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Grasping and Manual Estimation of the Muller-Lyer Illusion at Different Exposure Times

Samik Doshi*

The two-stream model of visual processing describes a distinction between vision for ‘perception’ and vision for ‘action’. The inability of visual illusions (for example, the Ebbinghaus illusion) to affect grasping actions despite affecting manual estimation has been used as evidence in support of this model, but there remains disagreement about the phenomenon. Moreover, it is unclear how long it takes the brain to process visual illusory information for both grasping and perception. The present study explores these temporal dynamics in the context of the Muller-Lyer illusion. Participants were presented with rectangular objects surrounded by Muller-Lyer illusory wings on a screen for either 50 or 1500 ms, after which visual feedback was removed. In grasping conditions, participants proceeded to reach out and pick up the object, and in perception conditions participants used their thumb and index fingers to indicate the size of the object. Our data show that grasping (maximum grip aperture) was not affected by the Muller-Lyer illusion regardless of exposure duration but manual estimation was affected only after a long exposure duration. This suggests the existence of a threshold above 50ms at which the perceptual system begins to integrate stimulus information with surrounding contextual information. Additionally, the inability of the Muller-Lyer illusion to affect prehension and not estimation provides further evidence for the two-stream model of visual processing.

Researchers have developed a strong case for the hypothesis that visual processing is the work of separate streams in the primate cerebral cortex. Melvyn Goodale and David Milner proposed what now is a standard model of visual processing that divides the system into two streams, one for perception and one for the control of action (what vs. how processing) (Goodale & Milner, 2006). Evidence for this dissociation has come largely from patients with selective brain lesions, neuroimaging, and neurophysiology (Kroliczak, Heard, Goodale, & Gregory, 2006). The ventral stream allows us to perceive the visual world as it is and store it in our memory, while the dorsal stream operates in real time, and allows us to guide our actions that depend on vision (Goodale & Milner, 2006). While the two streams may interact, it is the ventral stream that is mainly concerned with object shape and identification, whereas the dorsal stream has the purpose of planning and controlling visually guided actions (Goodale, Westwood, & Milner, 2004).

Many studies have shown the inability of visual illusions to affect grasping accuracy as much as they affect perception (Aglioti, DeSouza, & Goodale, 1995; Haffenden & Goodale, 1998), supporting the two-streams hypothesis. The Müller-Lyer illusion – in which the length of two identical lines appears to be different depending on the orientation of the wings attached to their ends (inward vs. outward) – is one particular visual illusion that has been used in quite a few demonstrations (e.g. Bruno, Bernardis, & Gentilucci, 2008). Even though evidence has been presented with visual illusions such as the Ebbinghaus illusion, there remains disagreement about this idea of division of visual processing and its evidence in grasping visual illusion studies. For example, various studies have found results that show grasping and perception both being affected by visual illusion (Franz, Gegenfurtner, Bulthoff, &

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Fahle, 2000; Franz, 2001; Pavani, Boscagli, Benvenuti, Rabuffetti, & Farnè, 1999). According to Franz & Gegenfurtner (2008), results that are congruent with the two-streams hypothesis may be products of different experimental measures used (i.e., experimental artifacts), and it is likely that a single image representation is used for both processing systems.

Studying the temporal dynamics of grasping and perception, particularly in the context of visual illusions, is relevant to understanding how the brain processes visual information. Previous research with magnetoencephalography (MEG) using the Müller-Lyer illusion found that in perceiving the illusion, activations in the early visual areas occur between 85 and 130 ms after stimulus presentation, and more lasting activations occur deeper in the ventral stream at approximately 200 ms (Weidner, Boers, Mathiak, Dammers, & Fink, 2009). The present study aimed to further explore the temporal dynamics of the Müller-Lyer illusion to observe the effect of illusory elements when presented for different durations. There is evidence that 'vision for action' has quicker access to visual information than 'vision for perception' (Pisella, Arzi, & Rossetti, 1998). In a recent study, de Wit, van der Kamp, and Masters (2011) tested for the existence of two separate visual time thresholds that correspond to each processing stream. In a pointing task, it was found that when the exposure time of the stimulus (12 ms) was shorter than the suggested perception threshold but greater than the suggested action threshold, movements were calibrated to the real size, not the perceived size, of the target in the context of the Müller-Lyer illusion. The purpose of the present project was to use a paradigm similar to that used in De Wit's study to test the effect of different exposure times of the Müller-Lyer illusion on grasping and manual estimation.

