Running head: Verbal Cue and Task-Set Activation

Separating the effect of verbal cue on task-set activation into stimulus- and response-related processes: An eye-tracking study

Erina Saeki (Kobe Women's University)

Satoru Saito (Kyoto University)

Correspondence to Erina Saeki

Faculty of Psychology

Kobe Women's University

4-7-2, Nakamachi, Chuo-ku

Kobe, Hyogo, 650-0046

Japan

E-mail: e-saeki@suma.kobe-wu.ac.jp

Abstract

In task selection, a verbal cue is interpreted as more meaningful, and thus, it can elicit a faster response than an arbitrary cue. To investigate the effect of verbal cues on activating target task information, we combined an eye-tracking technique with a task-switching paradigm using an arbitrary cue and a type of verbal cue—a word cue with a short cue–target interval (CTI) and long CTI. We measured stimulus-selection time (time to orienting a stimulus) and post-selection response time (time to respond to a stimulus after orienting to the stimulus), and separately examined the differential effect of cue types on these divided response times. Consequently, we found that word cues reduced stimulus-selection time and post-selection response time compared with arbitrary sign cues in both the long and short CTI conditions. The results suggest that verbal cues activate task information more quickly, including a stimulus dimension and stimulus–response rule, than arbitrary cues.

Keywords:

verbal cue; task-set activation; stimulus selection; response execution

Public Significant Statement

Using eye tracking, this study suggests that verbal cues can accelerate the detection of a target and execution of a correct response. People can follow verbal instructions efficiently, and this function of verbal cues may support the special human ability of action control.

Verbal Cue and Task-Set Activation

Verbal instructions are omnipresent in daily life. Many of our actions are responses to such instructions. For children, the ability to follow verbal instructions from others enables them to regulate their behavior (Luria, 1961). The importance of verbal instructions can also be observed in psychological laboratories as study designs of psychological experiments are heavily dependent on verbal instructions to participants. Participants can quickly learn how to respond to certain stimuli based on verbal instructions from an experimenter (Rogers & Monsell, 1995). Furthermore, recent studies in task-instruction learning have revealed that people can rapidly form a task set that allows them to identify an appropriate action in a situation based on verbal instructions alone without performing the task (e.g., Liefooghe et al., 2012, 2013; Meiran et al., 2014). This finding indicates that people can immediately link verbal instructions with actual actions possibly by efficiently recruiting an appropriate task set. In this study, to specify the impact of verbal instructions on momentary task-set control, we investigate how external verbal cues, which are simplified verbal instructions, influence cognitive processes underlying the selection and execution of a task set.

Previous studies have shown that verbal cues lead to better performance than arbitrary or sign cues that indicate to-be-performed tasks in switching tasks. For example, Arbuthnott and Woodward (2002) required participants to switch between three judgments (odd/even judgments for digits, vowel/consonant judgments for letters, and text/math judgments for symbols) in response to a cue that indicated the task to be performed. When performances between a verbal-cue condition (odd or even, consonant or vowel, and text or math) and an arbitrary shape-cue condition (★, ♫, and ❤) were compared, the verbal-cue condition was associated with shorter reaction times (RTs) and shorter delays in RTs accompanying the switching of the task (i.e., switch cost) than the shape-cue condition. The authors suggested that verbal cues facilitated the activation of the relevant stimulus characteristics or promoted response selection, leading to shorter RTs and switch costs.

Additionally, Miyake et al. (2004) reported the effect of verbal cues on task-set control in task-switching situations. In their study, participants were required to judge the shape (circle or triangle) or color (red or green) of a color patch superimposed on a shape. Participants were provided two types of cues: word cues, which explicitly indicated the required task's name (COLOR or SHAPE), and letter cues, which consisted of the first letters of the tasks' names (C or S). The researchers hypothesized that although the letter cues had some degree of association with the task, the word cues would have a stronger association with the task compared to the letter cues. Their results showed that switch costs tended to be less in the word-cue condition than in the letter-cue condition. This indicates that the difference in cue type, though subtle, affected task selection. Miyake et al. (2004) assumed that the two types of cues differed in the degree to which they automatically activated task-goal information. Explicit word cues can directly and rapidly activate task-goal information and can automatically direct the participant's attention toward a relevant stimulus dimension.

Saeki and Saito (2012) showed that verbal cues have a beneficial effect on task-set control without switching a task. They used Japanese kanji characters that represented the task requirement as a word cue and set two cues per task (e.g., both 色 and 彩 indicate "color"). When comparing word cues (i.e., Japanese kanji) with meaningless arbitrary sign cues, word cues resulted in faster responses, even in a condition of cue changes without task switching. This indicates that verbal cues also influence task-set selection processes apart from task switching (see also Logan & Bundesen, 2003; Mayr & Kliegl, 2003; Monsell & Mizon, 2006).

Nevertheless, the processes involved in executing a target task remain undetermined, although it is known that a verbal cue can accelerate them. To generate a response to an external cue, participants must decode and activate a task goal from the cue, direct their attention to a relevant stimulus attribute, and execute a response corresponding to the stimulus–response (S–R) mapping rule. Changes at any of these stages could potentially lead to changes in RTs. Hence, it is difficult to determine the factor leading to the beneficial effects of verbal cues. The aim of this study is to specify which processes are facilitated by a verbal cue using an eye-tracking technique.

Therefore, we employed an experimental paradigm almost identical to the one used by Mayr et al. (2013), which successfully captured the process of orienting to a task-relevant stimulus guided by a task cue (for the comparable task design used in the current study, see Figure 1).

Mayr et al. (2013) devised the experimental task to separate task-relevant objects across different stimuli on the screen to capture attending to the task-relevant object. In their procedure, participants were presented with three vertical bars whose positions formed an equilateral triangle and were required to identify a deviant color (dark blue or light blue) or the location of a gap (upside or downside) on only one bar in each trial according to a word cue (gap, color, space, and hue) presented before the trial. To perform either task, participants were required to attend to a task-relevant bar and apply the relevant S–R rules to the bar. Mayr et al. reported that the orientation to task-relevant bars was slower and less frequent in switch trials than in repetition trials. Therefore, their task captures the difference between switch and repetition trials when directing one's attention to a relevant stimulus. Moreover, the RT difference between the switch and repetition trials decreased as the preparation time before stimulus presentation increased and as the proportion of switch trials increased. This suggested that higher and strategic control is involved in the orientation to a target object in this task.

We used this experimental procedure and manipulated the type of task cue to reveal which processes are facilitated by a verbal cue (the processes of directing one's attention to a relevant stimulus or the processes of executing an S–R rule after attending to a relevant stimulus). Verbal cues in these experiments involved Japanese kanji characters, which are known to be logographic and directly associated with word meanings (e.g., the semantic coding of kanji characters is faster than that of phonological letters; Goryo, 1987). Therefore, this study extends one aspect of the flexible task-set control reported by Mayr et al. (2013) through the strong manipulation of the cue type. We measured the time spent before looking at a relevant stimulus as an index of stimulus-selection time and estimated the time taken to execute a manual response after orienting to the stimulus as an index of post-selection response time. This was calculated by subtracting stimulus-selection times from manual RTs.

