



Attenuation of size illusion effect in dual-task conditions

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ABSTRACT

We over-estimate or under-estimate the size of an object depending its background structure (e.g., the Ebbinghaus illusion). Since deciding and preparing to execute a movement is based on perception, motor performance deteriorates due to the faulty perception of information. Therefore, such cognitive process can be a source of a failure in motor performance, although we feel in control of our performance through conscious cognitive activities. If a movement execution process can avoid distraction by the illusion-deceived conscious process, the effect of the visual illusion on visuomotor performance can be eliminated or attenuated. This study investigated this hypothesis by examining two task performances developed for a target figure inducing the Ebbinghaus size illusion: showing visually perceived size of an object by index finger-thumb aperture (size-matching), and reaching out for the object and pretending to grasp it (pantomimed grasping). In these task performances, the size of the index finger-thumb aperture becomes larger or smaller than the actual size, in accordance with the illusion effect. This study examined whether the size illusion effect can be weakened or eliminated by the dual-task condition where actors' attention to judge the object's size and to produce the aperture size is interrupted. 16 participants performed the size-matching and pantomimed grasping tasks while simultaneously executing a choice reaction task (dual task) or without doing so (single task). Using an optical motion capture system, the size-illusion effect was analyzed in terms of the aperture size, which indicates the visually perceived object size. The illusion effect was attenuated in the dual task condition, compared to it in the single task condition. This suggests that the dual task condition modulated attention focus on the aperture movement and therefore the aperture movement was achieved with less distraction caused by illusory information.

1. Introduction

In many daily activities, visual information is critical for high performance; however, our visual perceptual system does not always provide precise information. For example, we may overestimate or underestimate an object's size depending on its background structure. An example of this misperception is the Ebbinghaus illusion, in which the visually perceived size of a circle is judged to be larger or smaller than its actual size when the circle is surrounded by other smaller or larger circles (Fig. 1: inset A). Therefore, when participants were asked to match the shape of an aperture produced using the index finger and thumb with the visually estimated size of a center circle of the Ebbinghaus figure (size-matching task), the size of the index finger-thumb aperture was larger or smaller than the actual size, which was in accordance with the illusion effect (Haffenden & Goodale, 1998). In contrast, in some studies, when participants grasped a circular object, which induces the Ebbinghaus illusion, they produced the index finger and thumb aperture movement according to the size of the target object without being affected by the size illusion (Aglioti, DeSouza,

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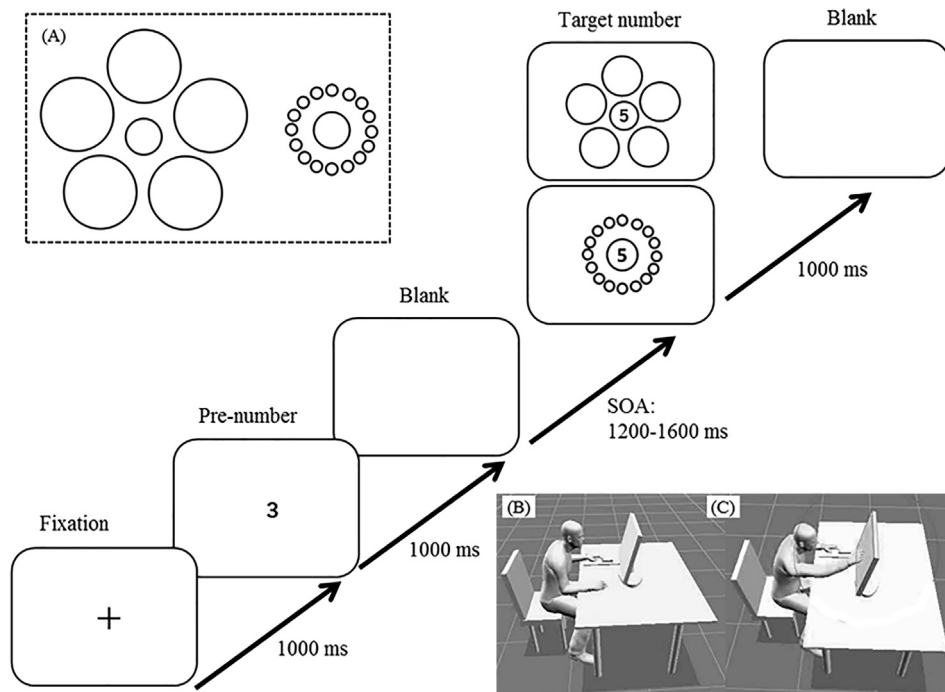


Fig. 1. Time duration of the task paradigm. At the beginning of each trial, the gaze fixation figure of “+” was displayed in the center of a screen. After 1000 ms, a pre-number, either zero or another number, was displayed for 1000 ms: The number 0 indicated single task, and a non-zero number indicated dual-task. 1200–1600 ms after the pre-number disappeared, a target figure (smaller looking or larger looking) appeared for 1000 ms. The figure was replaced by the fixation figure to fade out the afterimage of the target figure and to prepare for the next trial. (A) Ebbinghaus figure; (B) Initial posture: size-matching was performed with this posture. The distance between the starting hand position and the screen’s center was approximately 38 cm. The eye-screen distance was approximately 48 cm from a chin-rest, which was used to stabilize the participant’s head position during the movement. (C) Pantomimed grasping was performed by reaching toward the target figure.

