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Cultural Differences in Visual Search for Geometric Figures

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Abstract

While some studies suggest cultural differences in visual processing, others do not, possibly because the complexity of their tasks draws upon high-level factors that could obscure such effects. To control for this, we examined cultural differences in visual search for geometric figures, a relatively simple task for which the underlying mechanisms are reasonably well known. We replicated earlier results showing that North Americans had a reliable search asymmetry for line length: search for long among short lines was faster than vice versa. In contrast, Japanese participants showed no asymmetry. This difference did not appear to be affected by stimulus density. Other kinds of stimuli resulted in other patterns of asymmetry differences, suggesting that these are not due to factors such as analytic/holistic processing, but are based instead on the target-detection process. In particular, our results indicate that at least some cultural differences reflect different ways of processing early-level features, possibly in response to environmental factors. (155 words)

Cultural Differences in Visual Search for Geometric Figures

Culture appears to affect human perception and cognition in various ways (see, for example, Doherty, Tsuji, & Phillips, 2008; Kitayama, Snibbe, Markus, & Suzuki, 2004; Markus & Kitayama, 1991; Nisbett, 2003; Nisbett & Masuda, 2003; Norenzayan, Choi, & Peng, 2007; Shweder, 1991; for a review, see Han & Northoff, 2008). Most of the studies that have reported cultural differences in visual perception (especially those involving visual attention) assume that these differences are similar to those in higher-level processes such as thinking and reasoning (Abel & Hsu, 1949; Chua, Boland, & Nisbett, 2005; Ji, Peng, & Nisbett, 2000; Kitayama, Duffy, Kawamura, & Larsen, 2003; Masuda, Gonzalez, Kwan, & Nisbett, 2008; Masuda & Nisbett, 2001). In this view, Westerners (e.g., Europeans or Americans) tend to use *analytic* (or *focused*) processing, analyzing attributes of a salient object independently of its context, and using generic rules about categories to explain and predict its behavior. In contrast, East Asians (e.g., Japanese or Chinese) are more likely to engage in *holistic* (or *diffused*) processing, analyzing the perceptual field as a whole, emphasizing relationships between objects and the contextual field in which they are located, and explaining events on the basis of such relationships.

However, reports of cultural differences in visual perception are not entirely consistent: studies applying the same procedure often fail to replicate (e.g., Caldara, Zhou, & Miellet, 2010; Evans, Rotello, Li, & Rayner, 2009; Rayner, Castelhano, & Yang, 2009; Rayner, Li, Williams, Cave, & Well, 2007). Interestingly, such studies tend to involve tasks such as scene memory (Masuda & Nisbett, 2001), eye movements (Chua et al., 2005), and face perception (Miyamoto, Yoshikawa, & Kitayama, 2011), where stimuli were relatively complex. Even when the stimuli were simple geometric objects, the tasks themselves tended to be quite complicated (Ji et al., 2000; Kitayama et al., 2003; Zhou, Gotch, Zhou, & Liu, 2008). For such tasks, it is easy to accumulate errors, leading to considerable noise. Moreover, because language can trigger cultural bias in perception (Lucy, 1992a, b), these tasks are also susceptible to bias via the instructions given to participants. Hence, to definitively assess the generality of cultural differences in perception and attention, what is needed are simple tasks that use simple stimuli.

The main goal of the current study is to determine whether cultural differences truly exist in visual perception, and in particular, in the allocation of visual attention. A secondary goal is to test whether the analytic/holistic distinction often used to explain cultural differences between Westerners and East Asians can also explain any differences found here.

To achieve the first goal, we employed visual search, where an observer must report a given *target* among several non-target (or *distractor*) items as quickly as possible. This is a relatively simple speeded task, enabling it to largely exclude the effects of conscious reasoning and explicit knowledge (see Shen & Reingold, 2001). In particular, we used a detection task, where observers judge whether the given target is present or absent in the display (e.g., Treisman & Gormican, 1988; Wolfe, 2012). This enables us to study two different criteria for search termination: in target-present trials search simply ends when the observers find the target, whereas in target-absent trials termination is based on strategic considerations involving accumulated information, set size, crowdedness, and clutter (Chun & Wolfe, 1996; Wolfe, 2012). If cultural differences are based largely upon differences in strategic judgments, these differences would likely show up to a greater extent in target-absent trials.

A potential confound in this approach is the motivation of the participant, which might influence search speed. To compensate, we focused on one particular aspect of behavior: *search asymmetry* (Saiki, Koike, Takahashi, & Inoue, 2005; Treisman & Gormican, 1988; Treisman & Sato, 1990; Wolfe, 2001). This is a phenomenon where search efficiency significantly changes when target and distractor items are swapped (for example, searching for a Q among Os is significantly more efficient than searching for an O among Qs). Although differences in motivation might affect *absolute* efficiency, they should not affect *relative* measures: an asymmetry should not appear or disappear for different motivations as long as the same items are used in all conditions.

To help achieve our second goal, we used the fact that an analytic/holistic account is theoretically independent of the nature of stimulus property. Thus, if cultural differences in visual search result from a different engagement of analytic/holistic processing, they should be invariant across different kinds of stimuli. To examine this possibility, various kinds of stimuli were used here. If the analytic/holistic distinction is always the main factor, the same patterns of search asymmetries should always be found. If not, differences should likely appear.

Another possible test of the analytic/holistic account involves the mechanisms believed to underlie visual search. To account for search asymmetry, Treisman and Gormican (1988) proposed a *pooled-response* model, in which observers pool the activities of multiple items in a spatial neighborhood; they then compare the pooled activity of the group of items that include the target against the pooled activity of groups that do not. Assuming that the difference in signal needed to detect the target is a fixed fraction of the background signal (Weber assumption), signals must be pooled over smaller neighborhoods when the background has a higher average value to make the signal difference large enough (which results in relatively slow search). In contrast, they could be pooled over larger neighborhoods when the background has a lower average value. If holistic processing correlates with greater pooling (e.g., via greater grouping), this mode of processing would be relatively disadvantageous for backgrounds with a higher average value. As such, a higher density of items could enable even more grouping, leading to faster search and even greater search asymmetry.

In Experiment 1, we use the classic paradigm of Treisman and Gormican (1988) with a culturally neutral property: line length and manipulated the stimulus densities of the displays. We find that whereas a strong asymmetry exists for Western participants, no such asymmetry is found for Japanese participants, regardless of stimulus density. In Experiment 2 we examine other well-known asymmetries: circle vs. circle with an intersecting line, and vertical vs. tilted orientations. If analytic/holistic processing is the central factor in all these tasks, the same patterns of asymmetry differences should appear. Instead, we find different patterns for different stimulus types. In Experiment 3, we examine whether these effects are due to differences in discriminability between targets and distractors. We find that they are not. Taken together, then, these results indicate that cultural differences in attentional processing do exist, at least some of which are not attributable to differences in the engagement of analytic/holistic processing, but instead likely reflect differences in how visual stimuli are encoded at relatively early levels.

Experiment 1

To investigate whether differences in search asymmetry exist between Western and Japanese observers, we began with search for line length. Treisman and Gormican (1988) showed that for Westerners, long lines among short lines are easier to find than vice versa. The first question then is therefore whether a similar asymmetry exists for Japanese observers. Since the criterion for search termination differs between target-present and target-absent trials (Chun & Wolfe, 1996; Wolfe, 2012), we analyzed both target-present and target-absent trials (planned comparison). We also manipulated the stimulus densities of the displays to encourage more grouping (and perhaps, more holistic processing).

In a pilot study, we repeated Treisman and Gormican's (1988) difficult condition of Experiment 1 using Japanese participants from Kyoto University and North American participants from Michigan University (n = 17 and n = 15 respectively). Results showed that North American participants had a reliable asymmetry for line length whereas Japanese participants did not, $\eta_p^2 = .20$. Based on a power analysis of these results, we decided on the sample size for the main series of experiments: n = 24 for each group in Experiment 1, and n = 16 for each group in Experiments 2 and 3.

Method

Participants. These comprised 25 native English speakers (North American-born and -raised) from the University of British Columbia, and 26 native Japanese speakers (Japanese-born and -raised) from Kyoto University. All reported having normal or corrected-to-normal vision. The North American and Japanese participants were paid CA$10 and JPN¥1000 respectively for the one-hour experiment.

Stimuli and apparatus. Stimuli were long and short vertical lines subtending a visual angle of 1.1° and 0.9° respectively. These were distributed in 4 × 4 invisible matrix centered on the screen. The search display was 13.8° wide × 8.1° high in the low-density condition, and 9.6° wide × 6.8° high in the high-density condition; density was therefore about 70% greater in the high-density condition.

Set sizes were 3, 6, or 12 items, with each item randomly assigned to a cell such that density was approximately constant. A target was present in a randomly-selected half of all trials. All items were white and presented on a black background (see Fig. 1).

------------------------------Insert Figure 1 about here ------------------------------

The task was generated using an Apple Macintosh OS 9 computer, using the VSearch software (Enns, Ochs, & Rensink, 1990). All items were presented on a 19-inch cathode ray tube (CRT) monitor in a dimly lit room. Participants were seated in front of the monitor at a viewing distance of 57 cm.

Procedure. Participants were asked to detect the presence of a target with a key press as quickly as possible, and to keep their error rates under 5%. In each trial, the search display remained visible until participants responded, followed by a blank screen lasting for 300 ms. After each trial, a feedback sign appeared that lasted 600 ms.

To equalize error rates across cultures, participants were asked to repeat a practice block if they made more than two mistakes in any one of the presence × set size conditions in a block, or if they made more than six mistakes overall. Accuracy and reaction time (RT) were also shown at the end of each block. If the error rate reached 10% or more, a warning was added to these messages.

The tests were divided into two equal sessions, each having two equal sub-sessions, each involving a different density condition. Thus, there was a total of 720 trials: two sessions (one for each target length) with 12 blocks per session (five experimental and one practice for each of the two sub-sessions), and 30 trials per block.

