Does Object Size Matter with Regard to the Mental Simulation of Object Orientation?

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Abstract

Language comprehenders have been argued to mentally represent the implied orientation of objects. However, compared to the effects of shape, size, and color, the effect of orientation is rather small. We examined a potential explanation for the relatively low magnitude of the orientation effect: object size moderates the orientation effect. Theoretical considerations led us to predict a smaller orientation effect for small objects than for large objects in a sentence-picture verification task. We furthermore investigated whether this pattern generalizes across languages (Chinese, Dutch, and English) and tasks (picture-naming task). The results of the verification task show an orientation effect overall, which is not moderated by object size (contrary to our hypothesis) and language (consistent with our hypothesis). Meanwhile the preregistered picture-picture verification task showed the predicted interaction between object size and orientation effect. We conducted exploratory analyses to address additional questions.

Keywords: Sentence-Picture Verification Task, Match Advantages, Object Orientation, Object Size, Language Aspects

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Does Object Size Matter with Regard to the Mental Simulation of Object Orientation?

Theories of mental simulation propose that language comprehension involves the reactivation of perceptual experiences (e.g., Barsalou, 1999). In the past decades, these theories have acquired empirical evidence from a number of tasks, including the sentence-picture verification task. Studies using this task have found that reading a probe sentence that implies a particular perceptual feature facilitates verification responses for pictures representing the target objects with that particular feature (Connell, 2007; De Koning et al., 2017a; Stanfield & Zwaan, 2001; Zwaan & Madden, 2005; Zwaan & Pecher, 2012; Zwaan, Stanfield, & Yaxley, 2002).

Consider object shape. The probe sentence “He saw the eagle in the sky” implies the shape of a flying eagle, whereas the sentence “He saw the eagle in the nest” implies the shape of a perched eagle. Importantly, these sentences do not explicitly state that the eagle was flying or perched, respectively. The shape can be inferred from the eagle’s location. Moreover, the task was to indicate if the depicted entity was mentioned in the sentence, whereby a sentence could be followed by a picture that matched the shape implied by the sentence (e.g., a picture of a flying eagle after the “sky” sentence) or by a picture that mismatched the shape implied by the sentence (e.g., a picture of a flying eagle after the “nest” sentence), which means that “yes” responses were required irrespective of the picture. Nevertheless, responses were faster to shape-matching pictures than to mismatching ones (Zwaan et al., 2002). This match advantage is consistent with the idea of mental simulation arguing that the sentence could reactivate the particular perceptual experiences during language comprehension.

Comparisons of match advantages

Besides shape, three other perceptual features (orientation, color, and size) have been investigated in the literature. Orientation has shown the weakest effects compared to the other features. For object color, initial findings suggested a mismatch advantage (Connell,

2005, 2007). However, using the same materials, Zwaan and Pecher (2012) obtained a match advantage of object color in an experiment with a larger number of participants. Compared to Connell, who tested 40 to 60 participants, Zwaan and Pecher recruited 152 participants in their online study. Recently, the match advantage of color was confirmed in two separate laboratory studies using different sets of materials (De Koning et al., 2017a; Hoeben Mannaert, Dijkstra, & Zwaan, 2017).

Two lines of studies have investigated mental simulation of object size. The first line of research used probe sentences that described the distance between the reference point and the object (Vukovic & Williams, 2015; Winter & Bergen, 2012). These probe sentences implied far distance and near distance, and the size of picture presentations were respectively small and large. Winter and Bergen’s probe sentences implied the absolute distance between the observer and the object (e.g., “... the milk bottle in the fridge” vs. “... the milk bottle on the end of the counter”) and found a match advantage, whereas Vukovic and Williams’ probe sentences implied the relative distance between the observer and the object (e.g., “In front of you, ...” vs. “In the distance, ...”) and found a mismatch advantage. The second line of research manipulated the physical appearance of the object (De Koning et al., 2017b). The target pictures of one object had the same appearance but differed in size. The probe sentence implied a large object, such as “...the bone of a dinosaur” or a small object such as in “...the bone of a rabbit.” Consistent with the Winter and Bergen study, De Koning and colleagues found a match advantage of object size. Thus, the studies of object size show a robust match advantage for sentences that imply the absolute object size such as the physical appearance and the absolute distance.