Verbal labels (e.g., object names) improve the ability to attend to the named object in a visual search task (e.g., Lupyan & Spivey, 2008, 2010). Therefore, the beneficial effect of verbal cues may stem from accelerating the orientation to a relevant stimulus attribute. However, there is a difference between a visual search task and task switching: verbal labels in a visual search task facilitate target detection in a situation where participants are aware of the task (e.g., Lupyan & Spivey, 2008, 2010), whereas verbal cues in a task-switching paradigm indicate the identity of the task. Hence, the process of directing participants' attention to the task-related stimulus in a task-switching paradigm might differ from the process that operates in a visual search task. However, we assume that the first saccade to the task-related stimulus can reflect a sort of visual search components, which may be facilitated by verbal cues. Alternatively, the beneficial effect may emerge at a response phase by facilitating the response selection processes. This assumption is based on the findings that verbal instructions can rapidly and automatically form a task set (Cole et al., 2013; Liefooghe et al., 2013, 2012; Meiran et al., 2014). This indicates that it facilitates both orienting relevant stimulus attributes and executing a response after orientation.

There are several possibilities as to what may be included in the post-selection response time because the start of the selection or preparation of a response is debatable. Participants attend to a relevant stimulus, encode the stimulus, and then select and execute a response linked to the stimulus in an S–R rule. Some models have adopted this assumption, including Sohn and Anderson's model (2001), which assumes that response selection does not begin until a cue and target have been encoded. In the compound cue retrieval model (Schneider & Logan, 2005, 2009), a cue and target are used as joint retrieval cues to select a response. If the target has not been encoded, response selection does not occur. Schneider and Logan (2014) indicated the possibility that response selection occurs before the stimulus is encoded, modifying the assumption in their previous model that response selection was inactive until stimulus encoding. Moreover, given that decoding a cue can produce a task set (Meiran, 2000), it is likely that stimulus- and response-related components in the task-set are processed in parallel to an extent after cue presentation.

Therefore, all processes for response execution might not be necessary to be reflected in post-selection response time (time to respond to a stimulus after orienting to the stimulus). However, identifying a target is required to execute a correct response, and it is still possible to assume that the essential elements of response-related components, namely, response execution from response selection after identifying a target, are included in the post-selection response times. If a verbal cue leads to rapid and automatic activation of task-goal information, including a relevant stimulus dimension and an S–R rule, then the stimulus-selection time and post-selection response time should be shorter when a verbal cue is presented than when an arbitrary cue is presented. To examine the effect of verbal cues on orienting to a relevant stimulus and executing a response after stimulus selection, we compared stimulus-selection times and post-selection response times between experimental conditions in which kanji (word) cues were used and conditions in which arbitrary sign cues (i.e., #, %, $, and ※) were used.

Additionally, we manipulated the interval between the task cue and target stimulus (cue–target interval: CTI). It is well known that participants respond faster in a long CTI condition than in a short CTI condition. This is because in the former, participants can endogenously activate the upcoming task information before stimulus onset (e.g., Mayr & Kliegl, 2000; Meiran, 2000; Rogers & Monsell, 1995; Rubinstein et al., 2001). Mayr et al. (2013) showed that in conditions where the switch frequency was below 50%, the delay of the orientation to a target object in the switch trial was eliminated when a CTI was long. This suggests that participants could prepare for the next trial. Given that a word cue can activate task information faster than an arbitrary cue, the differences in the activation speed of the task information between the two cue types were expected to be most readily apparent with a short CTI. Therefore, if a long CTI provides an opportunity to activate task information before an upcoming stimulus presentation, this additional preparation time may compensate for the delay in the activation of the task information induced by an arbitrary cue.

However, there is some controversy as to whether participants can prepare all of the task information that is required to execute a response in the allotted preparation time. Some researchers have assumed that participants can activate all of this task information, including the relevant stimulus dimension and response information, during the preparation time (e.g., De Jong, 2000; Lien et al., 2005). If participants can activate all of the task information from an arbitrary cue before an upcoming stimulus presentation when a long CTI is used, then stimulus and response settings could be facilitated by the long preparation time to the same extent as those in the word-cue condition.

Other previous studies have suggested that an arbitrary sign cue cannot sufficiently activate an S–R rule before an upcoming stimulus presentation. For example, Mayr and Kliegl (2000) showed that an arbitrary spatial cue could not eliminate the retrieval demands of a task rule during preparation time whereas a cue that explicitly informed an S–R rule could. If arbitrary cues initiate limited preparation processes and are unable to activate the S–R rule information to the same extent as word cues, we would expect to observe longer post-selection response times when arbitrary cues with long CTIs are used than when word cues are used.

The short CTI was set to 300 ms and the long CTI was set to 1,000 ms because 800 ms CTI is sufficient to be observed asymptote of RTs (Monsell & Mizon, 2006). To examine whether verbal cues can facilitate stimulus-selection times and/or post-selection response times compared with arbitrary sign cues and whether the long preparation time can compensate for the delay of activation by arbitrary cues, we required participants to switch between color and gap tasks according to word cues and arbitrary cues with the short CTI and long CTI conditions.

Method

Participants

Thirty-two students (12 females and 20 males; aged between 18 and 28 years) from Kyoto University participated in this study in exchange for monetary compensation. This sample size achieves 80% power to detect a medium-sized interaction between cue type, CTI, and trial type when we set $\alpha = .05$. However, we failed to measure the eye positions of eight participants likely because they were wearing glasses. Consequently, we collected RT data and eye position data from 24 participants. They engaged in all four conditions: word short CTI, word long CTI, arbitrary short CTI, and arbitrary long CTI.

Apparatus, stimuli, and task

Bilateral eye movements were recorded using a Tobii T60 Eye Tracker (Tobii Technology AB) with a data-sampling rate of 60 Hz. The eye tracker was integrated into a 17-in monitor (1,280 × 1,024 pixels) that was used to present stimuli through a ThinkPad X200s laptop running E-prime Extensions for the Tobii Eye Tracker (Psychology Software Tools, Inc.).

Figure 1 shows a schematic of the sequence of events. The cues were 1.4° high and 1.4° wide and were presented at the center of the monitor. The stimuli were vertically oriented small bars, each 1.7° high and 0.34° wide. In each trial, three bars were simultaneously presented in 3 of 12 possible positions on a virtual circle (radius = 138 pixels or 3.5°) centered in the middle of the monitor. In each trial, the positions of the three bars always formed an equilateral triangle. Therefore, there were four possible patterns of bar positions. Although the four patterns of the equilateral triangles were presented at equal rates in each block of trials, the triangle arrangement was changed from one trial to the next, and the positions of the three types of bars were randomized. Thus, the position of the target bar was unpredictable and never successively repeated.

In each triangle composed of three bars, one bar differed in color (light blue or dark blue) from the other two bars. Additionally, of the two bars that had the same color, one had a small gap near either its top or bottom. The bar that had no gap and had the same color as the bar with the gap (light blue or dark blue) was the neutral stimulus, which never served as a target stimulus. The bar with the deviant color served as the target stimulus for the color task, and the bar with the gap served as the target stimulus for the gap task. The task-irrelevant bar (i.e., the bar with the deviant color in the gap task or the bar with the gap in the color task) was a distractor stimulus that had to be ignored.

In the color task, participants judged whether the color was light blue or dark blue by pressing the *O* (light blue) or *P* (dark blue) keys with the index or middle finger of the right hand. In the gap task, participants judged whether the gap was located toward the top or bottom by pressing the *W* (top) or *E* (bottom) keys with the middle or index finger of the left hand.

For the analysis of eye positions, three different areas of interest (AOIs) were defined, which corresponded to the target, distractor, and neutral stimulus. Each AOI was a 1.7° square around the center of each bar on the screen. Eye tracking in each trial started at the time of stimulus presentation. The duration from the first saccade to localization in any one of the three AOIs was recorded for analysis.