Results

The data of one North American participant and two Japanese participants were excluded because their error rates were over 15%.

Target-present trials. The results for target-present trials in Experiment 1 are shown in Fig. 2.

-----------------------------Insert Figure 2 about here ------------------------------

Reaction Times. A four-way (Culture × Density × Target type × Set size) analysis of variance (ANOVA) showed a significant interaction of density and set size, with shallower increases in RT with set size in the high-density condition than in the low-density condition, $F(2, 92) = 3.97$, $p = .022$, $\eta_p^2 = .08$. Furthermore, there was a significant interaction of cultural group, target type, and set size, $F(2, 92) = 4.80$, $p = .011$, $\eta_p^2 = .09$. For the Japanese group, there was no significant interaction between any two factors, $p > .05$. No significant difference was therefore found between search for longer and shorter lines in either density condition. For the North American group, in contrast, there was a significant interaction of target type and set size, $F(2, 46) = 14.92$, $p < .0001$, $\eta_p^2 = .39$, showing a strong search asymmetry in both density conditions.

Search slopes. Recasting RTs into search slopes, a three-way (Culture × Density × Target type) ANOVA showed a main effect of density, with slightly shallower slopes in the high-density condition (48.6 ms/item) than in the low-density condition (54.8 ms/item), $F(1, 46) = 5.26$, $p = .027$, $\eta_p^2 = .10$. Both Japanese and North American participants appeared to be equally affected by this. There was again a significant interaction of cultural group and target type, $F(1, 46) = 6.62$, $p = .013$, $\eta_p^2 = .13$, showing a clear asymmetry for North American (42.6 ms/item for long-line targets and 63.4 ms/item for short) but not Japanese participants (49.4 ms/item for long-line targets and 51.5 ms/item for short).

Error rates. A four-way (Culture × Density × Target type × Set size) ANOVA showed no significant interaction that included culture, $p > .05$.

Target-absent trials. The results for target-absent trials in Experiment 1 are shown in Fig. 3.

-----------------------------Insert Figure 3 about here ------------------------------

Reaction Times. The four-way ANOVA of mean RT showed that an interaction of density and set size was also significant in the target-absent condition, $F(2, 92) = 4.32$, $p = .016$, $\eta_p^2 = .09$. Furthermore, there was also a significant interaction of cultural group, target type, and set size, $F(2, 92) = 10.31$, $p = .0001$, $\eta_p^2 = .18$. Separate 2 (density) × 2 (target type) × 3 (set size) ANOVAs showed that for the Japanese group, there was no significant interaction of any two factors, $p > .05$, while for the North American group, there was a significant interaction of target type and set size, $F(2, 46) = 21.23$, $p < .0001$, $\eta_p^2 = .48$. As before, then, search asymmetries were not observed among Japanese participants in either density condition, but were for North American participants in both.

Search slopes. There was a significant effect of density on slopes, $F(1, 46) = 4.65$, $p = .036$, $\eta_p^2 = .09$, again suggesting that both Japanese and North American participants were affected. A significant interaction of cultural group and target type also appeared, $F(1, 46) = 11.59$, $p = .001$, $\eta_p^2 = .20$, showing search asymmetries (with shallower slopes in long-line search) for North American (97.1 ms/item for long lines vs. 138.4 ms/item for short lines) but not Japanese participants (119.5 ms/item for long lines vs. 121.4 ms/item for short lines).

Error rates. There was a main effect of target type, with lower error rates in searches for longer lines, $F(1, 46) = 8.03$, $p = .007$, $\eta_p^2 = .15$. For both target-present and target-absent trials, none of the interactions involved the factor of cultural group, suggesting that error rates did not reflect any differences between these groups.

Discussion

Experiment 1 showed a clear search asymmetry for North American participants but not for Japanese ones. This difference did not appear to be sensitive to stimulus density, although the absolute values of the slopes were affected. Scatterplots (Fig. 4) of individual performances indicate that most North American participants consistently showed asymmetry (more data points located above the orthogonal line) whereas Japanese participants did not in any of the conditions. Note that the lack of asymmetry in both density conditions (and for both target-present and target-absent trials) for Japanese participants indicates that they are likely not pooling over larger spatial neighborhoods (as might be suggested by a greater reliance on holistic processing), but using a different process entirely, one that does not rely on the Weber assumption.

------------------------------Insert Figure 4 about here -------------------------------

Experiment 2

If the cultural difference in search found in Experiment 1 is based exclusively on a differential engagement of analytic/holistic processing, Japanese participants should continue to show either no or small search asymmetry across different kinds of stimuli. Otherwise, a pattern of a different sort might be found.

Experiment 2 examined two types of stimuli: a circle vs. circle with an intersecting line (referred to here as "O vs. a reversed-Q"), and a vertical line vs. a tilted line. Previous work has shown that for Westerners, search for a circle with an intersecting line among circles is easier than vice versa (Treisman & Souther, 1985)[1], and Saiki (2008) and Saiki et al. (2005) showed a similar kind of asymmetry for Japanese participants. Westerners also show an asymmetry for a tilted line among vertical lines, with the vertical targets being more difficult to find (Treisman & Gormican, 1988). The question here is whether the degree of these asymmetries are the same in the two cultural groups.

Method

Participants. A group of 16 native English speakers (North American-born and -raised) from the University of British Columbia and a group of 16 native Japanese speakers (Japanese-born and -raised) from Kyoto University participated in Experiment 2. Payment was the same as for Experiment 1. All participants reported normal or corrected-to-normal vision.

Stimuli and apparatus. The O and reversed-Q stimuli subtended a maximum angle of 1.5° and 1.8° respectively. The angle of the intersecting line in the reversed-Q stimuli was 45° clockwise from the bottom (Fig. 5). For the orientation search stimuli, the vertical line

[1] Since the degree of asymmetry is smaller when the items are rotated to form "Qs" and "Os" (Rauschenberger & Yantis, 2006), we use the reversed forms here. The mirror-reversed version of 'Q' is also likely to have fewer cultural associations for Westerners than does the non-reversed version. Note that the letter 'O' is a common component of both targets and distractors, so that cultural (semantic) effects would be expected to be minimal here as well.

subtended a visual angle of 1.2°, and the tilted lines were formed by rotating this 15° clockwise. In all conditions, search items were distributed over an area 16.3° wide × 9.7° high. As before, set sizes were 3, 6, and 12 items. All were white and presented on a black background (see Fig. 5).

-----------------------------Insert Figure 5 about here ------------------------------

At Kyoto University, the task environment was created with Windows XP, using MATLAB software with the Psychophysics Toolbox extension and all items were presented on a 21-inch CRT monitor. At the University of British Columbia, the task environment was created with Apple Macintosh OS 9, using VSearch (Enns, Ochs, & Rensink, 1990) and all items were presented on a 19-inch CRT monitor. Experiments were conducted in a dimly lit room in both locations.

Procedure. At the beginning of each trial, a blank display was shown for 400 ms, followed by the search display, which remained visible until participants responded. After completion of a trial, a feedback sign appeared lasting 2000 ms.

Each test condition was divided into four blocks of 36 trials, which were preceded by 12 trials for practice. This resulted in a total of 624 trials for each participant.

Results

No participants' data were excluded, with all error rates being under 5%.

Target-present trials. The results for target-present trials in Experiment 2 are shown in Fig. 6.

-----------------------------Insert Figure 6 about here ------------------------------

Reaction Times. For the O vs. reversed-Q, a three-way (Culture × Target type × Set size) ANOVA showed a marginally significant interaction of cultural group, target type, and set size, $F(2, 60) = 2.39$, $p = .10$, $\eta_p^2 = .07$. For the Japanese group, there was a significant interaction of target type and set size, $F(2, 30) = 4.93$, $p = .014$, $\eta_p^2 = .25$, replicating the findings of Saiki (2008) and Saiki et al. (2005). For the North American group, this interaction was even stronger, $F(2, 30) = 16.67$, $p < .0001$, $\eta_p^2 = .53$, indicating that the degree of search asymmetry was larger.

For the vertical vs. tilted lines, a three-way ANOVA showed a significant interaction of cultural group, target type, and set size, $F(2, 60) = 3.17$, $p = .049$, $\eta_p^2 = .10$. For the Japanese group, there was a significant interaction of target type and set size, $F(2, 30) = 23.58$, $p < .0001$, $\eta_p^2 = .61$. For the North American group, this interaction was also highly significant, but not as strong, $F(2, 30) = 9.73$, $p = .0006$, $\eta_p^2 = .39$.

Search slopes. For the O vs. reversed-Q, a two-way (Culture × Target type) ANOVA showed a significant interaction of cultural group and target type, $F(1, 30) = 5.81$, $p = .022$, $\eta_p^2 = .16$. There was a strong search asymmetry among North American participants (2.5 ms/item for reversed-Q search vs. 18.1 ms/item for O search)[2], one much larger than that of the Japanese participants (4.9 ms/item for reversed-Q search vs. 12.2 ms/item for O search).

For the vertical vs. tilted lines, there was likewise a significant interaction of cultural group and target type, $F(1, 30) = 4.80$, $p = .036$, $\eta_p^2 = .14$. However, Japanese participants (5.7 ms/item for tilted vs. 46.3 ms/item for vertical lines) now showed a much larger asymmetry—at least in terms of slope differences—than North American participants (0.8 ms/item for tilted vs. 22.0 ms/item for vertical lines).

Error rates. For the O vs. reversed-Q, a three-way (Culture × Target type × Set size)

[2] These slopes and reaction times were closer to those for the circle and circle with vertical line search rather than the circle and circle with 45° counter-clockwise line (namely "O" and "Q"), consistent with the findings of Rauschenberger & Yantis (2006). These results also support the suggestion that the mirror-reversed version of "Q" has fewer cultural associations for Westerners and so cultural semantic effects would be less. However, we cannot conclude this categorically since our experimental settings were a little bit different from the previous study.