The match advantages for orientation were smaller than those for the other perceptual features and the findings were less consistent across studies, although it is unclear how these differences have come about (De Koning et al., 2017a). Stanfield and Zwaan (2001) reported the first finding about the match advantage of object orientation. Their study used sentences

that implied horizontal and vertical orientations of objects. For example, the sentence “Frank placed the iron onto the shelf, hoping he wouldn’t be late” implies a vertically oriented iron whereas the sentence “Frank pressed the iron onto his pants, hoping he wouldn’t be late” implies a horizontal iron. In use of materials such as this, Stanfield and Zwaan found a 44 ms match advantage of orientation in their laboratory study involving 40 participants.

Subsequent studies have investigated object orientation with slightly modified designs and obtained an inconsistent pattern of results. Using identical materials as Stanfield and Zwaan (2001) and a larger number of participants recruited on the internet ($n = 336$), Zwaan and Pecher (2012) obtained a roughly equal match advantage (35 ms). Using a memory task and Dutch materials, Pecher, van Dantzig, Zwaan, and Zeelenberg (2009) found match advantages for object shapes and orientations. However, other studies failed to obtain significant match advantages for object orientation. With the same Dutch materials as in Pecher et al. (2009), Rommers, Meyer, and Huettig (2013) found a non-significant 1 ms match advantage of object orientation in their study of sentence-picture verification task. Recently, De Koning et al. (2017a) also used Dutch sentences and also failed to find a significant orientation match advantage with a different set of materials: participants were only 7 ms faster on matching items than on mismatching items.

Studies involving primary school children (8 to 12 years old) also showed inconsistent findings between object shape and orientation. Similar to Rommers et al. (2013) and De Koning et al. (2017a), Engelen, Bouwmeester, de Bruin, and Zwaan (2011) investigated the match advantages of object orientation and shape by intermixing orientation trials and shape trials. Engelen et al. showed an averaged match advantage of 74 ms but the intermixed-trials design made it difficult to infer whether the match advantage was due to the orientation trials or the shape trials.

Two things set the above-mentioned studies (e.g., Engelen et al., 2011; De Koning et al., 2017a) apart from the original study and its replications. First, the latter did not employ

a task that kept participants focused on the meaning of the sentences. Stanfield and Zwaan (2001) had participants recall the target sentence after a certain number of trials, while Zwaan and Pecher (2012) used a sentence comprehension test. It is thus possible that the small effect sizes in the other studies are due to the lack of a task focusing on sentence comprehension. This is important because the effect is assumed to occur as a result of sentence comprehension. If participants are not prompted to comprehend the sentences, a reduction of effect size is plausible (Zwaan, 2014).

The second difference between these studies on the one hand and the studies by Stanfield and Zwaan (2001) and Zwaan and Pecher (2012) on the other hand, is that the former studies presented the sentences in Dutch, whereas the original study and its direct replications presented the stimuli in English.

These differences among orientation studies notwithstanding, the question remains why orientation yields a smaller effect than shape, size, or color on the same task is used. Consistent with the summary of Zwaan and Pecher (2012), the Cohen's d of orientation (.13) is less than half of that of shape (.31). De Koning et al. (2017a) also indicated that, using a direct comparison in a within-subjects design, the smallest effect sizes were related to object orientation (.07) and size (.07) compared to color (.48) and shape (.27).

We hypothesize that the relatively small effect of orientation is due to the nature of the objects being used in the orientation experiments. All of these studies used the visual stimuli from the original study (Stanfield & Zwaan, 2001) or stimuli that were based on or Dutch translations from the original ones. A common feature of the objects described and depicted in the stimuli used in these studies is that they can be manipulated by a single hand. Most (but not all) of these stimuli represent easily manipulable objects such as “hair brush” and “pencil”. Thus, for these items, the critical visual feature (orientation) can be changed by a simple manipulation during real-world action. This stands in contrast with the objects used in the shape (e.g., perched vs. flying eagle), color (e.g., red vs. green stoplight) and size

(e.g., dinosaur vs. rabbit bone) experiments, where such a featural change by manipulation is impossible.

