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Response interference between functional and structural actions linked to the same familiar object

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Abstract

Viewing objects with the intention to act upon them may activate task-irrelevant motor responses. Many manufactured objects are associated with two action classes: grasping in accordance with object structure and skillful use consistent with object function. We studied the potential for within-object competition during action selection by comparing initiation latencies for "conflict" objects (with competing structure and function responses) to "non-conflict" objects (with a single response). We demonstrated a novel pattern of within-object interference wherein actions involving conflict objects were slowed when participants skillfully used those objects (grasp-on-use interference) as well as a second pattern of interference when conflict objects were grasped after skillfully using the same objects in previous blocks (long-term use-on-grasp interference). These data suggest that actions to common objects are influenced by competition between rapid but briefly maintained grasp responses and slower but longer-lasting use responses, and advance our understanding of the process and neural substrates of selection for action.

Object and action processing are tightly coupled. Object recognition and selection often occur concomitant with the preparation of a motor plan to be executed once the object is found. For example, while searching through a kitchen drawer, one may have in mind both the visual appearance of a large wooden spoon and the action of grasping it. It is increasingly recognized that action preparation has a facilitative effect upon object selection (Botvinick, Buxbaum, Bylsma, & Jax, 2009; Craighero, Fadiga, Umiltá, & Rizzolatti, 1996; Pavese & Buxbaum, 2002). Conversely, viewing objects may prime their associated actions (Castiello, 1996; Humphreys & Riddoch, 2001; Tucker & Ellis, 1998).

Many familiar manufactured objects are associated with multiple actions depending on the actor's goal (Ansuini et al., 2006; 2008). The vast majority of prior action priming studies have examined prehensile actions such as precision (pinch) and power (clench) grips, which are used to grasp and move objects based on currently available visual information about their structural properties (e.g., shape, size, and orientation; Prabhu, Lemon, & Haggard, 2007). Prehensile actions differ in several respects from a second class of actions, functional use actions, which are strongly linked to object identity (Buxbaum, Veramonti, & Schwartz, 2000) and are associated with activation of conceptual information (Buxbaum & Saffran, 1998). Thus, an object such as a calculator may be associated with at least two responses: a structural "clench" response for grasping and a conceptual "poking" response to skillfully use the calculator and achieve a functional goal. As will be explained below, we conceptualize a calculator as a "conflict" object because it is associated with two conflicting responses.

Given that objects may activate their associated actions, and vice versa, there are a number of unanswered questions concerning interactions with manipulable objects. What factors govern the activation of responses to/by manufactured objects associated with multiple responses? Are *all* actions associated with an object facilitated during response planning? How long can actions interfere with (or facilitate) object processing? Though clearly relevant to real-life object interactions, these questions have not been studied empirically.

Previous work has shown that “grasp to move” and “skilled use” hand actions (hereafter “grasp” and “use”, respectively) are associated with different activation patterns in neuroimaging paradigms (Buxbaum, Kyle, Tang, & Detre, 2006; Culham & Valyear, 2006; Creem-Regehr & Lee, 2005; Johnson-Frey, 2004) and are disrupted by lesions in different neuroanatomic loci (Buxbaum, Kyle, Grossman, & Coslett, 2007; Buxbaum, Sirigu, Schwartz, & Klatzky, 2003; Sirigu et al., 1996). In response to such data, we (Buxbaum, 2001) and others (Johnson-Frey, 2004; Pisella, Binkofski, Lasek, Toni, & Rossetti, 2006) have proposed two major routes to action which appear to be rooted in dorso-dorsal and ventro-dorsal visual pathways (Rizzolatti & Mattelli, 2003). The first is a bilateral system, localized in part to the superior parietal lobules and intraparietal sulci, that is specialized for object acquisition (grasping and moving). This “Grasp” 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 (Cant, Westwood, Valyear, & Goodale, 2005; Garofeanu, Kroliczak, Goodale, & Humphrey, 2004). The second is a left-lateralized system centered on the inferior parietal lobule that is specialized for storage of familiar object-linked actions. This “Use” system subserves conceptual knowledge about functional actions (Buxbaum & Saffran, 1998) and maintains information over longer periods of time.

