Master's Thesis

Factors Modulating Key Press Durations in Choice Response Tasks

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Abstract

The purpose of this study is to explore the significance of response duration (RD) as a measure for understanding human psychological processes and to analyze the factors that modulate it. In Experiment 1, based on previous research results on RD influenced by participants' judgments, we investigated whether the difficulty of perceptual judgment affects RD. The results indicated that, RD clustered according to the attributes of participants judgments only at easy difficulty level. However, this varied significantly depending on the stimulus-response mapping. In Experiment 2, we examined the effect of the semantic attributes of language on response duration. RD was not affected by the semantic attributes of the words. However, similar to Experiment 1, the results varied depending on the stimulus-response mapping. Experiments 3 and 4 were conducted to explore the cause behind the interaction effects observed between the stimulus-key mapping and the stimuli in Experiments 1 and 2. Experiment 3 investigated whether there were functional differences between the right and left hands in the actions of pressing and releasing the keys. The results showed no functional differences. In Experiment 4, we examined the difference in response duration between the dominant and non-dominant hands when performing the same tasks as in Experiments 1 and 2 but using neutral stimuli. For neutral stimuli, there was no difference in response duration, but regardless of the stimulus, response duration was always shorter with the dominant hand. This study suggests that response duration (RD) can be a useful tool in understanding human psychological processes. Furthermore, it identifies the factors that influence RD to enhance its utility. The significance of this research lies in its comprehensive analysis of RD, an area that has not been extensively explored before. By providing new insights, this study lays the foundation for future research in this field.

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Introduction

Traditionally, reaction time (the interval between the onset of a stimulus and the response) has been measured and interpreted to understand cognitive and psychological processes (Teichner, 1954; Van Zandt & Townsend, 2014). Especially in cognitive psychology, reaction time has been conventionally used as a dependent variable in research to investigate various theories. However, there have been discussions about what this processing period means psychologically (Deese, 1969; Pachella, 2021).

These limitations are particularly evident in experiments studying ideomotor theory. Ideomotor theory suggests that our actions are guided by internal cognitive representations rather than external stimuli (Greenwald, 1970; James, 1890; Shin et al., 2010). Studies have tested this theory by manipulating action effects and presenting them as stimuli to measure reaction times (Elsner & Hommel, 2001; Hommel, 1996; Hommel et al., 2001).

However, it is difficult to determine the direct causal relationship between the measured reaction time and the cognitive representations recalled before voluntary actions. Previous research (Shin et al., 2023) explained this by using key press time (Response Duration or RD) as an indicator. They confirmed that categorical attributes of the subjects before their actions modulate the key press duration. Through the modulated response duration, they revealed psychological processes that are difficult to explain with reaction time alone.

Besides previous research, there are studies (Pfister et al., 2023) explaining the significance of response duration as a behavioral and psychological measure, but we still know little about the characteristics of RD. This study aims to explore what factors modulate the response duration.

We aim to investigate how the perceptual category difficulty affects the response duration. Using the same paradigm as in Shin et al. (2023), participants will be presented with six sets of visual-auditory stimuli in random order and will perform a task to judge whether the stimulus duration is short or long. In Experiment 1A, stimulus durations of 85, 100, 115, 135, 150, and 165 ms will be used, while in Experiment 1B, durations of 85, 100, 115, 173, 190, and 207 ms will be employed. Experiment 1A, with shorter intervals between boundary stimuli (115 vs. 135 ms), presents a level where a perceptual judgment of stimulus duration is difficult due to the high sensory similarity between the boundary stimuli. Experiment 1B, with longer intervals between boundary stimuli (115 vs. 173 ms), presents an easier level for perceptual judgment due to lower sensory similarity. We will observe whether the response duration, modulated by the categorical attributes of the participants, differs according to the perceptual judgment difficulty level.

Secondly, we aim to examine how semantic attributes influence the response duration. Categories are concretized through language. Participants will perform a task to choose a response using categorical verbal, specifically the Korean words “짧다” (short) or “길다” (long), as stimuli. We will observe whether the semantic attributes of the language regulate the key-pressing time.

In all experiments, the stimulus-key mapping will be designated as a within-subject factor to observe its interactions with stimulus duration and stimulus type. If an interaction effect between the mapping and the stimulus is observed, we will investigate whether the cause is the difference in response duration between the dominant hand and the non-dominant hand. Through this research, we expect to gain a better understanding of the characteristics of response duration and demonstrate that response duration can serve as a meaningful measurement variable for analyzing psychological processes.

Experiment 1

Method

Participants

Forty students from the Ulsan National Institute of Science and Technology participated in Experiment 1. Equal numbers were assigned at random to either Experiment 1A or Experiment 1B. The sample size was determined considering the effect-size estimations from previous studies (e.g., $n_p{}^2 = SS_{effect} / (SS_{effect} + SS_{error})$ = 0.389 for the effect on Experiment 1B in Shin et al., 2023). This research was authorized by the Institutional Review Board of Ulsan National Institute of Science and Technology (UNISTIRB-23-007-A). All methods were applied equitably and in compliance with the guidelines. In the analysis, two participants from Experiment A and one from Experiment 1B were omitted due to their left-handedness.

Apparatus and Stimuli

MATLAB and the Psychophysics Toolbox (Pelli, 1997) were utilized to produce the stimuli on a 23.6-inch monitor with Mac Pro (Late 2013) (Apple, Cupertino, CA, USA). The target stimulus was provided the same as in the study by (Shin et al., 2023)It consisted of 1 kHz pure tone and a dark gray square (2.3 cm x 2.3 cm). The target stimulus is represented by the center of the screen. In Experiment 1A, this target stimulus presentation lasted 85, 100, 115, 135, 150, or 165 ms; in Experiment 1B, it lasted 85, 100, 115, 173, 190, or 207 ms. The first three target stimuli are considered short stimuli, and the remaining three stimuli are considered long stimuli. For example, in experiment 1A 85, 100, and 115 ms are short stimuli, and others, 135, 150, and 165 ms, are long stimuli. The interval between the short and long stimulus boundary (between the 115 and 135 stimuli) used in Experiment 1A was 20 ms. The sensory similarity between the two boundary stimuli was high. In contrast, in Experiment 1B, the interval between the boundary stimuli was longer at 58ms (between 115ms and 173ms), and the sensory similarity was lower. Therefore, we assumed that the perceptual judgment difficulty would be higher in Experiment 1A, where the sensory similarity between the boundary stimuli was high, and easier in Experiment 1B, where the sensory similarity was low.

Procedure

The task of the participants was to judge the duration of six target stimuli, whether they were long or short, by pressing the "Z" or "/" key with their left or right index finger. The instruction was given to participants to respond as accurately and quickly as possible when the stimulus ended. Participants were not informed that six different stimulus durations were provided, or that the key pressing time was recorded. All participants performed two mappings between the duration of the stimulus and the correct key on separate days. After the instruction, participants input their sex, age, and dominant hand. When participants press any key, trials begin, and the fixation point is displayed for 200 ms. A target stimulus was presented after a blank screen for 500 ms. The target stimulus length showed random variations from trial to trial. After an inter-trial interval (ITI) of 1000 ms, the trial started with the presentation of a fixed point. If the participant pressed the correct key, a 1 kHz pure tone was presented for the duration of the key press (Figure 1). Participants received visual feedback if they pressed the response key too early before the stimulus disappeared or if their response was incorrect. The visual feedback message (“Too early!” or "Error!") was displayed in the center of the screen for 700 ms. There are four familiarization trials per duration (a total of 24 trials), after which three blocks of twelve trials per duration (a total of 216 trials) were conducted in both Experiments 1A and 1B. Therefore, since participants performed the experiment on two separate days with different key mappings, each participant performed a total of 432 trials. Only correct trials from right-handed participants were used for the data analysis.

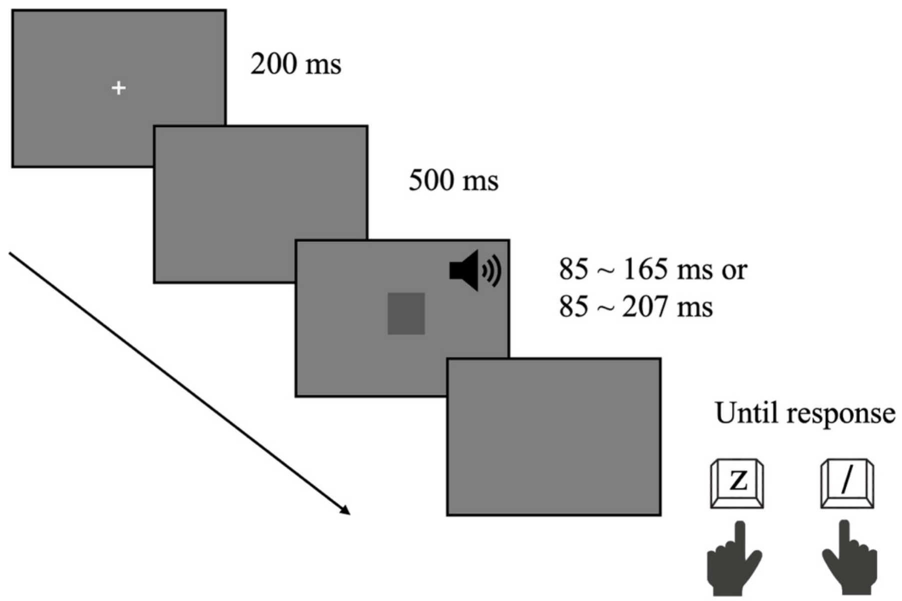

Figure 1. Task sequence in a single trial for experiment 1. Participants were initially instructed to press the 'Z' key if they judged the stimulus duration to be short, and the '/' key if they judged it to be long. On another day, the key assignment was reversed: participants pressed the '/' key if they judged the duration to be short, and the 'Z' key if they judged it to be long. The order of stimulus-key mapping was balanced. A 1kHz pure tone was provided while the participant pressed the correct key.

