An Electrophysiological Study of the Object-Based Correspondence Effect: Is the Effect Triggered by an Intended Grasping Action?

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Abstract

We examined Goslin et al.'s (2012) claim that the object based-correspondence effect (faster keypress responses when the orientation of an object's graspable part corresponds with the response location than when it does not) is the result of object-based attention (visual-action binding). In Experiment 1, participants determined the category of a centrally located object (kitchen utensil vs. tool), as in Goslin et al. The handle orientation (left vs. right) corresponded or not with the response location (left vs. right). We found no correspondence effect on response time (RT) for either category. The effect was also not evident in the P1 and N1 components of the event-related potentials, thought to reflect the allocation of early visual attention. This finding was replicated in Experiment 2 for centrally located objects, even when the object was presented 45 times (3 times more often than in Experiment 1). Critically, the correspondence effect on RT, P1, and N1 emerged only when the object was presented peripherally, where the object handle was clearly located to the left or right of fixation. Experiment 3 provided further evidence that the effect was observed only for the base-centered objects, where the handle was clearly positioned to the left or right of center. These findings contradict Goslin et al. and provide no evidence that an intended grasping action modulates visual attention. Instead, the findings support the spatial coding account of the object-based correspondence effect.

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People often respond faster when the orientation of an object's graspable part, irrelevant to the task, corresponds with the response location than when it does not (e.g., Bub & Masson, 2010; Tucker & Ellis, 1998). As a representative example, participants might make a left or right keypress in response to the category of an object with a graspable handle, oriented to the left or right. The basic finding is that responses are faster when the correct response is on the same side of the handle (e.g., a left key response when the handle is orientated to the left) than when it is on the opposite side of the handle (e.g., Tucker & Ellis, 1998). This *object-based correspondence effect* has been attributed by many authors to a grasping affordance (the object affordance account; e.g., Iani, Baroni, Pellicano, & Nicoletti, 2011; Pellicano, Iani, Borghi, Rubichi, & Nicoletti, 2010; Tucker & Ellis, 1998). However, other authors have proposed instead that the effect is due primarily, if not entirely, to location coding similar to that which underlies correspondence effects obtained for stimuli displayed in left and right locations (the spatial coding account; e.g., Bub & Masson, 2010; Cho & Proctor, 2010, 2011, 2012; see also Bub, Masson, & Lin, 2013).

Goslin, Dixon, Fischer, Cangelosi, and Ellis (2012) recently reported a study that they interpreted as providing electrophysiological evidence for the affordance account of such correspondence effects. In that study, participants categorized a centrally located picture of an object, for which the handle was left-facing or right-facing, as a kitchen utensil or tool by pressing a left key with the left hand or right key with the right hand. Their logic was that "affordance would lead to facilitation when the hand…was congruent with the direction the handle of the object was facing, and affordance would lead to inhibition when the handle

orientation and response hand were incongruent" (p. 152). To examine whether visual

processing is modulated by the afforded grasping action, Goslin et al. measured the P1 and N1

components of the event-related potential (ERP). When attention is allocated to a particular

location in the visual field, stimuli presented at that location are assumed to elicit an enlarged P1

(e.g., during the period 100-130 ms after stimulus onset) and N1 (e.g., 150-200 ms after stimulus

onset), relative to stimuli at unattended locations, especially at parietal and occipital electrode

sites (for reviews, see Luck, 2005; Mangun, 1995). Goslin et al. (2012) noted that other studies

have shown these ERP components to be sensitive to object-based features such as orientation

(e.g., Karayanidis & Michie, 1997), and reasoned that "if embodiment really is deeply embedded

in early visual processing, we would also expect that the P1 and N1 components would…be

modulated by the motor intentions of the participants" (p. 153).

In agreement with this reasoning, within a single experiment, Goslin et al. (2012) found

the correspondence effect between response hand and left-right handle orientation of the object

in response time (RT) and the P1 and N1 ERP components. The effect was also observed in the

stimulus-locked lateralized readiness potential (LRP), an index of the activation of response-

related processes (e.g., Coles, 1989; De Jong, Wierda, Mulder, & Mulder, 1988; Eimer, 1998).

Goslin et al. (2012) concluded that this correspondence effect is due to grasping affordance and

is driven by a binding between visual processing and action that takes place early in the sensory

pathways.

However, consideration of related research and a close examination of Goslin et al.'s

(2012) results suggest that their conclusion is premature. Bub and Masson (2010) noted that

although object-based correspondence effects obtained with actual *grasping* responses likely are

a consequence of representations associated with grasping the handle, there is little evidence to

indicate that such effects obtained with *keypress* responses are. Object-based correspondence effects obtained with keypresses "instead involve more abstract spatial codes activated by the orientation of an object that affect any left-right response discrimination (e.g., index vs. middle finger of the same hand)" (p. 341). Consistent with a spatial coding account, Cho and Proctor (2010, 2011, 2012) have shown that such effects are relatively large (~25 ms or more) when the handles appear in distinct left and right display locations from one trial to the next, but not when the entire object is centered (on the basis of total object width) and location codes for the handle are not obvious. In Goslin et al.'s (2012) study, the correspondence effect on RT was indeed small, being only 5 ms overall. Moreover, the effect was evident for tools (10 ms) but not kitchen utensils (0 ms), without any explanation provided for why the graspable utensils would not also yield an effect. Although both the P1 and N1 were modulated by the correspondence between response hand and handle orientation, these effects likewise were evident only for tools. Furthermore, the correspondence effect on P1 and N1 was negligible (see their Figure 1c).

As noted above, Goslin et al. (2012) also found that the pooled LRPs across tools and kitchen utensils were modulated by the correspondence between response hand and handle orientation, around 100-200 ms after stimulus onset. They took this finding as evidence that response activation triggered by intended grasping action (i.e., handle orientation) occurred during early visual processes. Nevertheless, caution should be exercised in accepting this interpretation. The divergence of LRPs for corresponding and noncorresponding trials in Goslin et al.'s study started about 100 ms after stimulus onset and lasted for at least 50 ms before the preparation shifted to the correct hand for the noncorresponding trials (see their Figure 1b). This shift of motor preparation was not fully reflected in the correspondence effect on RT, which was only 5 ms overall. Furthermore, as pointed out by Masaki, Wild-Wall, Sanglas, and Sommer

(2004), stimulus-locked LRPs emerge from multiple streams of activation (e.g., response activation by non-spatial stimulus features and motor activation by selecting response hands). Thus, the LRP data by themselves do not provide an unambiguous picture regarding whether response activation is triggered by the intended grasping action.

The Present Study

Given that the affordance view has implications for how vision and action are integrated, it is critical to verify whether the grasping affordance account is correct. There is a reason to be skeptical regarding Goslin et al.'s (2012) finding since their data did not consistently show a correspondence effect for graspable objects. Thus, the present study was conducted to examine their claim and to test further the affordance account against the spatial coding account of object-based correspondence effects. Our first step was to replicate Goslin et al.'s study in Experiment 1 and then examine whether the correspondence effect was primarily driven by the object affordance (as suggested by the affordance account) or object location (as suggested by the spatial coding account) in Experiments 2 and 3.

Experiment 1

In Experiment 1, we closely replicated Goslin et al.'s (2012) procedures using their stimuli. The objects were centrally located, as in their study. Participants determined whether the object was a kitchen utensil or a tool by pressing the left key with their left hand or the right key with their right hand. The handle orientation, though irrelevant to the task, corresponded or not with the response hand/location. We measured the correspondence effect (noncorresponding minus corresponding) on both behavioral and ERP data, as in Goslin et al.'s study.

Method

Participants. Twenty-nine undergraduate students from Oregon State University

participated in exchange for extra course credit. Data from three participants were excluded

from the final analyses due to excessive artifacts in the electroencephalographic (EEG) data (see

below). The remaining 26 participants (16 females) had a mean age of 20 years (range: 18-34).

Four were left handed and 22 were right handed. All reported having normal or corrected-to-

normal acuity.

<u>Apparatus, stimuli, and procedure.</u> Stimuli, displayed on a 19-inch monitor, were viewed

from a distance of about 55 cm. The complete set of 84 colored pictures of objects – 42 kitchen

utensils and 42 tools – from Goslin et al. (2012) was used (see their Figure 1a for an example of

the stimuli).[1] Within each category, half of the handles were on the left and half on the right. A

trial started with a fixation cross in the center for 1,000 to 1,200 ms, randomly selected from a

uniform distribution. The stimulus appeared in the center screen immediately after offset of the

fixation cross and remained present until participants made a response or when a 2,000-ms

deadline was reached. The participants' task was to indicate whether the stimulus was a kitchen

utensil or tool by pressing the leftmost response-box button with their left-index finger or the

rightmost button with their right-index finger. Feedback (a tone for an incorrect response or the

fixation display for a correct response) was presented for 100 ms. The next trial then began with

the fixation display (see Figure 1, Panel A).

Each participant completed two sessions, one with each of the two possible mappings of

response hand/location to the category (e.g., left hand for kitchen utensils and right hand for

tools, or vice versa). Session order was counterbalanced between participants. Within each

session, participants performed one practice block of 24 trials, followed by 6 experimental

blocks of 84 trials each (a total of 504 experimental trials for each session/mapping). Thus, each

object image repeated 12 times (6 times per session/mapping) for each participant. For 50% of

the trials, the response hand/location was corresponding with the orientation of the stimulus'

handle. For the remaining 50% of the trials, they were noncorresponding. Participants

completed these two sessions within a single visit and were given breaks between blocks and

between sessions.

EEG Recording. The EEG activity was recorded from F3, Fz, F4, C3, Cz, C4, P3, Pz,

P4, P7, P8, PO7, PO8, O1, and O2. These sites and the right mastoid were recorded in relation

to a reference electrode at the left mastoid. The ERP waveforms were then re-referenced offline

to the average of the left and right mastoids (Luck, 2005). The horizontal electrooculogram

(HEOG) was recorded bipolarly from electrodes at the outer canthi of both eyes, and the vertical

electrooculogram (VEOG) was recorded from electrodes above and below the midpoint of the

left eye. Electrode impedance was kept below 5 kΩ. EEG, HEOG, and VEOG were amplified

using Synamps2 (Neuroscan) with a gain of 2,000 and a bandpass of 0.1-40 Hz. The amplified

signals were digitized at 500 Hz.

Trials with artifacts were identified in two steps. First, trials with artifacts were rejected

automatically using a threshold of $\pm$ 75µV for a 1,000 ms epoch beginning 200 ms before

stimulus onset and ending 800 ms after stimulus onset. Second, each of these candidate artifact

trials was then inspected manually. Three of the original 29 participants were eliminated

because of artifact rejection on more than 25% of trials. Thus, only 26 participants' data were

included in the final analyses.