There is little research on whether activated representations in the Use and Grasp systems may be competitive versus facilitative. Recent work suggests Stroop-like interference occurs between object-related structural or functional actions, on the one hand, and trained actions arbitrarily associated with objects on the other (Bub, Masson, & Cree, 2008). However, direct competition between function- and structure-based responses within the same familiar object has not been explored.

In this study we sought to test several predicted patterns of interference on initiating actions to manipulable objects. We capitalized on the fact that “conflict” objects, such as calculators, are associated with different actions for structural and functional responses (in this case, clench to grasp, poke to use), whereas many other “non-conflict” objects, such as drinking glasses, are associated with one dominant action based on both structure and function (clench to grasp and use). We predicted, first, that as use but not grasp responses require activation of conceptual representations, initiating use movements would take longer than grasp movements. Second, because use activations are slowed by the activation of conceptual representations, we predicted the nature of the within-object interference for conflict objects would depend on the required task. When producing use responses, we predicted participants’ initiation latencies would be greater for conflict than for non-conflict objects because task-irrelevant grasp activations would temporally-precede use activations, allowing them to interfere with use responses. Conversely, when producing grasp responses, we predicted there would be no initiation time differences between conflict and non-conflict objects because task-irrelevant use activations would not be sufficiently activated before grasp responses could be produced. Finally, we predicted different longevities of activated information for grasp versus use. Because priming in the conceptual system can last weeks (Cave, 1997) whereas priming for grasping actions and other dorso-dorsal stream functions lasts only seconds (Jax & Rosenbaum, 2007, 2009), use activations should interfere with actions occurring many minutes later, whereas grasp activations should decay rapidly and have little effect on subsequent actions.

Confirmation of these predictions would suggest that multiple actions associated with single familiar objects may compete for the control of behavior, determined by task goals and by the characteristics of the underlying processing systems.

Method

Participants were fourteen (8 females) right-handed college students. Before the experiment participants were familiarized with the objects (Table 1) by viewing them individually for 2 seconds each. Participants performed two tasks. In the grasp task, they were instructed to reach for and “position your hand on the object as you would to hand it to another person”. In the use task, instructions were to reach for and “position your hand on the object as you would to use it”. Instructions were chosen so that a single movement was made in both tasks without any required subsequent movement (actually moving/using the object). Half of the participants performed four blocks of 22 use trials/block followed by a brief instruction break and then four blocks of 22 grasp trials/block (use-then-grasp order). The remaining participants completed the opposite task order (grasp-then-use order). Within each block, participants interacted with “conflict” objects on 10 trials, “non-conflict” objects on 10 trials, and a red cylinder on 2 no-go trials (included to encourage object identification before movement initiation). Trial types were randomly intermixed.

Trials began with the participant holding down a start button with their right hand in a fist with the thumb up (Figure 1), causing LCD goggles (Plato Technologies) to occlude the participant’s vision. The experimenter then placed an object on a platform 20 cm in front of the start button. After a warning tone and random delay (1000–1500 ms) the goggles cleared. The participant then made a movement to grasp or use the object, depending on the block’s instructions, or withheld a response if the no-go object was presented. Because the study employed everyday objects as stimuli, with different movements required to complete the grasp and use movements across objects, analyses focused on initiation latencies (time between goggles opening until hand lift-off), which would not be affected by these variables. Similar use of initiation times can be found in other studies of dorsal stream functioning (Garofeanu et al., 2004;Cant et al., 2005), and is supported by research indicating that neurons in anterior intraparietal cortex (AIP; a dorsal stream structure) are active before movement initiation (Baumann, Fluet, & Scherberger, 2009).