Results

In Experiment 1, we aimed to determine whether the difficulty of perceptual categories influences response duration. We conducted a repeated ANOVA with perceptual category difficulty set as a between-subjects factor. The perceptual category difficulty did not significantly affect response duration, $F(1, 35) = 1.34$, $p = 0.255$, $\eta p^2 = 0.038$. In other words, the sensory similarity between boundary stimuli did not influence the regulation of response duration. There was also no interaction effect between difficulty and stimulus-key mapping, $F(1, 35) = 0.06$, $p = 0.815$, $\eta p^2 = 0.002$.

Continuing, we investigated whether participants' judgment attributes modulated response duration as in previous studies. Using repeated ANOVA, we checked whether response duration was significantly modulated by stimulus duration, and based on the linear characteristics of the data, we fitted a linear model developed in previous studies to determine whether response duration was categorized according to participants' judgments. The model equation is as follows:

$$RD = a * stimulus\ duration + b + c_{long\ category}$$

where, $c_{long\ category}$, which only applies to long category replies, shows the category effect; b represents the intercept; and a indicates the slope of the entire linear effect.

First, we present the results for the high difficulty level combining the data from the two stimulus-key mappings (Figure 2). The repeated ANOVA analysis showed that stimulus duration had a significant effect on response duration, RDshort = 129, 131, and 135 ms vs. RDlong = 145, 149, and 152 ms, $F(5, 85) = 25.75$, $p < .001$, $\eta p^2 = 0.431$. The linear model results confirmed that participants' judgments of the duration as long significantly influenced the response duration (slope: mean = 0.22, $t(17) = 4.04$, Cohen’s $d = 0.95$, $p < .001$; category effect: mean = 6.33, $t(17) = 1.90$, Cohen’s $d = 0.45$, $p = 0.075$).

Although our experimental design differed by designating stimulus-response mapping as a within-subject factor, it appears that we failed to replicate the previous finding that participants' RD is influenced by judgment attributes when using the same stimulus duration as the prior study. RD was differentiated based on the duration of the stimulus; however, it was not significantly divided when participants responded with "long".

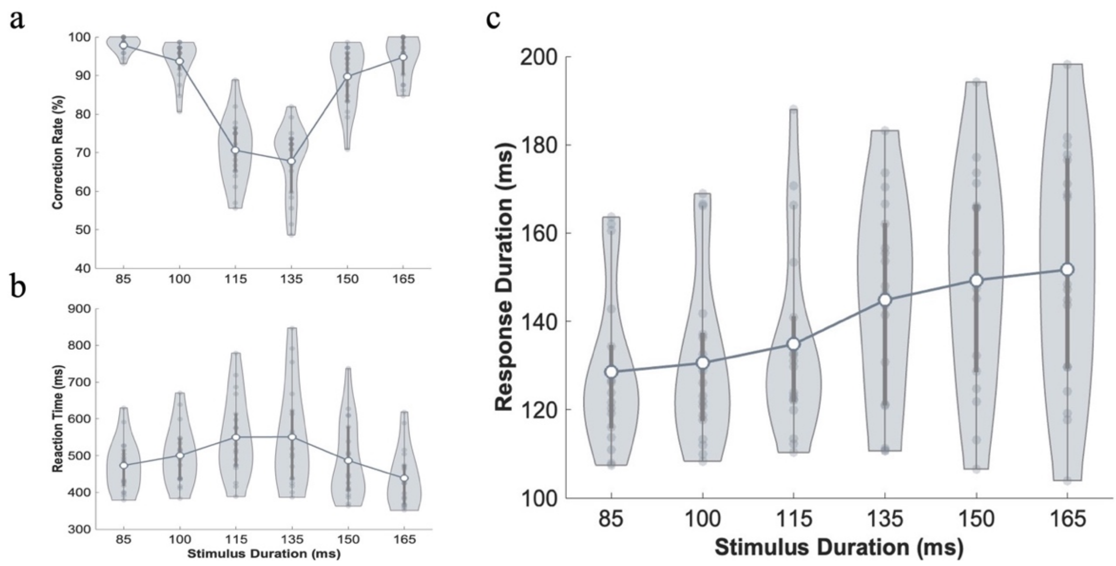

Figure 2. Results of Experiment 1A from combining data conducted across different mappings. (a) Mean accuracy declined as the stimuli located the decision boundary, 97, 93, 70, 67, 89, and 94%. (b) Reaction times increased. (c) Response duration was divided into two groups according to the categorization of participants.

In the easy difficulty level, we combined the data from the two stimulus-key mappings (Figure 3). Similar to the high difficulty level, stimulus duration significantly affected response duration, RDshort = 119, 119, and 122 ms vs. RDlong = 142, 145, and 149 ms, $F(5, 90) = 18.60$, $p < .001$, $\eta p^2 = 0.341$. The linear model results indicated that even in the easy difficulty level, participants' judgments of the duration as long significantly lengthened the response duration (slope: mean = 0.17, $t(17) = 2.87$, Cohen's $d = 0.68$, $p = 0.011$; category effect: mean = 17.98, $t(17) = 2.73$, Cohen's $d = 0.64$, $p = 0.014$).

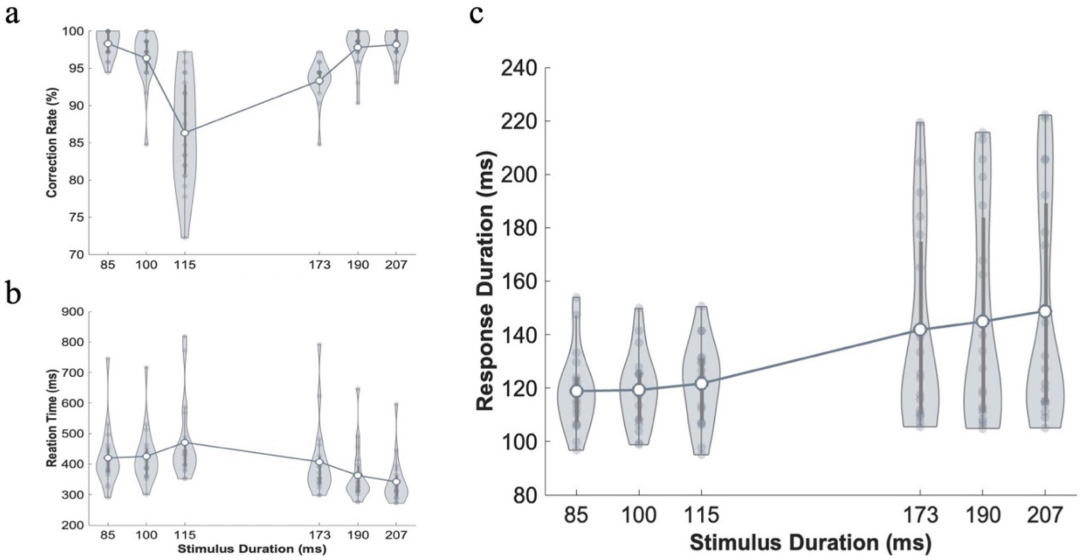

Figure 3. Results of Experiment 1B from combining data across different mappings. Overall, the mean accuracy and reaction time across stimulus durations are comparable to those observed under hard condition. However, (a) the mean accuracy of the boundary stimulus was 86.3%, which is significantly higher than in other difficulty level, overall mean accuracy 98, 96, 86, 93, 97, and 98%. Additionally, (b) reaction times were generally shorter. (c) Response duration reflected the judgment of participants.

We also observed the interaction effect between stimulus-key mapping and perceptual judgment difficulty. We designated stimulus-key mapping as a within-subjects factor at each difficulty level and analyzed the interaction effect between the mapping and stimulus duration. In the high difficulty level, the interaction between stimulus-key mapping and stimulus duration significantly affected response duration, $F(5, 85) = 16.47$, $p < .001$, $\eta p^2 = 0.326$. This difference was more pronounced when analyzing the mappings separately.