Results

We intended to exclude trials from the final analyses of behavioral data (RT and

proportion of error [PE]) and ERP data if RT was less than 100 ms, but no trials were in that

range. Rejection of trials with EEG artifacts led to the elimination of 5% of trials, with no more

than 14% rejected for any individual participant. Trials were also excluded from the RT and

ERP analyses if the response was incorrect (note that the trials were considered as incorrect if

participants failed to respond within the 2,000-ms deadline). An alpha level of .05 was used to

ascertain statistical significance.

Behavioral Data Analyses

An analysis of variance (ANOVA) was conducted including the within-subject variables

of object category (kitchen utensils vs. tools) and response-hand/handle-orientation

correspondence (corresponding vs. noncorresponding).[2] Table 1 shows the mean RT and PE for

each of these conditions.

Mean RT tended to be slightly longer for the tools (593 ms) than the kitchen utensils (585

ms), $F(1, 25) = 3.85$, $p = .0609$, $\eta_p^2 = .13$. The overall correspondence effect was only 1±4 ms

and not significant, $F<1.0$. The difference in the correspondence effect between kitchen utensils

(4±6 ms at the 95% confidence interval) and tools (-2±6 ms) was not significant, $F(1, 25) = 1.99$,

$p = .1706$, $\eta_p^2 = .07$, but note that the trend is in the opposite direction to that reported by Goslin

et al. (2012) where the kitchen utensils yielded a 0-ms effect and the tools a 10-ms effect.

Mean PE was .012 higher for the kitchen utensils (.055) than for the tools (.043), $F(1, 25)$

$= 16.07$, $p < .001$, $\eta_p^2 = .39$. As in the RT data, neither the main effect of correspondence nor its

interaction with category was significant, $Fs(1, 25) \leq 1.52$, $ps \geq .2293$, $\eta_p^2s \leq .06$. The

correspondence effect was only .004 (±.007) for the kitchen utensils and .003 (±.006) for the

tools.

ERP Data Analyses

P1 and N1. To quantify the overall magnitude of the P1 and N1 effects, we focused on

the time windows 100-130 ms and 150-200 ms after stimulus onset, respectively[3], and calculated

the mean amplitude from parietal and occipital electrodes: P7, P8, O1, and O2. Figure 2 shows

the scalp distribution of brain potentials during the critical time windows used to measure the P1

and N1. All ERP data were adjusted relative to the mean amplitude during a 200-ms pre-

stimulus onset baseline period. Note that if the P1 and N1 are modulated by the correspondence

between response location and handle orientation, corresponding trials should produce larger

ERP amplitudes than noncorresponding trials (i.e., more positive for corresponding than

noncorresponding trials). To ensure consistency, we measured the correspondence effect for

ERPs using the same equation as the behavioral data (noncorresponding minus corresponding).

Thus, we would expect the correspondence effect to be negative in value in ERP measures (P1

and N1) while being positive in behavioral measures (RT and PE).

Following Goslin et al. (2012), we analyzed the P1 and N1 data as a function of object

category (kitchen utensils vs. tools), handle orientation (left vs. right), response hand/location

(left vs. right), electrode site (parietal [P7, P8] vs. occipital [O1, O2]), and electrode hemisphere

(left [P7, O1] vs. right [P8, O2]). All factors were within-subjects variables. Figure 3 shows the

mean P1 and N1 amplitude averaged across the P7, P8, O1, and O2 electrodes for the kitchen

utensils and tools, as well as the pooled data from these two categories. Our primary interest was

whether the P1 and N1 were modulated by the correspondence between handle orientation and

response hand. As in Goslin et al., therefore, we report only these effects below. The complete

summary of the ANOVA is given in Appendix A.

For the P1 data, the correspondence effect (between response location and handle

orientation) was negligible (-0.010 µV) and non-significant, $F < 1.0$. The correspondence effect

was not significantly different between kitchen utensils and tools, $F(1, 25) = 2.41$, $p = .1334$, η_p^2

$= .09$. The correspondence effect was very small for both kitchen utensils and tools (0.120 µV

and -0.141 μV, respectively). Further analyses revealed that the correspondence effect was non-significant for both categories, $|ts(25)| \leq 1.26$, $ps \geq .2191$.

As in the P1 data, the N1 data showed that neither the interaction of response hand and handle orientation (i.e., the correspondence effect) nor its interaction with category was significant, $Fs < 1.0$. The correspondence effect was only -0.093 μV for kitchen utensils and -0.103 μV for tools. Further analysis also revealed that the correspondence effect was non-significant for both categories, $|ts(25)| < 1.0$. These findings suggest that both P1 and N1 were not modulated by the correspondence between response hand and handle orientation.

LRPs. As discussed above, the LRPs data do not allow a clear-cut interpretation of correspondence effects nor provide insight regarding whether response activation is triggered by the intended grasping action. Nevertheless, we also report the LRPs for the sake of completeness. As in Goslin et al. (2012), the LRPs were measured by calculating the difference waveforms between the C3 and C4 electrode sites using the following equation: LRP = (Left Hand [C4-C3] + Right Hand [C3-C4])/2. The average LRP amplitudes were analyzed over the five consecutive 100-ms time windows from 0 to 500 ms after stimulus onset, and were adjusted relative to the mean amplitude during a 200-ms baseline period prior to stimulus onset. The data were analyzed as a function of object category (kitchen utensils vs. tools) and correspondence between response hand and handle orientation (corresponding vs. noncorresponding). A complete summary of the ANOVA results is given in Appendix B. Figure 4 shows the LRPs for kitchen utensils and tools, as well as the pooled data from these two categories.

The main effect of correspondence was significant for all time windows, $Fs(1, 25) \geq 5.51$, $ps \leq .0324$, $\eta_p^2 s \geq .17$. The pattern of correspondence between response hand and handle orientation on LRPs was similar for kitchen utensils and tools from 0-ms to 300-ms after

stimulus onset, Fs(1, 25) $\leq$ 3.49, ps $\geq$ .07, η_p^2s $\leq$ .12. It appears that LRPs emerge early after

stimulus onset, which cannot be attributed purely to response activation or selection (which

typically occurs 200 ms after stimulus onset; see Masaki et al., 2004).

Discussion

The correspondence effects on RT were negligible for kitchen utensils and tools, Fs <

1.0. Also, the correspondence between response hand and handle orientation had no effect on P1

and N1 for either category, Fs < 1.0, arguing against the claim that visual-action binding taking

place early in the sensory pathways. These results provide no evidence to support Goslin et al.'s

(2012) claim that "some of the brain's earliest responses to an individual visual object are

modulated by the relation between the action associated with the object and the action intentions

of the observer" (p. 156).

Experiment 2

Previous studies have suggested that correspondence effects with keypresses are driven

by object location (the spatial coding account; e.g., Bub & Masson, 2010; Cho & Proctor, 2010)

rather than the orientation of grasping component. Specifically, Cho and Proctor (2012)

provided evidence that the object-based correspondence effect is absent when objects are

centered in the display. Thus, the absence of correspondence effects in the present Experiment 1

could be due to the lack of a left or right location code for the object (i.e., the object was located

centrally). Experiment 2 tested this hypothesis in the following manner.

In addition to presenting the stimulus in the center of the screen (the central location

condition), as in Experiment 1, we included a condition for which the stimulus was presented on

the left or right side of the screen (the peripheral location condition). For the peripheral objects,

the handle orientation (left vs. right) and object location (left vs. right) always corresponded,

which allowed us to assess the impact of the object location on the correspondence effect without pitting it against the handle orientation. That is, when the object was presented to the left location, the handle orientation was toward left. When the object was presented to the right location, the handle orientation was toward right. Thus, the peripheral location condition included an explicit left-right spatial code that the central location condition did not. We used only 8 kitchen utensils and 8 tools from Experiment 1, each with a distinct base and handle, which would make the direction of the grasping action toward the handles more explicit. The affordance view would predict correspondence effects in both the central and peripheral location conditions, whereas the spatial coding view would predict an effect in the peripheral location condition but not in the central location condition.

Method

Participants. There were 24 new participants, from the same participant pool as in Experiment 1. Four participants' data were excluded; three participants' EEG artifact rejection rate was more than 25% of trials, and one participant's EEG data failed to record. Therefore, data from 20 participants (15 females), mean age of 20 years (range: 18-22), were included in the final data analyses. Two were left handed and 18 were right handed. All reported having normal or corrected-to-normal acuity.

Apparatus, stimuli, and procedure. The tasks, stimuli, and equipment were the same as in Experiment 1, except for the following changes. First, only 8 kitchen utensils and 8 tools with distinct bases and handles from Experiment 1 were used (see Figure 1, Panel B, for an example of the objects used in Experiment 2). Again, within each category, half of the handles were on the left and half on the right. Second, the object was presented centrally, as in Experiment 1, or peripherally (5.19° from central fixation). Object location (central vs. peripheral) was randomly

intermixed within blocks. To manipulate the object location, it was necessary for us to change

the color of the image to grey and reduce the size of the original object images used in Goslin et

al. (2012) and in Experiment 1 by 50%. Third, we increased the total number of experimental

trials from 1,008 (504 trials per session [per S-R mapping]) in Experiment 1 to 1,440 (720 trials

per session) in Experiment 2. Thus, each object image repeated 45 times in each location. As in

Experiment 1, each participant performed two sessions with different S-R mappings (left hand

for kitchen utensils and right hand for tools vs. right hand for kitchen utensils and left hand for

tools). Session order (i.e., response mapping order) was counterbalanced between participants.

Results

The data analysis was similar to that of Experiment 1. Application of the pre-determined

RT cutoff (< 100 ms) did not eliminate any trials (note that the 2,000 ms response deadline was

also used in Experiment 2 as in our Experiment 1 and Goslin et al.'s [2012] study). Rejection of

trials with EEG artifacts led to the further elimination of 7% of trials, but no more than 19% for

any participant.

Behavioral Data Analyses

The behavioral data were analyzed as a function of object location (central vs.

peripheral), object category (kitchen utensils vs. tools), and response-hand/handle-orientation

correspondence (corresponding vs. noncorresponding). All factors were within-subject

variables. Table 2 shows the mean RT and PE for each of these conditions.