Because different hand postures were often required for the use of conflict (poke, palm) and non-conflict objects (pinch, clench; see Table 1), a control study was completed to insure there were no systematic differences in initiation times for the four hand postures (poke, palm, pinch, clench). Ten participants not in the main study completed the control task using the procedure described above except that objects were replaced by photographs of a right hand in one of the four hand postures. Movements were made to a neutral object affording all four hand postures (3 cm radius ball).

Results

Responses not corresponding to the typical hand postures produced for those objects in pilot testing (2.1% of trials) and trials with initiation times 3 standard deviations or more outside of that participant’s mean for a given block, task, and object type (2.9% of trials) were removed from analysis.

Initiation times in the control task were analyzed using a single-factor (Posture: clench, pinch, palm, poke) ANOVA. After confirming sphericity (Mauchly’s $W = .58$, $p = .523$), no effect of Posture was found ($F(3,27) = .29$, $p = .83$). Mean initiation times (and s.e.) for the clench, pinch, palm, and poke hand postures were 475.61 (22.18), 479.50 (24.12), 481.61 (24.50), and 478.45 (19.81), respectively.

Mean initiation time results for the grasp and use tasks (Figure 2) were analyzed with a 2 (Task: grasp, use) × 2 (Object: conflict, non-conflict) × 2 (Order: use-then-grasp, grasp-then-use) ANOVA. The results indicated main effects of Task (Use > Grasp; $F(1,12) = 16.51$, $p = .002$) and Object[1] (Conflict > Non-conflict; $F(1,12) = 54.58$, $p < .001$) as well as interactions between Task and Object, $F(1,12) = 6.44$, $p = .026$, between Object and Order, $F(1,12) = 10.29$, $p = .008$, and, most importantly, a three-way interaction between Task, Object, and Order, $F(1,12) = 8.98$, $p = .011$. The three-way interaction was explored by examining the interaction between Object and Order for each Task (i.e., separately for the two sides of Figure 2). In the use task (right side of Figure 2), only the main effect of Object was significant ($p < .001$). In the grasp task (left side of Figure 2), there were main effects of Object and Order ($p < .001$) and an interaction between Object and Order ($p < .001$), with the effect of Object being significant in the use-then-grasp order ($p < .001$) but not in the grasp-then-use order ($p = .88$). Thus, interference in the grasp task was significantly greater if the same object had been *used* earlier in the experiment, a pattern we termed “long-term *use-on-grasp* interference”.

To explore the duration of *use-on-grasp* interference (Figure 3), we used separate 2 (Object: conflict, non-conflict) × 2 (Order: use-then-grasp, grasp-then-use) ANOVAs for grasp trials in the early (blocks 1–2) and late (blocks 3–4) phases. Interactions between Object and Order were observed during the early ($p = .001$; left side of Figure 3) and late ($p = .012$; right side of Figure 3) phases. In these interactions the effect of Object was significant for the use-then-grasp order of both phases (solid lines in Figure 3; $p < .001$ and $p = .004$ for early and late, respectively), a finding not observed in the grasp-then-use order (dashed lines in Figure 3; $p = .456$ and $p = .686$ for early and late, respectively). These analyses confirm that *use-on-grasp* interference remained well after the change in tasks occurred.

Discussion

This study extends prior findings that intending to act upon objects affects object processing by demonstrating that both task-relevant and task-irrelevant attributes of a single familiar object may compete for the control of action. Two forms of interference were observed as a function of the type of action prepared, which we will discuss in turn.

First, latencies to initiate use movements to objects associated with different grasp actions were longer than to objects associated with the same grasp actions. For example, initiating movement to use a calculator with a “poking” action was slowed by the task-irrelevant activation of the “clench” action required to grasp the calculator. This within-object *grasp-on-use* interference occurred regardless of whether or not the to-be-used object was recently grasped. The absence of task order effects indicates that while an interfering grasp response is activated in a task-irrelevant manner, it remains active only briefly. Although evidence for grasp-on-use interference required comparing different sets of objects, data from the grasp task can rule out confounds emanating from visual and semantic processing-stage differences (e.g., perception; recognition). Any differences at these stages would be predicted to influence both the grasp and use tasks, although no effect of Object was observed in the grasp task of the grasp-then-use order. Similarly, the control task ruled out the possibility that differences in hand postures required to use conflict and non-conflict objects could explain the difference in initiation times between the two object types in the use task.