ANOVA showed main effects of culture, $F(1, 30) = 5.24$, $p = .029$, $\eta_p^2 = .15$, with lower error rates in searches for Japanese (0.65%) than for North American participants (1.87%). No other interactions concerning culture were significant.

For the vertical vs. tilted line stimuli, no main effects or interactions concerning culture were significant.

Target-absent trials. The results for target-absent trials in Experiment 2 are shown in Fig. 7.

-----------------------------Insert Figure 7 about here ------------------------------

Reaction Times. For the O vs. reversed-Q, a three-way ANOVA showed a significant interaction of target type and set size, $F(2, 60) = 45.70$, $p < .0001$, $\eta_p^2 = .45$, indicating that the RT increase with set size is smaller in reversed-Q search than O search. However, there was no significant interaction that included culture, $p > .05$.

For the vertical vs. tilted lines stimuli, the three-way ANOVA showed a marginally significant interaction of culture, target type, and set size, $F(2, 60) = 3.12$, $p = .051$, $\eta_p^2 = .09$. Through separate 2 (target type) × 3 (set size) ANOVAs, we found a larger search asymmetry for the Japanese participants than for the North American participants, $F(2, 30) = 39.96$, $p < .0001$, $\eta_p^2 = .73$ and $F(2, 30) = 29.67$, $p < .0001$, $\eta_p^2 = .66$, respectively.

Search slopes. For the O vs. reversed-Q, there was a significant effect of target type, $F(1, 30) = 53.85$, $p < .0001$, $\eta_p^2 = .64$, with shallower slopes for reversed-Q search (6.2 ms/item) than for O search (47.2 ms/item), but the interaction of cultural group and target type was not significant, $F < 1$.

For the vertical vs. tilted lines stimuli, there were likewise significant effects of target type, $F(1, 30) = 81.79$, $p < .0001$, $\eta_p^2 = .73$, with shallower slopes for tilted line search (19.3 ms/item) than for vertical line search (78.6 ms/item). There was also a marginally significant interaction of cultural group and target type, $F(1, 30) = 3.58$, $p = .068$, $\eta_p^2 = .11$, showing that search asymmetries among Japanese participants were larger than among North American participants.

Error rates. For the O vs. reversed-Q, there was a main effect of culture, $F(1, 30) = 7.45$, $p = .011$, $\eta_p^2 = .20$, with lower error rates in searches by Japanese (0.22%) than North American participants (1.17%).

For the vertical vs. tilted line condition, there were no significant main effects or interactions.

Discussion

The results of Experiment 2 showed that different stimulus types yielded different kinds of search asymmetry difference: the O vs. reversed-Q gave rise to larger asymmetries for Westerners (North Americans), whereas the vertical vs. tilted lines gave rise to larger asymmetries for East Asians (Japanese). Although a main effect of cultural group on error rates was observed in the O vs. reversed-Q set, any interactions that included cultural group were not statistically significant. Moreover, this main effect was observed in both target-present and target-absent trials but a cultural difference in search asymmetry was observed only in target-present trials, suggesting that the asymmetry difference observed in the O vs. reversed-Q stimuli may not be due to a general speed-accuracy trade-off. (Otherwise, this difference might also have been observed in target-absent trials.)

Since this is a within-observer design, we could compare the degree of asymmetry of individual observers (characterized by difference in slopes) between the two tasks. Analysis revealed that degrees of asymmetry were not correlated in target-present trials, $r(30) = .04$, $p = .81$, but were in target-absent trials, $r(30) = .51$, $p = .003$. These results suggest that processes underlying the two search tasks are independent in target-present trials, while the same criterion may be used in target-absent trials[3], supporting the view that the process of search termination differs between target-present and target-absent trials (Chun & Wolfe, 1996; Wolfe, 2012).

An analysis of individual slopes (Fig. 8) indicates that in the target-present trials of the O vs. reversed-Q search the data points of North American participants were further away from the diagonal line than those of Japanese participants (Fig. 8A). For the vertical/tilted line search, however, the data points of Japanese participants were further away from the diagonal line (Fig. 8C).

The different patterns of asymmetry for the different types of stimuli further support the proposal that simple analytic-/holistic-based accounts of search asymmetry cannot explain the results. Instead, the cultural differences found here would appear to depend on stimulus properties.

-----------------------------Insert Figure 8 about here ------------------------------

Experiment 3

One possible explanation of the results found here is the discriminability of the target and distractors. The Japanese observers in Experiment 1 may have engaged in a slow, serial item-by-item search due to the relatively small differences in length involved, and thus shown no asymmetry. In Experiment 2, however, stimuli were more discriminable (as shown by faster reaction times there), and Japanese observers showed asymmetry. If discriminability is responsible, asymmetry should then appear in Japanese observers even for line length search when target-distractor discriminability is sufficiently high.

To investigate this possibility, we tested Japanese participants on the low-density

[3] Similar results were observed in a different experiment, which was presented in the Conference of Vision Sciences Society by the first author (Ueda, Kurosu, & Saiki, 2015).

condition of Experiment 1, but with stimuli that had a larger difference in length. Following the setup of Treisman and Gormican (1988), we used lines subtending visual angles of 1.1° and 0.7°. (Treisman and Gormian (1988) found a strong asymmetry for Westerners for these: 7.6 ms/item for longer targets vs. 14.3 ms/item for shorter ones.) If the lack of search asymmetry for Japanese participants is due to poor discriminability, search asymmetry should now be observed.

Method

Participants. A total of 16 native Japanese speakers (Japanese-born and -raised) from Kyoto University participated in this experiment. All reported normal or corrected-to-normal vision and none had participated in Experiments 1 or 2.

Stimuli and apparatus. Stimuli were long and short vertical lines subtending a visual angle of 1.1° and 0.7° respectively. Other settings, such as the visual angle of the search display and set size, were the same as for the low-density condition of Experiment 1.

The task was generated on an Apple Macintosh OS X computer, using MATLAB with the Psychophysics Toolbox extension. All items were presented on a 21-inch CRT monitor in a dimly lit room. Participants were seated in front of the monitor at a viewing distance of 57 cm.

Procedure. At the beginning of each trial, a blank display was shown for 400 ms, followed by a search display that remained visible until participants responded. After completion of a trial, a feedback sign appeared lasting 2000 ms.

Each test condition was divided into four blocks of 36 trials, which were preceded by 12 practice trials. This resulted in a total of 312 trials for each participant.

Results

No participants' data were excluded, with all error rates being under 5%.

Target-present trials. The results for target-present trials in Experiment 3 are shown in Fig. 9.

-----------------------------Insert Figure 9 about here -------------------------------

Reaction Times. A two-way (Target type × Set size) repeated-measures ANOVA showed a significant main effect of set size, with RTs increasing with set size, $F(2, 30) = 77.24$, $p < .0001$, $\eta_p^2 = .84$. However, there was no significant main effect of target type or interaction of target type and set size, $p > .05$, demonstrating that there was no search asymmetry for Japanese participants even with a larger difference in line lengths.

Search slopes. A one-sample ANOVA showed no significant main effect of target type, indicating that there was no search asymmetry (13.5 ms/item for long line search and 15.5 ms/item for short line search), consistent with the RT results, $p > .05$.

Error rates. A two-way (Target type × Set size) ANOVA exhibited a main effect of set size, showing that error rates increased with set size, $F(2, 30) = 7.54$, $p = .002$, $\eta_p^2 = .33$, and a marginally significant interaction between target type and set size, $F(2, 30) = 2.89$, $p = .071$, $\eta_p^2 = .16$. However, separate one-sample (target type) ANOVAs showed that there was no significant difference in error rate at any set size, Fs $(1, 15) < 3.00$, $p > .10$, indicating that the results were not due to a speed-accuracy trade-off.

Target-absent trials. The results for target-absent trials in Experiment 3 are presented in Fig. 10.

-----------------------------Insert Figure 10 about here -------------------------------

Reaction Times. A two-way (Target type × Set size) ANOVA showed significant main effects of target type, with RTs less for longer-line search than for shorter-line search, $F(1, 15) = 5.07$, $p = .040$, $\eta_p^2 = .25$. It also showed significant main effects of set size, with RTs increasing with set size, $F(2, 30) = 45.26$, $p < .0001$, $\eta_p^2 = .75$. There was also a significant interaction of target type and set size, $F(2, 30) = 5.98$, $p = .007$, $\eta_p^2 = .28$, suggesting that search asymmetry was observed only in the target-absent trials.

Search slopes. A one sample ANOVA showed a main effect of target type, with a shallower slope when participants searched for longer lines (33.7 ms / item) than shorter ones (47.4 ms / item). This difference was significant, $F(1, 15) = 6.88$, $p = .019$, $\eta_p^2 = .31$.

Error rates. A two-way (Target type × Set size) ANOVA did not show any significant main effects or interactions, $p > .05$.

Discussion

In spite of the much greater discriminability of items (indicated by the shallower search slopes), the results of Experiment 3 largely replicated those of Experiment 1: for target-present trials, search asymmetry for line length was not observed for Japanese participants. In a post-hoc analysis, we conducted a three-way (Experiment × Target type × Set size) ANOVA of RTs of Japanese participants in Experiments 1 (low-density condition) and 3. A significant main effect of Experiment was found, $F(1, 38) = 61.02$, $p < .0001$, $\eta_p^2 = .62$, indicating that RTs in Experiment 3 were significantly shorter overall than in Experiment 1, consistent with increased discriminability. As such, these results indicate that the results for Japanese participants are not limited to a particular line length, and are not due to poor discriminability. Interestingly, the target-absent trials do reveal a search asymmetry. The scatterplot in Fig. 10C shows that—in contrast to the corresponding condition in Experiment 1—many observers had steeper slopes for the shorter-line search. These results suggest that search asymmetry for line length in the target-absent trials can be observed for Japanese participants when stimuli are easily discriminated. The difference between these results and those for target-present trials may again reflect (as do the results of Experiment 2) a difference in the mechanisms used for the two kinds of search termination (Chun & Wolfe, 1996; Wolfe, 2012).