Mean RT was 8 ms longer for peripherally located objects (547 ms) than centrally located

objects (538 ms), $F(1, 19) = 15.34$, $p < .001$, $\eta_p^2 = .45$. A significant correspondence effect of 14

ms was observed, $F(1, 19) = 53.46$, $p < .001$, $\eta_p^2 = .74$. The correspondence effect was larger for

the peripheral objects (at the 95% confidence level, 25±8 ms) than for the central objects (3±6

ms), $F(1, 19) = 15.54$, $p < .001$, $\eta_p^2 = .45$, with the former being significant, $t(19) = 6.54$, $p <$

.0001, but not the latter, $t(19) = 1.06$, $p = .3016$. Mean RT was shorter for kitchen utensils (534

ms) than tools (543 ms) when they were presented centrally, but was identical for both categories

when they were presented peripherally (547 ms for both), $F(1, 19) = 4.81$, $p = .0409$, $\eta_p^2 = .20$.

No other effects were significant.

Mean PE was .007 higher for peripherally located objects (.046) than centrally located

objects (.038), $F(1, 19) = 6.68$, $p = .0182$, $\eta_p^2 = .26$. PE was .008 higher for the kitchen utensils

(.046) than for the tools (.038), $F(1, 19) = 7.04$, $p = .0157$, $\eta_p^2 = .27$. A significant

correspondence effect of .012 was observed, $F(1, 19) = 21.56$, $p < .001$, $\eta_p^2 = .53$. As in the RT

data, the correspondence effect was larger for the peripheral objects (.022±.009) than for the

central objects (.001±.005), $F(1, 19) = 19.43$, $p < .001$, $\eta_p^2 = .51$. Further analyses revealed that

the correspondence effect was significant for the peripheral objects, $t(19) = 5.29$, $p < .0001$, but

not for the central objects, $t < 1.0$.

ERP Data Analyses

P1 and N1. We analyzed the P1 and N1 data as a function of object location (central vs.

peripheral), object category (kitchen utensils vs. tools), handle orientation (left vs. right),

response hand/location (left vs. right), electrode site (parietal [P7, P8] vs. occipital [O1, O2]),

and electrode hemisphere (left [P7, O1] vs. right [P8, O2]). All factors were within-subjects

variables. Figure 5 shows the P1 and N1 averaged across the P7, P8, O1, and O2 electrodes for

kitchen utensils and tools, as well as the pooled data from these two categories, for each location.

As in Experiment 1, we report only effects involving the correspondence between handle

orientation and response hand. A complete summary of the ANOVA results is given in

Appendix C.

For the P1 data, although the interaction of response hand and handle orientation (i.e., the correspondence effect) was not significant, $F < 1.0$, their 3-way interaction with object location was significant, $F(1, 19) = 4.88$, $p = .0396$, $\eta_p^2 = .20$. The correspondence effect on P1 was larger for peripheral objects (-0.313 µV) than central objects (0.185 µV). The further analyses revealed that only the former approached statistical significance, $|t(19)| = 1.83$, $p = .0823$, with the latter tending in the opposite direction, $t(19) = 1.54$, $p = .1404$. Object category did not interact with these variables, Fs < 1.0.

N1 data showed no interaction of response hand and handle orientation, $F < 1.0$. However, as in P1, the 3-way interaction of these variables and object location was significant, $F(1, 19) = 5.31$, $p = .0327$, $\eta_p^2 = .22$. The correspondence effect on N1 was larger for peripheral objects (-0.378 µV) than central objects (0.239 µV). The further analyses again revealed that the correspondence effect approached the .05 significant level for peripheral objects, $|t(19)| = 1.82$, $p = .0849$, but not for central objects, $t(19) = 1.48$, $p = .1556$. Object category did not interact with these variables, Fs < 1.0. These findings suggest that both P1 and N1 were modulated by correspondence between response hand and handle orientation only when objects were presented in a peripheral location rather than a central location.

LRPs. It should be noted that the LRP data do not allow us to test between the affordance account and the spatial coding account. Any object displayed in one visual field, as in the peripheral location condition, will produce different brain potentials between left and right hemifields in addition to the response code activated by the object itself. The lateralized brain activity could simply reflect differences in stimulus energy between left and right visual fields in the display (for further discussion, see Lien, Ruthruff, & Cornett, 2010; Lien, Ruthruff, Goodin, & Remington, 2008; Luck, 2005). Furthermore, attention allocation to a lateralized object would

also elicit an increased negativity over posterior, occipital, and temporal scalp contralateral to an attended stimulus, starting roughly 170 ms after stimulus onset (e.g., Eimer, 1996; Luck & Hillyard, 1990; Luck, Heinze, Mangun, & Hillyard, 1990). This attention allocation takes place prior to any processing of nonspatial features (e.g., Hillyard & Anllo-Vento, 1998). These factors would contribute to LRPs in the same polarity in Experiment 2 (note that object location and handle orientation always corresponded in our design). Thus, the LRP (differences in brain potentials between left and right hemifields [C3 and C4 electrodes]) would be exaggerated in the peripheral location condition (due to the combination of visual processing of object locations and features) compared to the central location condition. Despite this limitation, we report the data here for the sake of the completeness.

The LRP data were analyzed as a function of object location (central vs. peripheral), object category (kitchen utensils vs. tools), and correspondence between response hand and handle orientation (corresponding vs. noncorresponding). The complete summary of the ANOVA is in Appendix D. Figure 6 shows the LRPs for kitchen utensils and tools, as well as the pooled data from these two categories, for each location.

The correspondence effect approached significance for the first two time windows (0-100 and 100-200 ms), Fs(1,19) $\geq$ 3.86, ps = .06, η_p^2s $\geq$ .17. The effect was more pronounced for the peripheral objects than the central objects during the 100-200 ms window. This finding suggests that LRPs were modulated by object location. Again, the moderate modulation of correspondence on LRPs early in time (0-200 ms after stimulus onset) cannot be unambiguously attributed to response activation or selection.

Discussion

Replicating the findings of Experiment 1, central objects produced no significant

correspondence effect in RT (the 95% confidence interval was 3±6 ms, averaged across both categories). Consistent with the behavioral data, P1 and N1 showed no modulation by the correspondence between response hand and handle orientation. Once more, these findings are inconsistent with the grasping affordance account. Unlike central objects, peripheral objects elicited a large correspondence effect in RT (25±8 ms), similar in size to a standard Simon effect and to the object-based Simon effects obtained in Cho and Proctor's (2010, 2011) studies with kitchen utensils whose handle locations varied. The P1 and N1 were modulated by the correspondence between response hand and handle orientation for peripheral objects. Thus, the presence or absence of the correspondence effect strongly depends on the object location, supporting the spatial coding account.

For the peripheral objects, the handle orientation (left vs. right) and object location (left vs. right) always corresponded. One could still argue that the observed correspondence effect was due primarily to the joint effect from both handle orientation and object location. Although a joint effect seems unlikely due to the absence of the correspondence effect from the handle orientation in the center object condition, it is important to rule out this alternative explanation. Consequently, we conducted a behavioral experiment including only the peripheral object condition but with the handle orientation being varied (see also Symes, Ellis, & Tucker, 2005). That is, when the object was presented in the left location, the handle was orientated toward the left for a random half of the trials and toward the right for the other half. The same was also true when the object was presented in the right location. If the correspondence effect is primarily due to the spatial coding of the object location, and not the joint influence of both handle orientation and object location, then one would expect similar correspondence effects regardless of handle orientation.

Data from this control experiment with 92 new participants showed that a significant overall correspondence effect of 12±3 ms between object location and response location, $F(1, 91) = 56.91$, $p < .0001$, $\eta_p^2 = .38$. Critically, this effect did not depend on handle orientation, $F(1, 91) = 2.55$, $p = .1139$, $\eta_p^2 = .03$; the effect was 14±4 ms and 10±4 ms for the corresponding and non-corresponding handle orientations, respectively. These variables did not interact with category either, $F < 1.0$. These results replicated Symes et al.'s (2005) Experiment 1 where they found that the correspondence effect between object location and response location did not depend on handle orientation. Thus, the finding from our control experiment converges on the conclusion that the object-based correspondence effect is primarily due to object location, not object affordance.

Experiment 3

In Experiment 2, the correspondence effect was observed only when the object was presented to the left or right (the peripheral condition), not when the object was presented centrally (the central condition). Along with the finding in Experiment 1, the results converge on the conclusion that the object-based correspondence effect is primarily driven by object location (the spatial coding account; e.g., Bub & Masson, 2010; Cho & Proctor, 2010) rather than the orientation of object grasping component (the object affordance account; Goslin et al., 2012; Iani et al., 2011; Pellicano et al., 2010; Tucker & Ellis, 1998).

Experiment 3 further tested our conclusion by employing Cho and Proctor's (2011) approach of using the central condition only but with either the base of the object or the whole object being in the center. In the *base-centered* condition, the base of the object was in the center, so the handle was clearly positioned to the left or right side. In the *object-centered* condition, the object was in the center, so the handle was relatively positioned in the median line

as in the central object condition of Experiment 2. This was similar to the object presentation in Experiment 1 and Goslin et al.'s (2012) study, except for the color and size of the object. If the object affordance is the key triggering the correspondence effect, as suggested by the affordance account, then similar correspondence effects should be observed in both conditions. On the contrary, the spatial coding account predicts the presence of the correspondence effect in the base-centered condition but not in the object-centered condition because the lack of a spatial code in the latter case.

Method

Participants. There were 24 new participants, from the same participant pool as in Experiment 1. Two participants' EEG data failed to record. Therefore, data from 22 participants (12 females), mean age of 21 years (range: 18-30), were included in the final data analyses. All were right handed and reported having normal or corrected-to-normal acuity.

Apparatus, stimuli, and procedure. The tasks, stimuli, and equipment were the same as in Experiment 2, except for the following changes. The object always appeared roughly in the center of the screen depending on the condition. The *object-centered* condition was identical to the central object condition of Experiment 2 (see also Experiment 1); thus, the handle position was not clearly to left or right. The *base-centered* condition was similar to the object-centered condition except that the base of the object was presented centrally, resulting in the handle position being explicitly left or right. Again, within each condition, half of the handles were oriented to the left and half to the right. Object condition (object-centered vs. based-centered) was randomly intermixed within blocks. As in Experiment 1, each participant performed two sessions with different S-R mappings (left hand for kitchen utensils and right hand for tools vs. right hand for kitchen utensils and left hand for tools). Session order (i.e., response mapping

order) was counterbalanced between participants.

Results

The data analysis was similar to that of Experiment 2. No trials fell outside the range of the pre-determined RT cutoff (< 100 ms). Rejection of trials with EEG artifacts led to the further elimination of 6% of trials, but no more than 20% for any participant.

Behavioral Data Analyses

The behavioral data were analyzed as a function of object condition (object-centered vs. base-centered), object category (kitchen utensils vs. tools), and response-hand/handle-orientation correspondence (corresponding vs. noncorresponding). All factors were within-subject variables. Table 3 shows the mean RT and PE for each of these conditions.