& Goodale, 1995; Haffenden & Goodale, 1998; Haffenden, Schiff, & Goodale, 2001). These findings led to the proposal that the movement to grasp an object is not based on the same representation about the object’s size as a conscious perception about the size. However, some studies have also reported contradictory findings that the grasping movement is affected by size illusion (Franz, Gegenfurtner, Bühlhoff, & Fahle, 2000; Pavani, Boscagli, Benvenuti, Rabuffetti, & Farnè, 1999). These conflicts in findings are an important issue because deciding and preparing to execute a movement are based on perception; therefore, motor performance deteriorates due to faulty perception of information. Thus, even though we feel in control of our performance through conscious cognitive activities, such cognitive processes can be sources of failures in motor performance. If a movement execution process can avoid distraction by the illusion-deceived conscious process, errors in visuomotor performance could be reduced. Therefore, the question is not only whether a movement is affected by size illusion but also whether the effect of the visual illusion can be eliminated or attenuated. Motivated by the above proposition, examining the illusion effect on cognition-based motor performance can be a useful method to determine how the cognitive process plays a role in executing motor performance based on perception.

This study addresses the aforementioned question by examining whether size-illusion effect can be weakened or eliminated by dual-task conditions where actors’ conscious cognitive activities to execute a size-matching task in response to an illusory visual target are disturbed. To this end, I disturbed a participant’s conscious cognitive process for size-matching performance under a dual-task condition. A dual-task paradigm, in which a primary task is performed while simultaneously executing a secondary task, was employed to examine the automaticity of the primary task performance or magnitude of cognitive load to execute the task (Cameron, Franks, Enns, & Chua, 2007; Goh, Gordon, Sullivan, & Winstein, 2014; McNevin & Wulf, 2002). In the dual-task situation, cognitive load for achieving the goal is increased and the participants’ attention on producing the aperture movement is distracted. In this study, I used a choice reaction task as the secondary task because the task movement is produced based on a cognitive decision about stimulus identification and response selection with respect to the stimulus. By focusing the participants’ attention on cognitive information processing for the choice reaction task, attention on size matching is expected to be disturbed. Therefore, the judgment made about the object’s size and awareness required to produce the aperture size will be interrupted. If the size-illusion effect on the aperture is weakened or eliminated in the dual task, the dual-task condition can modulate attention on the aperture movement; distracting attention from illusory information is effective in preventing performance error caused by misperception.

When performing size matching, the participants produce an aperture configuration based on the visually recognized size of the object. For this visuomotor process, attention must be paid to the object’s configuration and aperture movement that are being consciously performed. Therefore, this type of conscious process can be susceptible to the target’s illusory background. In contrast, when a participant is asked to reach for the center circle of the Ebbinghaus figure and pretend to grasp it (pantomimed grasping), it

does not explicitly require us to show the perceived size of the object by the aperture configuration. However, participants reportedly scaled the size of an aperture produced using the thumb and index finger to grasp an object according to its size (Jeannerod, 1981, 1984). Based on this finding, the aperture size produced during pantomimed grasping will be scaled according to the perception of the object's size. From this perspective, although pantomimed grasping is regarded as cognition-based motor performance, pre-shaping the aperture configuration to the object's size, as the hand approaches the object, is an implicit process that is performed unconsciously. Therefore, examining the size-illusion effect on this movement in the dual-task condition will be interesting.

This study investigates the influence of the dual-task condition in the magnitude of the size-illusion effect on size matching and pantomimed grasping. The results are discussed in terms of the possibility of visuomotor performance without distraction by the conscious cognitive process.

2. Method

2.1. Participants

Sixteen healthy graduate and undergraduate students (seven males and nine females; average age = 21 ± 1.5 years), who were assessed as right-handed by the Edinburgh inventory (Oldfield, 1971), participated in this study. After the purpose and procedure of the experiment were explained, each participant signed an informed consent form. The study was conducted according to the principles stated in the Helsinki Declaration and was approved by the appropriate ethics committee.

2.2. Setup

An optical motion capture system (OptiTrack, Natural Point, Corvallis, OR) recorded the aperture movement of the index finger and thumb at a sampling frequency of 120 Hz by attaching reflective markers to the carpometacarpal joint on the thumb and nails of the index finger and thumb used during the task.

Four different Ebbinghaus figures were used as visual targets: a center circle (diameter of 3.5 or 4 cm) surrounded by larger or smaller circles in the center (a diameter of 7 cm; smaller looking figure and diameter of 1.2 cm; larger looking figure). To prevent the participants' aperture movement from being influenced by the surrounding circles as obstacles, the distances between the center circle and surrounding circles were made constant for both the smaller looking and larger looking figures, following the studies of Danckert, Sharif, Haffenden, Schiff, and Goodale (2002).

The instrument used for the choice reaction task was a wooden lever with its rotational axis fixed on a table. The participants moved the lever right or left on a horizontal plane, and the rotation of the lever was sampled at 200 Hz using a goniometer. Data collection software (LabView, National Instruments, Austin, TX) was used to display the target figure and align the data obtained by the motion capture system and goniometer.

2.3. Task and task conditions

The size-matching task was used to visually estimate the size of the center circle of the Ebbinghaus figure displayed in the center of the computer screen (DELL E193FPC; 1920×1080 pixels, 19 in., 60 Hz) and to show the perceived size by the index finger–thumb aperture of the right hand, whereas pantomimed grasping was used to reach out and pretend to grasp the center circle using a pinch grip. In both tasks, the participants started each trial by placing the right hand at the starting location marked on a table top with the index finger and thumb aperture closed and staring at the fixation point on the screen (the starting posture is shown in Fig. 1: inset B). In response to the appearance of the target figure, they initiated the task movement as quickly as possible. They were also asked to keep their eyes on the figure during execution of the task movements.