General Discussion

This study demonstrated two things. First, visual search—and in particular, search asymmetry—can differ significantly between Western (North American) and East Asian (Japanese) observers, even when search items involve only relatively simple geometric properties; among other things, this suggests that the processes underlying visual search may not be culturally neutral. Second, our results strongly suggest that the analytic/holistic distinction often used to explain cultural differences does not suffice to explain all cultural influences on visual perception—differences in other mechanisms must also be involved. In particular, our results suggest that the differences found here are not due to differences in general processing strategy or simple discriminability. An interesting possibility is that they may be due to differences in the coding of visual stimuli at relatively early levels of processing.

Differences in Visual Search

Experiment 1 showed that North Americans exhibit significant asymmetry for line length, whereas Japanese do not. This difference was robust against changes in display density, and thus unlikely to be due to differences in the grouping of items or the pooling of their activities. These conclusions were reinforced by the results of Experiment 2, where the direction of the asymmetry difference depended on the particular type of stimulus used: North American participants exhibited larger asymmetries in search for a circle vs. a circle with line, whereas Japanese participants exhibited larger asymmetries in search for a vertical line vs. a tilted line. Finally Experiment 3 showed that when the target was present, the Japanese group did not exhibit search asymmetry for line length even when the discriminability of targets and distractors was much higher.

This is the first report of cultural differences in visual search with geometric items that differ only in a simple property (length). Unlike previous work (Malinowski & Hübner, 2001; Shen & Reingold, 2001), we did not use items with meanings that differ between cultures (e.g., Chinese characters). As such, our results cannot be accounted for by the effects of explicit knowledge. And because our task is highly perceptual in nature, our results are unlikely to be due to differences in memory, decision making, or conscious strategy selection. These differences appear to be quite robust across experiments in target-present search. To explain them by differences in motivation or any other strategic effect, we would have to assume that the Japanese participants varied in motivation for different conditions (including target-present and target-absent trials) and that North American participants also varied in motivation, but differently for different kinds of stimuli. Such an assumption appears unlikely.

Interestingly, asymmetry differences were far less striking in target-absent search. For line length, Experiment 1 showed virtually no asymmetries for Japanese participants, whereas Experiment 3 exhibited clear ones. In contrast, North American participants consistently demonstrated strong asymmetry for line length in all conditions. Perhaps even more importantly, cultural differences largely disappeared in target-absent trials for the circle vs. circle with line and vertical vs. tilted line stimuli, suggesting that there may be relatively few cultural differences in the strategic considerations involved in target-absent search (cf. Chun & Wolfe, 1996; Wolfe, 2012). On the other hand, it is important to keep in mind that the cultural differences in target-absent trials are simply more difficult to detect because the process is more complicated, creating a greater susceptibility to accumulated errors.

In any event, the clear differences encountered in target-present trials show that current models of search (e.g. Treisman & Gelade, 1980; Treisman & Gormican, 1988; Wolfe, 2007) are incomplete: they cannot explain the existence of such differences, much less the particular patterns found here. The revision of these models (or the creation of new ones) will be challenging, in that they must not only account for the different patterns in terms of particular mechanisms, but must also explain why particular mechanisms would be associated with particular cultures.

Involvement of Analytic/Holistic Processing

Cultural differences in perception and cognition have often been explained in terms of differences in the degree to which analytic or holistic processing is used, with Westerners using an analytic mode which emphasizes isolated units, and East Asians a holistic mode which emphasizes relationships (Nisbett, 2003). This factor, however, is unlikely to explain all the results found here. First, since this factor relates to how the observer focuses on information, any differences that it causes should be invariant across stimulus types. Such invariance was not found. Moreover, asymmetry differences were found regardless of the shape of the set-size/RT function. For example, linear functions were observed in the high-density condition of Experiment 1, whereas negatively accelerated functions—suggesting parallel processing (Kristofferson, 1972; Treisman & Gelade, 1980)—were observed in the low-density condition. But the same asymmetry patterns were found in both cases.

More generally, our results indicate that asymmetry differences do not depend on the size of the attentional window, or the extent of parallel processing that might be associated with analytic or holistic processing. If analytic/holistic processing relates to the size of the pooled group (i.e., holistic processing encourages more pooling), Japanese participants might show larger asymmetry in lower stimulus densities (larger display size) than North American participants. But the results of Experiment 1 were contrary to this prediction.

Alternatively, it might be that Japanese (East Asians) are more likely to engage attention based on relationships between objects and the contextual field. If so, discrimination between targets and distractors would be based on relative differences rather than the absolute values. In such a case, asymmetry might not exist. But then, search for Japanese participants should be symmetric for all conditions in Experiment 2. And this was not found.

Consequently, the differences in search found here are unlikely to be due to differences in a general analytic/holistic processing mode. And given that they are also unlikely to be due to differences in discriminability, they are likely due to some other reason, such as differences in the encoding of items at early levels of visual processing.

Implications for Visual Coding

Could cultural differences exist in the way visual stimuli are encoded? One possibility (admittedly speculative rather than explanatory) is that the visual system of an observer might be affected by the orthographical systems with which they are familiar. For example, people using hiragana and Chinese characters might be more sensitive to line length (e.g., the letters い vs. り, or 土 vs. 士 differ only in the length of some components), intersection points (e.g., さ vs. き, は vs. ほ, め vs. ぬ, or わ vs. ね), and presence of an element (e.g., か vs. が, は vs. ぱ, or 大 vs. 犬, and 太). Meanwhile, people using Roman characters might be more sensitive to orientation (e.g., "u" vs. "v", "a" vs. "o" for cursive handwriting, or "H" vs. "N"). These critical features might be discriminated more effectively, leading to smaller Weber fractions and relatively weak search asymmetry for tasks based on these features, even for meaningless geometric figures. As such, our hypothesis may also help explain the findings of Malinowski & Hübner (2001), in which asymmetry was not found with “N” vs. mirror-reversed “N” for participants who were familiar with both letter shapes (Slavic) whereas it was for participants who were familiar with only one (German).

Recent research using tasks other than visual search also support this proposal: culture-specific tuning of visual attention and oculomotor control can occur by adapting to environmental factors such as the artifacts encountered in everyday life (Miyamoto , Nisbett, & Masuda, 2006; Ueda & Komiya, 2012). Interestingly, in some computational models search asymmetry can emerge as a byproduct of bottom-up processing with environmentally-tuned neurons (Bruce & Tsotsos, 2011; Zhang, Tong, Marks, Shan, &

Cottrell, 2008). Although these studies suggest that visual environment can influence visual attention, the critical factors remain unclear.

It might also be noted that orientation is an elementary feature, in that a simple linear filter can extract it; it is also known to be processed in primary visual cortex (V1). Meanwhile, line length and the circle/circle-with-line distinction are more complex, requiring operations involving local grouping and the correlation of outputs of neighboring linear filters (Freeman, Ziemba, Heeger, Simoncelli, & Movshon, 2013; Rensink & Enns, 1995); these are therefore likely to be processed in extrastriate cortical areas, such as V2, V3, and V4. This might be connected with the finding that different kinds of brain activity can result from different kinds of literacy: familiarity with the Western (Roman) alphabet can lead to increased activation in cortical area V1, while familiarity with Chinese characters leads to increased activation in areas V3 and V4 (Szwed, Quao, Jobert, Dehaene, & Cohen, 2014).

Future Directions

Our study provides some hints for future explorations, not only of the nature of cultural differences in perception, but also more generally the role of visual experience in the development of early visual processing. For example, it would be worth conducting visual search studies using other stimuli known to cause asymmetry in Westerners (e.g., dark vs. light), or having an additional discrimination task of letter shapes precede the main search task. It would also be worth carrying out more empirical studies (as well as extending current computational models) to determine which aspects of stimulus encoding might underlie the asymmetry differences found here, and to understand how they depend on the nature of the surrounding visual environment.

Finally, it is worth noting that our results do not necessarily contradict previous proposals of an effect of analytic/holistic processing on particular aspects of perception and attention (Masuda & Nisbett, 2001; Masuda & Nisbett, 2006; Miyamoto et al., 2006). Instead, our results simply show that the analytic/holistic processing distinction cannot account for all such effects; a new factor appears to be responsible, one that involves the stimulus properties themselves. As such, our proposal opens up some interesting new possibilities for explaining various cultural effects on perception (e.g., Caparos, Ahmed, Bremner, de Fockert, Linnell, & Davidoff, 2012; Doherty et al., 2008), effects that have previously been explained only in terms of differences in analytic/holistic processing.

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Figure captions

Fig. 1. Examples of the search displays used in Experiment 1.

Fig. 2. Mean reaction times and error rates (A and B) and search slopes (C) of target-present trials in Experiment 1. In A and B, the lines show the mean reaction times and the bars show the error rates. Error bars indicate standard errors of the mean. RT = reaction time.

Fig. 3. Mean reaction times and error rates (A and B) and search slopes (C) of target-absent trials in Experiment 1. In A and B, the lines show the mean reaction times and the bars show the error rates. Error bars indicate standard errors of the mean. RT = reaction time.

Fig. 4. Scatterplots of search slopes for individual participants in Experiment 1 for low-density target-present trials (A), low-density target-absent trials (B), high-density target-present trials (C), and high-density target-absent trials (D).

Fig. 5. Examples of the search displays used in Experiment 2.