An overall correspondence effect of 8 ms was significant, $F(1, 21) = 12.19$, $p < .01$, $\eta_p^2 = .37$, which was larger for tools (11 ms) than for kitchen utensils (4 ms), $F(1, 21) = 5.54$, $p = .0284$, $\eta_p^2 = .21$. Critically, the correspondence effect was larger for the base-centered condition (the 95% confidence level was 16±6 ms) than for the object-centered condition (-2±5 ms), $F(1, 21) = 28.09$, $p < .0001$, $\eta_p^2 = .57$, with the former being significant, $t(21) = 5.67$, $p < .0001$, but not the latter, $t < 1.0$. Mean RT was shorter for kitchen utensils (509 ms) than tools (524 ms), $F(1, 21) = 30.99$, $p < .0001$, $\eta_p^2 = .60$.

A significant correspondence effect of .011 was observed in the PE data, $F(1, 21) = 11.00$, $p < .01$, $\eta_p^2 = .34$. As in the RT data, the correspondence effect was larger for the base-centered condition (.025±.011) than for the object-centered condition (-.002±.007), $F(1, 21) = 23.53$, $p < .0001$, $\eta_p^2 = .53$. Further analyses revealed that the correspondence effect was significant for the base-centered condition, $t(21) = 4.70$, $p < .001$, but not for the object-centered condition, $t < 1.0$. Both kitchen utensils and tools produced similar large correspondence effect

in the base-centered condition, whereas the effect was relatively small for tools and even became negative for kitchen utensils in the object-centered condition, $F(1, 21) = 6.19$, $p = .0213$, $\eta_p^2 = .23$ (see Table 3). No other effects on RT and PE were significant.

ERP Data Analyses

P1 and N1. We analyzed the P1 and N1 data as a function of object condition (object-centered vs. base-centered), object category (kitchen utensils vs. tools), handle orientation (left vs. right), response hand/location (left vs. right), electrode site (parietal [P7, P8] vs. occipital [O1, O2]), and electrode hemisphere (left [P7, O1] vs. right [P8, O2]). All factors were within-subjects variables. Figure 7 shows the P1 and N1 averaged across the P7, P8, O1, and O2 electrodes for kitchen utensils and tools, as well as the pooled data from these two categories, for each location. As in Experiment 2, we report only effects involving the correspondence between handle orientation and response hand. A complete summary of the ANOVA results is given in Appendix E.

For the P1 data, neither the interaction of response hand and handle orientation (i.e., the correspondence effect) nor its interaction with object condition was significant, $Fs < 1.0$. The correspondence effect on P1 was 0.009 µV for the object-centered condition and was -0.036 µV for the base-centered condition. Object category did not interact with these variables, $Fs < 1.0$. The further analyses revealed that none of the correspondence effects was significant for kitchen utensils and tools in either object condition, $|ts| < 1.0$. The correspondence effects on P1 were 0.054 µV and -0.037 µV for kitchen utensils and tools, respectively, in the object-centered condition, and were -0.133 µV and 0.060 µV in the base-centered condition.

As P1, N1 data showed no interaction between response hand and handle orientation as well as its interactions with object condition and/or category, $Fs < 1.10$. Again, the further

analyses revealed that none of the correspondence effects was significant for kitchen utensils and tools in either object condition, $|ts| < 1.0$; the correspondence effects on N1 were 0.203 μV and 0.078 μV for kitchen utensils and tools, respectively, in the object-centered condition, and were -0.106 μV and 0.108 μV, respectively, in the base-centered condition. These findings suggest that both P1 and N1 were not modulated significantly by correspondence between response hand and handle orientation in either the object-centered condition or base-centered condition.

LRPs. The LRP data were analyzed as a function of object condition (object-centered vs. base-centered), object category (kitchen utensils vs. tools), and correspondence between response hand and handle orientation (corresponding vs. noncorresponding). The complete summary of the ANOVA is in Appendix F. Figure 8 shows the LRPs for kitchen utensils and tools, as well as the pooled data from these two categories, for each condition.

The correspondence effect on LRP was significant for every 100 ms time windows between 100 and 500 ms, $Fs(1,21) \geq 6.60$, $ps \leq .0179$, $\eta_p^2 s \geq .24$. The effect was more pronounced for the base-centered objects than the object-centered conditions during the 200-500 ms window, $Fs(1,21) \geq 4.73$, $ps \leq .0412$, $\eta_p^2 s \geq .18$. The correspondence effect on LRP was not significantly different between kitchen utensils and tools between 0-400 ms time windows, Fs <1.0. These findings suggest that early LRPs were not modulated by category but object location where the whole object or the object base was centrally located.

Discussion

Replicating the findings of Experiments 1 and 2, the correspondence effect was not evident when the midline of the object was presented in the screen center (-2±5 ms). Nevertheless, a large significant effect was observed when the base of the object was centrally located (16±6 ms), so that the handle was clearly positioned to either the left or right of center.

This finding replicates Cho and Proctor's (2011) and is consistent with the spatial coding account, which predicts that the correspondence effect should be absent for object-centered condition but present for base-centered condition. The absence of the correspondence between response hand and handle orientation for either condition on P1 and N1 provides no evidence that an intended grasping action modulates visual attention.

General Discussion

The aim of the present study was to examine whether object-based correspondence effects with keypress responses are driven primarily by the orientation of an object's graspable component or by the object's location. According to Goslin et al. (2012), the correspondence effect is the result of visual-action binding where the response is primed by deploying visual attention toward the object's graspable component. Consistent with this claim, they found correspondence effects on RT and sensory-evoked P1 and N1 ERPs, which have been assumed to reflect early processing of visual-spatial attention. However, their observed correspondence effects in both the RT and ERP were small (for tools) or even nonexistent (for kitchen utensils).

The close replication of Goslin et al.'s (2012) study in our Experiment 1 indeed yielded no significant correspondence effects in RT (overall 1±4 ms). Consistent with the behavioral data, P1 and N1 ERPs were also not modulated by correspondence between response hand and object handle orientation. Thus, these ERP results are inconsistent with the hypothesis that, when making keypress responses, visual processing is modulated by the intended object grasping action (e.g., Goslin et al., 2012; Handy, Grafton, Shroff, Ketay, & Gazzaniga, 2003).

Likewise, for centrally-presented objects in Experiments 2 and 3 there was no significant correspondence effect for any of the measures. The pooled data on the centrally located object condition from a total of 68 participants in all three experiments revealed that the correspondence

effect on RT was negligible (1±3 ms at the 95% confidence interval) and not significant, $F < 1.0$, neither was the interaction of correspondence and object category significant, $F < 1.0$. The effect was only -1±4 ms for kitchen utensils and 2±4 ms for tools. Consistent with the RT data, both pooled P1 and N1 data showed no main effect of correspondence, Fs ≤ 1.38, nor an interaction with category, Fs < 1.0. Thus, even with a slightly larger sample size (68 in ours and 65 in Goslin et al., 2012) and twice as many trials (1008 in our Experiment 1 and 504 in theirs), we found no evidence for the affordance account of the correspondence effect. It should also be noted that the correspondence effect reported in Goslin et al.'s (2012) single experiment was only 5 ms overall, with the effect being observed only for tools (10 ms) and not for kitchen utensils. Using G*Power 3 analyses, we estimated that the power to observe an effect of 5 ms (the size reported by Goslin et al.; a 2-tail test, .05 level) with our pooled sample size of 68 is 0.94 (Faul, Erdfelder, Lang, & Buchner, 2007). Thus, our nonreplication of their single experiment finding cannot be attributed to inadequate power to detect a meaningful effect. It is possible that Goslin et al.'s results may be due to a Type I error.

Experiments 2 and 3 provided further evidence that object locations rather than handle orientations produce a correspondence effect. In Experiment 2, the effect was observed when object appeared peripherally not centrally. In Experiment 3, the effect emerged only for the base-centered objects, where the handle was clearly positioned to the left or right of center, a finding in agreement with Cho and Proctor's (2011) results obtained with door-handle stimuli. Results from the three experiments contradict Goslin et al.'s (2012) claim and provide no evidence that correspondence effects result from an afforded grasping action. Instead, they show that spatial coding (i.e., object location) is the primary contributor to correspondence effects obtained with keypress responses.

There are two notable findings from the ERPs in the present study. First, Experiment 2 showed that the presence of P1 and N1 modulations by the correspondence for the peripheral objects and their absence for the central objects suggest that object location, not handle orientation, guides the allocation of visual/spatial attention. Although one might also expect the base-centered condition to show the modulation of P1 and N1 by correspondence in Experiment 3, the object location (left and right of center) was not as distinct as it was in the peripheral object condition in Experiment 2. These findings are in line with Luck et al.'s (1990) study showing that P1 and N1 were enhanced in response to attended unilateral stimuli. They concluded that these ERP components reflect early visual processing of selection based on stimulus location.

Second, the overall N1 effect was much larger in Experiments 2 and 3 than in Experiment 1. Previous studies have found that the N1 effect is mediated by stimulus repetition – a decreased N1 effect associated with repeating auditory stimuli but increased N1 effect associated with repeating visual stimuli (e.g., Olofsson & Polich, 2007; Sable, Low, Maclin, Fabiani, & Gratton, 2004). Given that our stimuli were presented visually and more often in Experiments 2 and 3 than in Experiment 1 (45 times vs. 12 times, respectively), one would expect increased N1 effects in Experiments 2 and 3, as we observed.

In conclusion, the present study confirms that effects on performance attributable to the correspondence of object locations with keypresses occurs when both can be spatially coded as left or right. Moreover, in agreement with findings of Bub and Masson (2010) and Cho and Proctor (2011, 2012), our results provide no evidence that object-handle orientations produce such correspondence effects with keypresses when the displayed object is centered. The pooled data from the present three experiments also further rule out the possible effect of handle

orientation. Not surprisingly, correspondence effects also tend to appear in the electrophysiological measures of P1 and N1 when the objects are displayed in distinct left and right locations, but not when they are centered. Correspondence effects for handle location and keypresses do occur, however, when the object is presented in such a way that the handle itself was clearly positioned to the left or right side of the center (Cho & Proctor, 2010, 2011, 2012), but this is because the handle produces a location code similar to that generated by varying the left-right location of the object in the present Experiments 2 and 3.