In particular, we hoped to answer the following question to elucidate the neural processing underlying the Müller-Lyer illusion, by performing a grasping and manual estimation experiment: Is there a temporal threshold for the perceptual system at which the illusory elements depicted by the Müller-Lyer illusion begin to be integrated with object information? If such a threshold exists and it is higher than the threshold for 'vision for action', one would expect to observe an effect of the visual illusion on manual estimation (i.e. perceived line length would be affected by illusory "wings") for long but not short exposure durations of the illusory elements. In contrast, grasping should not be affected by the illusion regardless of exposure duration of illusory elements; visually guided actions such as grasping rely on more reliable distance cues, such as vergence, in computing the perceived size of objects. Vergence is the process by which the lines of vision of each eye either converge or diverge to accommodate a change in distance of an object, which is changing in grasping but not perception tasks. It is conceivable that under short exposure durations, this vergence information is present and consequently allows accurate grasping.

To summarize, this study explored grasping and manual estimation tasks in the context of the Müller-Lyer illusion for short and long exposure conditions, to assess the temporal dynamics of the processing of visual information relevant to the illusion.

Methods

Participants

16 right-handed participants (average age 18.9; 4 males) took part in this study at the University of Western Ontario. Each participant was required to fill out the Edinburgh handedness questionnaire to ensure right-handedness in everyday activities (Oldfield, 1971) and had normal or corrected-to-normal vision. Participants were unaware of the purpose of the study, and received a research credit for their participation in the study. Our methods were compliant with the rules and regulations of the University of Western Ontario Ethics Review Board.

Materials/Apparatus

Participants were seated on a height-adjustable chair in front of a 32 in. NEC multisync LCD monitor (1024 by 768 pixel resolution) screen tilted at 10 degrees above the plane of the floor. One of three different backgrounds was presented in the center at one time: outward wings, inward wings, or parallel lines perpendicular to the grasping motion (see Figure 1). The outward and inward backgrounds generated the Müller-Lyer illusion, while the parallel line background represented a control condition. The backgrounds were red lines on a grey background, and shaft stimuli were physically laid on the center of the screen. The lines that made the wings were 1.5 cm wide and 6.5 cm long. Six red, opaque, rectangular block objects were used as shaft stimuli, each with different dimensions but constant surface area and depth (see Figure 2). Two objects (6.0x2.0 cm and 4.0x3.0 cm) were the focus of the analysis and represented 60/84 trials in a block. The other four objects (3.5x3.4 cm, 4.5x2.7 cm, 4.8x2.5 cm, and 5.0x2.4 cm) represented catch objects that inhibited the learning and/or memory effects associated with the 6.0 and 4.0 height objects. As was done in a study by Brown, Halpert, and Goodale (2005), surface area of the objects was held constant to ensure that brightness was not used as a means for size discrimination.

To begin all trials, participants pressed down on a black response button that was centered in the left-right direction and was embedded in a metal fixture between the screen and the participant.

PLATO goggles (Translucent Technologies, Toronto, ON, Canada) were worn by participants through all trials in order to vary stimulus/illusion viewing duration and allow open-loop grasping and estimation (no visual feedback while making the motion/judgement). Participant hand position and other trajectory data were recorded using an Optotrak 3D motion-analysis system (Northern Digital, Waterloo, ON, Canada) that determined the spatial position of three infrared emitting diodes (IREDs) placed on the index finger, thumb and the back of the hand. Optotrak recorded data at 100 Hz. IREDs were secured to the hand by tape. Sounds were played through an Altec Lansing computer speaker system.