The task instructions for the size-matching task were as follows: (1) adopt the starting posture; (2) when the target figure appears on the screen, show the size of the center circle of the Ebbinghaus figure by the index finger–thumb aperture without moving the hand from the starting location and hold the pinch-grasping posture (Fig. 1: inset B). The task instructions for pantomimed grasping were as follows: (1) adopt the starting posture; (2) when the target figure appears on the screen, reach for the center circle of the Ebbinghaus figure to grasp it by the index finger–thumb pinch grip but stop before the fingers touch the screen and hold the pinch-grasping posture (Fig. 1: inset C). For prehensile motions during pantomimed grasping, instructions about specific hand trajectory to the target and hand orientation for the grasping posture to be made were not given (Refer to Fig. 2 for trajectories of the index finger and thumb in pantomimed grasping). For a given distance from the start position to the center of the screen (~ 38 cm), the distance that the hand moved for pantomimed grasping was 33.8 ± 0.8 cm (89.0% of the distance from the start position to the screen center). The peak aperture occurred at 82.8% of the hand-moving distance (73.6% of the distance from the start position to the screen center).

For the choice reaction task, the participants manipulated the lever with their left hand to perform a visual discrimination task, as shown in Fig. 1 (inset B and C). A number appeared on the screen for 1000 ms, after which it was replaced by the Ebbinghaus figure, and then another number was displayed inside the center circle. The choice reaction task involved moving the lever arm to the left when the target number was smaller than the previous number and moving it to the right when the target number was greater than the previous one. The task instruction for the dual-task emphasized simultaneous execution of the two task movements as quickly and accurately as possible after target onset.

The order of each task block (size matching and pantomimed grasping) was counterbalanced across participants. The conditions

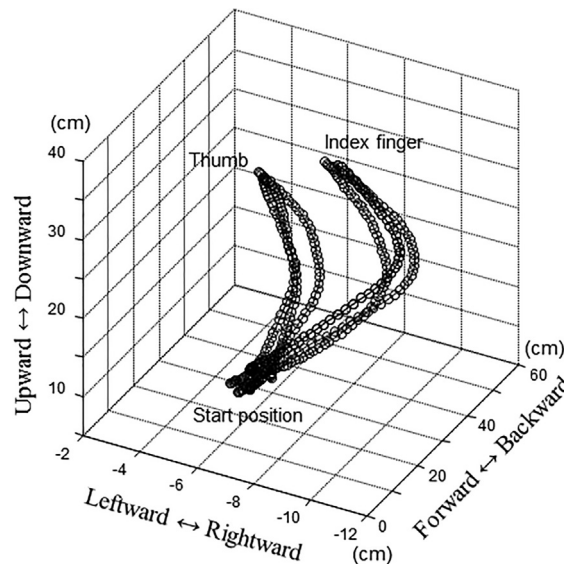


Fig. 2. Trajectories of index finger and thumb in pantomimed grasping. Exemplary three trials from one participant were shown.

in each task block comprised the secondary task requirement (dual task and single task), illusion effect (larger looking and smaller looking), and object sizes (two different diameters). Different-sized objects were used to prevent the participants from repeating the same aperture movements for same-sized objects. For each of the four different target figures, the participants performed eight trials for both the single and dual tasks (64 total trials), and the trial order was randomized within each task block.

2.4. Experimental procedure

If the Ebbinghaus structure used in the experiment was unsuitable for the participants to be fooled by the size illusion, the aperture movement in the experiment will not show the size-illusion effect. However, such a result cannot be an evidence of performances immune to the size illusion. Prior to data acquisition, it was confirmed that the Ebbinghaus figure used in the experiment can induce the size-illusion effect on the participants' visual estimation about the object's size by the method of limits. The Ebbinghaus figure and a comparison figure, i.e., a single circle with a diameter of 1.5 or 6 cm, were shown on a computer screen. The participants used the mouse to manipulate the tool bar to modulate the size of the comparison circle until they determined that the circle size matched the size of the Ebbinghaus center circle. They repeated this task 28 times (seven trials for each of the four Ebbinghaus figures described above). If the participants were susceptible to the size illusion, they would modulate the size of the comparison circle to be larger for the larger looking figure than for the smaller looking figure. This prediction was confirmed using repeated-measures analysis of variance (ANOVA) with the main illusion effects (smaller looking and larger looking) and object sizes (two diameters) and was conducted for each participant separately. For all the participants, a significant effect of the illusion effect and object size was obtained ($p < .01$).

Data collection was conducted as the participants placed their right hand on the start position for aperture movement and their left hand on the lever arm for the choice reaction. The time duration of the task performance is shown in Fig. 1. In response to the appearance of the target figure, the participants initiated the task movement as quickly as possible. In the dual task, they initiated the choice reaction movement as quickly as possible and concurrently with the aperture movement. They took short breaks between the tests and a long break between trial blocks to avoid becoming fatigued during the full set of trials. The entire process lasted approximately 1.5 h for each participant. After the data collection process was completed, the participants performed choice reaction without executing size matching or pantomimed grasping to identify the choice reaction time in the control condition (32 trials in total). The second number for the choice reaction is shown in the Ebbinghaus figures as in the procedure of the main experiment. I collected the data of the choice reaction in the control condition to examine whether an increase in cognitive load by the dual-task condition also affected the execution of the choice reaction task, as indicated by a longer choice reaction time in the dual-task condition than in the control condition.

2.5. Analysis

The marker position data were smoothed by a second-order, low-pass filter, with a cutoff frequency of 20 Hz. The aperture movement was examined by the distance between the marker positions on the index finger and thumb (because the distance was calculated by the positions of two markers, it was consistently larger than the actual distance between the positions of the index finger and thumb across the participants.). The onset of the aperture movement was defined by the moment at which the rate of change in the marker distance, calculated using numerical differentiation, increased beyond 3% of its peak value. Aperture movement

termination was the moment at which the rate of change in the distance decreased below 3% of the peak value. With the choice reaction performance, the onset of reaction movement was when the lever angular velocity, calculated by numerical differentiation of the goniometer data, reached 3% of its peak value.