Goslin et al. (2012) emphasized intention in their account, stating that processing "is modulated by the action associations of objects and the intentions of the viewer" (p. 152). It should be noted, however, that the viewer's intentions were to produce left or right keypresses and not to grasp the pictures of objects that are shown on the screen. These intentions therefore prime left or right stimulus location and weight these location codes more heavily in the decision process (e.g., Yamaguchi & Proctor, 2012). That intentions to make keypress responses do not as a rule prime the processing of object properties related to grasping was articulated clearly by Bub and Masson (2010) in explaining why they found no object-based correspondence effects in their Experiment 2, which used keypress responses:

> Apparently, a key press is too far removed from any action compatible with the irrelevant object to evoke motor representations that favor one hand over another. Moreover, depressing a finger already resting on a response key does not involve the process of transporting the hand to a target location in space and forming the hand shape to fit that target. (p. 349)

We fully agree that "intentions of the viewer" are important in human information processing, but a wealth of data indicate that keypress responses are coded mainly in terms of spatial location

(Proctor & Vu, 2006). Both the behavioral and electrophysiological evidence in the present study support the view that the "automatic" processing of objects that occurs (resulting in correspondence effects) in tasks requiring keypresses is a consequence of overlap of the spatial codes for the stimuli with those for the responses (e.g., Kornblum, Hasbroucq, & Osman, 1990), as in other spatial compatibility effects.

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Appendix A

A Summary Table for ANOVAs on Mean P1 and N1 as a Function of Object Category (Kitchen Utensils vs. Tools), Handle Orientation (Left vs. Right), Response Hand (Left vs. Right), Electrode Site (Parietal vs. Occipital), and Electrode Hemisphere (Left vs. Right) in Experiment 1.

Effect	df	P1			N1		
		F	p	η_p^2	F	p	η_p^2
Category (C)	1,25	5.84	.02	.19	<1.0	—	—
Handle Orientation (H)	1,25	1.68	.21	.06	1.54	.23	.06
Response Hand (R)	1,25	<1.0	—	—	<1.0	—	—
Electrode Site (S)	1,25	7.02	.01	.22	4.69	.04	.16
Electrode Hemisphere (E)	1,25	18.94	<.001	.43	14.60	<.001	.37
C × H	1,25	<1.0	—	—	<1.0	—	—
C × R	1,25	<1.0	—	—	<1.0	—	—
C × S	1,25	1.40	.25	.05	1.30	.27	.05
C × E	1,25	<1.0	—	—	5.32	.03	.18
H × R	1,25	<1.0	—	—	<1.0	—	—
H × S	1,25	<1.0	—	—	8.92	<.01	.26
H × E	1,25	<1.0	—	—	43.97	<.0001	.64
R × S	1,25	1.98	.17	.07	2.43	.13	.09
R × E	1,25	<1.0	—	—	<1.0	—	—
S × E	1,25	28.41	<.001	.53	11.78	<.01	.32
C × H × R	1,25	2.41	.13	.09	<1.0	—	—
C × H × S	1,25	<1.0	—	—	1.66	.21	.06
C × H × E	1,25	2.90	.10	.10	36.35	<.0001	.59
C × R × S	1,25	1.45	.24	.05	1.84	.19	.07
C × R × E	1,25	1.32	.26	.05	<1.0	—	—
C × S × E	1,25	<1.0	—	—	2.70	.11	.10
H × R × S	1,25	<1.0	—	—	<1.0	—	—
H × R × E	1,25	<1.0	—	—	<1.0	—	—
H × S × E	1,25	<1.0	—	—	2.37	.14	.09
R × S × E	1,25	1.65	.21	.06	2.15	.15	.08
C × H × R × S	1,25	1.78	.19	.07	<1.0	—	—
C × H × R × E	1,25	1.36	.25	.05	<1.0	—	—
C × H × S × E	1,25	3.11	.09	.11	4.89	.04	.16
C × R × S × E	1,25	2.90	.10	.10	3.54	.07	.12

H × R × S × E	1,25	<1.0	—	—	<1.0	—	—
C × H × R × S × E	1,25	1.22	.28	.05	3.91	.06	.14

Appendix B

A Summary Table for ANOVAs on the Mean LRP as a Function of Object Category (Kitchen Utensils vs. Tools), and

Correspondence between Response Hand and Handle Orientation (Corresponding vs. Noncorresponding) for the Five Consecutive

100-ms Time Windows from 0 to 500 ms After Stimulus Onset in Experiment 1. Cat: Category; Corr: Correspondence.

Effect	df	0-100 ms			100-200 ms			200-300 ms			300-400 ms			400-500 ms		
		F	p	η_p^2	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Cat	1,25	6.08	.02	.20	3.55	.07	.12	1.81	.19	.07	5.26	.03	.17	7.23	.01	.22
Corr	1,25	5.11	.03	.17	6.18	.02	.20	6.98	.01	.22	10.66	.003	.30	10.33	.004	.29
Cat × Corr	1,25	3.49	.07	.12	3.37	.08	.12	3.42	.08	.12	6.75	.02	.21	11.12	.003	.31

Appendix C

A Summary Table for ANOVAs on Mean P1 and N1 as a Function of Object Location (Central

vs. Peripheral), Object Category (Kitchen Utensils vs. Tools), Handle Orientation (Left vs.

Right), Response Hand (Left vs. Right), Electrode Site (Parietal vs. Occipital), and Electrode

Hemisphere (Left vs. Right) in Experiment 2.

Effect	df	P1			N1		
		F	p	η_p^2	F	p	η_p^2
Location (L)	1,19	28.41	<.001	.60	10.87	<.01	.36
Category (C)	1,19	15.42	<.001	.45	5.53	.03	.23
Handle Orientation (H)	1,19	<1.0	—	—	1.14	.30	.06
Response Hand (R)	1,19	<1.0	—	—	2.04	.17	.10
Electrode Site (S)	1,19	<1.0	—	—	5.86	.03	.24
Electrode Hemisphere (E)	1,19	9.14	<.01	.32	1.61	.22	.08
L × C	1,19	4.87	.04	.20	<1.0	—	—
L × H	1,19	1.56	.23	.08	1.60	.22	.08
L × R	1,19	<1.0	—	—	<1.0	—	—
L × S	1,19	4.35	.05	.19	<1.0	—	—
L × E	1,19	5.87	.03	.24	<1.0	—	—
C × H	1,19	<1.0	—	—	3.10	.09	.14
C × R	1,19	<1.0	—	—	<1.0	—	—
C × S	1,19	9.32	<.01	.33	1.84	.19	.09
C × E	1,19	5.51	.03	.22	6.98	.02	.27
H × R	1,19	<1.0	—	—	<1.0	—	—
H × S	1,19	<1.0	—	—	3.00	.10	.14
H × E	1,19	1.21	.29	.06	27.13	<.0001	.59
R × S	1,19	<1.0	—	—	1.77	.20	.09
R × E	1,19	1.23	.28	.06	<1.0	—	—
S × E	1,19	25.45	<.0001	.57	8.02	.01	.30
L × C × H	1,19	3.56	.07	.16	3.00	.10	.14
L × C × R	1,19	1.13	.30	.06	<1.0	—	—
L × C × S	1,19	2.29	.15	.11	<1.0	—	—
L × C × E	1,19	<1.0	—	—	6.37	.02	.25
L × H × R	1,19	4.88	.04	.20	5.31	.03	.22
L × H × S	1,19	1.37	.26	.07	2.38	.14	.11
L × H × E	1,19	13.52	<.01	.42	10.03	<.01	.35

L × R × S	1,19	<1.0	—	—	5.40	.03	.22
L × R × E	1,19	2.04	.17	.10	4.29	.05	.18
L × S × E	1,19	13.64	<.01	.42	<1.0	—	—
C × H × R	1,19	<1.0	—	—	<1.0	—	—
C × H × S	1,19	2.81	.11	.13	1.12	.30	.06
C × H × E	1,19	1.99	.17	.09	3.21	.09	.14
C × R × S	1,19	1.31	.27	.06	<1.0	—	—
C × R × E	1,19	<1.0	—	—	<1.0	—	—
C × S × E	1,19	<1.0	—	—	1.81	.19	.09
H × R × S	1,19	1.53	.23	.07	5.01	.04	.21
H × R × E	1,19	1.53	.23	.07	1.75	.20	.08
H × S × E	1,19	<1.0	—	—	23.40	<.0001	.55
R × S × E	1,19	<1.0	—	—	6.74	.02	.26
L × C × H × R	1,19	<1.0	—	—	<1.0	—	—
L × C × H × S	1,19	2.17	.16	.10	<1.0	—	—
L × C × H × E	1,19	<1.0	—	—	3.07	.10	.14
L × C × R × S	1,19	5.33	.03	.22	3.46	.08	.15
L × C × R × E	1,19	1.47	.24	.07	<1.0	—	—
L × C × S × E	1,19	<1.0	—	—	<1.0	—	—
L × H × R × S	1,19	<1.0	—	—	<1.0	—	—
L × H × R × E	1,19	<1.0	—	—	1.78	.20	.09
L × H × S × E	1,19	3.14	.09	.14	27.22	<.0001	.59
L × R × S × E	1,19	<1.0	—	—	3.56	.07	.16
C × H × R × S	1,19	1.80	.20	.09	<1.0	—	—
C × H × R × E	1,19	1.48	.24	.07	7.30	.01	.28
C × H × S × E	1,19	<1.0	—	—	7.06	.02	.27
C × R × S × E	1,19	<1.0	—	—	<1.0	—	—
H × R × S × E	1,19	3.15	.09	.14	6.83	.02	.26
L × C × H × R × S	1,19	1.03	.32	.05	1.75	.20	.08
L × C × H × R × E	1,19	<1.0	—	—	<1.0	—	—
L × C × H × S × E	1,19	<1.0	—	—	<1.0	—	—
L × C × R × S × E	1,19	5.49	.03	.22	2.93	.10	.13
L × H × R × S × E	1,19	<1.0	—	—	2.56	.13	.12
C × H × R × S × E	1,19	<1.0	—	—	1.33	.26	.07
L × C × H × R × S × E	1,19	<1.0	—	—	8.33	<.01	.30

Appendix D

A Summary Table for ANOVAs on Mean LRP as a Function of Object Location (Central vs. Peripheral), Object Category (Kitchen Utensils vs. Tools) and Correspondence between Response Hand and Handle Orientation (Corresponding vs. Noncorresponding) for the Five Consecutive 100-ms Time Windows from 0 to 500 ms After Stimulus Onset in Experiment 2. Loc: Location; Cat: Category; Corr: Correspondence.