Procedure

At the beginning of each testing session, participants were asked to place a stimulus object in what they perceived to be the horizontal and vertical center of a Müller-Lyer neutral condition illusion. Tape was placed on the screen in this spot in order to calibrate the location of the center of the illusion from the point of view of the participant.

Trials would be started only if the participant was pressing down on the starting button with the thumb and index fingers pinched together. At the beginning of a grasping trial, the PLATO goggles became transparent for either 50 or 1500 ms, during which the participant viewed the Müller-Lyer illusory wings in 2d and the shaft in 3d. Following the exposure period, a visual mask was displayed for 50 ms to remove any iconic memory effects. After the mask, a computerized sound (1000 Hz frequency, 100 ms duration) was played from the speakers. The sound was the signal for the participant to reach out and grasp (by its length as shown in Fig. 3) the object that represented the shaft of the illusion. The time between the auditory cue and the release of the button represented the reaction time of the participant. Once the button was released, the goggles returned to their opaque state such that the grasping was performed in open-loop (to prevent on-line grip aperture control) (Haffenden & Goodale, 1998). The participant was asked to grasp naturally. He or she picked up and placed the object back down, and returned to the start button (see Figure 3). In manual estimation trials, the same procedure was used, but upon button release, participants were instructed to adjust the separation between the index finger and thumb of their right hand to match the size of the stimulus object. They performed this above the starting button, and created an opening that was aligned with the front-to-back axis. In addition, in one eighth of manual estimation trials, participants were asked to reach out and grasp the object after giving a manual estimation, in order to maintain haptic feedback (Haffenden & Goodale, 1998).

A custom designed Matlab program was used to control the order of goggle opening and closing, stimulus presentation, masking, and the sound signal. For grasping trials, Optotrak recorded for 4s (participants had 4 seconds to complete the trial) beginning with the opening of the goggles. For estimation trials, Optotrak was triggered manually once the participant had a steady estimation, and it recorded for 1000 ms.

Design

All sixteen participants performed tasks under binocular conditions. Each participant had one 84 trial block of grasping (split into two parts to allow a brief rest period) followed by one 84 trial block of manual estimation (also split into two parts to allow a brief rest period). In a testing block, there were 2 exposure durations (50 ms and 1500 ms), 2 objects (6.0 cm and 4.0 cm heights), and 3 illusory conditions (wings-in, wings-out, and parallel lines), with 5 repetitions per condition, for a total of 60 trials to be analysed. Each block was completely balanced (same number of trials with each object, same number of trials with each exposure duration, and same number of trials with each illusory condition). The remaining 24 trials were catch trials, using 4 different objects, the same two exposure durations, and the same three illusory conditions. The presentation of the trials followed a randomized order and did not include practice trials that were completed before each block began. To change the object between trials, an experimenter removed the object from the previous trial and replaced it with the object corresponding to the next trial. Illusory elements (i.e. the wings) were varied according to a pre-set order through Matlab. Each experimental session had a maximum duration of 60 minutes.

Data Analysis

Raw data of the X, Y, and Z positions of each IRED (as recorded by Optotrak) were analyzed using a customized software written in LabView (National Instruments, Newbury, UK). The beginning and end of grasping motions were quantified by cutting at points where the back-of-hand IRED reached a velocity of 40 mm/s, while manual estimation trials were not cut. The reaction time, peak velocity, and maximum grip aperture (MGA) of each trial were obtained and used for further analysis. The MGA was defined as the maximum distance between the thumb and index finger's IRED positions. A three-way analysis of variance (ANOVA) was carried out on the data with Object Length (6.0 cm vs. 4.0 cm), Exposure Duration (50 ms vs. 1500 ms), and Background Condition (inward wing vs. outward wing vs. null) as main factors. Multiple post-hoc comparisons were performed with a Bonferroni correction ($p < 0.05$).

Results

Figure 4 shows the mean maximum grip aperture (MGA) for each condition of the grasping task while Figure 5 shows the mean grip aperture for each condition of the manual estimation task.