Procedure

Participants were seated 60 cm away from the eye tracker and were then instructed on the two tasks and meaning of the cues. In the word-cue conditions, the Japanese kanji 色 and 彩 (both meaning "color") were cues for the color task and 間 and 切 (both meaning "gap") were cues for the gap task. In the arbitrary sign-cue conditions, the symbols % and # were cues for the color task and $ and ※ were cues for the gap task. To facilitate cue encoding regardless of trial type and to eliminate cue-repetition effects (Logan & Bundesen, 2004), the cue was always changed, even in task-repetition trials. The word and arbitrary cues were alternated between blocks of trials. CTI length (300 or 1,000 ms) was manipulated within each block of 48 trials with the switch-to-repetition ratio set to 1:2 to prevent excessive expectations regarding task switching (see Mayr et al., 2013). The long and short CTIs were counterbalanced between the switch and repetition trials. This resulted in 8 switch trials and 16 repetition trials with short CTIs and the same number of trials with long CTIs within a block. The long and short CTIs occurred in a random order within each block.

In each trial (see Figure 1), a fixation cross (+) was presented for 1,000 ms, followed by a cue. The cue was presented for 200 ms and was followed by a blank screen that remained blank for either 100 ms (short CTI) or 800 ms (long CTI) before the stimuli appeared. The stimuli remained until a response was made, and the next trial was initiated following the response. Therefore, the interval between the onset of cue presentation and onset of stimulus presentation was either a short (300 ms) CTI or a long (1,000 ms) CTI. The response–stimulus interval was 2,100 ms in all three conditions. The same timing settings were used in the practice and test blocks. In the practice block, when a participant made an error, feedback was displayed for 1,500 ms. Feedback was not provided in the test blocks.

Participants started with practice trials. For each cue type, there was a single-task block of 24 trials for each task and one mixed-task block of 48 trials. In the single-task blocks, participants were required to learn the meaning of each cue as well as the S–R rules. Half of the participants started with a word-cue block, and the other half started with an arbitrary cue block. Participants practiced single-task blocks using their first type of cue before moving on to the blocks using the other type of cue and then completed a mixed-task block.

Following a practice period, participants performed 10 mixed-task blocks for the word-cue condition and 10 blocks for the arbitrary-cue conditions, alternating between cue types. Half of the participants started with a word-cue block, and the other half started with an arbitrary cue block. In each block, the CTI length (300 or 1,000 ms) counterbalanced between the switch and repetition trials and randomly changed in each trial type. In total, participants performed 960 trials: 80 short CTI switch trials, 80 long CTI switch trials, 160 short CTI repletion trials, and 160 long CTI repetition trials in each cue condition.

Before the first test block began, an automatic five-point eye-tracking calibration was performed. Subsequently, a recalibration was performed after every five blocks. The experiment took approximately 90 min, and the participants could take a short break after performing each block if necessary.

Results

The data from 3 of the 24 participants were excluded from the analysis because 2 participants had much longer RTs (above 3 SD) than the other participants in certain blocks, and one participant had an error rate above 20% for all trials. The first trial in each block and first trial following an error were excluded from the analysis. RTs greater than ±3 SD from the mean for each participant and for each trial type (4.1%) were eliminated from the analysis, as were RTs from error trials.

For each dependent variable, we performed a 2 (cue type) × 2 (CTI) × 2 (trial type) repeated measures analysis of variance (ANOVA). The data from the color and gap tasks were integrated for simplicity.[1] When including the task factor in the analyses, the important patterns of the results were not changed. The effect sizes for ANOVAs were given as generalized eta squared (η^2_G; Olejnik & Algina, 2003). The results from the ANOVAs are presented as tables in the Appendix, and statistics for post-hoc tests are reported in the text.

RTs and accuracy

Before analyzing the eye-movement data, we analyzed the data in a standard way, that is, irrespective of the AOI status. The left side of Table 1 shows RTs (standard RTs) and error rates for each condition. The results from ANOVAs for RTs and error rates are summarized in Appendix 1. We observed task-switch costs and the significant interaction cue type and trial type in the standard RTs. Switch costs were smaller in the word-cue condition than in the arbitrary-cue condition. The beneficial effect of word

[1] The data from each task were reported in supplementary tables.

cues was observed in both repetition trials, t (20) = 7.65, $p < .001$, and switch trials, t (20) = 3.62, $p = .001$. Additionally, cue type interacted with CTI, and the beneficial effect of word cues was more pronounced in the short CTI condition, t (20) = 7.65, $p < .001$, than in the long CTI condition, t (20) = 3.62, $p < .001$. The trial type interacted with CTI and switch costs were reduced in the long CTIs. A three-way interaction was not significant.

The ANOVA for error rates showed a significant interaction between all three factors. To examine the effect of cue type in short CTI and long CTI conditions, a cue type × trial type ANOVA was conducted on error rate from each CTI. In the short CTIs, the interaction between cue type and trial type was significant, F (1, 20) = 12.67, $p = .002$, $\eta_G^2 = .038$, and the effect of cue type was significant in switch trials, t (20) = 4.87, $p < .001$, but not in repetition trials, t (20) = 0.39, $p = .77$. In the long CTIs, the main effect of cue type, F (1, 20) = 0.64, $p = .043$, $\eta_G^2 = .003$, and the interaction between cue type and trial type, F (1, 20) = 0.036, $p = .85$, $\eta_G^2 < .001$, were not significant.

To examine the effect of CTI in verbal-cue and arbitrary-cue conditions, a CTI × trial type ANOVA was conducted on error rates from each cue type. In the word-cue condition, the effect of trial type was modulated by the length of the CTI, F (1, 20) = 5.65, $MSE = 3.47$, $p = .028$, $\eta_G^2 = .018$. Switch costs were observed in the long CTI, t

(20) = 3.95, p = .001, but not in the short CTI, t (20) = 0.98, p. = .33. Error rates did not show significant difference between the short and long conditions in repetition trials, t (20) = 1.00, p = .32, and in switch trials, t (20) = 1.67, p = .11. In the arbitrary-cue conditions, the simple main effects of trial, F (1, 20) = 29.56, MSE = 15.27, p < .001, η_G^2 = .059, and CSI, F (1, 20) = 8.88, MSE = 9.25, p = .007, η_G^2 = .018, were significant. The interaction between CTI and trial type was marginally significant, F (1, 20) = 4.31, MSE = 4.14, p = .051, η_G^2 = .014. and the error rates in the long CTIs tended to be lower than those in the short CTIs.

The results of RTs showed the beneficial effect of verbal cues in the short and long CTI conditions. Regarding error rates, verbal-cue effects were observed only in switch trials with the short CTI. In the long CTI condition, there was no significant difference between verbal cues and arbitrary cues. In the verbal-cue condition, the number of errors increased in switch trials with long CTIs, although there was no significant difference between the short CTI and long CTI conditions. Therefore, the preparation effects on RT switch cost were observed in both types of cues. However, in the word-cue condition, a speed–accuracy tradeoff may occur.

AOI proportion

We categorized each trial into target AOI, nontarget AOI, or outside of AOI based on the position of the first saccade. Target AOI indicates the area around the target bar, whereas nontarget AOI indicates the area around either the distractor or the neutral bar. Outside of AOI indicates a failure to record the eye position in either of these AOIs through a trial. Appendix 2 shows the percentage of each AOI. Error rates are higher in trials where the first saccade deviated from the target. However, errors also occurred in the target AOIs where the first saccade correctly oriented to the target.

To investigate whether cue type and CTI affected the gaze direction to the target AOI, we calculated the percentages of the target AOI and nontarget AOI trials. We were able to measure eye positions in both (see Table 2). The trials of outside of AOI were excluded in the calculation because the direction of the gaze was not identified.

A cue type × CTI × trial type ANOVA was conducted on this proportion measure (see Appendix 3). The ANOVA indicated a main effect of cue type and trial type. Verbal cues increased the frequency of first seeing the target compared to arbitrary cues. The interaction between cue type and trial type was marginally significant and the beneficial effect of verbal cue tended to be more pronounced in switch trials, t (20) = 3.34, p = .001, than in repetition trials, t (20) = 1.80, p = .04.