Effect	df	0-100 ms			100-200 ms			200-300 ms			300-400 ms			400-500 ms		
		F	p	η_p^2	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Loc	1,19	<1.0	—	—	<1.0	—	—	7.77	.01	.29	19.20	<.001	.50	1.59	.22	.08
Cat	1,19	2.66	.12	.12	3.88	.06	.17	2.30	.15	.11	<1.0	—	—	<1.0	—	—
Corr	1,19	3.86	.06	.17	4.16	.06	.18	<1.0	—	—	<1.0	—	—	8.38	<.01	.31
Loc × Cat	1,19	<1.0	—	—	<1.0	—	—	1.84	.19	.09	<1.0	—	—	<1.0	—	—
Loc × Corr	1,19	1.84	.19	.09	14.93	<.001	.44	1.35	.26	.07	6.69	.02	.26	3.01	.10	.14
Cat × Corr	1,19	<1.0	—	—	<1.0	—	—	<1.0	—	—	<1.0	—	—	3.24	.09	.15
Loc × Cat × Corr	1,19	<1.0	—	—	<1.0	—	—	<1.0	—	—	4.81	.04	.20	10.70	<.01	.36

Appendix E

A Summary Table for ANOVAs on Mean P1 and N1 as a Function of Object Condition (Object-Centered vs. Base-Centered), Object Category (Kitchen Utensils vs. Tools), Handle Orientation (Left vs. Right), Response Hand (Left vs. Right), Electrode Site (Parietal vs. Occipital), and Electrode Hemisphere (Left vs. Right) in Experiment 3.

Effect	df	P1			N1		
		F	p	η_p^2	F	p	η_p^2
Object Condition (O)	1,21	3.74	.07	.15	<1.0	—	—
Category (C)	1,21	43.39	<.0001	.67	9.87	<.01	.32
Handle Orientation (H)	1,21	1.14	.30	.05	2.68	.12	.11
Response Hand (R)	1,21	<1.0	—	—	4.31	.05	.17
Electrode Site (S)	1,21	2.47	.13	.11	1.19	.29	.05
Electrode Hemisphere (E)	1,21	20.68	<.001	.50	9.51	<.01	.31
O × C	1,21	7.85	.01	.27	1.14	.30	.05
O × H	1,21	2.97	.10	.12	<1.0	—	—
O × R	1,21	<1.0	—	—	1.85	.19	.08
O × S	1,21	7.39	.01	.26	4.93	.04	.19
O × E	1,21	4.95	.04	.19	2.99	.10	.12
C × H	1,21	<1.0	—	—	<1.0	—	—
C × R	1,21	<1.0	—	—	<1.0	—	—
C × S	1,21	32.01	<.0001	.60	1.85	.19	.08
C × E	1,21	27.75	<.0001	.57	1.28	.27	.06
H × R	1,21	<1.0	—	—	<1.0	—	—
H × S	1,21	1.72	.20	.08	1.34	.26	.06
H × E	1,21	4.46	.04	.18	18.91	<.001	.47
R × S	1,21	<1.0	—	—	9.90	<.01	.32
R × E	1,21	2.18	.15	.09	1.17	.29	.05
S × E	1,21	27.98	<.0001	.57	6.52	.02	.24
O × C × H	1,21	<1.0	—	—	<1.0	—	—
O × C × R	1,21	<1.0	—	—	1.69	.21	.07
O × C × S	1,21	17.60	<.001	.46	<1.0	—	—
O × C × E	1,21	6.91	.02	.25	<1.0	—	—
O × H × R	1,21	<1.0	—	—	<1.0	—	—
O × H × S	1,21	2.21	.15	.10	6.97	.02	.25
O × H × E	1,21	<1.0	—	—	<1.0	—	—

O × R × S	1,21	1.37	.26	.06	<1.0	—	—
O × R × E	1,21	<1.0	—	—	5.26	.03	.20
O × S × E	1,21	<1.0	—	—	11.80	<.01	.36
C × H × R	1,21	<1.0	—	—	<1.0	—	—
C × H × S	1,21	3.22	.09	.13	1.08	.31	.05
C × H × E	1,21	<1.0	—	—	1.78	.20	.08
C × R × S	1,21	2.94	.10	.12	<1.0	—	—
C × R × E	1,21	1.84	.19	.08	<1.0	—	—
C × S × E	1,21	3.00	.10	.12	3.55	.07	.14
H × R × S	1,21	1.24	.28	.06	<1.0	—	—
H × R × E	1,21	<1.0	—	—	2.59	.12	.11
H × S × E	1,21	<1.0	—	—	6.68	.02	.24
R × S × E	1,21	<1.0	—	—	8.28	<.01	.28
O × C × H × R	1,21	<1.0	—	—	1.84	.19	.09
O × C × H × S	1,21	3.57	.07	.15	14.03	<.01	.40
O × C × H × E	1,21	3.27	.08	.13	1.43	.24	.06
O × C × R × S	1,21	<1.0	—	—	13.68	<.01	.39
O × C × R × E	1,21	<1.0	—	—	2.04	.17	.09
O × C × S × E	1,21	<1.0	—	—	3.12	.09	.13
O × H × R × S	1,21	1.31	.27	.06	5.53	.03	.21
O × H × R × E	1,21	<1.0	—	—	<1.0	—	—
O × H × S × E	1,21	1.01	.33	.05	2.46	.13	.10
O × R × S × E	1,21	<1.0	—	—	1.38	.25	.06
C × H × R × S	1,21	<1.0	—	—	<1.0	—	—
C × H × R × E	1,21	4.05	.06	.16	2.20	.15	.09
C × H × S × E	1,21	1.82	.19	.09	9.81	<.01	.32
C × R × S × E	1,21	<1.0	—	—	<1.0	—	—
H × R × S × E	1,21	3.23	.09	.13	1.30	.27	.06
O × C × H × R × S	1,21	<1.0	—	—	7.63	.01	.27
O × C × H × R × E	1,21	<1.0	—	—	1.95	.18	.08
O × C × H × S × E	1,21	8.80	<.01	.30	7.27	.01	.26
O × C × R × S × E	1,21	2.27	.15	.10	<1.0	—	—
O × H × R × S × E	1,21	1.16	.29	.05	<1.0	—	—
C × H × R × S × E	1,21	6.31	.02	.23	<1.0	—	—
O × C × H × R × S × E	1,21	<1.0	—	—	<1.0	—	—

Appendix F

A Summary Table for ANOVAs on Mean LRP as a Function of Object Condition (Object-Centered vs. Based-Centered), Object Category (Kitchen Utensils vs. Tools) and Correspondence between Response Hand and Handle Orientation (Corresponding vs. Noncorresponding) for the Five Consecutive 100-ms Time Windows from 0 to 500 ms After Stimulus Onset in Experiment 3. O: Object Condition; Cat: Category; Corr: Correspondence.

Effect	df	0-100 ms			100-200 ms			200-300 ms			300-400 ms			400-500 ms		
		F	p	η_p^2	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
O	1,21	1.53	.23	.07	3.04	.10	.13	7.12	.01	.25	2.62	.12	.11	1.52	.23	.07
Cat	1,21	<1.0	—	—	<1.0	—	—	<1.0	—	—	<1.0	—	—	6.41	.02	.23
Corr	1,21	<1.0	—	—	63.56	<.0001	.75	13.99	<.01	.40	32.53	<.0001	.61	6.60	.02	.24
O × Cat	1,21	<1.0	—	—	<1.0	—	—	<1.0	—	—	<1.0	—	—	<1.0	—	—
O × Corr	1,21	<1.0	—	—	<1.0	—	—	5.30	.03	.20	4.73	.04	.18	7.75	.01	.27
Cat × Corr	1,21	<1.0	—	—	<1.0	—	—	3.56	.08	.14	<1.0	—	—	<1.0	—	—
O × Cat × Corr	1,21	2.96	.10	.12	5.16	.03	.20	1.57	.22	.07	<1.0	—	—	13.53	<.01	.39

Author Note

Footnotes

1. We thank Jeremy Goslin for providing the colored object pictures.

2. The session/mapping order had no main effect or interactions with other variables on either

    RT, Fs(1, 24) ≤ 2.75, ps ≥ .1106, η_p^2s ≤ .10, or PE, Fs(1, 24) ≤ 1.20, ps ≥ .2846, η_p^2s ≤ .05.

    Therefore, we analyzed all data averaged across the two session/mapping orders to simplify

    the analyses.

3. Visual inspection of the averaged P1 and N1 effects in our data revealed that these two

    effects occurred somewhat later than those in Goslin et al.'s (2012) study. We performed

    scalp topography which revealed large activity during the time window 100-200 ms after

    stimulus onset (see Figure 2). Therefore, we used the time window 100-130 ms to assess the

    P1 effect and the time window 150-200 ms to assess the N1 effect, which coincide with the

    time window suggested by Luck (2005). However, we also conducted the analyses using the

    time windows of Goslin et al. (2012) – 70-100 ms and 120-170 ms after stimulus onset for P1

    and N1, respectively, and found similar results. No significant interaction between response

    hand/location and handle orientation was found for either P1 or N1, Fs< 1.0.

Table 1. Mean Response Time (RT) in Milliseconds and Proportion of Errors (PE) as a Function

of Object Category (Kitchen Utensils vs. Tools) and Response-Hand/Handle-Orientation

Correspondence (Corresponding vs. Noncorresponding) in Experiment 1.

Object Category	Correspondence		*Correspondence Effect*
	Corresponding	Noncorresponding	
RT			
Kitchen Utensil	583 (14)	587 (14)	*4 (2.70)*
Tool	594 (15)	592 (14)	*-2 (2.74)*
PE			
Kitchen Utensil	.053 (.005)	.057 (.005)	*.004 (.003)*
Tool	.041 (.005)	.045 (.005)	*.003 (.003)*

Note: The standard error of the mean is shown in parentheses.

Table 2. Mean Response Time (RT) in Milliseconds and Proportion of Errors (PE) as a Function of Object Location (Central vs. Peripheral), Object Category (Kitchen Utensils vs. Tools), and Response-Hand/Handle-Orientation Correspondence (Corresponding vs. Noncorresponding) in Experiment 2.

Object Category	Correspondence				Correspondence Effect	
	Corresponding		Noncorresponding			
	RT	PE	RT	PE	*RT*	*PE*
Central Location						
Kitchen Utensil	535 (15)	.041 (.007)	533 (15)	.045 (.007)	*-1 (2.84)*	*.005 (.003)*
Tool	539 (14)	.034 (.007)	546 (15)	.033 (.006)	*7 (4.02)*	*-.002 (.004)*
Peripheral Location						
Kitchen Utensil	535 (17)	.039 (.008)	559 (14)	.060 (.009)	*24 (4.20)*	*.022 (.004)*
Tool	534 (15)	.030 (.008)	560 (15)	.053 (.008)	*26 (5.34)*	*.023 (.005)*

Note: The standard error of the mean is shown in parentheses.

Table 3. Mean Response Time (RT) in Milliseconds and Proportion of Errors (PE) as a Function

of Object Condition (Object-Centered vs. Base-Centered), Object Category (Kitchen Utensils vs.