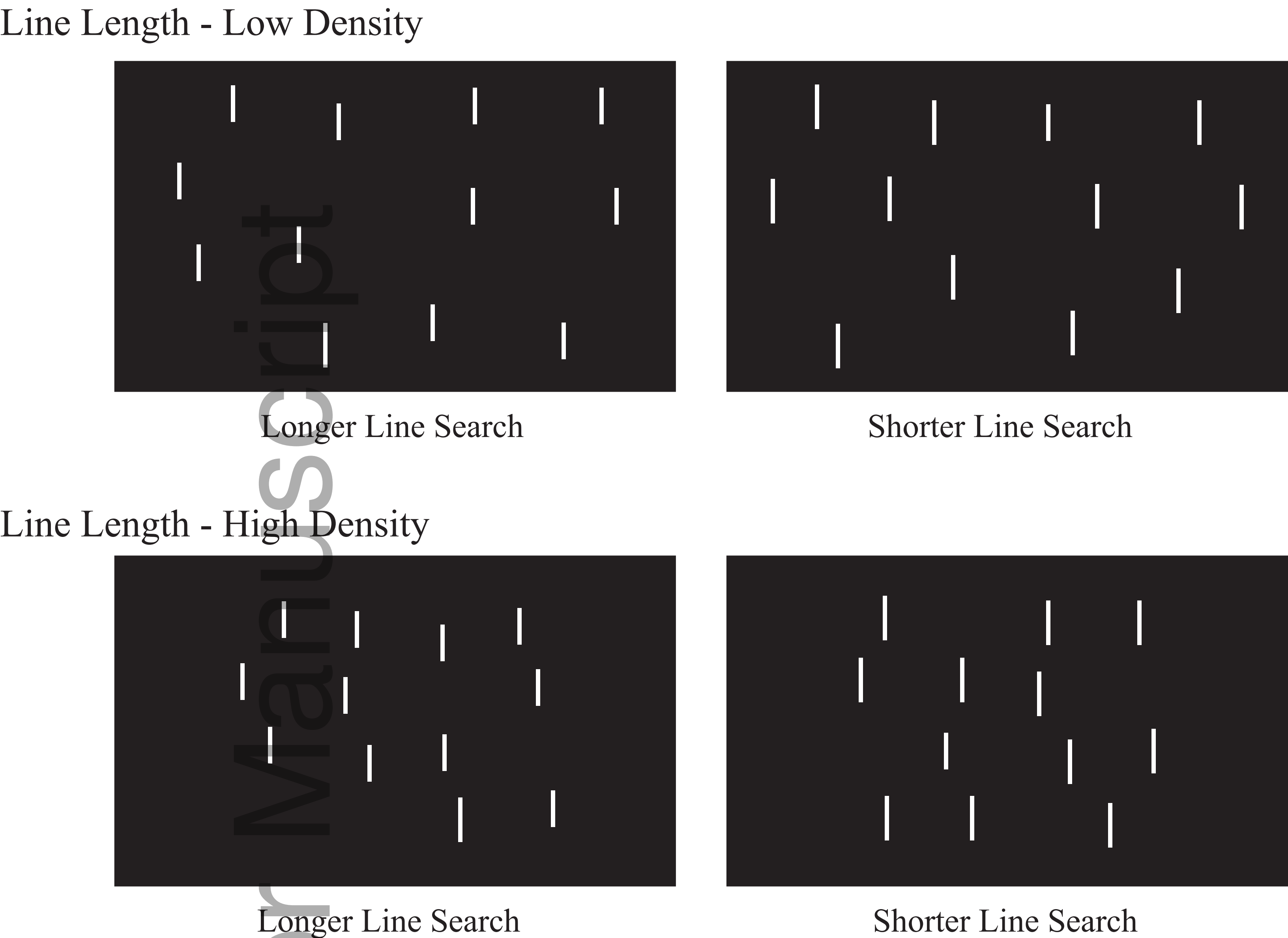
Fig. 6. Mean reaction times and error rates, and search slopes for the target-present trials in Experiment 2, for both the O vs. reversed-Q (A and C) and vertical vs. tilted line (B and D) stimuli. In A and B, the lines show the mean reaction times and the bars show the error rates. Error bars indicate standard errors of the mean. RT = reaction time.

Fig. 7. Mean reaction times and error rates, and search slopes for the target-absent trials in Experiment 2, for both the O/reversed-Q (A and C) and vertical/tilted line (B and D) stimuli. In A and B, the lines show the mean reaction times and the bars show the error rates. Error bars indicate standard errors of the mean. RT = reaction time.

Fig. 8. Scatterplots of search slopes for individual participants in Experiment 2, for O vs. reversed-Q search in target-present trials (A), O vs. reversed-Q search in target-absent trials (B), vertical vs. tilted line search in target-present trials (C), and vertical vs. tilted line search in target-absent trials (D).

Fig. 9. Mean reaction times and error rates (A), and search slopes (B), of target-present trials, and a scatterplot of search slopes for individual participants (C) in Experiment 3. In A, the lines show the mean reaction times and the bars show the error rates. Error bars indicate standard errors of the mean. RT = reaction time.

Fig. 10. Mean reaction times and error rates (A), and search slopes (B) of target-absent trials, and a scatterplot of search slopes for individual participants (C) in Experiment 3. In A, the lines show the mean reaction times and the bars show the error rates. Error bars indicate standard errors of the mean. RT = reaction time.



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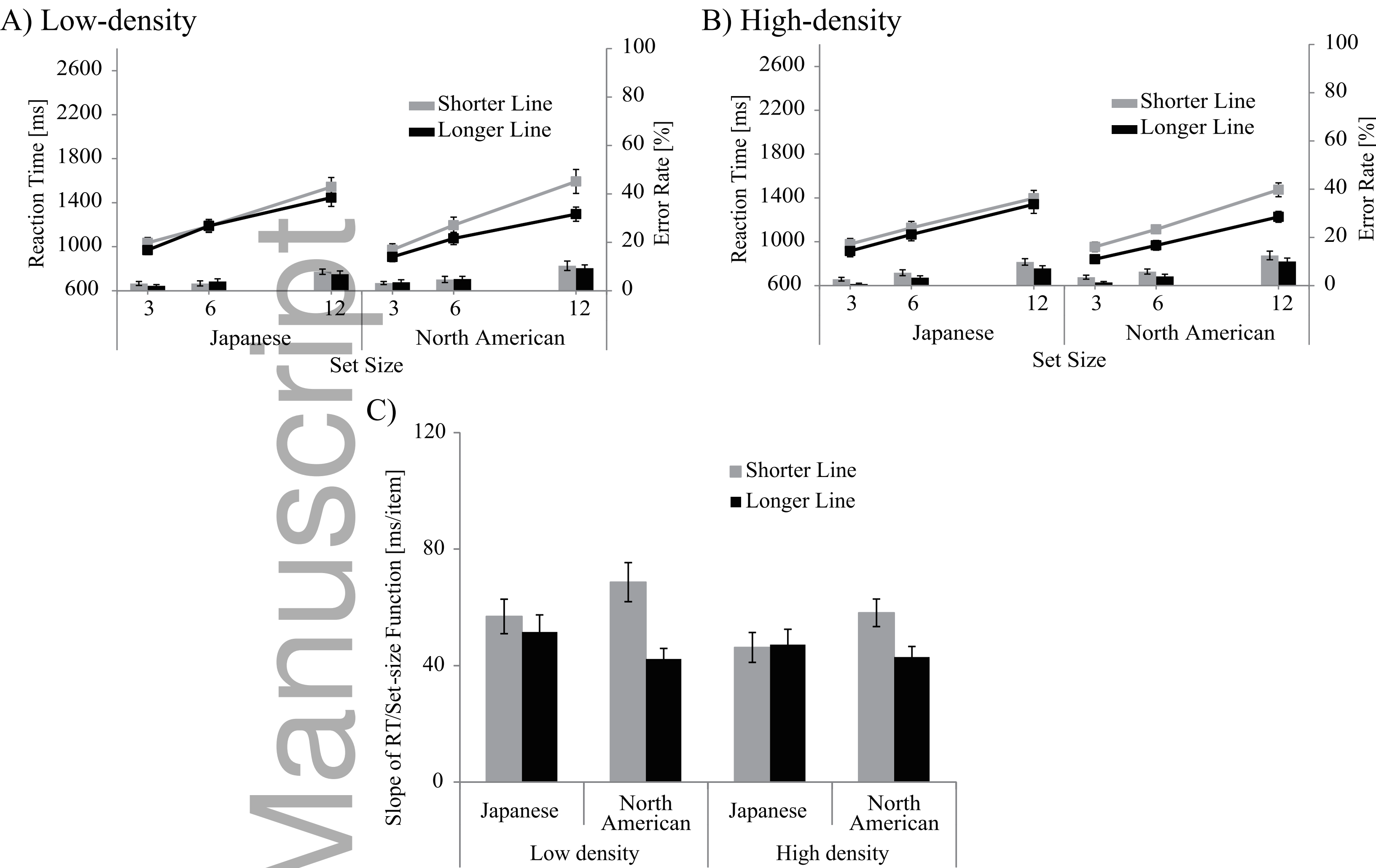