When the short stimulus was mapped to the 'z' key and the long stimulus to the '/' key (Figure 4), unlike previous results, stimulus duration did not significantly affect response duration, RDshort = 137, 139, and 142 ms vs. RDlong = 139, 144, and 145 ms, $F(5,85) = 0.94$, $p = 0.460$, $\eta p^2 = 0.052$. The linear model results showed a negative category effect (slope: mean = 0.19, $t(17) = 3.43$, Cohen's d = 0.81, $p = 0.003$; category effect: mean = -6.71, $t(17) = -1.41$, Cohen's d = -0.33, $p = 0.176$). In other words, participants' judgment properties did not regulate response duration in the high difficulty level.

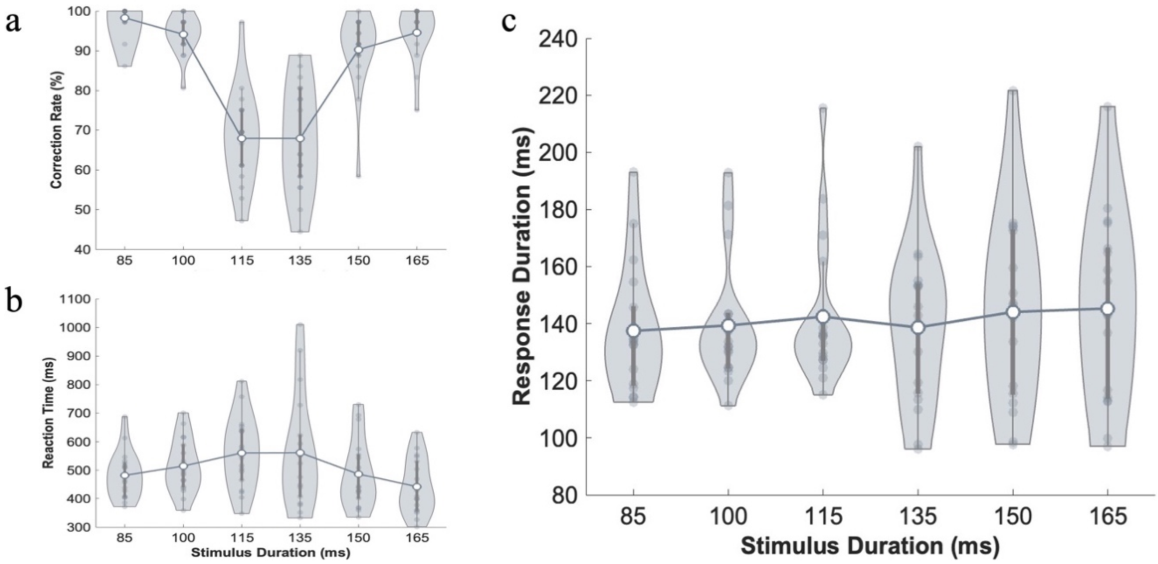

Figure 4. Results of the mapping where the stimulus categorized as 'short' was assigned to the 'z' key and judged as 'long' to the '/' key in hard difficulty level. (a) Mean accuracy, 98, 94, 67, 67, 90, and 94% and (b) reaction time resemble the results of combining data across two mappings. For boundary stimuli, reaction time increased and mean accuracy decreased. In contrast, (c) the results for response duration were very different. RDs did not differ significantly across stimulus durations and were not modulated by subject categorization.

When the short stimulus was mapped to the '/' key and the long stimulus to the 'z' key, the results were different (Figure 5). Stimulus duration significantly affected response duration, $F(5,90) = 60.12$, $p < .001$, $\eta p^2 = 0.780$. The linear model also showed a large category effect (slope: mean = 0.24, $t(17) = 3.82$, Cohen's $d = 0.90$, $p = 0.001$; category effect: mean = 20.43, $t(17) = 6.48$, Cohen's $d = 1.53$, $p < .001$).

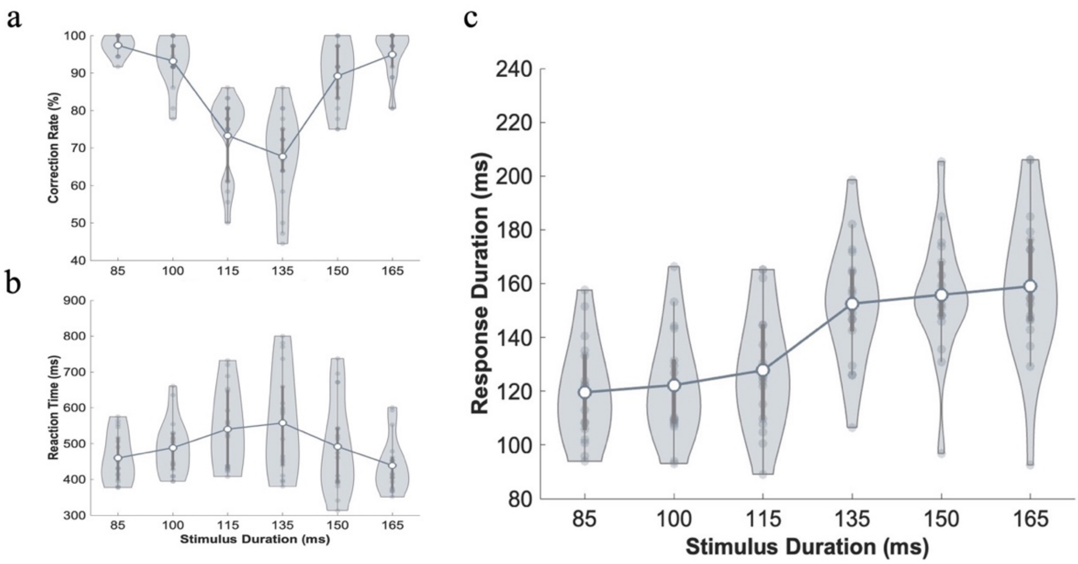

Figure 5. Results of the mapping where participants pressed the 'z' key for stimuli judged as long and the '/' key for stimuli judged as short in hard difficulty level. The results of (a) Mean accuracy and (b) reaction time did not differ from the results of other mapping. The (c) response duration results showed noticeable differences compared to other mapping. Consistent with Figure 3, RDs clustered according to participant judgments.

In the easy difficulty level, we also confirmed the interaction effect between the stimulus-key mapping and stimulus duration, $F(5, 90) = 2.76$, $p = 0.020$, $\eta p^2 = 0.071$. When the short stimulus was mapped to the 'z' key and the long stimulus to the '/' key (Figure 6), stimulus duration significantly affected response duration, $F(5, 90) = 3.02$, $p = 0.015$, $\eta p^2 = 0.144$, RDshort = 125, 124, and 127 ms vs. RDlong = 138, 143, and 145 ms. The linear model results showed a positive slope and a category effect. However, the mean value of the category effect was not significant (slope: mean = 0.19, $t(17) = 3.43$, Cohen's $d = 0.81$, $p = 0.003$; category effect: mean = 9.33, $t(17) = 1.02$, Cohen's $d = 2.46$, $p = 0.320$).

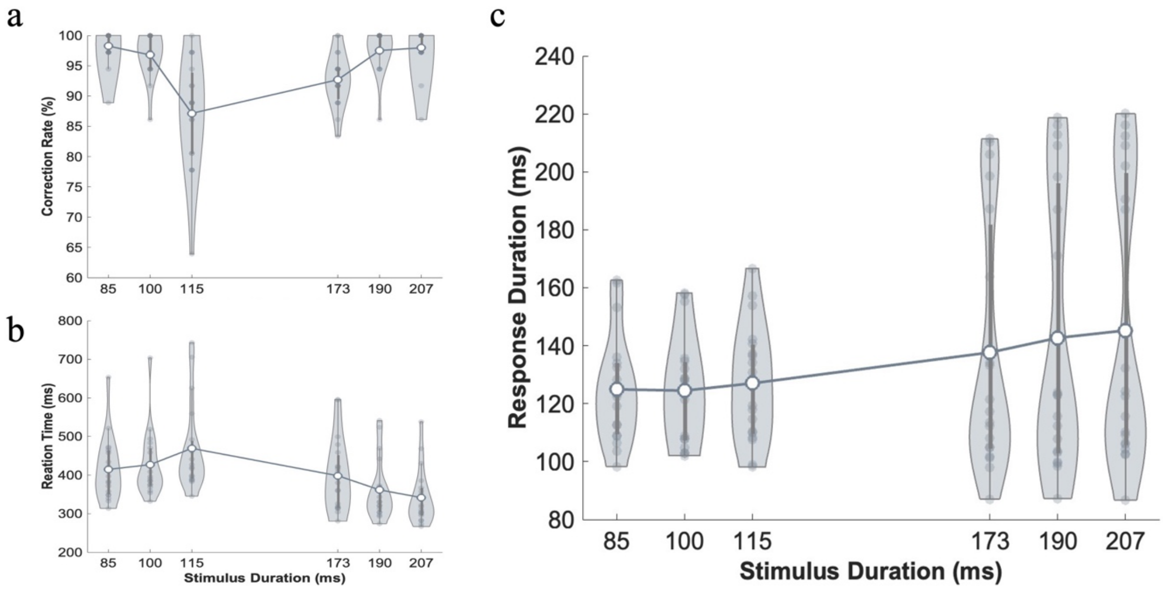

Figure 6. Results of the mapping where the stimulus categorized as 'short' was assigned to the 'z' key and judged as 'long' to the '/' key in easy difficulty level. (a) Mean accuracy, 98, 96, 87, 92, 97, and 97% (b) reaction time, and (c) response duration.