RTs in target and nontarget AOIs

To examine whether the initial orientation to a stimulus modulated RTs and whether the effect of cue type depended on the initial gaze direction, we analyzed RTs from trials in which the first orientation entered the AOI of a target stimulus (target AOI trials) and trials in which the first orientation entered the AOIs of a distractor or neutral stimulus (nontarget AOI trials). Trials that were excluded from the analysis of standard RTs were not used in the RT analysis. Outside of AOI trials were also excluded from this analysis[2].

The RT data (see Table 3) were submitted to a 2 (AOI) × 2 (cue type) × 2 (CTI) × 2 (trial type) repeated measures ANOVA. The results are summarized in Appendix 4. Initial eye movements toward the target stimulus generally resulted in faster responses regardless of cue type and CTI length, all *p*s < .01. Cue type interacted with AOI, CTI, and trial type factors. Word cues led to faster RTs than arbitrary cues regardless of AOI, trial type, and CTI length, all *p*s < .001 and the beneficial effect of verbal cue on RT was not limited to the target AOI. Switch costs were smaller in the word-cue condition than in the arbitrary-cue condition. The interaction between trial type and CTI was not significant in this analysis.

---

[2] To ensure that the RTs outside of AOI trials had a similar trend to that in the target and nontarget AOI trials, we conducted a 2 (cue type) × 2 (CTI) × 2 (trial type) ANOVA on RTs outside of AOI trials. The ANOVA showed significant main effects of cue type, F (1, 20) = 17.86, MSE = 5678.48, $p < .001$, $\eta^2_G = .006$, and the cue type interacted with the CTI F (1, 20) = 18.16, MSE = 1835.74, $p < .001$, $\eta^2_G = .002$,. However, in both CTI conditions, the verbal cues facilitated faster responses than arbitrary cues. RTs outside of AOI trials had a similar pattern to that observed in the AOI trials.

Stimulus-selection times and post-selection response times in target AOIs

Finally, we examined whether cue types affected the speed of orienting to the target and executing a response after selecting the target. The analysis of stimulus-selection times (i.e., the time between the presentation of the stimulus and reaching the first orientation to AOI) and post-selection response times (i.e., the time between stimulus selection and response execution) was limited to data from the target AOI trials. Nontarget AOI trials in which the initial eye movement deviated from the target AOI should take variable times to select a target bar after the initial eye movement. Therefore, stimulus-selection times and post-selection response times from nontarget AOI trials might potentially be affected by unknown factors other than target cognitive processes.[3]

We first reported the analysis of stimulus-selection time (from stimulus presentation to orientation to the target bar), followed by that of the selection response time (from orientation to the target bar to the manual response). Subsequently, we examined the effect of practice by separately analyzing the first and second halves of the 20 test blocks.

The stimulus-selection times (the left panel of Figure 2) were submitted to a 2 (cue

[3] Stimulus-selection times and post-selection response times in nontarget AOI were reported in Supplementary Table 8. Stimulus-selection times in nontarget AOI mean the time of the first orientation to a distractor or neutral stimuli.

type) × 2 (CTI) × 2 (trial type) repeated measures ANOVA[4] (see the left side of Appendix 5). The results showed that the stimulus-selection times in word cues were faster than those in arbitrary cues. Additionally, the interaction between cue type and CTI was significant and the effects of cue type were attenuated in the long CTI, t (20) = 2.16, p = .04, compared with the short CTI, t (20) = 5.37, p < .001. The effects of CTI were observed in verbal cues, t (20) = 3.78, p = .001, and in arbitrary cues, t (20) = 4.99, p < .001, but CTI did not interact with trial type.

On post-selection response times[5] (the right panel of Figure 2), word cues resulted in faster times than arbitrary cues (see the right side of Appendix 5). The interaction between cue type and CTI was significant. The effects of cue type were observed in both short CTIs, t (20) = 5.40, p < .001, and long CTIs, t (20) = 2.56, p = .018. This interaction reflected that the beneficial effects of long CTIs were observed in the arbitrary cue blocks, t (20) = 4.07, p = .001, and the effect was not significant in the word-cue blocks, t (20) = 0.266, p = .79. This suggests that word cues can highly activate response-related processes even in the short CTIs.

The analysis of the target AOI data clearly shows verbal-cue effects on stimulus-

---

[4] Including an AOI factor in ANOVA (AOI × cue type × CTI × trial type) for stimulus-selection times, the main effects of AOI was significant, F (1, 20) = 99.05, MSE = 3383.30, p < .001, η^2_G = .096. Stimulus-selection times in nontarget AOI were faster than those in target AOI.

[5] Including an AOI factor in ANOVA (AOI × cue type × CTI × trial type) for post-selection-response times, the main effect of AOI was significant, F (1, 20) = 130.840, MSE = 9493.83, p < .001, η^2_G = .225. As shown in the analysis of AOI RT, post-selection response times were faster in the target AOI than in the nontarget AOI.

selection times and post-selection response times in both CTI conditions. Considering that practice typically leads to a reduction of RTs, it is likely that practice influenced the effect of cue type and CTI. In particular, arbitrary cues should have weak associations with a task requirement at the beginning of the experiment. However, with practice, the association between the arbitrary cue and task requirement should strengthen. Consequently, arbitrary cues may be able to activate task information as quickly as verbal cues. In this experiment, participants performed 20 blocks, including 10 blocks for each cue type. Therefore, it was possible to investigate the practice effects. Although this analysis is post-hoc and exploratory, it is worth examining the influence of the practice effect considering the nature of the arbitrary cues.[6] Subsequently, we divided the data into the first and second halves of each session and compared the two halves (see Table 4).

The results from the first half-sessions showed a pattern similar to that of the overall results from all 20 blocks (see the left side of Appendix 6): the beneficial effects of word cues were consistently observed in stimulus-selection time and post-selection response time. For post-selection response time, CTI had a beneficial effect only in the arbitrary-cue condition, t (20) = 3.90, p = .001, but not in the word-cue condition, t (20)

[6] To ensure the quality of the data over time, we compared error rates observed in the first and second half sessions. There were no significant main effects of session in the word-cue condition, t (20) = 0.18, p = .85, and in the arbitrary-cue condition, t (20) = 0.28, p = .77.

= 0.69, p = .493. This indicates that in the word-cue condition, participants made fast responses to a target from a relatively early stage in the experiment.

The results from the second half sessions (see the right side of Appendix 6) showed that the beneficial effects of verbal cues on performance decreased or disappeared in the long CTI condition, and the effect of long CTI decreased or disappeared in the word-cue condition. Regarding stimulus-selection times, the effects of cue type were present in the short CTI condition, t (20) = 5.13, p < .001, but disappeared in the long CTI condition, t (20) = 1.20, p = .24. Regarding post-selection response times, the cue-type effects were observed in the short CTI condition, t (20) = 7.24, p < .001, but not in the long CTI condition, t (20) = 1.36, p = .188. Therefore, the results from the latter half sessions suggest that with practice, participants can respond at the same speed in both the arbitrary-cue condition and word-cue condition.

However, the analysis of the practice effect is post-hoc, and the number of observations was reduced after dividing the data into two parts. Consequently, if observations were available, we might have found the effect of cue type in the second half session. Therefore, these analyses require cautious interpretation.

General Discussion

Verbal information can help people quickly decide how to respond to a given situation. To investigate how a verbal prompt facilitates the selection and execution of a task, participants were required to perform one of two tasks on each trial in response to either relevant word cues or arbitrary sign cues in short or long CTI conditions and examined the cue-type effect on stimulus-selection and post-selection response times using an eye-tracking technique.

