change conditions are again no different, thus negating the existence of “use-on-lift” interference. Performing a use-action again in the Object Change condition (presumably imposing a task-set bias for use) was not favoured over performing a lift-use-action (Both Change). Second, the main effect of action indicates that even under conditions wherein participant imitate pictures there is a preference for use-actions. Thus, we are again showing that use-actions are faster than lift-actions when objects are continuously visible to participants.

Overall Discussion

Recent evidence indicates that lift-actions are faster than use-actions and that a “use-on-lift” interference occurs and produces switch costs when changing from a use- to a lift-action (Jax & Buxbaum, 2010; Osiurak & Badets, 2016). These effects have been linked to cortical areas in the brain; specially, the left-lateralized system, accessed for conceptual knowledge of objects, and a bilateral system, related to structural and feature-based object information.

Presumably, “use-on-lift” interference results from two possible factors. First, because use-actions are related to the conceptual left-lateralized system, they are slower to produce and are sustained, thus interfering with the production of lift-actions. Second, the blocked nature of the paradigm that produces “use-on-lift” interference effects may impose a task-set bias that favours use-actions. In this thesis, the evidence for “use-on lift” interference and rapid lift/slow use-action production is challenged on both theoretical and methodological grounds.

Methodologically, the sudden appearance of objects in previous studies (Jax & Buxbaum, 2010; Osiurak & Badets, 2016) is thought to invoke a fast visuomotor response that acts independently of object identity and depends only on feature-based information. This is in contrast to an everyday situation in which objects are visually available before action production is required.

From a theoretical standpoint, lift-actions can be produced in two distinct ways. In one case, lift-actions may occur rapidly to the sudden appearance of objects. In other situations, lift-actions may require access to stored knowledge - much like use-actions - such as object weight (Osiurak, Roche, Ramone, & Chainay, 2013). Thus, there are reasons to question the notion that lift-actions work independently of stored motor representations. We attempted to produce similar results to Jax and Buxbaum (2010) with a critical change to their methodology: objects were continuously

visible to participants. Our reasoning for this difference is simple: if we are to broaden our understanding of control mechanisms related to object interactions it is arguably advantageous to utilize paradigms that promote real-world scenarios. Consider the following example: while preparing a meal one might use a knife to chop vegetables before switching to stir a pot with a spoon and then use a pencil to make some changes to a recipe. Certainly, these objects that are in use would not materialize out of the blue. It is our assumption that allowing the objects to be visible at all times will invoke stored knowledge and representations for both use- and lift-actions. In turn, this will prevent use-actions from interfering with lift-actions when switching between the two, as both actions will depend on access to stored knowledge. In Experiment I, we demonstrated that imitation of reach-and-grasp actions on familiar objects does not produce differences in the speed of use and lift-actions. This null result provides a baseline against which to compare the results of experiments that demand more generative pathways to action. In Experiment II, imperative sentences produced asymmetries in use- and lift-action speeds such that use-actions are faster than lift-actions. This is an important finding, as it contrasts with previous research indicating that lift-actions are faster than use-actions (Jax and Buxbaum, 2010; Osiurak and Badets, 2016). Generating a new action to the same object via language incurs a switch cost. An additional cost was observed when switching an action to a different object (Object Change and Both Change conditions). Further, equivalent performance in the Object Change and Both Change conditions prove no evidence for the existence of a task set involving use- or lift-actions. Presumably, a task-set bias towards use-actions would be manifested as faster response times in the Object Change condition relative to the Both Change condition (wherein the action class changed as well as the object). However, this phenomenon did not occur. Turning

to a paradigm modelled after Jax and Buxbaum's (2010) design, Experiment III sought to emulate the rapid lift/slower use-action and "use-on-lift" interference effects. However, even with a blocked-task procedure that would presumably impose a task-set bias (through blocked production of use-actions that could potentially generate interference with a block of subsequent lift -actions), we did not find evidence for asymmetries in the speed of use- and lift-actions. Rather, this experiment established that performance on lift-actions were faster after a block of use-actions. In contrast, carrying out a block of lift-actions had no impact on the subsequent block of use-actions. This outcome is of interest, and suggests that, contrary to Jax and Buxbaum (2010), prior access to use-actions facilitates access to lift-actions on the same set of objects. In a final experiment, we considered the effect of an action goal (e.g. either use or lift) on interim actions. Interestingly, this arrangement established that in the context of a use-goal, a lift-action occurred more rapidly to the same object than a different object. Furthermore, use-actions are generated faster than lift-actions. Overall, the findings across these four experiments contribute to the task-switching literature on the cognitive control of motor processes associated with use- and lift-actions. Specifically, critical distinctions are identified between actions produced in the context of non-naturalistic and realistic settings. When faced with the sudden appearance of objects, we react quickly to program a lift-action independent of object identity and functionality. However, the sudden appearance of objects is rather unrealistic, and if we are to broaden our understandings of the control mechanisms associated with reach-and-grasp actions on objects, it is hugely important to implement paradigms that promote real-world scenarios. When we switch actions on objects in settings consistent with our daily lives - with objects that are visually available to us such as on our desks or in our kitchens - use-actions are faster to produce than

lift-actions, and even facilitate the production of lift-actions. Further, when we have a use-action goal in mind, we are able to access the appropriate lift-action along the way to the intended use-action. Thus, while preparing breakfast (as in the example at the beginning of this thesis), you are focused on the functionality of each object that you interact with, which in turn enables you to lift those objects as well. We hope that the results from this thesis deter from an erroneous view that the cognitive mechanisms associated with lift- and use-actions are mutually exclusive; rather, we show that use-actions facilitate lift-actions and that, in realistic settings, both lift- and use-actions require access to stored knowledge.

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