When the short stimulus was mapped to the '/' key and the long stimulus to the 'z' key, the results were as follows (Figure 7). Stimulus duration significantly affected response duration, $F(5, 90) = 26.07$, $p < .001$, $\eta p^2 = 0.592$, RDshort = 113, 115, and 116 ms vs. RDlong = 146, 149, and 152 ms. The linear model results showed a positive slope and a much larger category effect, and it also indicated that the value of the category effect was significant (slope: mean = 0.24, $t(17) = 3.82$, Cohen's $d = 0.90$, $p = 0.001$; category effect: mean = 27.77, $t(17) = 5.37$, Cohen's $d = 1.27$, $p < .001$).

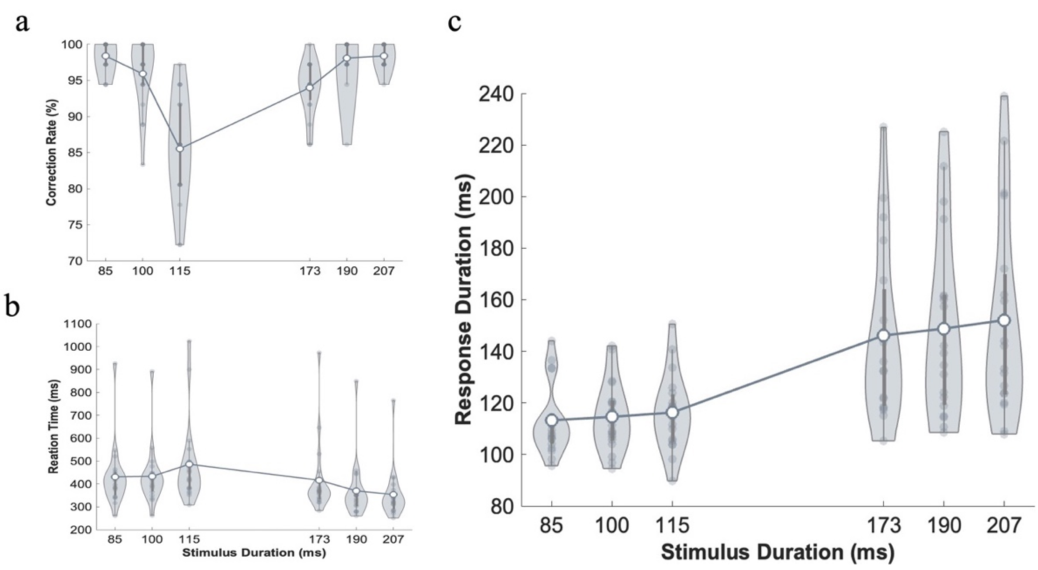

Figure 7. Results of the mapping where participants pressed the 'z' key for stimuli judged as long and the '/' key for stimuli judged as short in easy difficulty level. The results of (a) Mean accuracy, and (b) reaction time did not statistically differ from the results of other mapping. (c) Response duration also showed a similar pattern to other mapping; However, the mean values of the category effects were significantly different.

In summary, we investigated whether the difficulty of perceptual category judgments regulates response duration. We confirmed that participants' judgments of "long" significantly affected RD at the easy difficulty level. However, there was no significant difference in the category effect between the two perceptual judgment difficulty levels, $t(34) = -1.58$, Cohen's $d = -0.53$, $p = 0.124$. We found that the interaction between stimulus-key mapping and stimulus duration significantly influenced response duration. The categorization attributes modulating response duration varied depending on the mapping.

Reaction time was significantly influenced by difficulty, $F(1, 35) = 18.28$, $p < .001$, $\eta p^2 = 0.350$. Intuitively, the combined data from the two stimulus-key mappings showed that reaction time was always longer in the hard difficulty level compared to the easy difficulty (Hard difficulty level: RTs = 473, 500, 550, 551, 487, and 438 ms, Easy difficulty level: RTs = 420, 426, 471, 407, 363, and 342 ms) (Refer to Figures 2 and 3). There was no interaction effect between difficulty and mapping on reaction time, $F(1, 35) = 0.25$, $p = 0.618$, $\eta p^2 = 0.007$. There was also no interaction effect between stimulus duration and stimulus-key mapping on reaction time, $F(1, 35) = 0.25$, $p = 0.938$, $\eta p^2 = 0.007$.

Experiment 2

Method

Participants

Twenty students from the Ulsan National Institute of Science and Technology who were naive to the purpose of the experiment participated. The Institutional Review Board of the Ulsan National Institute of Science and Technology approved this research (UNISTIRB-23-058-A). All participants were provided a written consent form before the experiment, which they signed, and received a monetary reward regardless of their performance. Methods were implemented fairly and adhered to the established guidelines.

Apparatus and Stimuli

The stimuli were generated using MATLAB and the Psychophysics Toolbox (Pelli, 1997) on a 23.6-inch monitor connected to a Mac Pro (Late 2013) (Apple, Cupertino, CA, USA).

The target stimuli were presented in Korean, written as 'short' or 'long', using a font size of 24 and Malgun Gothic typeface. The target stimulus, displayed as white text on a gray background at the center of the screen, was presented for 120 ms. Simultaneously, a pure tone of 1 kHz was also presented for 120 ms along with the target stimulus.

Procedure

The task for the participants was as follows: When the words 'short' or 'long' written in Korean were presented, they were required to press either the 'z' or '/' key using their right or left index finger. The mapping was count-balanced, and the accompanying pure tone was unrelated to the task. Participants were instructed to respond both quickly and accurately as soon as the stimulus concluded (Figure 8). All subjects performed different key mappings for the same stimuli on separate days. We did not inform the subjects that reaction times or keypress durations would be measured or recorded. After seeing the instructions, the subjects were required to enter their gender, age, and dominant hand. Upon entering this information, they would press any key to start the experiment. The experiment began, and a fixation point was displayed for 200 ms. Following a 500 ms period of a blank screen, a target stimulus appeared. The target words "short" and "long" were presented uniformly and randomly. A fixed point was presented at the beginning of the trial, following an inter-trial interval (ITI) of 1000 ms. Pressing the correct key resulted in the emission of a 1 kHz pure tone for as long as the key was held down. Visual feedback was provided to participants who pressed the response key prematurely or responded incorrectly before the stimulus vanished. For 700 ms, the screen's center displayed the visual feedback message, either “Too early!” or "Error!". There were six practice trials for each type of stimulus (a total of 12 trials). Following this, three blocks of thirty-six trials for each type of stimulus were carried out, amounting to a total of 216 trials. Consequently, since participants performed the experiment on two separate days with different key mappings, each participant completed a total of 432 trials. Data analysis utilized only the correct trials from right-handed participants.

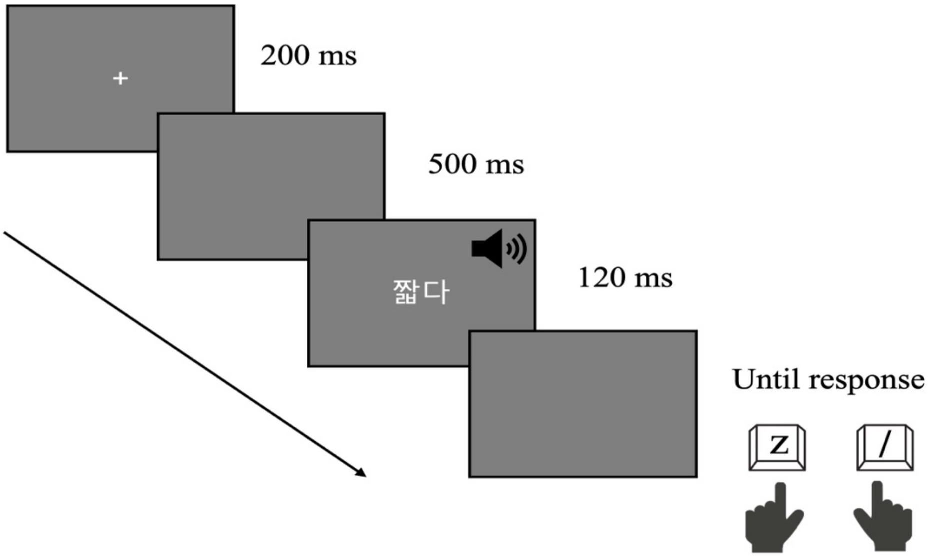

Figure 8. Task sequence in a single trial for experiment 2. Participants were initially instructed to press the 'z' key when presented with the Korean word for 'short' and to press the '/' key for 'long.' On different days, the key assignments were reversed—'short' was mapped to the '/' key and 'long' to the 'z' key—and the order of the mapping was counterbalanced. A 1 kHz pure tone was provided while the participant pressed the correct key.