The results of the experiment showed the benefit of verbal cues on standard RT in the long and short CTI conditions, although the effects on error rates were observed only in switch trials in the short CTI condition. Stimulus-selection times and post-selection response times were faster when word cues were used than when arbitrary cues were used in both short and long CTI conditions. Moreover, the frequency of the first saccade correctly oriented to the target was higher in the word cue than in arbitrary cue. Therefore, it appears that verbal cues enable more rapid activation of a task set than arbitrary cues.

However, when the influence of practice was considered, the results of CTI manipulation on verbal-cue effects changed from the first to the second half: the beneficial verbal-cue effect on stimulus-selection time and post-selection response time diminished or disappeared under long CTIs in the latter half. Therefore, when participants are allowed time to practice the tasks and time to activate the next task set, they can select the relevant stimulus, activate the appropriate S–R rule, and execute the required response as quickly when using both arbitrary sign cues and word cues.

Importantly, there was a clear verbal effect in the short CTI condition even in the second half of the experiment; that is, the word cue shortened the stimulus-selection time and post-selection response time in the short CTI condition. Although the combination of practice and long CTI could compensate for the performance delay associated with the arbitrary cue, it was not the case that after extensive practice performance in response to an arbitrary sign cue was equivalent to that in response to a word cue.

Regarding retrieval from an arbitrary cue versus one that is meaningful and relevant to the task, the mediated retrieval hypothesis (Logan & Schneider, 2006) assumes that arbitrary and meaningful cues share a common retrieval pathway. An arbitrary cue requires the retrieval of a mediator or meaningful cue (e.g., task name) that is directly associated with the task goal. It is the ability to skip a step that yields the benefit of a word cue. This hypothesis also assumes that with practice, participants abandon the use of this mediator and directly retrieve the association between the arbitrary cue and task goal. Although our study did not address this hypothesis, the fact that the beneficial effect of verbal cues was still observed after practice in the short CTI condition suggests that the association between a verbal cue and task goal differs from (or is at least much stronger than) the association between an arbitrary cue and a task goal at least in our experimental setting. Therefore, the task-goal information acquired by decoding a word cue differs from the internally generated task-goal information that is triggered by an arbitrary cue. However, significant experience using an arbitrary cue as a task cue might make it behave like a verbal cue.

As shown in studies of instructed rapid learning (Cole et al., 2013; Liefooghe et al., 2013, 2012; Meiran et al., 2015), verbal information is expected to be strongly associated with task semantics, including response representations and rapidly activated task goals. This leads to a fast response at a markedly early stage of the experiment despite short preparation time. In particular, the use of kanji characters as a verbal cue in our study may have influenced the beneficial effect of verbal cues in the short CTI condition. The dual-route model of reading assumes that the meaning of written words is activated via a phonologically mediated route and by nonphonologically mediated or direct access (e.g., Coltheart et al., 2001). Reading kanji enables more direct access to meaning than phonologically mediated access (Shibahara et al., 2003). Thus, kanji cues may enable participants to quickly activate a task goal, including response representation, despite short preparation time.

However, verbal cues were unable to eliminate the difference between repetition trials and switch trials. An observed switch cost in the word-cue condition indicated the existence of specific processes for task switching beyond cue switching even in the word-cue condition. The effect of switch costs on stimulus-selection times suggested that the difference between the repetition trials and switch trials occurred during the decoding of the task cue before the first eye movement toward the target (Arrington et al., 2007). This implies that switch specific delays (e.g., reactive carryover of previous task parameters; Waszak et al., 2003) could not be overcome with a verbal cue.

One puzzling question about the results in this study is that well-known preparation effects on switch costs were not observed in the target AOI trials. The preparation effect on standard RTs suggests that participants utilized the long CTI to prepare to switch tasks. One possibility is that the analysis of target AOI trials suffered from the lack of power to detect the interaction. We conducted the experiment for 32 participants with 80% expected power to detect a medium-sized interaction between cue type, CTI, and trial type. However, 11 participants were excluded from all analyses because we failed to measure eye movements from some participants and found many errors in others. Additionally, approximately 20% of the trials were excluded from the analysis related to AOIs because eye movements were not recorded in AOI areas (see Appendix 2). The total number of observations in each condition from the remaining 21 participants seemed moderate (above approximately 1,600), which can secure the power according to the recommendation by Brysbaert and Stevens (2018). However, the number of observations in the switch trials on the target AOI, especially in the post-hoc practice analysis, did not meet this criterion. Consequently, removing the data from the analysis might have made the experiment underpowered to detect the interaction between trial type and CTI.

Alternatively, the target AOI RTs reflect performance in the trial with successful activation of the task goal immediately after the cue presentation. Kiesel et al. (2010) reviewed preparation effects in task-switching studies and suggested that preparation effects were not restricted to switch trials but rather that preparation processes also occur in repetition trials. Mayr et al. (2013), who used a nearly identical experimental procedure to our study, showed that the task-set control in switch and repetition trials depended on context (e.g., switch probability) and suggested that preparation processes could occur in repetition trials. Thus, a long CTI could be beneficial in both switch trials and repetition trials. However, the presence of the larger benefit of a long CTI in switch trials than in repetition trials indicates that certain switching-specific processes are sensitive to preparation times. The trials in which the first eye movement successfully entered the target AOI might skip these processes, leading to the absence of the switching-specific benefit of the long CTI. However, this explanation is speculative, and the source of the discrepancy remains unclear.

Additionally, this study has further limitations. If the long CTI had been set to an interval much longer than 1,000 ms in this study, the arbitrary cue might have received a larger benefit. Consequently, the effect of verbal cue use in the long CTI condition might have been attenuated. Furthermore, to examine the response-related processes, we calculated the post-selection response time by subtracting the time to fixate on a stimulus (i.e., stimulus-selection time) from manual RT. Considering that cue decoding produces more abstract task representation, including a response set as discussed in this study, it is possible that some response-related processes begin before target selection. The present experiment was not designed to address such response-related processes that might start before the target presentation. Further research is required to examine the influences of verbal cue on response-related processes in a much wider time frame.

Conclusion

This study provided evidence that verbal cues representing the task name can activate a task goal much faster than arbitrary sign cues and can facilitate stimulus selection and response execution. The verbal-cue effect was attenuated with practice in long preparation time conditions but was consistently present in conditions of short preparation time. A decodable, highly transparent cue or verbal information informs people directly and quickly about what to do and how to do it. This may be a unique process by which we control our actions. This study furthers our understanding of the mechanisms involved in verbal cognitive control, and further studies will shed much needed light on the characteristics of representations endowed by decoding verbal cues.

References

Arbuthnott, K. D., & Woodward, T. S. (2002). The influence of cue-task association and location on switch cost and alternating-switch cost. *Canadian Journal of Experimental Psychology*, *56*(1), 18–29.

Arrington, C. M., Logan, G. D., & Schneider, D. W. (2007) Separating cue encoding from target processing in the explicit task-cuing procedure: Are there "true" task switch effects?, *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *33*(3), 484–502.

Baguley, T. (2012). Calculating and graphing within-subject confidence intervals for ANOVA. *Behavior Research Metohds*, *44*, 158-175.

Brysbaert, M., & Stevens, M. (2018). Power analysis and effect size in mixed effects models: A tutorial. *Journal of Cognition*, *1*(1), 1–20. https://doi.org/10.5334/joc.10

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cadcaded model of visual word recognition and reading aloud. *Psychological Review*, 108, 204-256

Cole, M. W., Laurent, P., & Stocco, A. (2013). Rapid instructed task learning: a new window into the human brain's unique capacity for flexible cognitive control. *Cognitive, Affective & Behavioral Neuroscience*, *13*(1), 1–22.