Tools), and Response-Hand/Handle-Orientation Correspondence (Corresponding vs.

Noncorresponding) in Experiment 3.

Object Category	Correspondence				Correspondence Effect	
	Corresponding		Noncorresponding			
	RT	PE	RT	PE	*RT*	*PE*
Object Centered						
Kitchen Utensil	513 (15)	.044 (.007)	508 (13)	.033 (.005)	*-5 (3.83)*	*-.011 (.003)*
Tool	524 (15)	.035 (.006)	528 (15)	.041 (.007)	*3 (3.23)*	*.006 (.005)*
Base Centered						
Kitchen Utensil	502 (14)	.023 (.004)	515 (14)	.051 (.008)	*13 (2.76)*	*.029 (.006)*
Tool	513 (14)	.030 (.004)	532 (14)	.052 (.008)	*19 (4.07)*	*.022 (.006)*

Note: The standard error of the mean is shown in parentheses.

Figure Captions

Figure 1. Panel A shows an example of event sequence used in Experiment 1. Panel B shows the

subset of objects from Goslin et al.'s (2011) stimuli that we used in Experiments 2-3. For the

purpose of our study, we changed the color to grey scale and reduced the size of the objects to

approximately 50% of the original size. Only left handle, centrally located objects are shown.

The permission of using Goslin et al.'s stimuli was obtained by email on February 20th, 2012.

Figure 2. The scalp distribution of event-related potentials for every 24-ms interval during the

time window 100-200 ms after stimulus onset in Experiment 1. These topographies indicated

increased activity for parietal and occipital sites during this time window.

Figure 3. Grand average P1 and N1 waveforms across P7, P8, O1, and O2 electrodes for kitchen

utensils and tools in Experiment 1. In addition, pooled data were obtained by averaging the P1

and N1 across the two object categories. Data are plotted as a function of whether the response

hand and the handle orientation were corresponding (both left or both right) or noncorresponding

(one left and one right). The unfilled rectangular boxes indicate the time window used to assess

the P1 effect (100-130 ms after stimulus onset) and the N1 effect (150-200 ms after stimulus

onset). Negative is plotted upward and time zero represents stimulus onset.

Figure 4. Grand average LRP waveforms for kitchen utensils and tools in Experiment 1. In

addition, pooled data were obtained by averaging the LRPs across the two object categories.

Data are plotted as a function of whether the response hand and the handle orientation were

corresponding (i.e., both left or both right) or noncorresponding (one left and one right).

Negative is plotted upward and time zero represents stimulus onset.

Figure 5. Grand average P1 and N1 waveforms across P7, P8, O1, and O2 electrodes for kitchen

utensils and tools when they were centrally located vs. when they were peripheral located in

Experiment 2. In addition, pooled data were obtained by averaging the P1 and N1 across the two

object categories for each location. Data are plotted as a function of whether the response hand

and the handle orientation were corresponding (both left or both right) or noncorresponding (one

left and one right). The unfilled rectangular boxes indicate the time window used to assess the

P1 effect (100-130 ms after stimulus onset) and the N1 effect (150-200 ms after stimulus onset).

Negative is plotted upward and time zero represents stimulus onset.

Figure 6. Grand average LRP waveforms for kitchen utensils and tools when they were centrally

located vs. when they were peripheral located in Experiment 2. In addition, pooled data were

obtained by averaging the LRPs across the two object categories for each location. Data are

plotted as a function of whether the response hand and the handle orientation were corresponding

(both left or both right) or noncorresponding (one left and one right). Negative is plotted upward

and time zero represents stimulus onset.

Figure 7. Grand average P1 and N1 waveforms across P7, P8, O1, and O2 electrodes for kitchen

utensils and tools in the object-centered condition vs. in the base-centered condition in

Experiment 3. In addition, pooled data were obtained by averaging the P1 and N1 across the two

object categories for each condition. Data are plotted as a function of whether the response hand

and the handle orientation were corresponding (both left or both right) or noncorresponding (one

left and one right). The unfilled rectangular boxes indicate the time window used to assess the

P1 effect (100-130 ms after stimulus onset) and the N1 effect (150-200 ms after stimulus onset).

Negative is plotted upward and time zero represents stimulus onset.

Figure 8. Grand average LRP waveforms for kitchen utensils and tools in the object-centered

condition vs. in the base-centered condition in Experiment 3. In addition, pooled data were

obtained by averaging the LRPs across the two object categories for each condition. Data are

plotted as a function of whether the response hand and the handle orientation were corresponding

(both left or both right) or noncorresponding (one left and one right). Negative is plotted upward

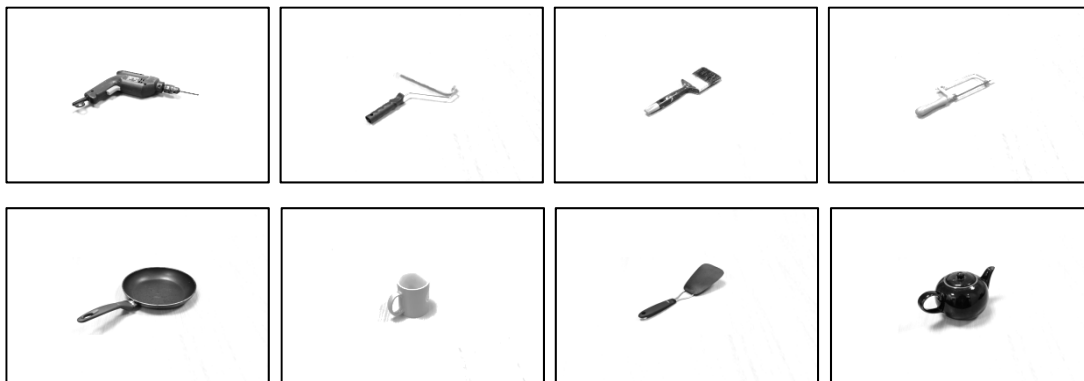and time zero represents stimulus onset.