Results

All participants conducted the experiments on different days using two distinct mappings. One subject who responded as left-handed was excluded from the analysis. In Experiment 2, we aimed to investigate whether the semantic attributes of categorical language stimuli modulate response duration. The semantic attributes of the language did not affect response duration (Figure 9C). In other words, the key press time was not modulated by the semantic attributes of the words 'short' or 'long'. RD_{short} = 115 ms, RD_{long} = 116 ms, $t(18) = -0.66$, Cohen's $d = -0.15$, $p = 0.520$, $F(1, 18) = 0.22$, $p = 0.639$, $\eta_p^2 = 0.006$.

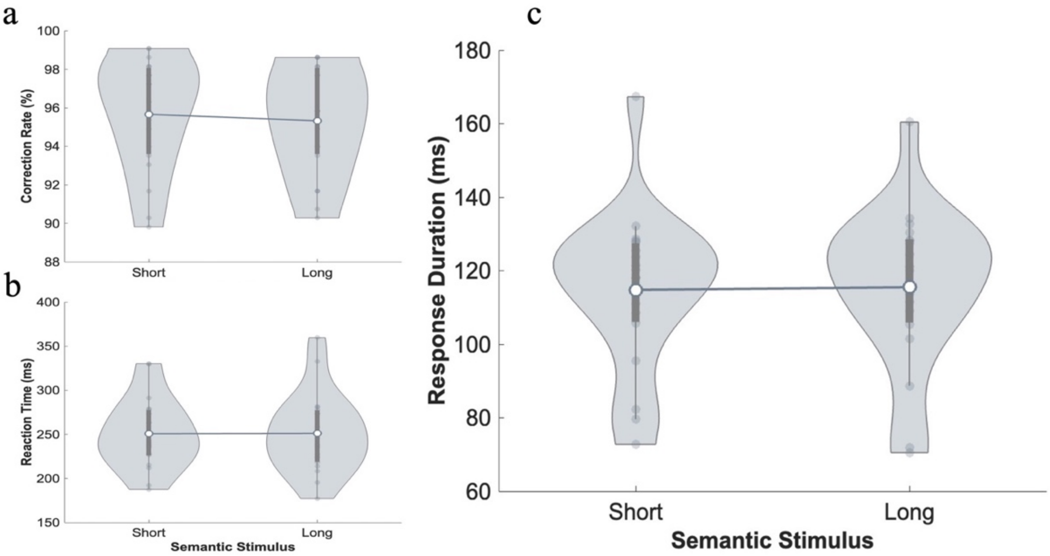

Figure 9. Result of combining data from two mappings. (a) mean accuracy has no difference between stimuli, 95.5% in the 'short' word and 94.9% in the 'long' word. (b) Reaction time and (c) response duration also show no significant differences.

However, the interaction effect between semantic attributes and mapping significantly influenced response duration, $F(1, 18) = 16.19$, $p < .001$, $\eta p^2 = 0.310$. Based on the interaction effect, we separately analyzed the mappings where participants pressed the 'z' key for the word 'short' and the '/' key for the word 'long' (Figure 10). Unlike the combined data from the two stimulus-key mappings, significant differences in response durations were observed when the words 'short' and 'long' were presented. Participants pressed the key for a longer duration when they were presented with the Korean word for 'short' compared to when they saw the word for 'long', $RD_{short} = 119$ ms, $RD_{long} = 112$ ms, $t(18) = 2.87$, Cohen's $d = 0.66$, $p = 0.010$, $F(1, 18) = 8.24$, $p = 0.010$, $\eta p^2 = 0.314$.

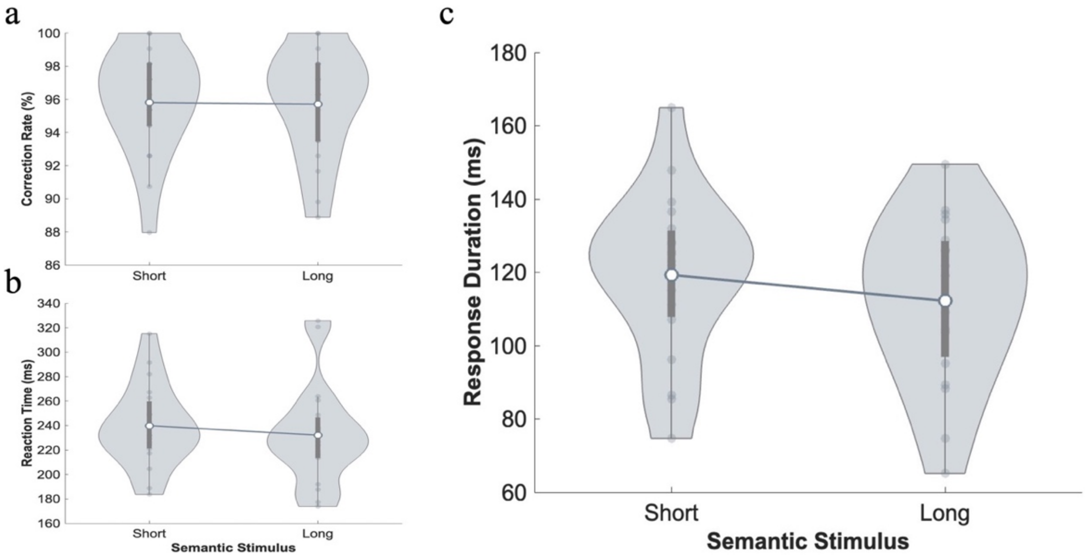

Figure 10. Results of the mapping where the word 'short' was assigned to the 'z' key and 'long' to the '/' key. (a) Mean accuracy was nearly the same for both stimuli 95.8% in the ‘short’ word and 95.7% in the ‘long’ word. (b) The reaction time for the 'short' word stimulus was slightly longer, but the difference was not statistically significant. (c) The response duration for the 'short' word stimulus was significantly longer than that for the 'long' word stimulus.

In the mapping where participants pressed the '/' key for 'short' and the 'z' key for 'long', the opposite result was observed (Figure 11C). When presented with the Korean word for 'long,' participants pressed the key for a longer duration compared to their response to the word 'short', RDshort = 110 ms, RDlong = 119 ms, $t(18) = -2.86$, Cohen’s $d = -0.66$, $p = 0.010$, $F(1, 18) = 8.19$, $p = 0.010$, $\eta p^2 = 0.313$. In this mapping, it was observed that response duration was modulated by the semantic attributes of the language.

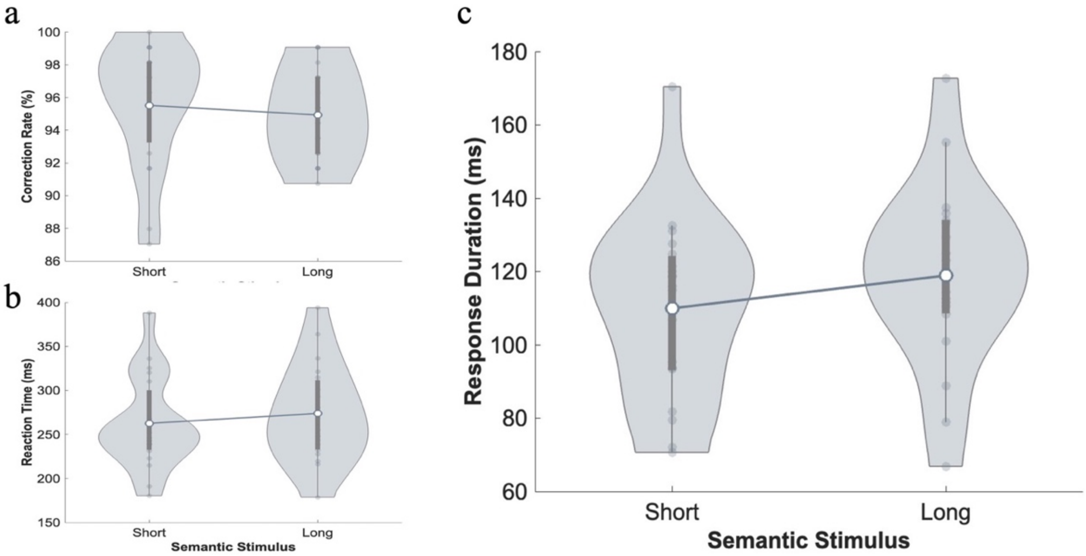

Figure 11. Results of the mapping where the word 'short' was assigned to the '/' key and 'long' to the 'z' key. (a) There was nearly the same mean accuracy across both stimuli 95.5% in the ‘short’ word and 94.9% in the ‘long’ word. (b) Although the reaction time was marginally shorter for the 'short' word stimulus, this disparity lacked statistical significance. (c) Conversely, the response duration for the 'short' word stimulus was notably shorter than for the 'long' word stimulus.