For grasping trials, maximum grip aperture measurements were clearly affected by the object length ($F(1.15) = 172.769$, $p < 0.001$): shorter objects produced smaller MGAs than the longer objects. No significant effects were found for the main factors (Exposure Duration and Background), or their interaction (Fig. 4). For manual estimation trials, thumb-index aperture measurements for shorter objects were significantly smaller than those for longer objects, indicating that object length had an effect on manual estimates ($F(1.15) = 269.405$, $p < 0.001$). Significant differences were also found between background conditions ($F(1.15) = 8.681$, $p = 0.001$). More importantly, the interaction between Exposure Duration and Background Condition reached significance ($F(1.15) = 3.952$, $p < 0.030$). Post-hoc multiple comparisons revealed that manual estimations were significantly different between inward and outward conditions for both objects, and that manual estimations were significantly different between control and outward conditions for the longer object (Fig. 5). The results displayed in Figure 4 demonstrate that in grasping tasks, MGAs were scaled according to the real size of the object regardless of the surrounding context. This implies that MGAs were resistant to visual illusion for both short and long presentation to the illusory display. In contrast, results from

Figure 5 show that manual estimations were sensitive to visual illusions when the illusory elements were presented for a long exposure duration (1500 ms), suggesting that the visual illusion had a time-dependent effect on manual estimation.

Discussion

The present study was designed to determine if illusory conditions – as created by the Müller-Lyer illusion – exhibit a time-dependent effect on grasping and manual estimation tasks. In summary, our results were in agreement with our hypotheses: while grasping was not affected by the illusion regardless of exposure duration, manual estimation was affected by the illusion only when the illusory context and stimulus were viewed for a long duration. The results for grasping tasks were also congruent with the common finding in literature that grasping motions are insensitive to visual illusions. Even though both exposure durations used in the study were well above the proposed vision for action threshold (de Wit, van der Kamp, & Masters, 2011), action movements were always accurately calibrated to the real size of the object despite our manipulation of the surrounding context. A reasonable explanation for this result is that binocular information – in particular, vergence – provides reliable distance cues that allow participants to accurately perform reach-to-grasp movements (Loftus et al., 2004). Nevertheless, the theory of two streams of visual processing as well as the claim that action movements such as grasping are insensitive to visual illusion both have evidence contrary to them, and are therefore still controversial in literature (Bruno, 2001). However the results of the present study provide additional evidence to the argument that visual illusions do not affect prehension, suggesting that similar findings reported in the literature are not simply experimental "artifacts" (Bruno, 2001) and that there exists a dissociation between action and perception in the context of visual illusions.

The results from the manual estimation tasks were also in agreement with our hypothesis that the visual illusion would affect manual estimation only in a long exposure condition. Moreover, our findings are consistent with the results reported by de Wit et al. (2011). In their study they found that when the surrounding elements of the Müller-Lyer were presented above a "threshold" (the illusion was presented for 1500 ms in the long-exposure condition), perceptual reports were sensitive to the illusion. Given that in both de Wit et al. and our studies, perceptual judgments were only affected in the long exposure condition, the evidence strongly suggests that there is a threshold for the brain at which the perceptual system begins to integrate object/stimulus information with surrounding contextual information. Our data suggest that this threshold is higher than 50 ms. Consequently, for an exposure time lower than such a threshold, the perceptual system would not have enough time to process contextual cues and therefore manual estimation is not affected by the illusory elements of the Müller-Lyer illusion. Additional experiments, however, are necessary to determine more specifically the critical time window in which context and object information are integrated together to form size perception.