Figure 1

Panel A

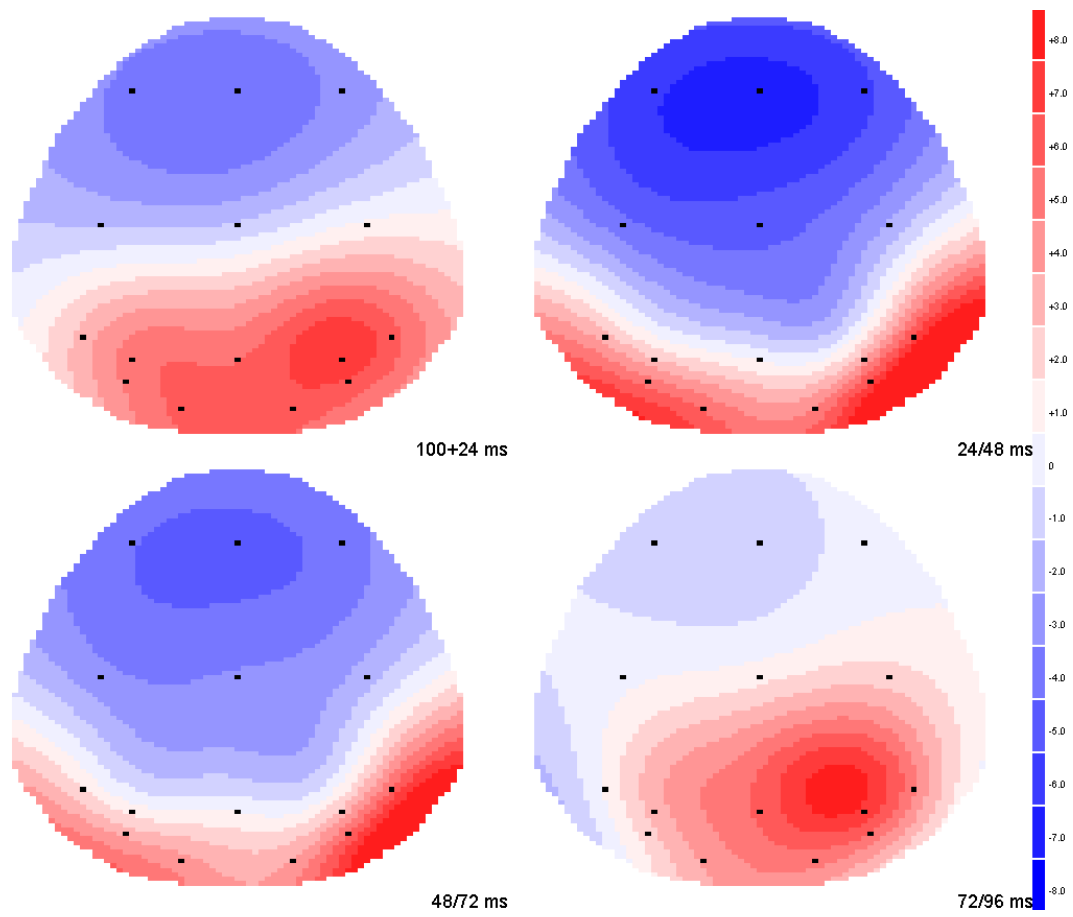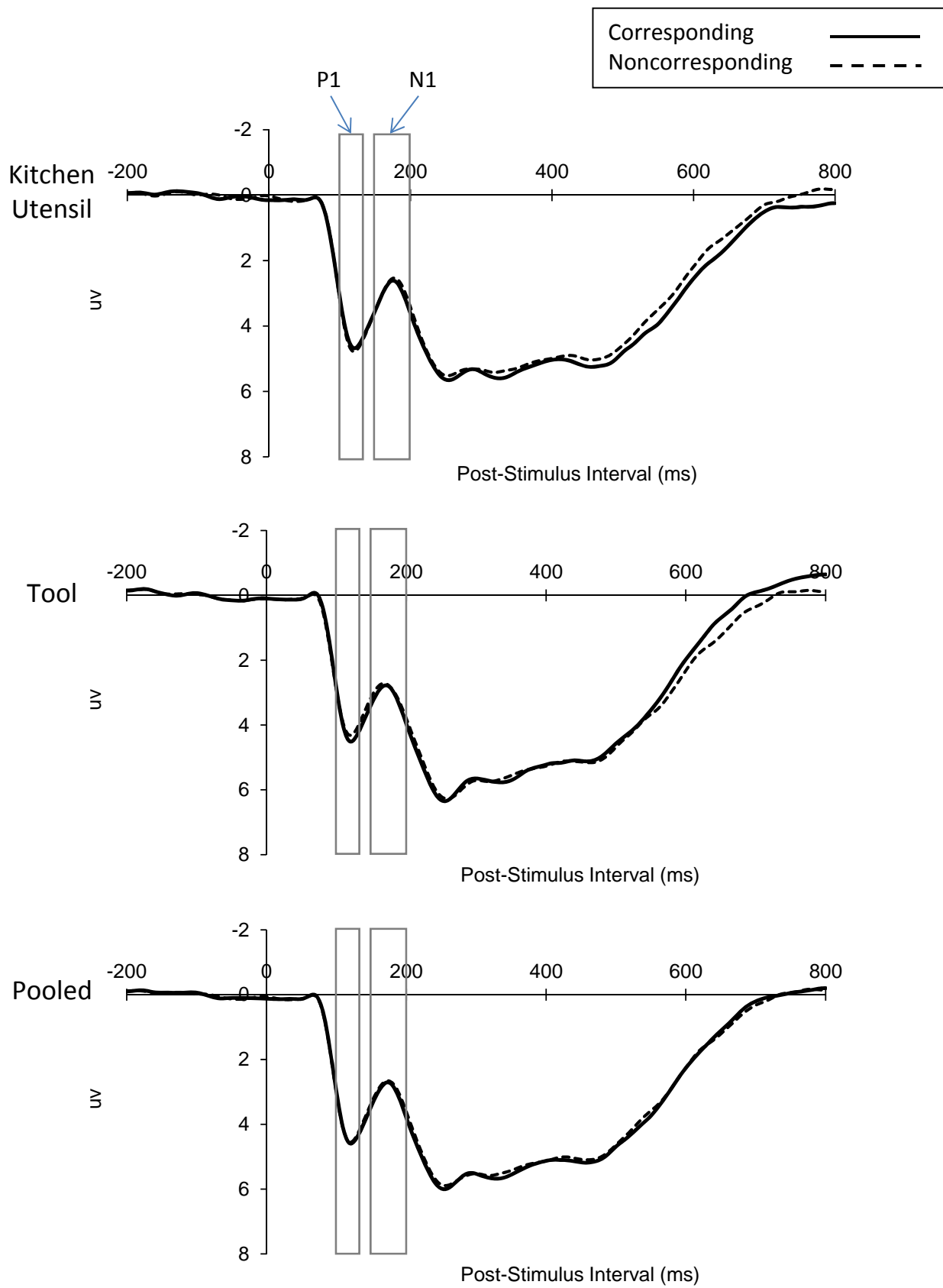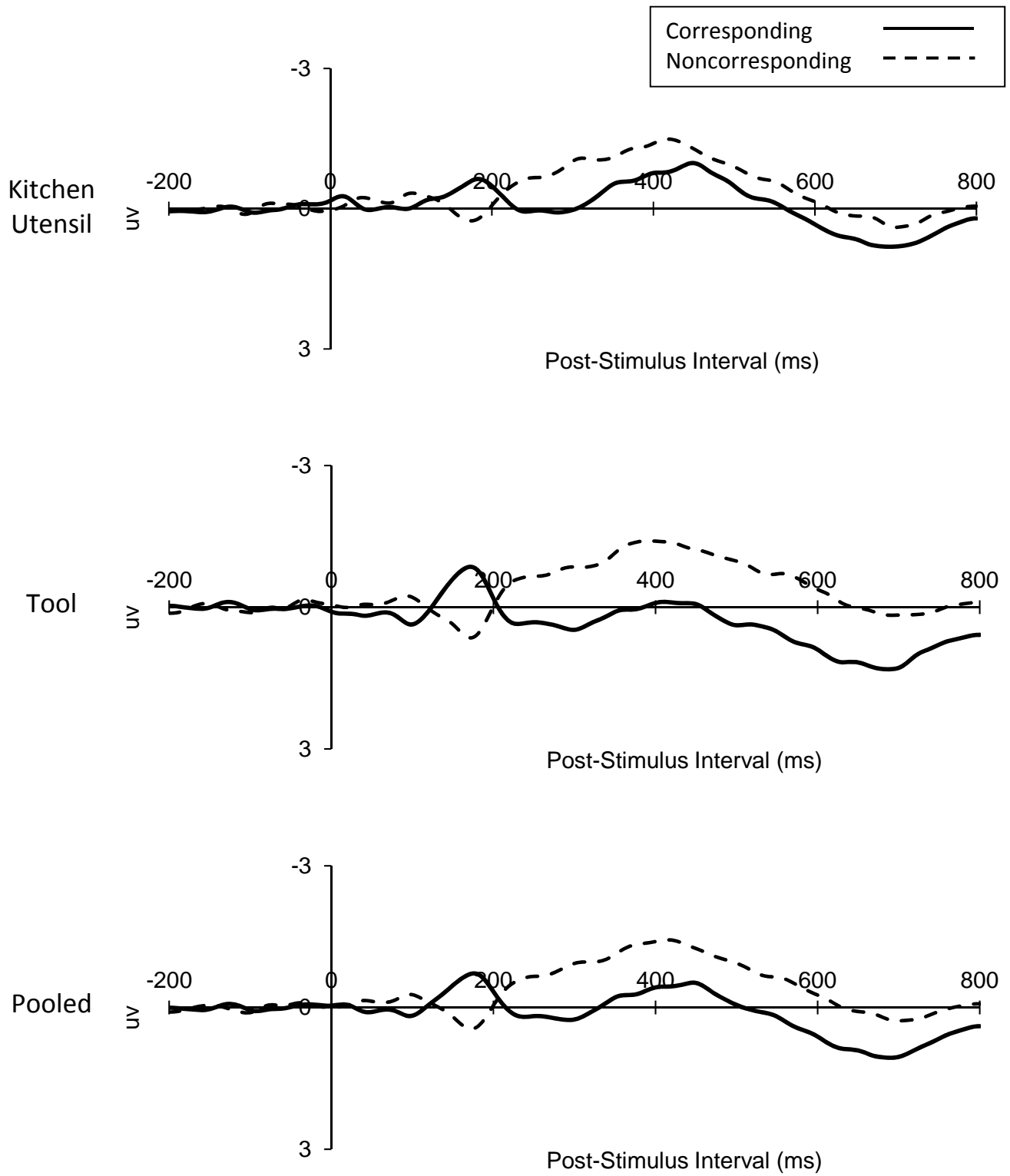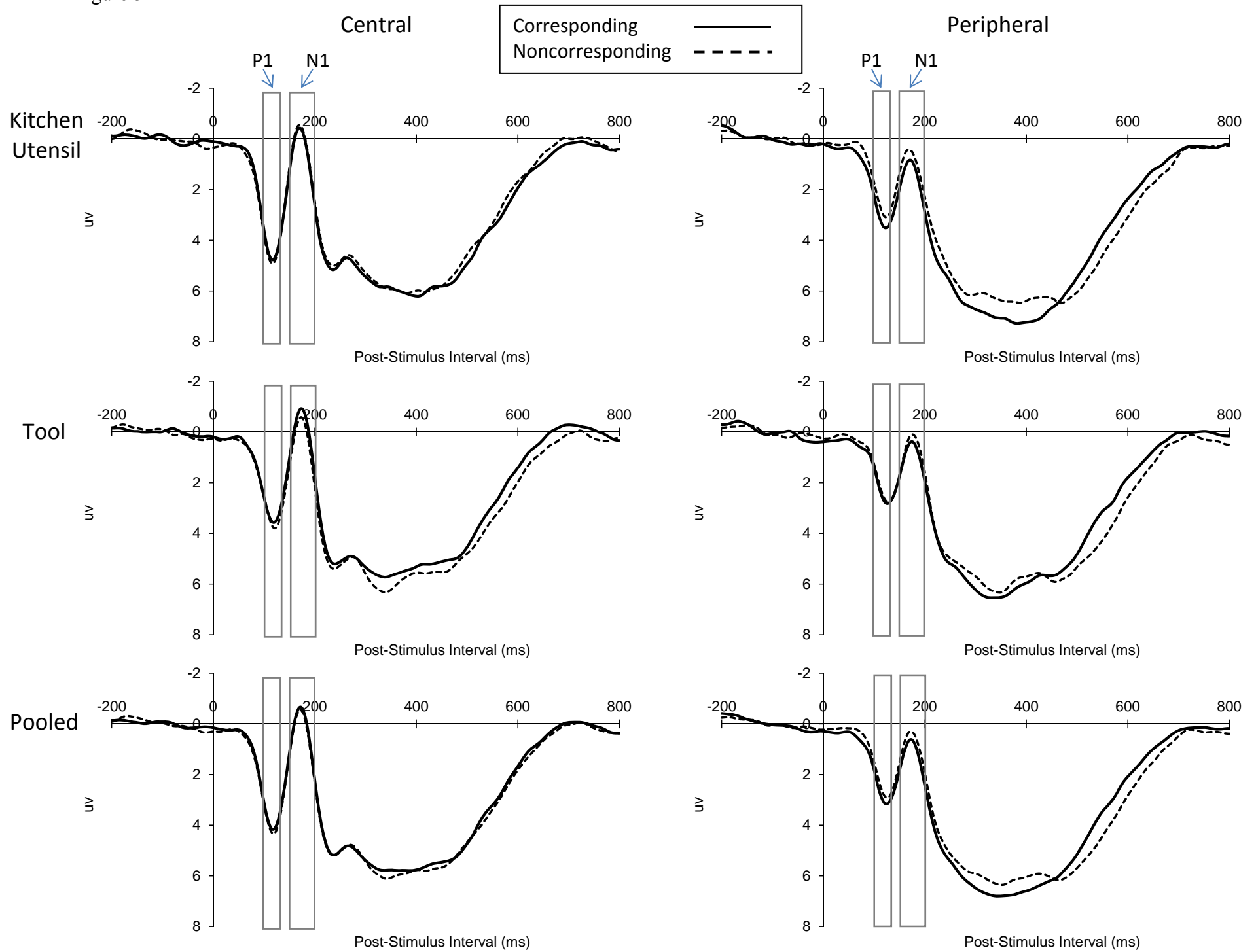| Fixation	Target	Feedback
1,000-1,200 ms	Until Respond or 2,000 ms	100 ms

Time

Panel B

Figure 2

100+24 ms

24/48 ms

48/72 ms

72/96 ms

Figure 3

Figure 4

Figure 5

Figure 6

Corresponding ——————
Noncorresponding — — — —

Central

Peripheral

Kitchen Utensil

Tool

Pooled

uv

-200   0   200   400   600   800

Post-Stimulus Interval (ms)

Figure 7

Figure 8

Object-Centered

Corresponding ⎯⎯⎯
Noncorresponding ⎯ ⎯ ⎯

Base-Centered

Kitchen
Utensil

Tool

Pooled

Post-Stimulus Interval (ms)