To summarize, we investigated whether the semantic attributes of language modulate response duration. The semantic attributes of language did not have a significant effect on response duration. However, in certain mappings, it was observed that response duration was modulated by the semantic attributes of language.

We analyzed the data to see if there was a difference in response duration between the right and left hands depending on the stimulus. When the word 'short' was presented, there was a significant difference between the key press time with the right hand and the left hand, RDright = 110 ms, RDleft = 120 ms, $t(18) = -2.26$, Cohen’s $d = -0.52$, $p = 0.037$. However, when the word 'long' was presented, there was no significant difference in RDs between key presses with the right and left index fingers, $t(18) = -1.49$, Cohen’s $d = -0.34$, $p = 0.154$. An analysis was conducted to determine if there was a difference in response duration between key presses with the right and left hands, independent of the stimulus. RDright (106 ms) was significantly shorter than RDleft (113 ms), t(18) = -3.13, Cohen’s d = -0.72, p = 0.006 (Figure 12).

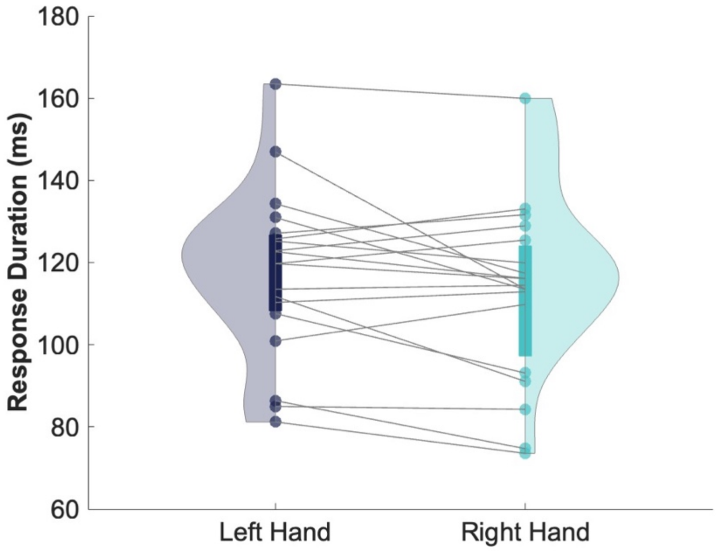

Figure 12. Stimuli-Independent Response Durations for Both Hands The mean response duration for the left hand (113 ms) was longer than the mean response duration for the right hand (106 ms), and the difference was statistically significant.

We also examined the relationship between the semantic attributes of language and reaction time. Semantic attributes did not affect reaction time, $F(1, 18) = 0.24$, $p = 0.628$, $\eta p^2 = 0.007$. However, an interaction effect between stimulus type and mapping was observed, $F(1, 18) = 6.89$, $p = 0.013$, $\eta p^2 = 0.161$. When the 'short' word was mapped to the 'z' key and the 'long' word to the '/' key, reaction time was not significantly different based on semantic attributes, RTshort: 240 ms, RTlong: 232 ms, $t(18) = 1.88$, Cohen's $d = 0.43$, $p = 0.076$, $F(1, 18) = 3.54$, $p = 0.076$, $\eta p^2 = 0.164$ (Refer to Figure 10B). Similarly, when the 'short' word was mapped to the '/' key and the 'long' word to the 'z' key, reaction time was not significantly different based on semantic properties, RTshort: 263 ms, RTlong: 274 ms, $t(18) = -1.89$, Cohen's $d = -0.43$, $p = 0.075$, $F(1, 18) = 3.58$, $p = 0.075$, $\eta p^2 = 0.166$ (Refer to Figure 11B).

Experiment 3

Method

Participants

Ten students from the Ulsan National Institute of Science and Technology participated in Experiment 3. One participant who reported left-handed people was excluded from the analysis. All methods were performed equally according to the instructions. Before the experiment, each participant signed a written informed consent form, and regardless of their performance, they were all rewarded. This research was authorized by the Institutional Review Board of the Ulsan National Institute of Science and Technology (UNISTIRB-23-058-A).

Apparatus and Stimuli

To generate the stimuli, MATLAB and the Psychophysics Toolbox (Pelli, 1997) were used on a 23.6-inch monitor with Mac Pro (Late 2013) (Apple, Cupertino, CA, USA). The composition of the target stimulus is the same as the Experiment 2. The target stimulus, which is composed of a 1 kHz pure tone and a dark gray square (2.3 cm x 2.3 cm), is displayed at the center of the screen. The visual-audio stimuli are presented at durations of 50, 100, 150, 200, or 250 ms. There are two conditions in experiment 3; however, the stimulus durations are the same for both conditions.

Procedure

Participants perform the task to create a duration identical to the presented audio-visual stimulus duration by pressing the 'g' key with their left index finger or the 'h' key with their right index finger (Figure 13). All participants were instructed to match the length of the stimulus as accurately as possible. They performed two conditions, utilizing their left or right hand, on the same day. The order of conditions was count-balanced. Before trials begin, participants input their sex, age, and dominant hand. When any key is pressed, trials start, presenting the fixation point for 200 ms. A target stimulus was displayed after 500 ms of a blank screen. The duration of the stimulus was presented randomly for each trial. Following a 1000 ms inter-trial interval (ITI), a fixation point was presented to signal the start of the trial. A 1 kHz pure tone played throughout the key press as participants pressed the key. If participants press the response key too early, they receive a visual feedback message ("Too early!") for 700 ms in the center of the screen. This experiment was conducted with twenty trials for each duration in one block (a total of 100 trials). As a result, since participants performed the task under two conditions on the same day, every participant undertook 200 trials throughout the entire experiment. Before initiating the experiment, there were two preliminary trials conducted for each duration, totaling 10 trials. Only trials from participants who reported right-handed were used for the data analysis.

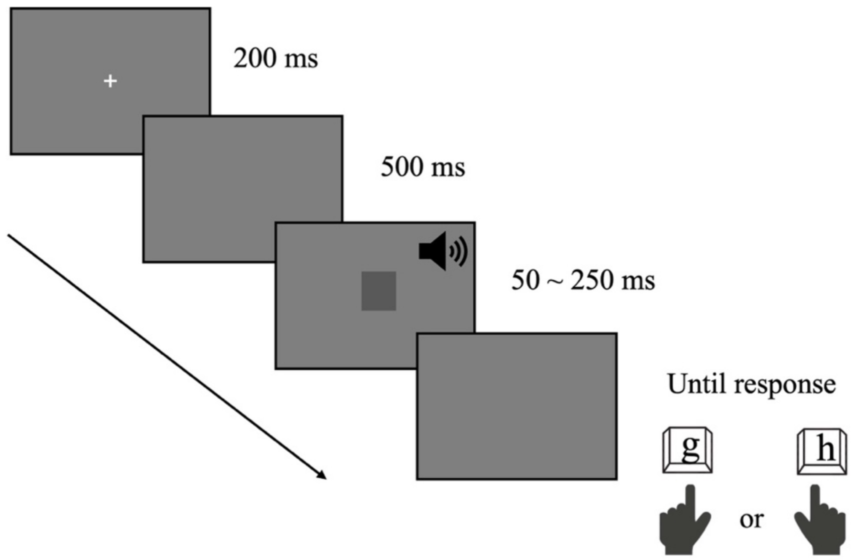

Figure 13. Task sequence in a single trial for experiment 3. When audio-visual stimuli were presented, participants were instructed to press the 'h' key with their right index finger to closely match the given auditory stimulus. On the same day, they were directed to press the 'g' key with their left index finger to match the sound of the stimulus. The order of these tasks was count-balanced.

Results

We conducted Experiment 3 to investigate whether the interaction effect between mapping and stimulus observed in Experiments 1 and 2 was due to functional differences between the right and left hands. The length of the target stimulus in experiment 3 included the stimulus duration in experiment 1. Stimulus duration was presented randomly for each trial. Firstly, this is the result of analyzing the response duration when the participant pressed the key with their right index finger to match the duration of the presented target stimulus. The RDs by right hand were significantly different across the stimulus duration, RDright = 90, 129, 193, 234, and 269 ms, $F(4, 1) = 288.42$, $p < .001$, $\eta p^2 = 0.973$ (Figure 14).