Further research is also needed to investigate the mechanisms behind size-distance integration in grasping and manual estimation tasks. One way to understand this process is to study behaviour without binocular cues that allow size-distance integration. Specifically, further experiments should answer the following question: are monocular perception and grasping more susceptible to visual illusion than binocular perception and grasping? Research in monocular grasping and estimation of object size has demonstrated that when binocular cues are not available, grasping is more affected by the Ebbinghaus (Titchener circles) illusion (Marotta, DeSouza, Haffenden, & Goodale, 1997). Moreover, it has been shown that in patients with visual form agnosia (and therefore cannot use pictorial cues to compute object distance), grip scaling accuracy is reduced under monocular viewing conditions, suggesting that binocular vergence cues are of primary importance to accurate action processing

(Marotta, Behrmann, & Goodale, 1997). Contrary to these results, Otto-de Haart, Carey, and Milne (1999) found that under monocular viewing conditions, matching performance (perception), but not grasping, was affected by visual illusion. The exploration of a monocular condition will hopefully allow researchers to further investigate the role played by binocular vs. monocular vision in both grasping and manual estimation, in conditions in which the exposure time of illusory elements is varied. In agreement with previous research and the two-streams hypothesis, it is predicted that under monocular viewing, grasping will be more vulnerable to the visual illusion for the long exposure than the short exposure. The lack of vergence and other binocular distance cues, combined with the fact that for long exposure the illusory elements will have been processed by the perceptual system, lead to this prediction.

While there remain open questions on the temporal dynamics of dorsal and ventral streams in the processing of visual illusions, the results from the present study suggest that there is a threshold above which the brain is able to integrate stimulus information with surrounding contextual cues.

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Appendix

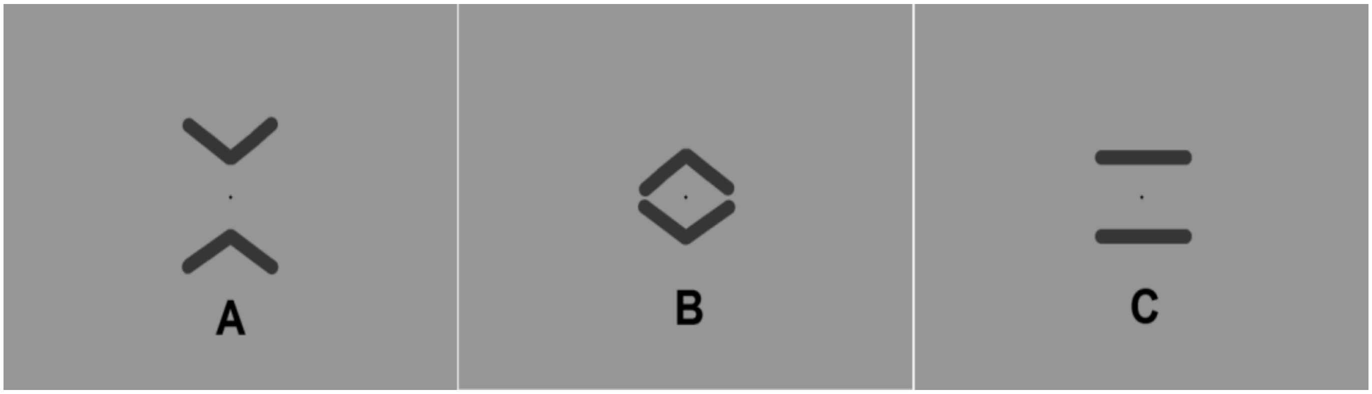

Figure 1. The outward wings (A), and inward wings (B) Muller-Lyer illusory backgrounds used in the study. A third background of parallel lines (C) was also used as a neutral condition. The illusory elements were all red lines on a grey background.