[1]Initiation time differences between conflict and non-conflict objects could not be explained by differences in required movement distance (distance between the start button and typical object contact point), as these two variables were not correlated ($r = .088$, $p = .60$).

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The second form of interference, long-term *use-on-grasp* interference, occurred when participants produced grasp responses, and resulted from experience gained at least several minutes earlier. Differences in initiation of grasp responses for conflict and non-conflict objects were only observed when those objects had recently been used. Thus, for the identical task with the same exact objects, previous use experience clearly interfered with participant's ability to grasp conflict objects. This *use-on-grasp* interference lasted approximately 20 minutes, the time it took to complete all grasp blocks. The long-lasting nature of this interference effect, along with the observation that no order effect was observed when switching from grasp to use, suggests that it cannot be explained by general task switching difficulties (Monsell, 2003).

We propose that the intention to act on an object triggers a race-like competition between functional and structural responses during action selection. Only functional responses require activation of long-term conceptual representations; thus, structural responses can be activated more quickly than functional responses. This difference in activation timing explains why grasp responses requires less time to initiate than use responses. In addition, the proposal that grasp responses "win the race" with use responses, and can thus interfere with the production of use movements, explains why conflict effects are observed asymmetrically when grasp is performed before use.

On the race model, there are at least two possible explanations for *use-on-grasp* interference. First, prior object-specific information may remain active after object use. For example, lingering activation from making a "poke" response to use a calculator may cause interference later when a "clench" response is required to grasp that same calculator. Second, *use-on-grasp* interference could be attributable to task-level, rather than object-specific, interference. That is, repeatedly using objects may bias the motor system to activate use responses when viewing objects, even if those particular objects were not recently used. Similar biasing effects leading to privileged processing in one stream over another as a function of recent experience has been reported in other motor (Tessari & Rumiati, 2004) and cognitive domains (Cohen, Dunbar, & McClelland, 1990). Because participants always interacted with the same objects during use and grasp blocks, additional studies will be required to adjudicate between the two explanations.

In keeping with both neuroscientific (Desimone and Duncan, 1995; Duncan, Humphreys, and Ward, 1997) and behavioral (Tipper, Howard, and Jackson, 1997) theories of action selection, the present account accords a central role to feature-based competition. Unlike other models of selection for action focusing on multi-object arrays (Ward, 1999), competing features influencing *grasp-on-use* interference are located within single objects. Others have proposed that multiple features of the same object may be processed in parallel without interference (Duncan, 1984), suggesting that attention can operate in object-based frames. However, when one feature has greater behavioral relevance than another, feature-based selection may accelerate reaction times associated with the relevant features at the cost of processing less-relevant features more slowly (Wegener et al., 2008). Such response time disparities may result from active inhibition of irrelevant object features (Fanini, Nobre, & Chelazzi 2006; Nobre, Rao, & Chelazzi 2006).

A widely distributed and integrated network of brain regions in frontal, temporal, and parietal cortex are likely involved in resolving attentional competition, whether in object-based or feature-based frames (see Duncan, 2006). Posterior brain regions such as the lateral occipital area have been implicated in the spread of attention in object-based reference frames (He et al., 2008; de-Wit, Kentridge, & Milner, 2009), and the dorsolateral prefrontal cortex may play a role in the top-down modulation of object-based attention driven by behavioral relevance (Sinnett, Snyder, & Kingstone, 2009).