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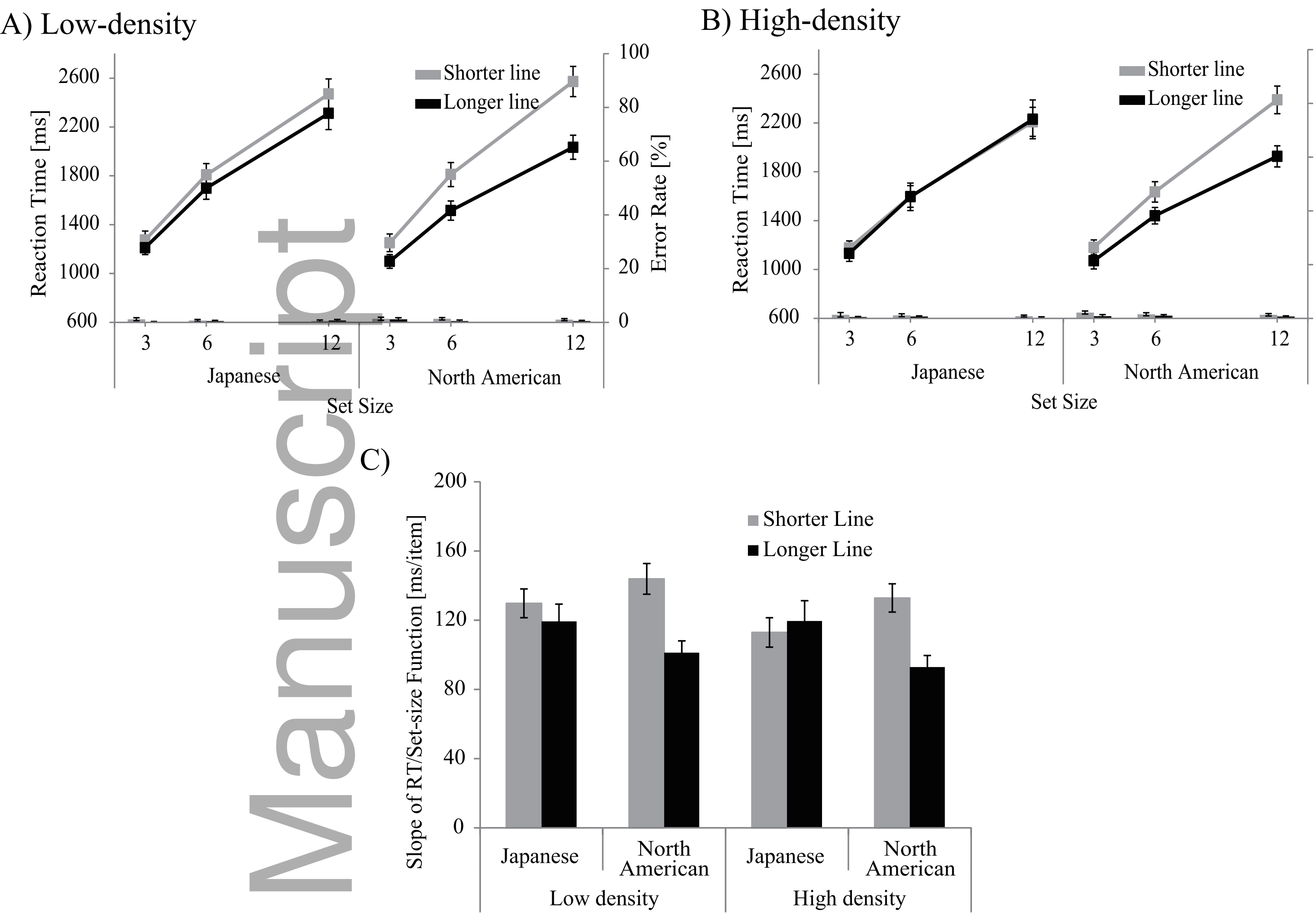

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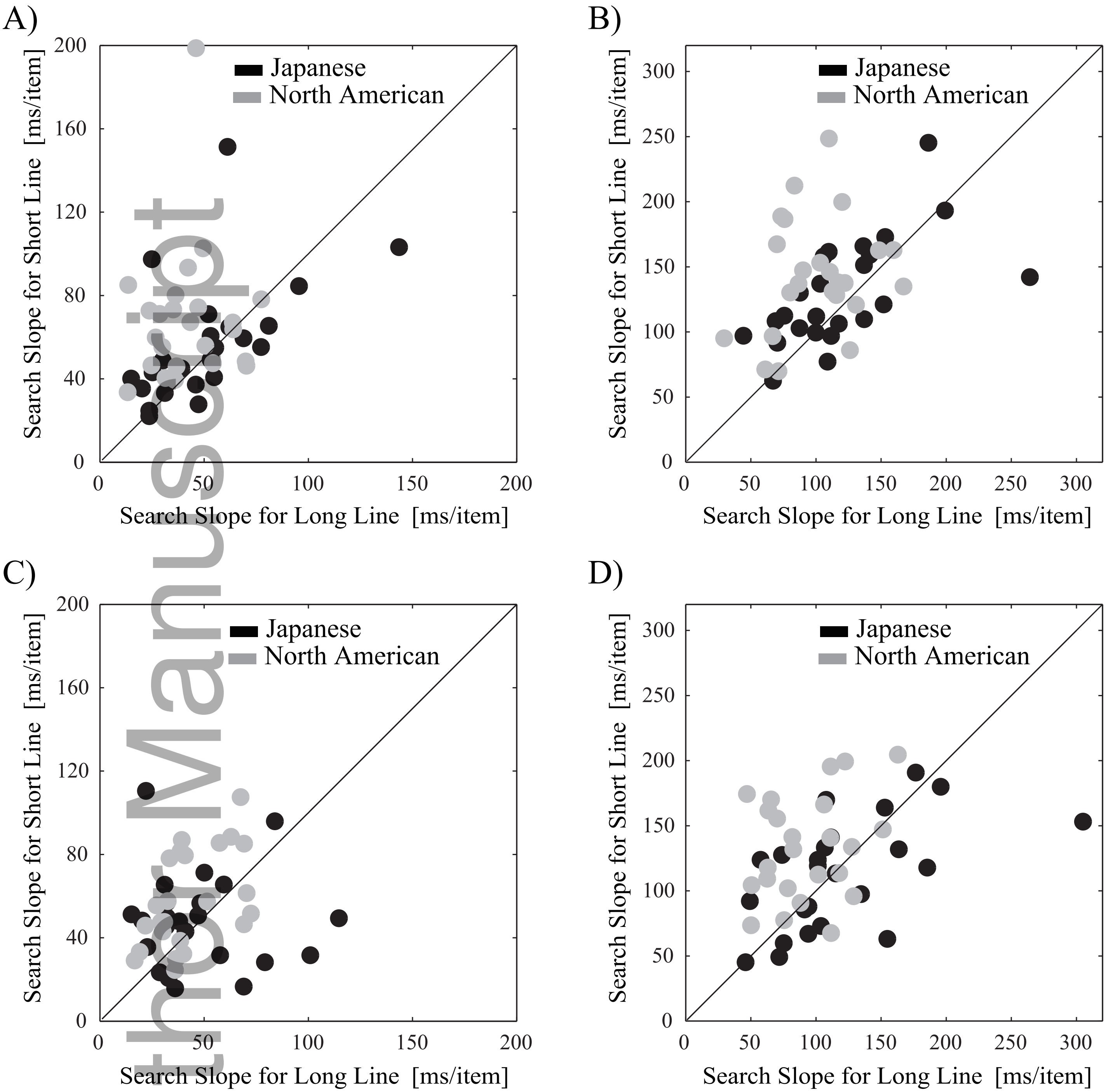

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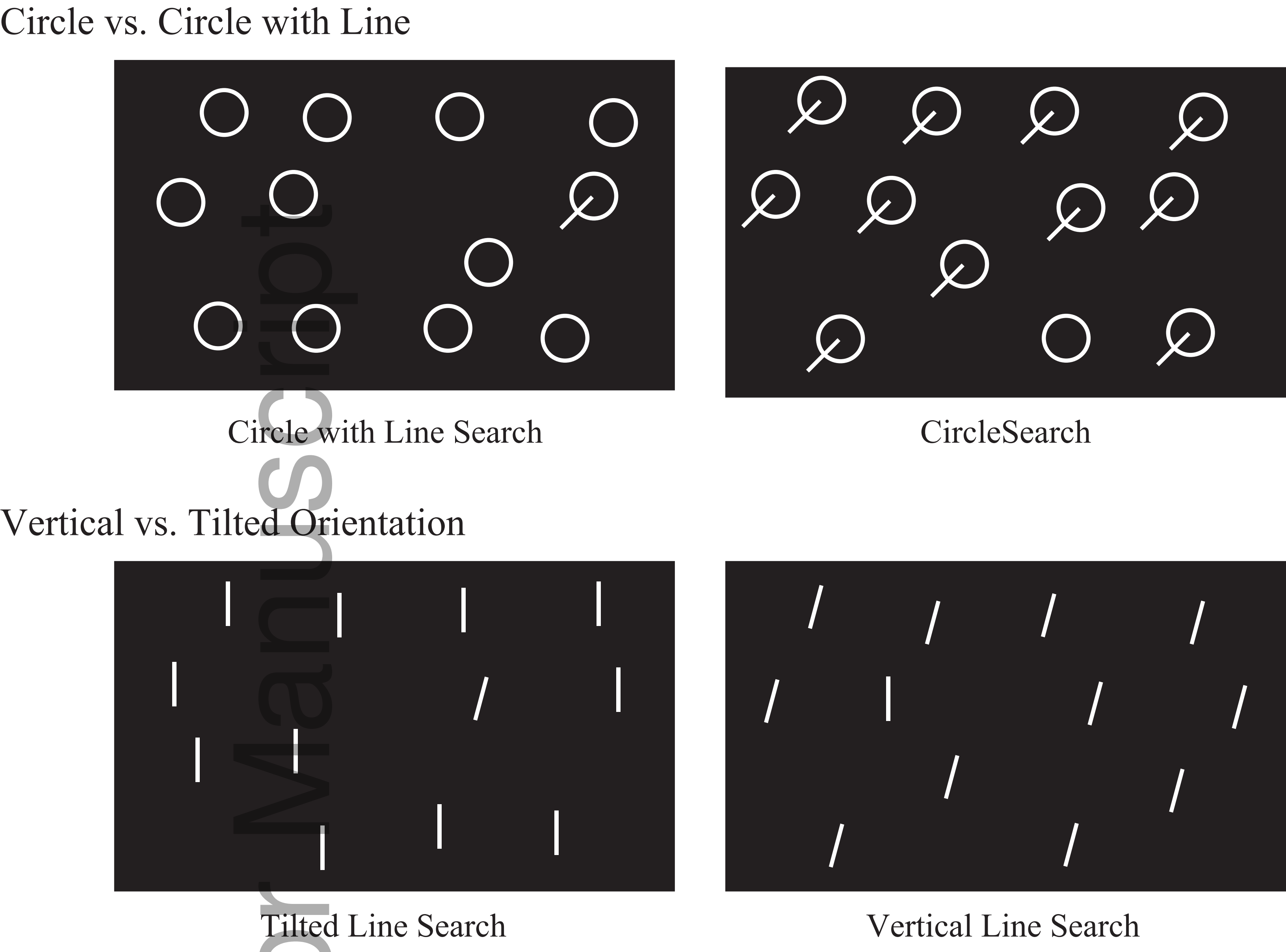