Based on the linear scaling relationship between the size of the index finger–thumb aperture and object to be grasped (Jeannerod, 1981, 1984), the size-illusion effect on aperture movement in pantomimed grasping was assessed by the peak value of the aperture during task movement (peak aperture) because previous studies have used it to indicate the visually perceived object size (Aglioti et al., 1995; Franz, Fehle, Bulthoff, & Gegenfurtner, 2001; Haffenden & Goodale, 1998). Regarding the size-matching performance, the illusion effect was examined by the aperture distance at the termination of aperture movement (final aperture) when the participants indicated their visually perceived size of the objects. The final aperture was determined by the mean value of the aperture distance calculated using the data for 300 ms after aperture movement termination. The magnitude of the illusion effect on the peak and final apertures was examined by the difference in these aperture sizes between the larger looking and smaller looking figures.

Trials showing a response before the target onset and any significantly late responses (reaction times > 800 ms) were excluded from the analysis. These trials comprised 1.1% of the total trials across all participants. False choice reactions comprised 2.6% of the total trials across all participants. This low rate of failure indicated that the participants could perform the choice reaction properly under the dual-task condition.

2.5.1. Hypothesis test

The primary interest of this study was to examine the influence of the dual-task condition on the magnitude of the size-illusion effect on grip opening. The size-illusion effect can be examined by comparing the aperture measures between the larger looking and smaller looking figures. To test the hypothesis that the size-illusion effect can be weakened or eliminated by the dual-task condition, the size-illusion effect was compared between the dual-task and single-task conditions. Although aperture movement is produced according to the visually perceived size of the objects in both tasks, the process to produce the aperture size in size matching can be different from that in pantomimed grasping due to task requirement and instruction; the participants were not explicitly required to produce the aperture size according to the object's size. Therefore, examining the difference in the size-illusion effect between these two tasks is also interesting. However, according to previous studies (Franz et al., 2000; Franz, 2003; Hesse, Franz, & Schenk, 2016), direct comparison of the aperture measures between size matching and pantomimed grasping is not appropriate because the responsiveness of the perceptual system for a given set of stimuli under different task conditions can be different. Therefore, in their studies, the response function, which is the linear regression calculated by the dependent variable (aperture size) and independent variable (physical size of the target object used in the experiment), was obtained and the illusion effect was corrected by dividing it by the slope of the regression function. This corrected illusion effect was used to compare different tasks. The present study followed the above-mentioned studies by computing the corrected illusion effect to compare the aperture size between size matching and pantomimed grasping.

$$\text{Corrected illusion effect} = \frac{\text{Mean illusion effect}}{\text{Mean slope}}$$

where mean illusion effect is the difference in the aperture sizes between the mean values for larger looking and smaller looking figures and mean slope is the mean values of the slopes of the linear regression related to the aperture sizes of the small and large target circles (i.e., the difference in the aperture size between the large and small circles divided by the physical difference in the diameter of the large and small circles). The corrected illusion effects were compared using repeated-measures ANOVA with the factors of the task (size matching and pantomimed grasping) and secondary task requirement (dual task and single task). The results were regarded as statistically significant when $p < .05$.

2.5.2. Follow-up test

In the above hypothesis test, if the corrected illusion effect in the dual-task condition is significantly lesser than the corrected illusion effect in the single-task condition, the dual-task condition could effectively disturb the execution of size matching and pantomimed grasping. Such disturbances can be confirmed in terms of kinematic parameters, which were examined in a previous study that investigated the effect of the dual-task condition on grasping square target objects with different sizes (Singhal, Culham, Chinellato, & Goodale, 2007); Disturbed grasping performance was evidenced by the reaction time of the grasping movement, which was longer in the dual-task condition than in the single-task condition. In addition, they also demonstrated reciprocal interference such that the reaction time of the secondary task became slower when it was performed with the grasping task. These results indicate that distracted attention due to the dual-task condition slowed the reaction to initiate task movements. Thus, if the dual-task condition in this study is effective in disturbing the participants' attention or increasing cognitive load to execute size matching and pantomimed grasping, the reaction time of these movements (i.e., the duration between the target onset and aperture movement onset) in the dual-task condition is expected to be longer than that in the single-task condition. Furthermore, given the finding of reciprocal interferences between the tasks in the dual-task condition by Singhal et al. (2007), the dual-task condition might interrupt the execution of not only the aperture movement but also the choice reaction movement. Thus, choice reaction time is also expected to be slower than the reaction time in the control condition, demonstrating that the dual-task condition could be challenging. Therefore, the reaction time of the aperture movement was compared between the dual-task and single-task conditions in terms of their effect sizes. The choice reaction time was also compared between the dual-task and control conditions by calculating Cohen's d (Cohen, 1988, 1992). The results were interpreted based on the criteria of $d = 0.8$ as the large effect, $d = 0.5$ as the medium effect, and $d = 0.2$ as the small effect.