De Jong. (2000). An intention-activation account of residual switch costs. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 357-376). Cambridge, MA: MIT Press.

Goryo, K. (1987) *Ninchi kagaku sensho 5, Yomu to iu koto* [The Facts about reading, Selected readings in cognitive sciences 5] Tokyo: University of Tokyo Press.

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching-a review. *Psychological Bulletin*, *136*(5), 849–74.

Liefooghe, B., De Houwer, J., & Wenke, D. (2013). Instruction-based response activation depends on task preparation. *Psychonomic Bulletin & Review*, *20*(3), 481–487.

Liefooghe, B., Wenke, D., & De Houwer, J. (2012). Instruction-based task-rule congruency effects. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *38*(5), 1325–1335.

Logan, G. D., & Bundesen, C. (2003). Clever homunculus: Is there an endogenous act of control in the explicit task-cuing procedure? *Journal of Experimental Psychology: Human Perception and Performance*, *29*(3), 575–599.

Logan, G. D., & Bundesen, C. (2004). Very clever homunculus: compound stimulus strategies for the explicit task-cuing procedure. *Psychonomic Bulletin & Review*, *11*(5), 832–840.

Logan, G. D., & Schneider, D. W. (2006). Interpreting instructional cues in task switching procedures: the role of mediator retrieval. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *32*(2), 347–363.

Lupyan, G., & Spivey, M. J. (2008). Perceptual processing is facilitated by ascribing meaning to novel stimuli. *Current Biology, 18 (10)*, 410-412

Lupyan, G., & Spivey, M. J. (2010). Redundant spoken labels facilitate perception of mulltiple items. *Attention, Perception & Psychophysics, 72 (8)*, 2236-2253.

Luria, A. R. (1961) The development of the regulatory role of speech. In J. Tizars (Ed.). *The role of speech in regulation of normal and abnomal behavior*, Pp. 50-96. New York: Liveright.

Mayr, U., & Kliegl, R. (2000). Task-set switching and long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(5), 1124–1140.

Mayr, U., & Kliegl, R. (2003). Differential effects of cue changes and task changes on task-set selection costs. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*(3), 362–372.

Mayr, U., Kuhns, D., & Rieter, M. (2013). Eye movements reveal dynamics of task control. *Journal of Experimental Psychology. General*, *142*(2), 489–509.

Meiran, N. (2000). Reconfiguration of stimulus task sets and response task sets during task switching. In S. Monsell & J. Driver (Eds), *Control of cognitive processes: Attention and performance XVIII*, Pp. 377-399. Cambridge, MA: MIT Press.

Meiran, N., Pereg, M., Kessler, Y., Cole, M. W., & Braver, T. S. (2014). The Power of Instructions: Proactive Configuration of Stimulus – Response Translation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *41*(3), 768–786.

Miyake, A., Emerson, M. J., Padilla, F., & Ahn, J. (2004). Inner speech as a retrieval aid for task goals: the effects of cue type and articulatory suppression in the random task cuing paradigm. *Acta Psychologica*, *115*(2–3), 123–142.

Monsell, S., & Mizon, G. A. (2006). Can the task-cuing paradigm measure an endogenous task-set reconfiguration process? *Journal of Experimental Psychology. Human Perception and Performance*, *32*(3), 493–516.

Olejnik, S., & Algina, J. (2003). Generalized eta squared statistics: Measures of effect size for some cmmon research designs. *Psychological Method, 8 (4)*, 434-447.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*(2), 207–231.

Rubinstein, J. S., Meyer, D. E., & Evans, J. E. (2001). Executive control of cognitive processes in task switching. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(4), 763–797.

Saeki, E., & Saito, S. (2012). Differential effects of articulatory suppression on cue-switch and task-switch trials in random task cueing with 2 : 1 mapping. *The Quarterly Journal of Experimental Psychology*, *65(8)*, 37–41.

Schneider, D. W., & Logan, G. D. (2005). Modeling task switching without switching tasks: a short-term priming account of explicitly cued performance. *Journal of Experimental Psychology. General*, *134*(3), 343–367.

Schneider, D. W., & Logan, G. D. (2009). Selecting a response in task switching: testing a model of compound cue retrieval. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *35*(1), 122–136.

Schneider, D. W., & Logan, G. D. (2014). Modelling response selection in task switching: testing the contingent encoding assumption. *The Quarterly Journal of Experimental Psychology*, *67*(6), 1074–95.

Sohn, Myeong-Ho., & Anderson, J. R. (2001). Task preparation and task repetition:

Two component model of task switching. *Journal of Experimental Psychology General*, *130*(4), 764–778.

Shibahara, N., Zorzi, M., Hill, M,P., Wydell, T., & Butterworth, B. (2003). Semantic effects in word naming; Evidence from English and Japanese Kanji, *The Quarterly Journal of Experimental Psychology*, *56*(2), 263–286.

Waszak, F., Hommel, B., & Allport, A. (2003). Task-switching and long-term priming: Role of episodic stimulus–task bindings in task-shift costs. *Cognitive Psychology*, *46*(4), 361–413.

Table 1.

Mean reaction times and mean error rates as a function of cue type, CTI and trial type

	RT		Error rate	
	Repeat	Switch	Repeat	Switch
Word Short	642 (17)	705 (17)	3.09 (0.54)	3.69 (0.82)
Word Long	595 (16)	650 (13)	2.64 (0.44)	5.17 (1.00)
Arbitrary Short	765 (18)	887 (26)	2.82 (0.48)	7.02 (1.01)
Arbitrary Long	636 (13)	713 (30)	2.35 (0.55)	4.70 (0.89)

Note. Reaction times are expressed in milliseconds. Error rates are expressed in percentage. The numbers in parentheses show Cousineau–Morey 95 % CI adjusted for differences between means by Baguley (2012).

Table 2. Mean proportions of eye movements to target AOI as a function of cue type, CTI and trial type.

	Repeat	Switch
Word Short	69.82 (2.05)	62.81 (2.18)
Word Long	69.29 (2.49)	67.51 (2.19)
Arbitrary Short	67.24 (1.67)	59.70 (2.68)
Arbitrary Long	67.80 (2.09)	61.42 (2.58)

Note. Proportions are represented as a percentage. The numbers in parentheses show Cousineau–Morey 95 % CI adjusted for differences between means by Baguley (2012).

Table 3. Mean reaction times in target AOI and nontarget AOI as a function of cue type, CTI and trial type.

	Target AOI		Nontarget AOI	
	Repeat	Switch	Repeat	Switch
Word Short	672 (17)	728 (19)	706 (19)	783 (23)
Word Long	638 (19)	706 (14)	663 (18)	719 (15)
Arbitrary Short	796 (21)	888 (27)	890 (23)	984 (36)
Arbitrary Long	679 (18)	767 (30)	735 (21)	855 (34)

Note. Reaction times are expressed in milliseconds. The numbers in parentheses show Cousineau–Morey 95 % CI adjusted for differences between means by Baguley (2012).

Table 4. Stimulus-selectin times and post-selection-response times in target AOI as a function of cue type, CTI and trial type in the first half sessions and the second half of sessions.