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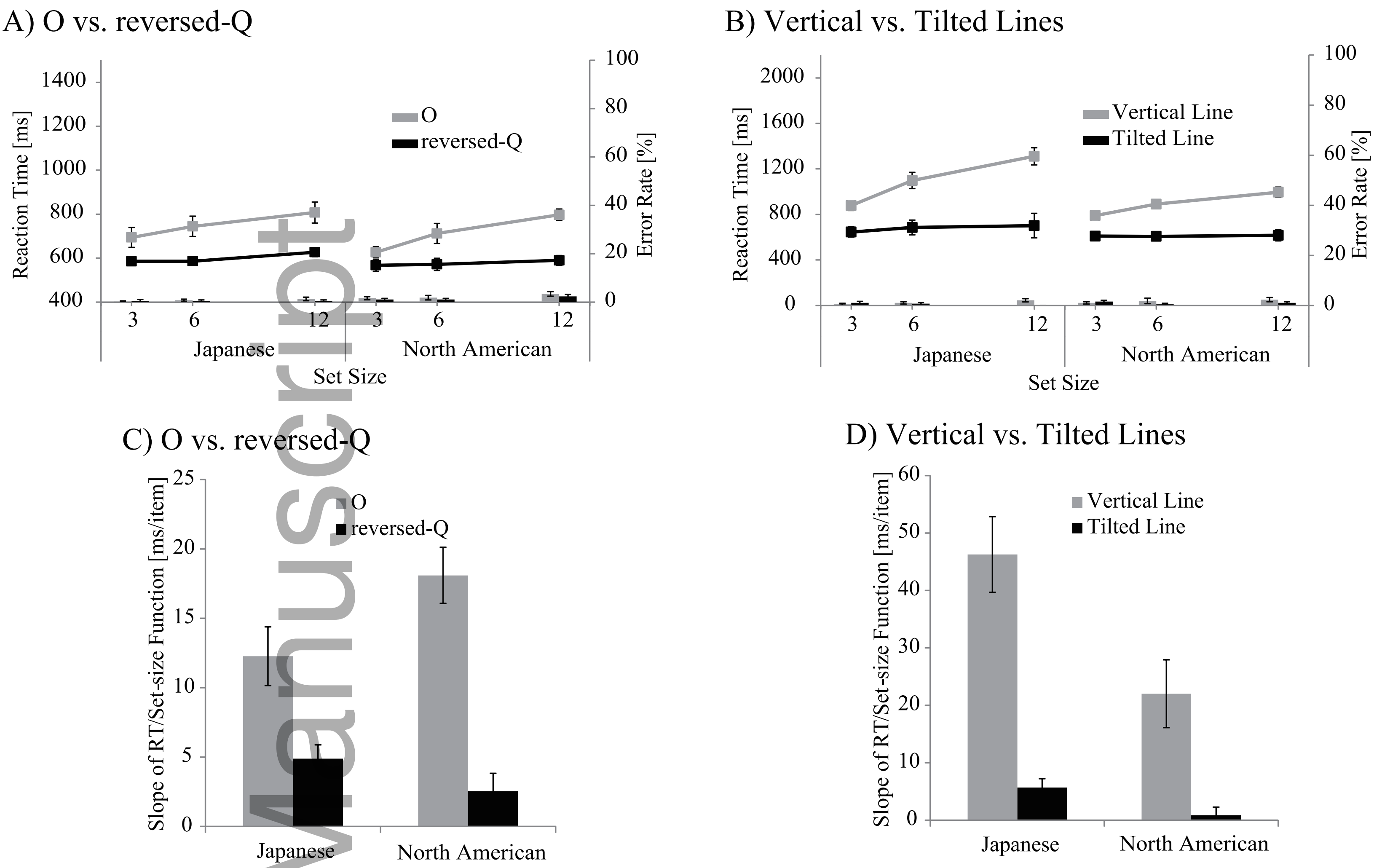

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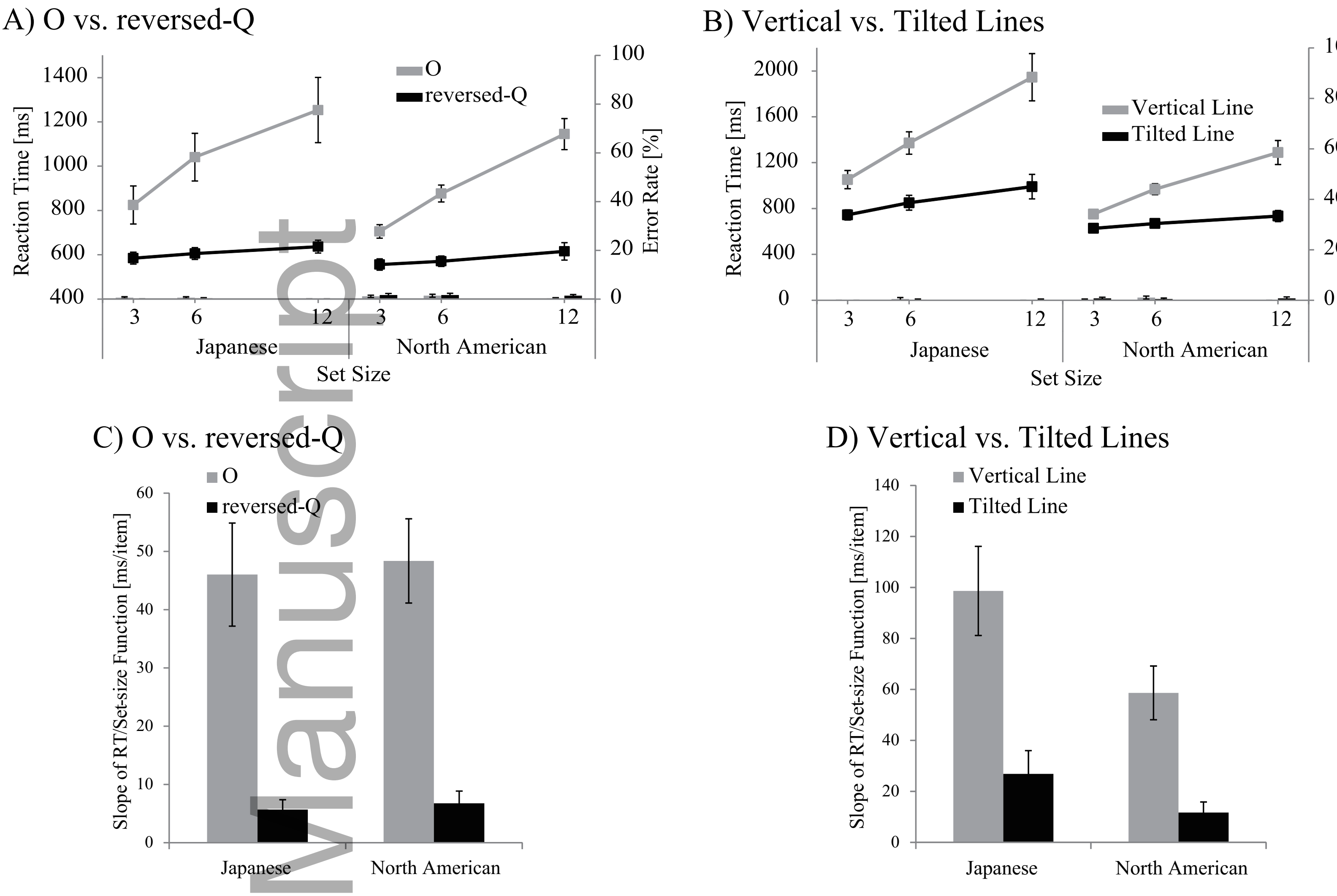