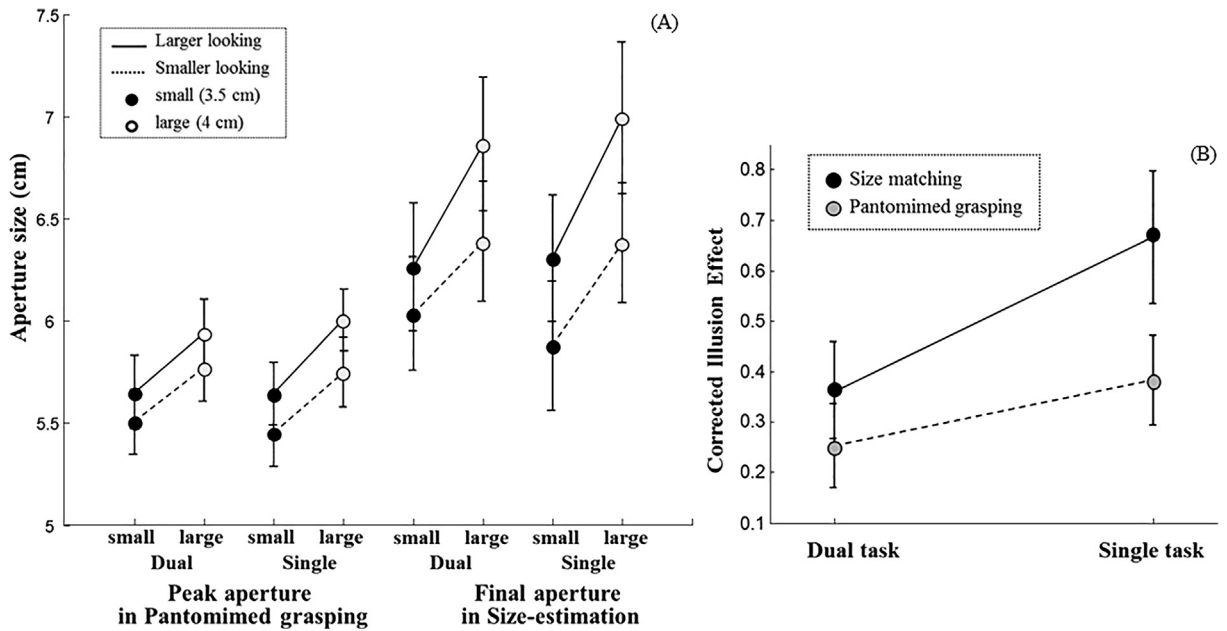


Fig. 3. Grand averages of within-participant mean value: (A) Peak aperture of pantomimed grasping and Final aperture for size matching; (B) Corrected illusion effect final aperture in size matching and peak aperture in pantomimed grasping. The diameter of the target circle was 3.5 cm and 4 cm for the small and larger circle, respectively. Error bars show the between-participant standard error of the mean.

If the dual-task condition was effective in interfering with attention to size matching and pantomimed grasping, the aperture movement will become less consistent than that in the single task. Therefore, the variability of the aperture size (final aperture and peak aperture) in the dual-task condition is expected to be larger than the variability in the single-task condition. Based on this, variability was examined by calculating the root mean square of the difference between the aperture size of each trial and mean aperture size in each task condition for each participant (Total variability; refer to Schmidt & Lee, 2011). These total variabilities were also compared between the dual-task and single-task conditions in terms of Cohen's d .

3. Results

3.1. Hypothesis test

3.1.1. Peak aperture and final aperture

The grand averages of the final aperture in size matching and peak aperture in pantomimed grasping for each task condition are shown in Fig. 3-A. The participants could produce aperture sizes according to the different objects' sizes. A larger aperture size was produced for larger looking figures than for smaller looking figures, indicating that aperture movement was affected by size illusion. These results were observed not only in the single-task condition but also in the dual-task condition, confirming that the participants' performances were produced in accordance with the task conditions. The results of the corrected illusion effects are reported below.

3.1.2. Corrected illusion effect of final aperture and peak aperture

The means of the corrected illusion effect calculated for the final aperture and peak aperture across participants are shown in Fig. 3-B. According to the figure, the size-illusion effect appeared to decrease in the dual-task condition than in the single-task condition. Repeated-measures ANOVA for the main effects of the task (size matching and pantomimed grasping) and secondary task requirement (dual task and single task) showed a significant main effect of the secondary task requirement ($F(1, 15) = 8.117$, $p = .012$), indicating that the corrected illusion effect was larger in the single-task condition than in the dual-task condition. Therefore, the magnitude of the size-illusion effect on aperture movement was reduced when the participants simultaneously executed the secondary task with size matching or pantomimed grasping.

In Fig. 3-B, the size-illusion effect on pantomimed grasping appeared to be smaller than the size-illusion effect on size matching, and the attenuation of the size-illusion effect on size matching due to the dual-task condition appeared to be more prominent than that on pantomimed grasping. However, a significant effect was not obtained ($F(1, 15) = 2.460$, $p = .138$), indicating that the magnitude of size-illusion affecting the aperture movement was not consistently different between size matching and pantomimed grasping. An interaction between the task and secondary task requirement was also not significant ($F(1, 15) = 1.832$, $p = .196$), indicating that the amount of the size illusion being attenuated by the dual-task condition was not consistently different between size matching and pantomimed grasping.