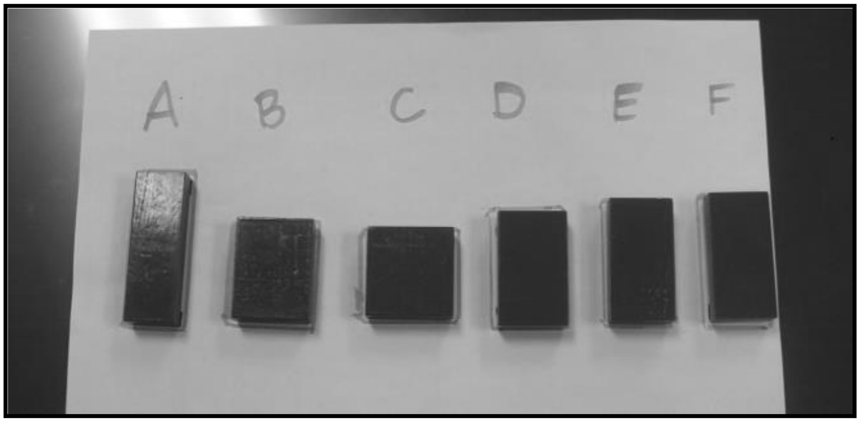

Figure 2. The six shaft stimuli that were placed in the center of the illusory backgrounds. The stimuli had heights of 6.0 cm (A), 4.0 cm (B), 3.5 cm (C), 4.5 cm (D), 4.8 cm (E), and 5.0 cm (F). Trials using objects A and B were analysed while trials using objects C to F represented catch trials. All stimuli had the same surface area.

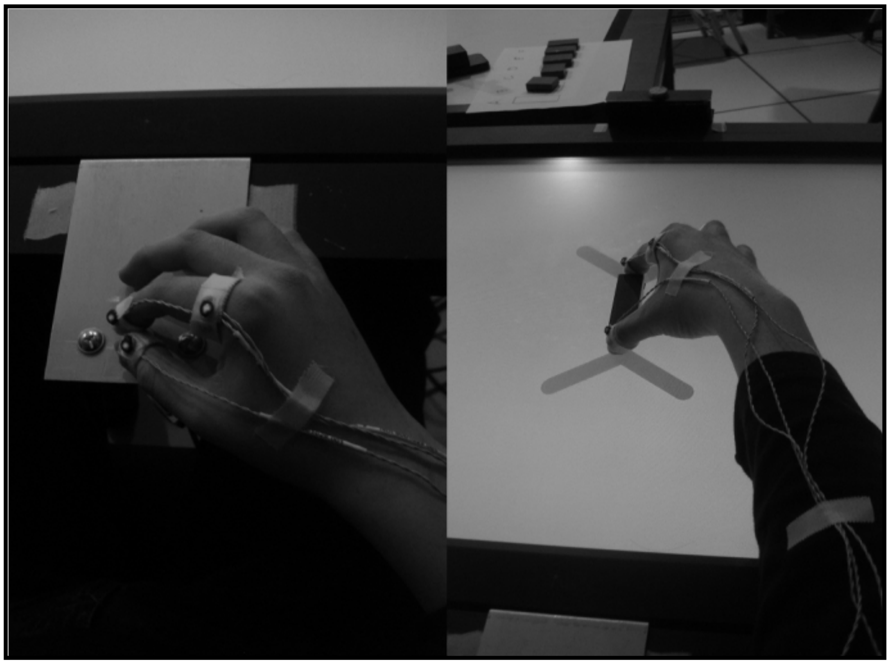

Figure 3. The procedure of a grasping trial. The starting position was the button on which the subject has pressed down. Once signalled to go, the subject reached outwards and grasped the stimuli shaft as shown. The subject then released the object and returned to the starting position (not shown). Note the infrared light-emitting diodes attached to the thumb and index fingers, and back of hand/bottom of index finger.