	Stimulus-selection times		Post-selection-response times	
	Repeat	Switch	Repeat	Switch
		The first-half sessions		
Word Short	436 (16)	474 (16)	274 (35)	291 (35)
Word Long	402 (13)	413 (18)	246 (23)	301 (44)
Arbitrary Short	473 (11)	513 (27)	367 (20)	423 (21)
Arbitrary Long	417 (23)	453 (20)	290 (20)	340 (18)
		The second-half sessions		
Word Short	405 (11)	433 (15)	231 (12)	265 (11)
Word Long	395 (10)	414 (14)	231 (16)	279 (24)
Arbitrary Short	453 (14)	492 (19)	291 (18)	352 (24)
Arbitrary Long	402 (17)	436 (14)	241 (17)	308 (20)

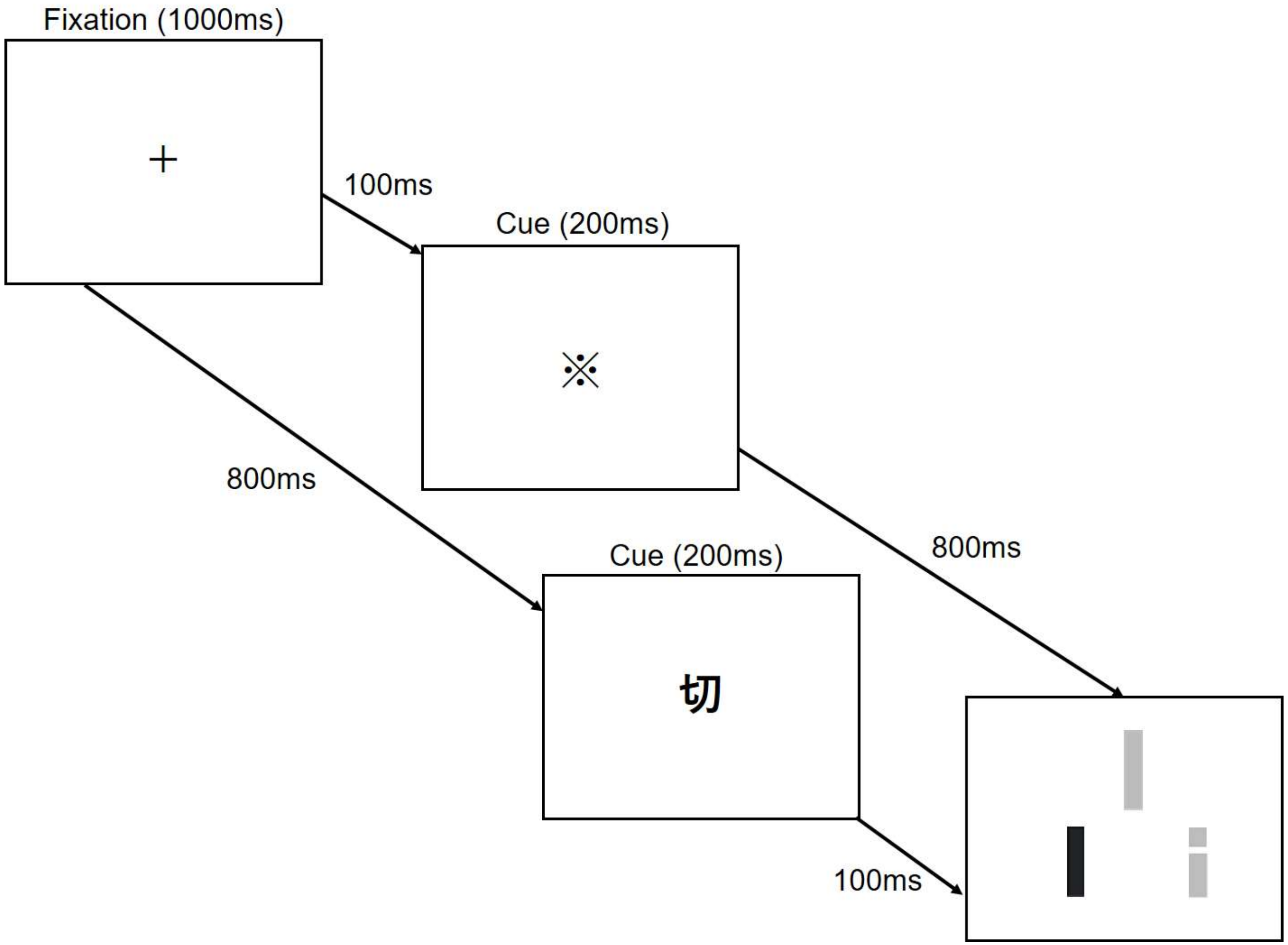
Note. Reaction times are expressed in milliseconds. The numbers in parentheses show Cousineau–Morey 95 % CI adjusted for differences between means by Baguley (2012).

Figure captions

Figure 1. A schematic illustration of the sequence of the events for a single trial that happened in the word cue with short CTI condition (the lower side) and the arbitrary cue with long CTI condition (the upper side). Cues and stimuli were not drawn to scale and stimuli were actually presented in light blue and dark blue.

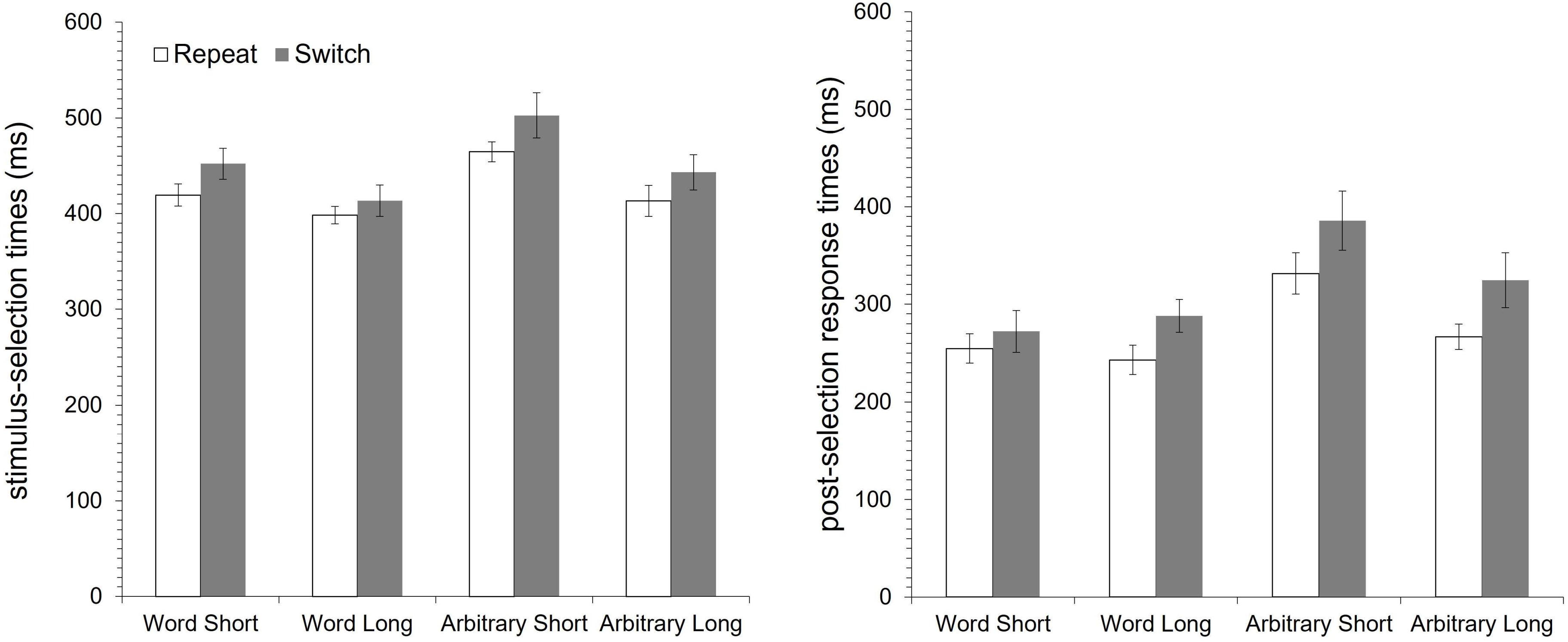
Figure 2. Mean stimulus-selection times and post-selection response times in target AOI as a function of cue type, CTI and trial type in Experiment 2. The left figure shows the stimulus-selection times and the right figure shows the post-selection-response times. The bars represent Cousineau–Morey 95 % CI adjusted for differences between means by Baguley (2012).