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In conclusion, these data support prior claims that preparing object-direction actions may activate task-irrelevant motor responses (Castiello, 1996; Humphreys & Riddoch, 2001; Tucker & Ellis, 1998; Rafal, Ward, & Danziger, 2006). To our knowledge, we are the first to examine action selection of multiple responses linked to the same familiar object, a situation with clear relevance to everyday life. Similarly, because participants interacted with actual 3-dimensional objects and initiated responses based on non-arbitrary mappings, our methods were more naturalistic than other studies (Tucker & Ellis, 1998; Bub, Masson, & Cree, 2008). Finally, elucidation of the processing characteristics of structural and functional activations associated with objects creates a bridge to the substantial literature on priming of conceptual representations (e.g., Grill-Spector, Henson, & Martin, 2006) and encourages synergy between the study of action selection and object representations.

Acknowledgments

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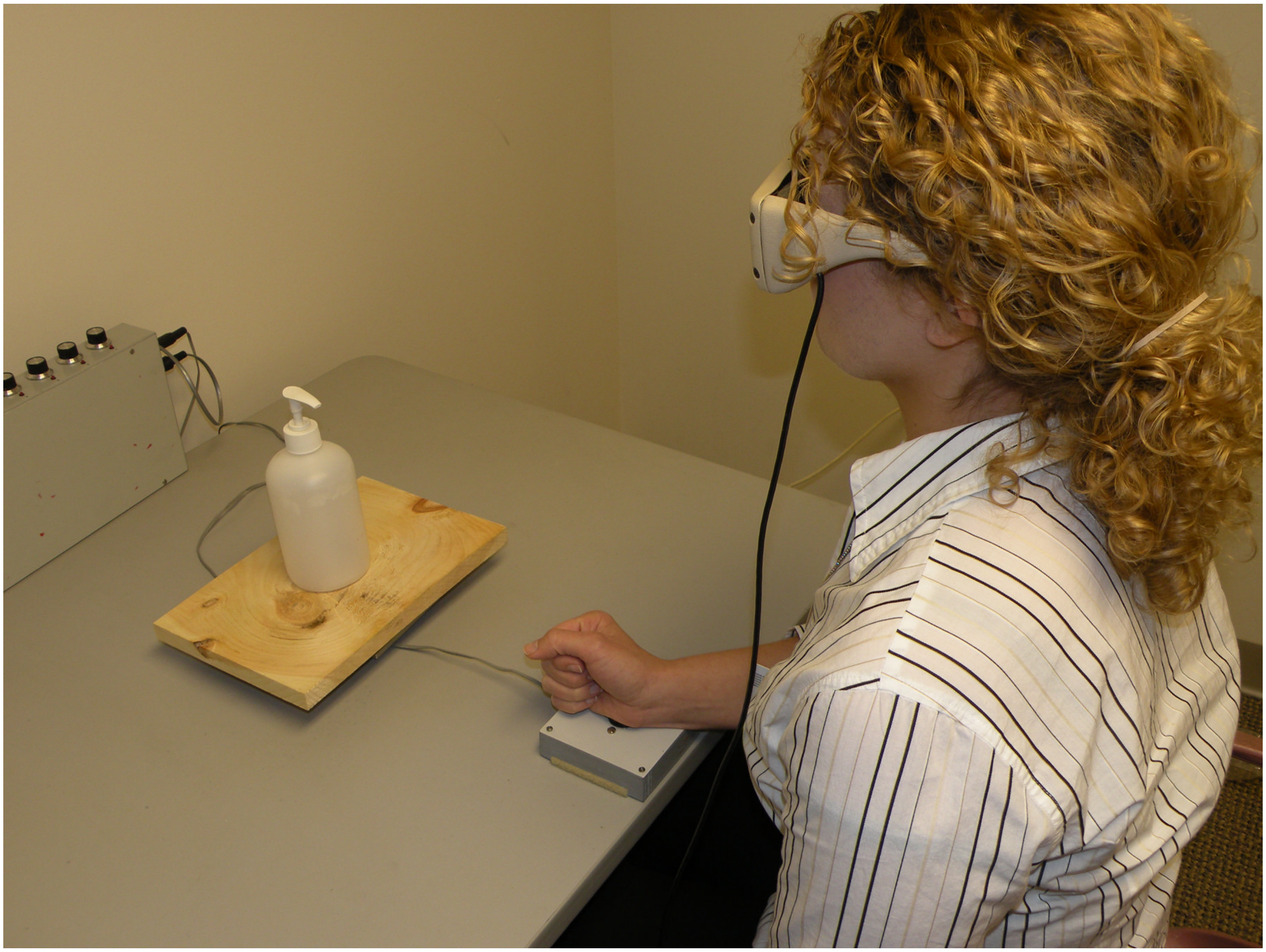

Figure 1.
Experimental setup.