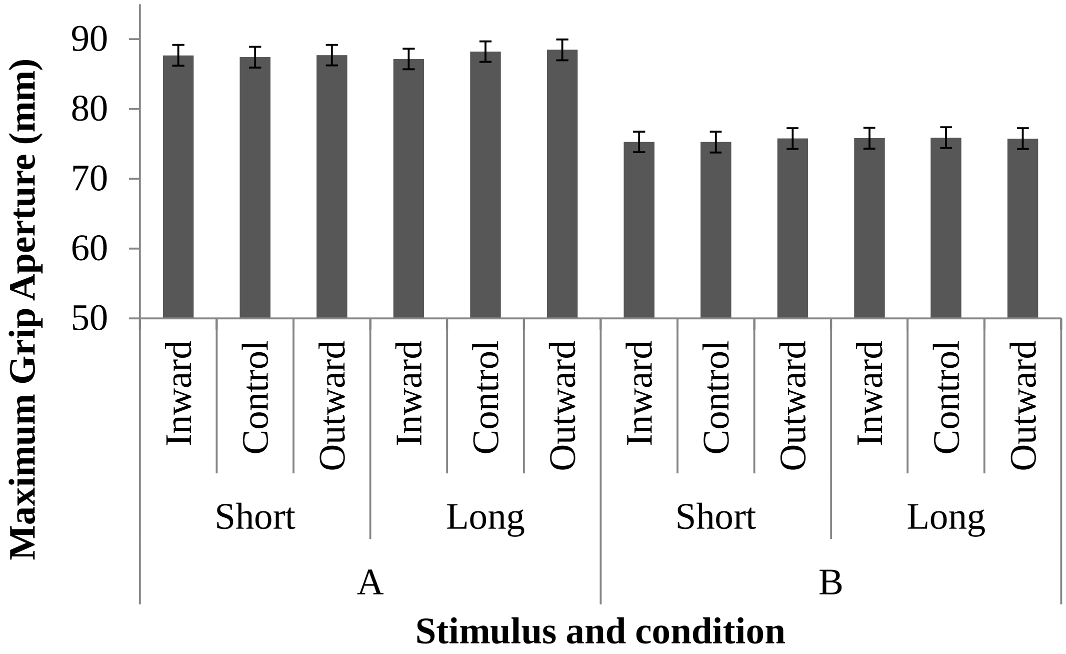

Figure 4. Mean maximum grip aperture measurements (± WSCI 95%, Loftus & Masson, 1994) in grasping motions for various objects, exposure durations, and background conditions. Lines between means with an asterisk above represent means that are significantly different (*P* < 0.05) according to post-hoc pairwise comparisons with Bonferonni correction.

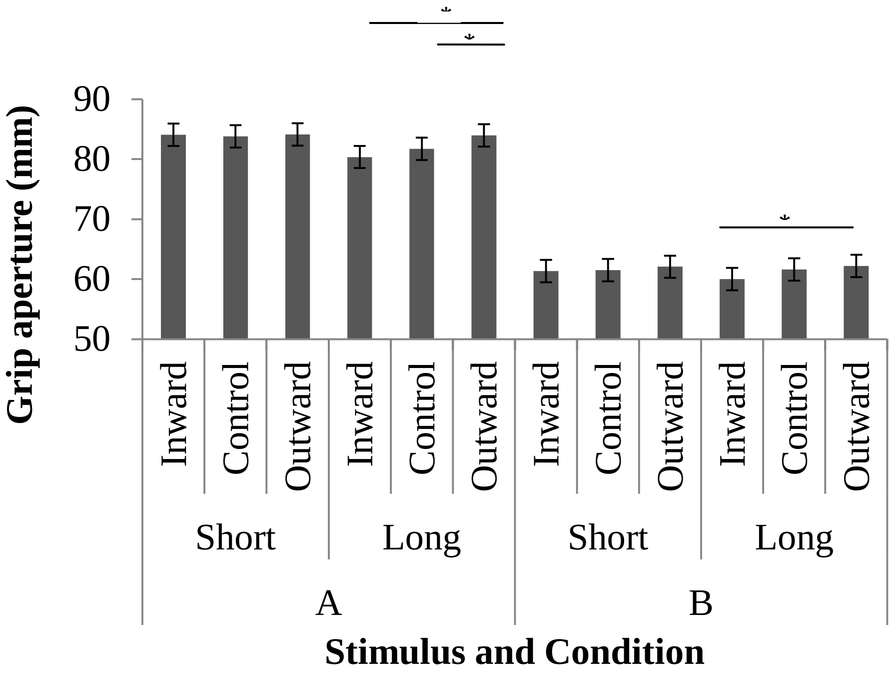

Figure 5. Mean grip aperture measurements (± WSCI 95%, Loftus & Masson, 1994) in manual estimation tasks for various objects, exposure durations, and background conditions. Lines between means with an asterisk above represent means that are significantly different (*P* < 0.05) according to post-hoc pairwise comparisons with Bonferonni correction.