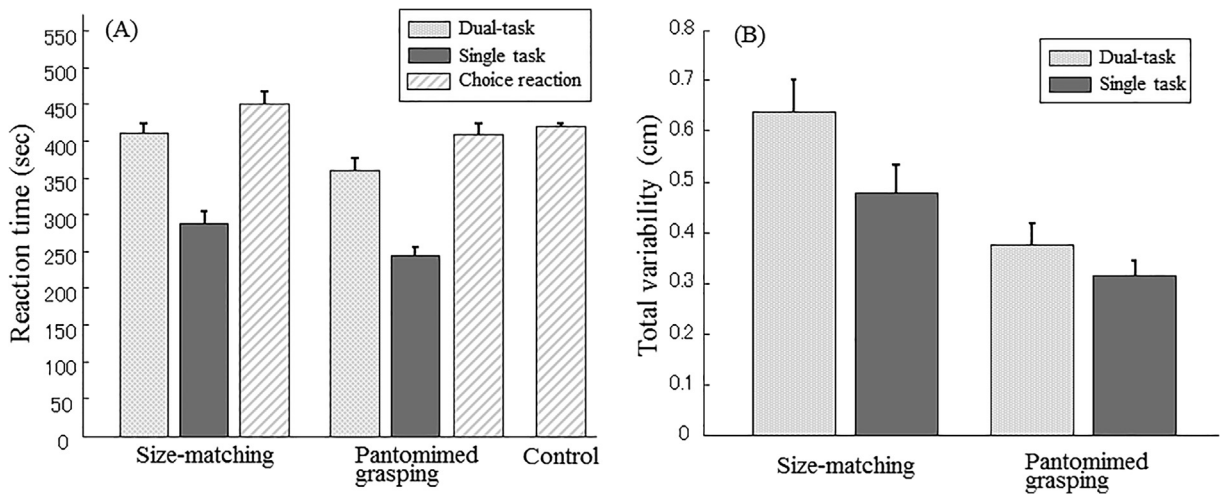


Fig. 4. Grand averages of within-participant mean value: (A) Reaction time of aperture movement in size matching and pantomimed grasping, and choice reaction time; (B) Total variability of final aperture in size matching and peak aperture in pantomimed grasping, calculated by the root mean square of the difference between the aperture size of each trial and the mean aperture size in each task condition for each participant.

3.2. Follow-up test

The within-participant mean of the reaction time and total variability in the dual-task and single-task conditions were calculated and the grand averages of these mean values are shown in Fig. 4.

3.2.1. Reaction time

Fig. 4-A shows the grand averages of the reaction time of size matching and pantomimed grasping and choice reaction time. The mean values of size matching were 411 ± 52 ms in the dual-task condition and 287 ± 67 ms in the single-task condition, whereas those of pantomimed grasping were 360 ± 62 ms in the dual-task condition and 244 ± 42 ms in the single-task condition. According to Fig. 4-A, the reaction time in the dual-task condition was slower than the reaction time in the single-task condition in both size matching and pantomimed grasping, which was confirmed by the effect size of size matching ($d = 2.07$) and pantomimed grasping ($d = 2.19$). Therefore, compared with the single-task condition, the dual-task condition was effective in disturbing the aperture performances.

Regarding choice reaction time, the grand average in the dual-task condition was 450 ± 63 ms in size matching and 409 ± 59 ms in pantomimed grasping, whereas the control choice reaction time was 419 ± 21 ms. According to Fig. 4-A, compared with the reaction times of aperture movements, the difference in choice reaction time between the dual-task and control conditions was not evident. The effect sizes of these comparisons were Cohen's $d = 0.66$ in size matching and Cohen's $d = 0.23$ in pantomimed grasping, indicating that the choice reaction time in size matching was shorter than the choice reaction time in the control. Therefore, reciprocal interference between size matching and choice reaction was observed in the dual-task condition. However, such a difference between the dual-task and control conditions was not evident in pantomimed grasping.

3.2.2. Total variability of aperture size

Fig. 4-B shows the grand averages of the total variability of the final aperture in size matching and peak aperture in pantomimed grasping. The variability became larger in the dual-task condition than in the single-task condition, and this tendency was prominent in size matching. Regarding the size effects, Cohen's d was 0.68 in size matching and 0.44 in pantomimed grasping. Therefore, the variability of the final aperture of size matching in the dual-task condition was larger than the variability in the single-task condition; however, this tendency was less pronounced in the peak aperture of pantomimed grasping.

4. Discussion

The present study revealed the following: (a) the aperture size produced for the target object was affected by size illusion; (b) the task goal (producing an aperture configuration according to the objects' size) was achieved even in the dual-task condition and most importantly, (c) allocating attention to simultaneously execute another task could attenuate the illusion effect on aperture movement, evidenced by a significant decrease in the corrected illusion effect of final aperture in size matching and peak aperture in pantomimed grasping. Thus, size-illusion effect was weakened by the dual-task condition where the participants' conscious cognitive activities to execute a size-matching task were disturbed. These findings demonstrate that attention on aperture movement was modulated and thus size matching was achieved with less distraction caused by illusory information, suggesting that task performance can be improved by distracting attention from obstructive information to execute a task movement. A possible drawback of the secondary

task is that it may distract the participants to visually recognize the object's size and prevent them from properly performing aperture movement according to size perception. However, this concern can be withdrawn, given the results of this study (refer to Fig. 3-A): (1) the peak and final apertures were scaled according to the objects' sizes, indicating that the participants could discriminate the difference in the objects' sizes and produce the aperture size accordingly and (2) the aperture size was similarly scaled to the difference in the sizes of the target objects in the single-task and dual-task conditions.