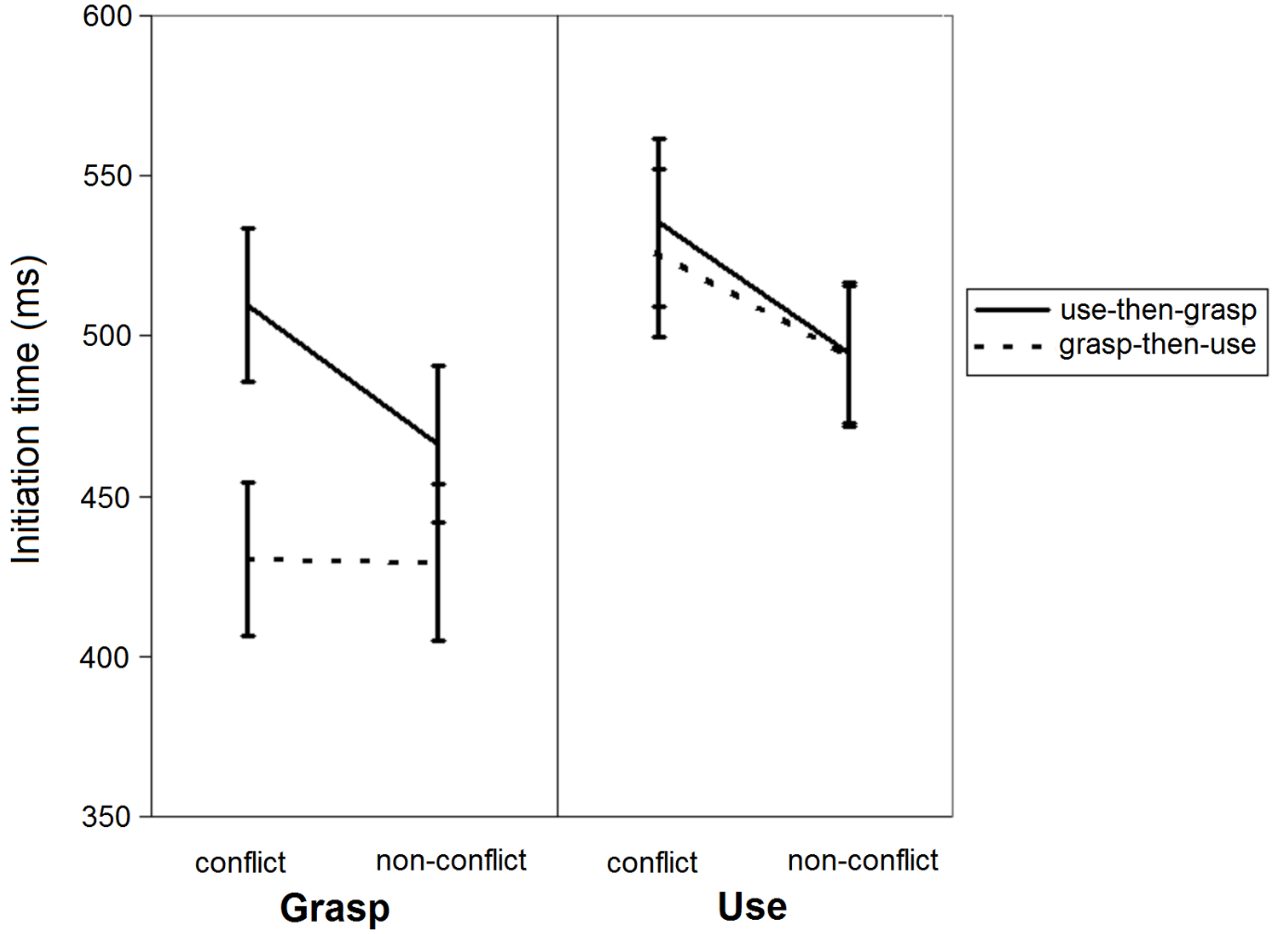

Figure 2.
Mean initiation times (±1 SE) for the grasp and use tasks.