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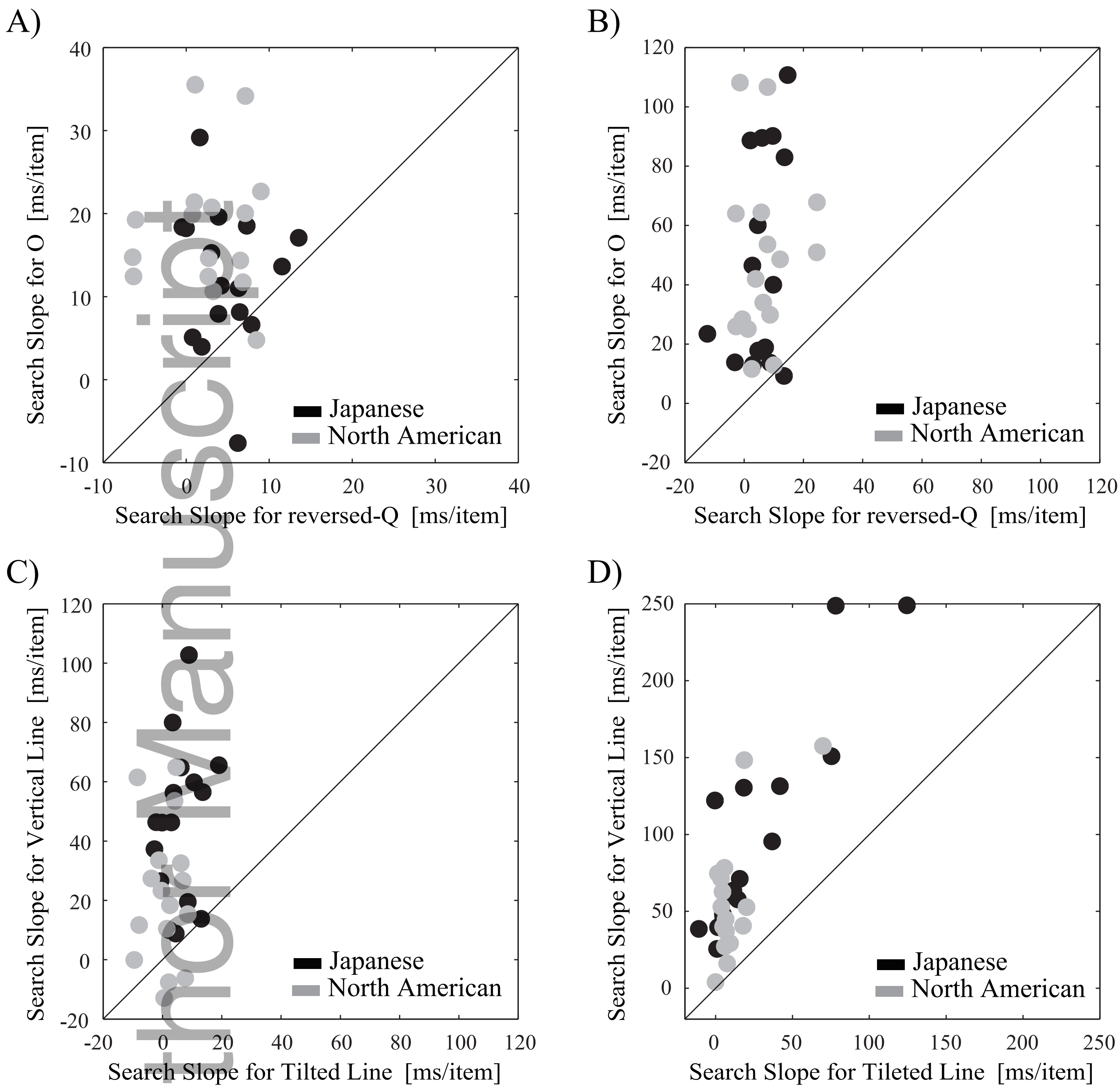

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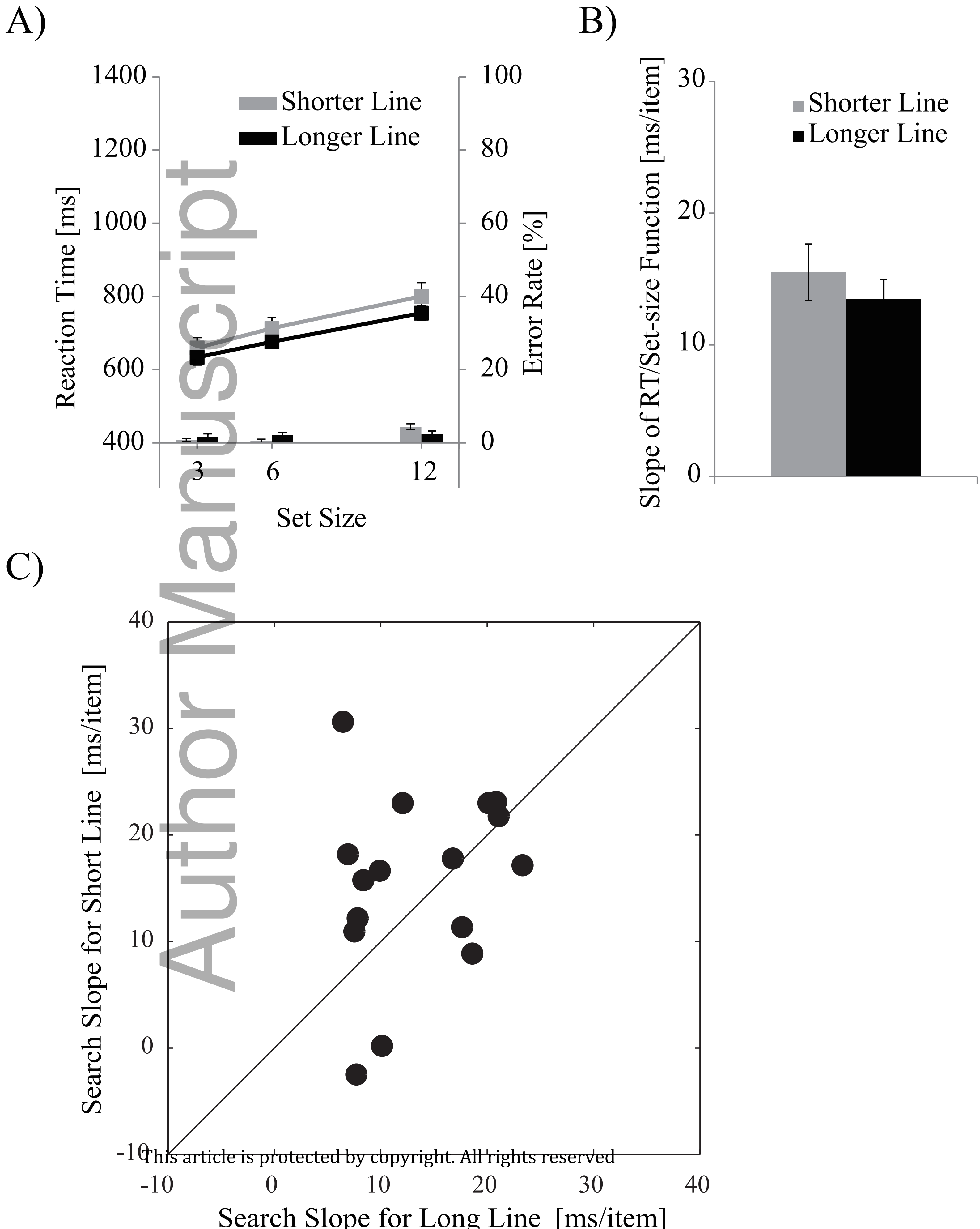

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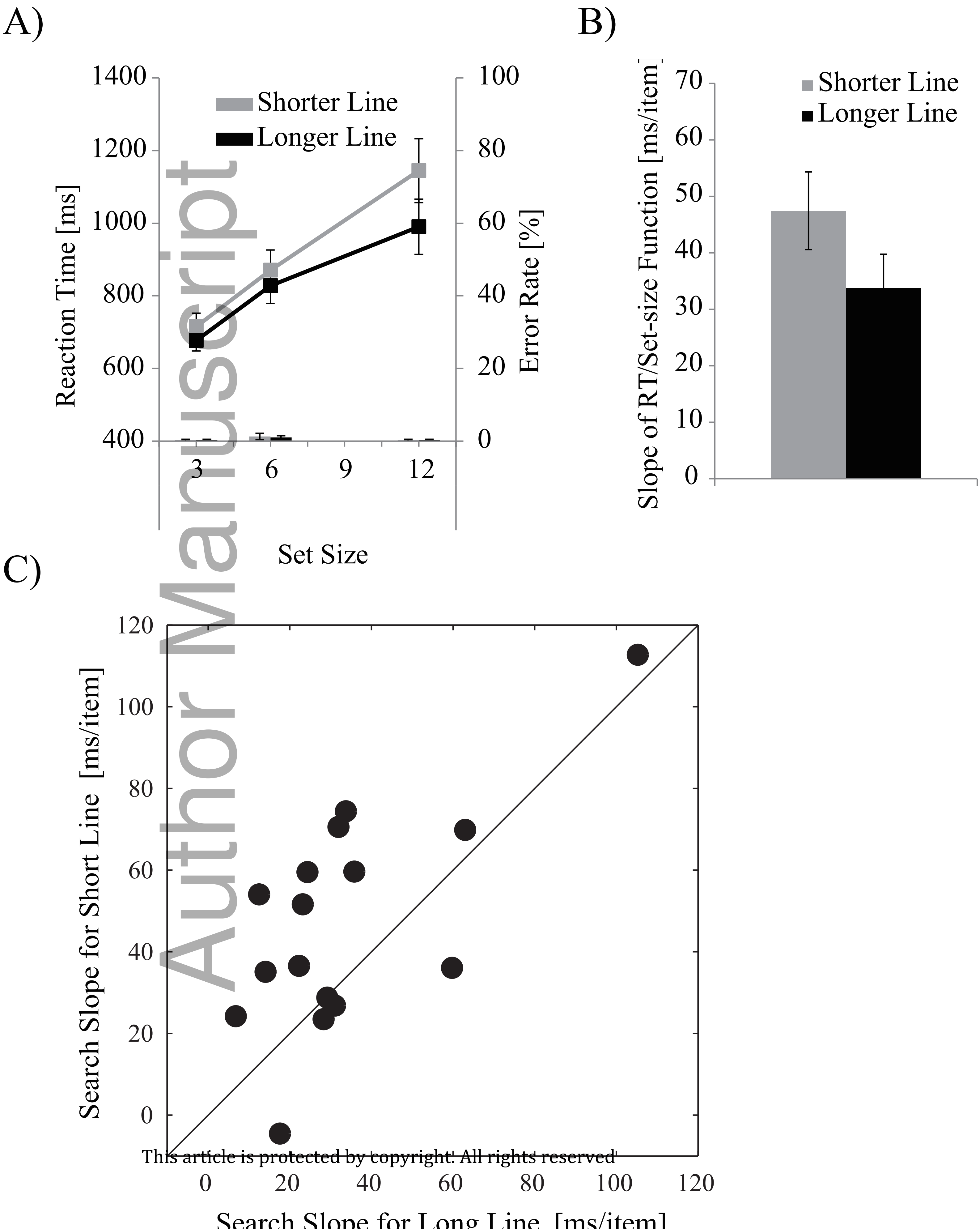
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