How could the aperture size be correctly scaled according to the target object's size while the magnitude of the illusion effect was reduced by the dual-task condition? When simultaneously executing the two tasks, foveal vision may contribute to recognizing the number, whereas peripheral vision may contribute to perceiving the object size. In the dual-task condition, the participant had to recognize the number within the center circle of the Ebbinghaus figure to execute the choice reaction. While this recognition process requires foveal vision, peripheral vision could be used to perceive the shape and size of the target object. According to the diameter of the target circle (3.5 or 4 cm) and eye-screen distance (48 cm), which comprised 4.2° or 4.8° of the visual field, the target circle was located within the margin of the foveal vision (5° of the visual field) (Millodot, 2008). Thus, information about the choice reaction task and size of the center circle could be obtained while capturing the whole structure of the Ebbinghaus figure. While producing aperture movement, perception might already be affected by the size illusion before the size of the center circle is judged, according to a study of visual object recognition (Goffaux & Rossion, 2006), in which recognizing an object comprises two perceptual processes, visual perception about the whole structure, characterized by the spatial relationship among components of the objects (holistic perception), and visual perception about component details (analytic processing). Furthermore, holistic perception precedes analytic processing in the visual recognition process due to rapid derivation of the global shape as compared with the relatively slow derivation of the local shape structure (Leek, Roberts, Oliver, Cristino, & Pegna, 2016). In addition, no regions of the early visual cortex were sensitive to specific object sizes (Jacoby, Kamke, & Mattingley, 2013). The visual illusion effect can be induced within a very short time. For example, viewing a visual stimulus for 40 ms can induce size illusion (Plewan, Weidner, & Fink, 2012). These findings suggest that holistic perception plays a role in capturing the whole structure of the Ebbinghaus figure; therefore, illusion-affected perception will be induced in the early stage of visual processing before the size of the center circle is recognized by analytic processing. According to a study by Lee and van Donkelaar (2002), aperture movement could be produced according to the object size by the dorsal stream, one of the cortical visual pathways, while being affected by the size illusion through the ventral stream process, another cortical visual path. In their study, to examine how the contribution of the dorsal and ventral streams functioned to execute the task movement, they applied transcranial magnetic stimulation to these streams to disturb visual processing for the task performance and checked whether size-illusion effect on the pointing movement remained or decreased. The results showed that, owing to dorsal stream processing, the pointing movement could be precisely produced with respect to the target size, whereas the ventral stream contributed to organizing the movement based on the illusion-affected relative object size. By applying their results to the present study, the aperture size could be produced according to the difference in the large and small target objects by the dorsal stream function, while being affected by the size illusion by the ventral stream function. The findings described above led to the following supposition and can be a subject for further study. Two processes may occur to execute the size-matching and pantomimed grasping tasks: the cognitive process to recognize the whole object, which is susceptible to the illusion, and the visuomotor process to produce the aperture opening according to the different objects' sizes. When the cognitive load to execute the task performance is increased by the dual-task condition, the magnitude of the illusion effect can be reduced due to disturbed cognitive process.

In the follow-up test, reciprocal interference between size matching and choice reaction (i.e., the slow choice reaction time in the dual-task condition) and increased variability of the final aperture were observed in size matching; however, they were less pronounced in pantomimed grasping, speculating that pantomimed grasping could be executed with less distraction by the secondary task. However, such speculations should be cautioned because the above measures cannot be compared directly between the two tasks due to the differences in the tasks. Although the effect of the choice reaction task to disturb size matching and pantomimed grasping cannot be compared, a study conducted by Greenwald and Shulman (1973) provided a clue to interpret the results. According to their study that examined the reaction time of the second of the two closely spaced stimuli, when the stimulus and response were compatible, the choice reaction time was not affected by the execution of the first task and was consistent with the reaction time of the control condition; therefore, perceiving the object's size (stimulus identification) and producing an aperture configuration based on size perception (response production) in pantomimed grasping could be considered compatible. Thus, the effect of the secondary task in distracting attention to execute pantomimed grasping could be less than the effect to execute size matching. In contrast, the stimulus-response process in size matching is less compatible and more complicated because estimating the object size and associating it with a particular aperture size are explicitly required to execute the size-matching performance. Moreover, the task goal of pantomimed grasping is not to show the judged object size by the aperture configuration. The corrected illusion effect analysis to examine the responsiveness to size illusion showed no difference between size matching and pantomimed grasping. Therefore, while the reaction and production of movement appear to be different between size matching and pantomimed grasping, these tasks share similar perceptual processes. Given the results in the present study, an interesting issue is the investigation of real grasping. By applying the present study's experimental design to examine grasping of a real object using the Ebbinghaus effect, the effect of the dual-task condition in size matching and real grasping can be compared. In the study by Singhal et al. (2007), grasping square objects was examined under the dual-task condition. They reported slow reaction and movement times and an increased peak grip aperture in the dual-task condition as compared with those in the single-task condition. Therefore, the effect of the dual-task condition on size illusion is also expected in real grasping. Such an investigation can add knowledge about how the ventral and dorsal streams function to execute perceptual-motor performances. I consider this examination as a next step and am preparing for it. Regarding another extension of the present study, the experimental design to investigate the size-illusion effect on cognition-based performance in the dual-task condition can be applied to different task conditions as reported in previous studies; for

example, using pointing movement developed for the Müller-Lyer figure (Hesse et al., 2016), controlling or eliminating visual feedback during execution of a movement (Franz et al., 2001; Heath, Westwood, Rival, & Neely, 2005), and using different types of secondary tasks (McNevin & Wulf, 2002; Wulf, Mercer, McNevin, & Guadagnoli, 2004). By accumulating information from these examinations, generalization of the finding about the attenuation of the illusion effect on cognition-based perceptual-motor performance by the dual-task condition can be achieved, thereby contributing to understanding the nature of attention and control of a task movement.

5. Conclusion

The illusory background of the Ebbinghaus figure induces size illusion about a target object. This incorrect perception in judging the object's size can be a source of failure in movement execution. If attention to perform a task movement is distracted from unwanted information, which causes the deterioration of performance by disturbing perceptual-motor processes to achieve a goal of movement, misperception and/or performance error can be avoided or reduced. I have investigated this hypothesis by examining size-illusion effect on the performance of size matching and pantomimed grasping. The illusion effect on the aperture size was attenuated under the dual-task condition, without scaling the aperture size according to the objects' sizes being disturbed, suggesting that the dual-task condition modulates attention on the aperture movement and is therefore achieved with less distraction caused by illusory information.