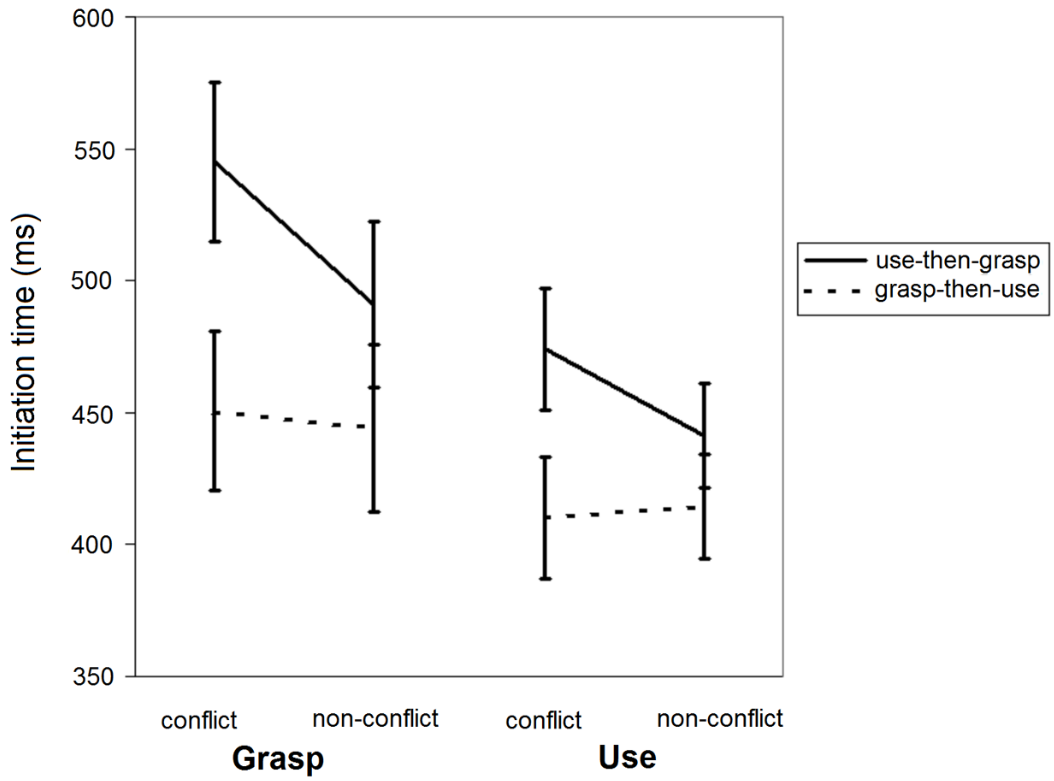

Figure 3.
Mean initiation times (±1 SE) comparing early and late phases of the grasp task.

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Table 1

	Conflict Objects		Non-conflict Objects	
Object	**Grasp posture**	**Use posture**	**Object**	**Grasp/Use posture**
Calculator	clench	poke	Floss	Clench
Blender	clench	poke	ice cream scoop	Clench
shaving cream	clench	poke	salt shaker	Clench
light switch	clench	poke	Baseball	Clench
Toaster	clench	poke	dish detergent	Clench
pump soap	clench	palm	Flashlight	Clench
3-hole punch	clench	palm	Sponge	Clench
Stapler	clench	palm	Glue	Clench
Padlock	clench	pinch	Cup	Clench
Timer	clench	pinch	Screwdriver	Clench