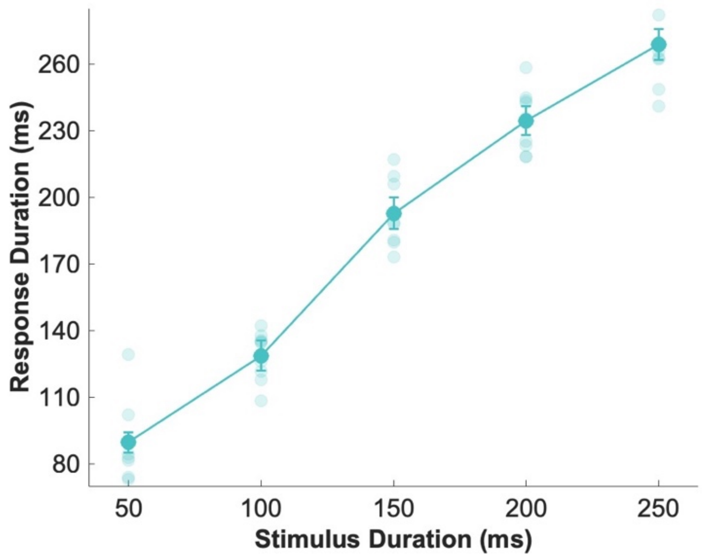

Figure 14. Results of response duration according to stimulus duration when tasks were performed with the right index finger. The average of the standard deviations of all subjects is expressed as an error bar.

Correspondingly, when participants pressed the keys with the left index finger, the RDs were substantially different across the stimulus duration, RDleft = 88, 127, 188, 241, and 274 ms, $F(4, 1) = 380.83$, $p < .001$, $\eta p^2 = 0.979$ (Figure 15).

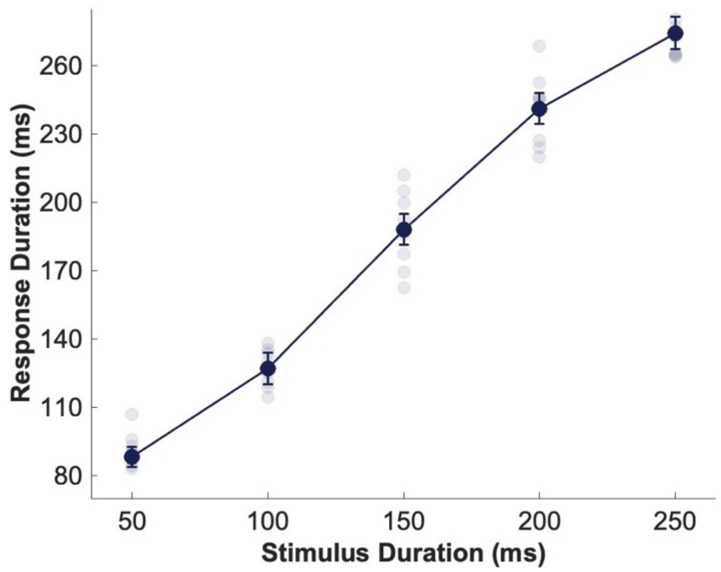

Figure 15. Results of response duration according to stimulus duration when tasks were performed with the left index finger. An error bar represented the mean of the standard deviations of all participants.

Subsequently, a two-way repeated measures ANOVA was conducted to analyze whether there was a significant difference in RDs between pressing keys with the right hand and the left hand across the entire dataset. The results indicated that there were no significant differences in RDs between using the right index and the left index finger overall, $F(1, 7) = 0.04$, $p = 0.853$, $\eta p^2 = 0.005$. Following this, a Bayesian paired sample t-test was performed to determine whether the RDs differed between pressing with the left index finger and the right index finger for each stimulus duration separately (50 ms, 100 ms, 150 ms, 200 ms, 250 ms). The stimulus duration that showed the smallest difference between pressing a key with the right hand and pressing a key with the left hand is 50 ms. The results were as follows, Bayes factor (BF_{10}) = 0.330, credibility interval (CI) = [-0.51, 0.65]. The stimulus duration that showed the greatest difference in RDs when pressing a key with the right hand versus the left hand is 200 ms, BF_{10} = 0.525, CI = [-0.92, 0.30]. The analysis results for other stimulus durations can be found in Table 1. The results of Experiment 3 confirmed that there was no functional difference in the actions of pressing and releasing the key between the right and left hands.

Table 1

Results of Bayesian Paired Sample t-test by Stimulus Duration.

Stimulus Duration	Bayes factor (BF_{10})	Credibility interval (CI)
50 ms	0.330	[-0.51, 0.65]
100 ms	0.342	[-0.47, 0.68]
150 ms	0.388	[-0.40, 0.78]
200 ms	0.525	[-0.92, 0.30]
250 ms	0.476	[-0.88, 0.32]

Experiment 4

Method

Participants

Twenty participants enrolled at the Ulsan National Institute of Science and Technology, who reported not having red-green color blindness, took part in Experiment 4. One participant who self-reported as left-handed was excluded from the analysis. All method was applied equally and in compliance with the guidelines. Every participant completed a written informed permission form before the experiment, and they were all awarded regardless of how well they performed. The Institutional Review Board (UNISTIRB-23-058-A) of the Ulsan National Institute of Science and Technology approved this study.

Apparatus and Stimuli

MATLAB and the Psychophysics Toolbox (Pelli, 1997) were used to generate stimuli on a 23.6-inch monitor with Mac Pro (Late 2013) (Apple, Cupertino, CA, USA). The color stimulus, which is a red or green square (2.3 cm x 2.3 cm), is presented in the middle of the screen. The color stimuli are presented at a duration of 120 ms.

Procedure

Participants are tasked with pressing the 'z' key or the '/' key when the stimulus is red or green using the index finger on either side (Figure 16). Participants were instructed to answer as fast and precisely as possible after the stimulation disappeared. On separate days, participants completed two mappings between the color of the stimulus and the response key. Participants were not informed about the measurement and recording of response time or key press duration. Participants recorded their age, sex, and dominant hand after receiving instruction. Trials start when participants hit any key, and the fixation point is shown for 200 ms. After 500 ms of a blank screen, a color stimulus was displayed. The color of the stimulus is presented randomly for each trial. After the response of the participant, a 1000 ms inter-trial interval (ITI) occurs. A fixation point then appears, and the next trial begins. A 1 kHz pure tone played for as long as the participant pressed down the accurate key. If a participant pressed the response key too soon before the stimulus faded away, or if their response was inaccurate, they received visual feedback. For 700 ms, the visual feedback message "Too early!" or "Error!" was shown in the middle of the screen. Participants completed 5 practice trials for each color (10 trials total), followed by 1 block of 50 trials per color (a total of 100 trials). Therefore, as the experiment was conducted with two different mappings on separate days, each participant completed 200 trials throughout the entire experiment. The data analysis only included correct trials from right-handed participants.

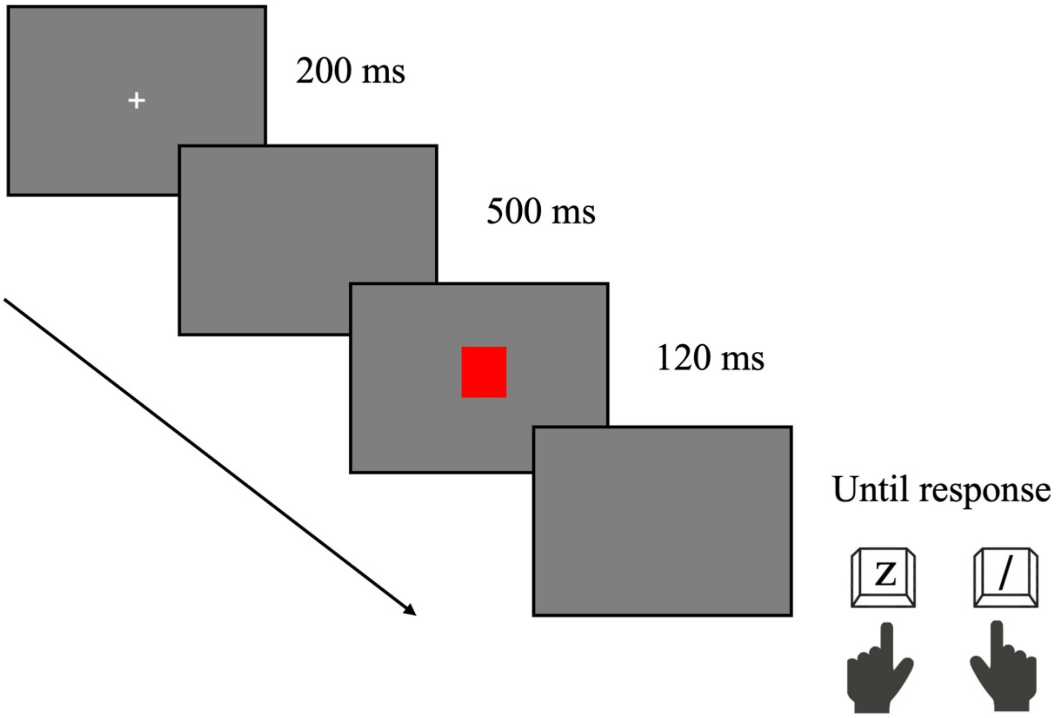

Figure 16. Task sequence in a single trial for experiment 4. Participants were initially instructed to press the 'z' key when presented with the red visuo-auditory stimulus and to press the '/' key for a green visuo-auditory stimulus. On different days, the key assignments were reversed—'red' was mapped to the '/' key and 'green' to the 'z' key—and the order of the mapping was counterbalanced. A 1 kHz pure tone was provided while the participant pressed the correct key.