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Appendix A. Supplementary data

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References

- Aglioti, S., DeSouza, J. F. X., & Goodale, M. A. (1995). Size-contrast illusions deceive the eye but not the hand. *Current Biology*, 5, 679–685.
- Cameron, B. D., Franks, I. M., Enns, J. T., & Chua, R. (2007). Dual-target interference for the 'automatic pilot' in the dorsal stream. *Experimental Brain Research*, 181(2), 297–305.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). New York: Academic Press.
- Cohen, J. (1992). A power primer. *Psychological Bulletin*, 112(1), 155–159.
- Danckert, J. A., Sharif, N., Haffenden, A. M., Schiff, K. C., & Goodale, M. A. (2002). A temporal analysis of grasping in the Ebbinghaus illusion: Planning versus online control. *Experimental Brain Research*, 144, 275–280.
- Franz, V. H. (2003). Manual size estimation: A neuropsychological measure of perception? *Experimental Brain Research*, 151, 471–477.
- Franz, V. H., Fahle, M., Bühlhoff, H. H., & Gegenfurtner, K. R. (2001). Effects of visual illusions on grasping. *Journal of Experimental Psychology: Human Perception and Performance*, 27, 1124–1144.
- Franz, V. H., Gegenfurtner, K. R., Bühlhoff, H. H., & Fahle, M. (2000). Grasping visual illusions: No evidence for a dissociation between perception and action. *Psychological Science*, 11(1), 20–25.
- Goffaux, V., & Rossion, B. (2006). Faces are “spatial” - Holistic face perception is supported by low spatial frequencies. *Journal of Experimental Psychology: Human Perception and Performance*, 32, 1023–1039.
- Goh, H. T., Gordon, J., Sullivan, K. J., & Winstein, C. J. (2014). Evaluation of attentional demands during motor learning: Validity of a dual-task probe paradigm. *Journal of Motor Behavior*, 46(2), 95–105.
- Greenwald, A. G., & Shulman, H. G. (1973). On doing two things at once: Elimination of the psychological refractory period effect. *Journal of Experimental Psychology*, 101(1), 70–76.
- Haffenden, A. M., & Goodale, M. A. (1998). The effect of pictorial illusion on prehension and perception. *Journal of Cognitive Neuroscience*, 10(1), 122–136.
- Haffenden, A. M., Schiff, K. C., & Goodale, M. A. (2001). The dissociation between perception and action in the Ebbinghaus illusion: Nonillusory effects of pictorial cues on grasp. *Current Biology*, 11, 177–181.
- Heath, M., Westwood, D. A., Rival, C., & Neely, K. (2005). Time course analysis of closed- and open-loop grasping of the Müller-Lyer illusion. *Journal of Motor Behavior*, 37, 179–185.
- Hesse, C., Franz, V. H., & Schenk, T. (2016). Pointing and anti-pointing in Müller-Lyer figures: Why illusion effects need to be scaled. *Journal of Experimental Psychology: Human Perception and Performance*, 42(1), 90–102.
- Jacoby, O., Kamke, M. R., & Mattingley, J. B. (2013). Is the whole really more than the sum of its parts? Estimates of average size and orientation are susceptible to object substitution masking. *Journal of Experimental Psychology: Human Perception and Performance*, 39(1), 233–244.
- Jeannerod, M. (1981). Intersegmental coordination during reaching at natural visual objects. In J. Long, & A. Baddeley (Eds.), *Attention and performance* (pp. 153–168). Hillsdale, NJ: Erlbaum.
- Jeannerod, M. (1984). The timing of natural prehension movements. *Journal of Motor Behavior*, 16, 235–254.
- Lee, J. H., & van Donkelaar, P. (2002). Dorsal and ventral visual stream contributions to perception-action interactions during pointing. *Experimental Brain Research*, 143, 440–446.
- Leek, E. C., Roberts, M., Oliver, Z. J., Cristino, F., & Pegna, A. J. (2016). Early differential sensitivity of evoked-potentials to local and global shape during the perception of three-dimensional objects. *Neuropsychologia*, 89, 495–509.
- McNevin, N. H., & Wulf, G. (2002). Attentional focus on supra-postural tasks affects postural control. *Human Movement Science*, 21(2), 187–202.
- Millodot, M. (2008). *Dictionary of optometry and visual science* (7th ed.). UK: Elsevier Health Sciences.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9(1), 97–113.
- Pavani, F., Boscagli, I., Benvenuti, F., Rabuffetti, M., & Farnè, A. (1999). Are perception and illusion affected differently by the Titchener circles illusion? *Experimental Brain Research*, 127, 95–101.
- Plewman, T., Weidner, R., & Fink, G. R. (2012). The influence of stimulus duration on visual illusions and simple reaction time. *Experimental Brain Research*, 223, 367–375.
- Schmidt, R. A., & Lee, T. D. (2011). *Motor control and learning: A behavioral emphasis*. Champaign, IL: Human Kinetics.
- Singhal, A., Culham, J. C., Chinellato, E., & Goodale, M. A. (2007). Dual-task interference is greater in delayed grasping than in visually guided grasping. *Journal of Vision*, 7(5) 5, 1–12.
- Wulf, Gabriele, Mercer, John, McNevin, Nancy, & Guadagnoli, Mark A. (2004). Reciprocal influences of attentional focus on postural and suprapostural task performance. *Journal of Motor Behavior*, 36(2), 189–199. <https://doi.org/10.3200/JMBR.36.2.189-199>.