Figure 1



Fixation (1000ms)
+
100ms
Cue (200ms)
※
800ms
800ms
Cue (200ms)
切
100ms

Figure 2.



Repeat
Switch
stimulus-selection times (ms)
600
500
400
300
200
100
0
Word Short
Word Long
Arbitrary Short
Arbitrary Long
post-selection response times (ms)
600
500
400
300
200
100
0
Word Short
Word Long
Arbitrary Short
Arbitrary Long

Appendix 1. ANOVA results on mean reaction times and error rates.

		Reaction time				Error rate			
Effect	*dfs*	*F*	*MSE*	*p*	η^2_G	*F*	*MSE*	*p*	η^2_G
Cue type	1, 20	42.07	10389.81	<.001	.122	2.15	6.40	.158	.006
CTI	1, 20	79.40	5421.45	<.001	.120	0.95	8.50	.341	.004
Trial	1, 20	88.22	2967.61	<.001	.077	39.40	6.23	<.001	.096
Cue type × CTI	1, 20	41.35	2552.24	<.001	.032	13.13	2.94	.002	.017
Cue type × Trial type	1, 20	15.34	1384.15	.002	.005	5.05	6.08	.036	.013
CTI × Trial type	1, 20	4.42	1521.15	.035	.002	<0.01	3.73	.941	<.001
Cue type×CTI×Trial type	1, 20	2.70	1341.50	.116	<.001	9.65	3.88	.006	.016

Appendix 2. Percentage of each AOI to all trials as a function of cue-CTI and trial type.

	Target AOI		Nontarget AOI		Outside of AOI	
	Repeat	Switch	Repeat	Switch	Repeat	Switch
Word Short	53.57 (1.90)	52.43 (2.01)	20.89 (3.69)	26.73 (3.74)	25.53 (4.96)	20.83 (6.93)
Word Long	50.99 (1.36)	51.29 (2.60)	21.93 (4.26)	24.02 (9.42)	27.06 (3.90)	24.68 (6.11)
Arbitrary Short	57.43 (1.49)	53.90 (3.90)	24.51 (4.60)	32.73 (7.99)	18.05 (5.40)	13.35 (17.47)
Arbitrary Long	53.71 (1.42)	50.57 (2.23)	22.47 (3.67)	29.61 (7.25)	23.81 (3.73)	19.81 (6.27)

Note. The number in parentheses indicates percentage of errors in each cell as function of AOI, cue-CTI and trial type.

Appendix 3. ANOVA results on AOI proportion.

Effect	*dfs*	*F*	*MSE*	*p*	η^2_G
Cue type	1, 20	10.27	0.004	.004	.034
CTI	1, 20	1.50	0.001	.234	.009
Trial	1, 20	14.76	0.009	.001	.095
Cue type × CTI	1, 20	0.24	0.004	.628	<.001
Cue type × Trial type	1, 20	3.51	0.002	.076	.006
CTI × Trial type	1, 20	2.84	0.004	.107	.008
Cue type×CTI×Trial type	1, 20	1.22	0.004	.282	.004

Appendix 4. ANOVA results on mean reaction times for target AOI and nontarget AOI.

Effect	*dfs*	*F*	*MSE*	*p*	η^2_G
AOI	1, 20	33.47	8376.61	<.001	.029
Cue type	1, 20	46.69	26977.36	<.001	.118
CTI	1, 20	43.78	14100.11	<.001	.061
Trial type	1, 20	52.69	10571.47	<.001	.107
AOI × Cue type	1, 20	16.83	3340.03	<.001	.006
AOI × CTI	1, 20	7.78	1633.25	.011	.001
AOI × Trial type	1, 20	1.19	2089.93	.020	.002
Cue type × CTI	1, 20	17.81	9547.85	<.001	.018
Cue type × Trial type	1, 20	5.31	4605.33	.032	.003
CTI × Trial type	1, 20	0.04	5433.41	.849	<.001
AOI×Cue type×CTI	1, 20	0.01	2013.94	.895	<.001
AOI×Cue type×Trial type	1, 20	0.22	3735.06	.644	<.001
AOI×CTI×Trial type	1, 20	0.01	6840.97	.957	<.001
Cue type×CTI×Trial type	1, 20	0.19	7101.61	.667	<.001
AOI×Cue type×CTI×Trial type	1, 20	1.38	3754.74	.253	<.001

Appendix 5. ANOVA results on stimulus-selection times and post-selection response times for target AOI.

		Stimulus-selection time				Post-selection response time			
Effect	*dfs*	*F*	*MSE*	*p*	η^2_G	*F*	*MSE*	*p*	η^2_G
Cue type	1, 20	19.13	2700.47	<.001	.035	23.58	6997.56	<.001	.103
CTI	1, 20	28.16	2711.33	<.001	.050	9.84	3945.27	.005	.026
Trial type	1, 20	17.56	2000.38	<.001	.024	29.79	2680.13	<.001	.053
Cue type × CTI	1, 20	5.88	1178.88	.025	.005	18.31	2429.22	<.001	.030
Cue type × Trial type	1, 20	1.32	844.34	.263	<.001	3.00	2154.11	.099	.004
CTI × Trial type	1, 20	1.98	923.86	.174	.001	0.87	2936.49	.363	.002
Cue type×CTI×Trial type	1, 20	0.23	934.56	.630	<.001	1.06	1379.14	.314	.001

Appendix 6. ANOVA results on stimulus-selection times and post-selection response times in the first-half and second-half sessions for target AOI.

		Stimulus-selection time				Post-selection response time			
Effect	*dfs*	*F*	*MSE*	*p*	η^2_G	*F*	*MSE*	*p*	η^2_G
					The first-half sessions				
Cue type	1, 20	7.08	6409.64	.015	.021	20.17	12295.74	<.001	.103
CTI	1, 20	33.03	3562.47	<.001	.054	12.68	6628.66	.002	.037
Trial type	1, 20	7.15	5620.51	.015	.019	18.41	4565.48	<.001	.037
Cue type × CTI	1, 20	0.40	2718.88	.530	<.001	9.12	5841.58	.007	.024
Cue type × Trial type	1, 20	0.95	1946.10	.341	<.001	0.79	3663.62	.383	.001
CTI × Trial type	1, 20	1.64	1524.90	.214	.001	0.87	3191.21	.360	.001
Cue type×CTI×Trial type	1, 20	0.52	2707.53	.478	<.001	1.74	2918.61	.202	.002
					The second-half sessions				
Cue type	1, 20	11.89	4055.43	.003	.035	21.97	4138.89	<.001	.056
CTI	1, 20	12.58	3859.44	.002	.035	4.31	3849.57	.051	.011
Trial type	1, 20	21.61	1742.34	<.001	.028	32.08	3656.99	<.001	.071
Cue type × CTI	1, 20	13.43	1198.35	.002	.012	13.05	2429.22	.002	.019
Cue type × Trial type	1, 20	1.41	1406.73	.248	.001	2.27	2273.39	.147	.003
CTI × Trial type	1, 20	0.36	1509.72	.552	<.001	0.17	5597.48	.679	<.001
Cue type×CTI×Trial type	1, 20	0.01	1920.17	.914	<.001	0.09	2483.28	<.001	<.00