Results

We conducted Experiment 4 to investigate whether there was a difference in the key press time with the right hand versus the left hand when performing the same task as in Experiment 1 or Experiment 2. For neutral stimuli, there was no difference in response duration, RDred = 113 ms, RDgreen = 113 ms, $t(18) = 0.27$, Cohen's $d = 0.06$, $p = 0.793$ (Figure 17). However, regardless of the stimulus, it was observed that the response duration was always shorter with the dominant hand, RDright = 110 ms, RDleft = 117 ms, $t(37) = -2.85$, Cohen's $d = -0.65$, $p = 0.011$ (Figure 18).

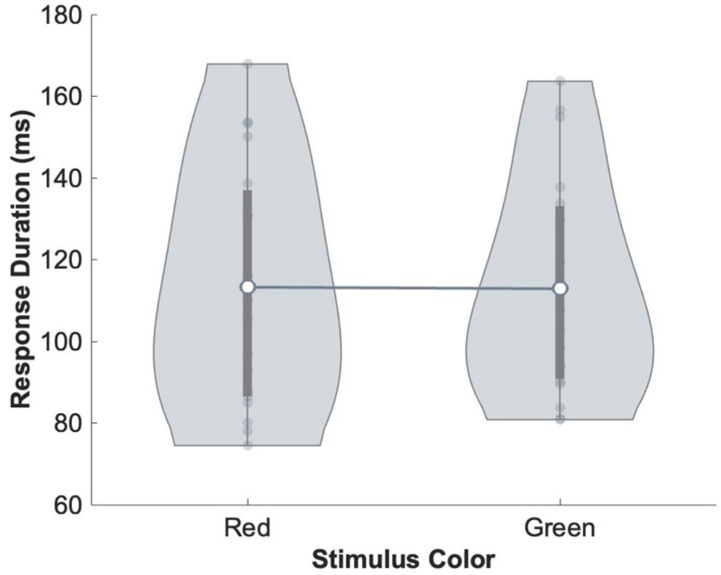

Figure 17. Results of response duration from combining data performed across different mappings for two color stimuli. The mean response durations were the same across stimuli.

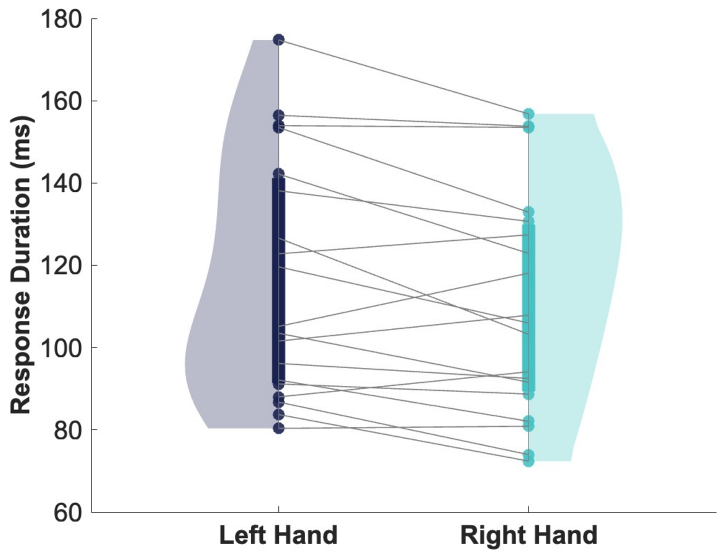

Figure 18. Regardless of the stimulus, the results of response duration when pressing keys with the right hand versus the left hand. There was a noticeable difference.

In summary, we found that when participants performed a choice reaction task with neutral stimuli, there was a difference in key press time between the dominant and non-dominant hands, independent of the task.

Discussion

Our goal was to explore the significance of response duration as a measure for understanding human psychological processes and to analyze the factors that regulate response duration. First, we investigated how the categorical difficulty of perceptual judgment affects response duration. Experiment 1A showed that, despite using the same stimulus duration as in previous research, participants' judgments of "long" did not affect RD. In Experiment 2, we found that participants' judgment attributes significantly affected RD. However, the linear model we used is the same as the one used in previous research. Considering that this study newly designated stimulus-response mapping as a within-subject factor, we need to modify the linear model to more accurately investigate the factors affecting RD. Additionally, an interaction effect between mapping and stimulus duration was observed. Significant differences were found in the extent to which response duration is modulated depending on the mapping.

We observed that the semantic attributes of categorical language do not modulate response duration in a response choice task. This differs from observations that semantic processing occurs in the motor system (Grisoni et al., 2016). Grisoni et al. (2016) observed that event-related potentials revealed that action-related words produced significantly larger stimulus-evoked (Mismatch Negativity-like) and predictive brain responses (Readiness Potentials) when presented in action sound contexts that were incongruent with the associated body parts (e.g., “kiss” in a footstep sound context; “kick” in a whistle context) compared to congruent contexts. We suggest that although a semantic priming effect has been observed in the motor system, additional processes beyond simply choosing a response based on semantic attributes are necessary for semantic attributes to directly influence action (response duration).

Finally, we observed that there was no functional difference between the dominant and non-dominant hands when performing a one-hand task, but there was a difference in response duration between the dominant and non-dominant hands when performing a two-hand task. This finding distinguishes from the study (Nisiyama & Ribeiro-do-Valle, 2014), which reported no difference in reaction time between the right and left hands of right-handed individuals. Given the rarity of studies showing differences in key-press times between the dominant and non-dominant hands during two-hand tasks, our results provide a deeper understanding of the characteristics of response duration as a behavioral measure.

Based on the results of our study, we propose the following future research directions: adding sensory properties to categorical language stimuli to explore how these properties affect response duration. Unlike studies that investigate the effects of sensory properties on responses (Ng & Chan, 2012; Spierer et al., 2010), this approach is significant as it allows for the observation of how sensory properties modulate action compared to semantic properties.

We investigated new factors that modulate key press duration in choice response tasks. We expect our research findings to provide new insights into response duration and help understand human psychological processes.

References

Deese, J. (1969). Behavior and fact. *American Psychologist*, *24*(5), 515.

Elsner, B., & Hommel, B. (2001). Effect anticipation and action control. *Journal of experimental psychology: human perception and performance*, *27*(1), 229.

Greenwald, A. G. (1970). Sensory feedback mechanisms in performance control: with special reference to the ideo-motor mechanism. *Psychological review*, *77*(2), 73.

Grisoni, L., Dreyer, F. R., & Pulvermüller, F. (2016). Somatotopic semantic priming and prediction in the motor system. *Cerebral Cortex*, *26*(5), 2353-2366.

Hommel, B. (1996). The cognitive representation of action: Automatic integration of perceived action effects. *Psychological research*, *59*(3), 176-186.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and brain sciences*, *24*(5), 849-878.

James, W. (1890). The Principles of Psychology.

Ng, A. W., & Chan, A. H. (2012). Finger response times to visual, auditory and tactile modality stimuli. Proceedings of the international multiconference of engineers and computer scientists,

Nisiyama, M. a., & Ribeiro-do-Valle, L. (2014). Relative performance of the two hands in simple and choice reaction time tasks. *Brazilian Journal of Medical and Biological Research*, *47*, 80-89.

Pachella, R. G. (2021). The Interpretation of reaction time in information-processing research 1. In *Human information processing* (pp. 41-82). Routledge.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: transforming numbers into movies. *Spatial vision*, *10*(4), 437-442.

Pfister, R., Neszmélyi, B., & Kunde, W. (2023). Response durations: A flexible, no-cost tool for psychological science. *Current Directions in Psychological Science*, *32*(2), 160-166.

Shin, Y. K., Choe, S., & Kwon, O.-S. (2023). Strong evidence for ideomotor theory: Unwilled manifestation of the conceptual attribute in movement control. *Frontiers in Psychology*, *14*, 1066839.

Shin, Y. K., Proctor, R. W., & Capaldi, E. J. (2010). A review of contemporary ideomotor theory. *Psychological bulletin*, *136*(6), 943.

Spierer, D. K., Petersen, R. A., Duffy, K., Corcoran, B. M., & Rawls-Martin, T. (2010). Gender influence on response time to sensory stimuli. *The Journal of Strength & Conditioning Research*, *24*(4), 957-963.

Teichner, W. H. (1954). Recent studies of simple reaction time. *Psychological bulletin*, *51*(2), 128.

Van Zandt, T., & Townsend, J. T. (2014). Designs for and analyses of response time experiments. *The oxford handbook of quantitative methods: Foundations*, *1*, 260.