That the past orientation studies employed small objects is relevant for at least two reasons. First, in the real world, such small objects are seen as constantly changing orientation. Take for instance a pen, which is frequently seen lying flat on a desk, standing upright in a pen holder or being held by someone writing a note, or even being twiddled idly in someone's hand. This means that we have a great deal of experience seeing small objects rapidly change from one orientation to the next and back. Non-manipulable objects or those that can only be manipulated by two hands usually are not observed changing orientations in close temporal succession (e.g., a street lantern is often seen standing upright, unless it is being transported on a truck to a new location but does not rapidly change orientation). As a result, our visual experience with small manipulable objects is different from that with larger objects that are more difficult or impossible to manipulate.

Second, for objects that are manipulable with one hand it is relatively easy to obtain a different orientation, either by physically or mentally transforming the object to another orientation. There is behavioral and neuro-imaging evidence that visual mental rotation and manual rotation rely on overlapping neural substrates (e.g., Parsons et al., 1995; Wexler, Kosslyn, & Berthoz, 1998; Windischberger, Lamm, Bauer, & Moser, 2003; Wohlschläger & Wohlschläger, 1998). It might therefore be hypothesized that visual mental rotation is facilitated by motor mental rotation. As a result, participants should be able to quickly “recover” from seeing a mismatching picture. This would reduce the advantage for a matching picture. For example, a pen can easily be turned from a vertical to a horizontal position with the hand or one can imagine doing so. These lines of thinking lead us to predict a shorter simulation time for the orientation of small objects compared to large objects.

Exploration of a mental rotation account

A second aim of the current study is to explore to what extent mental rotation can account for not finding a match advantage of object orientation. De Koning et al. (2017a) suggested that mental rotation as an alternative process to mental simulation could quickly erase the mismatched orientation replacing it with the orientation that matches the one described in the sentence (Cohen & Kubovy, 1993; Yaxley & Zwaan, 2007). However, so far this suggestion is speculative at best given that de Koning and colleagues did not directly test this in their study and their findings barely supported their assumption because they had only the results in terms of the small and manipulable objects. To put De Koning et al.'s suggestion to the test, we draw upon mental rotation research.

Among the various mental rotation paradigms (Cohen & Kubovy, 1993; Shepard & Metzler, 1971; Zwaan & Taylor, 2006), the reaction times to verify whether two figures presented in a variety of different orientations are the same or different have been typically used to measure mental rotation. In Study 2 reported in this paper, we used a version of this standard mental rotation paradigm (Shepard & Metzler, 1971) and employed the real-world objects used in the sentence-picture verification task as our stimuli. The task was thus a picture-picture verification task in which participants verified whether the two simultaneously, side-by-side presented pictures were the same or different in a same orientation (horizontal-horizontal; vertical-vertical) or in a different orientation (horizontal-vertical; vertical-horizontal). If the account of mental rotation is plausible, we expect that the large and non-manipulable objects would require more rotation time than the small and manipulable objects. Empirical support for this hypothesis would provide converging evidence for the hypothesis that mental simulation effects will be smaller for small items than for large items.

The present study

The present study aims to extend prior research on the mental simulation of object orientation during language comprehension. In three experiments, we tested the preregistered predictions outlined above using the sentence-picture verification task and the picture-picture verification task. We tested these predictions in three languages: English, Dutch, and Chinese. Whereas English (Stanfield & Zwaan, 2001; Zwaan & Pecher, 2012) and Dutch (De Koning et al., 2017a, 2017b; Rommers et al., 2013) have been studied before. However, while the shape effect has been replicated and extended in Chinese (Gao & Jiang, 2017), we know of no research on the orientation effect in Chinese. Thus, including Chinese allows us to further investigate the generalizability of the orientation effect across languages.

In Study 1, we investigated whether verification times of pictures depicting horizontal and vertical objects in the sentence-picture verification task were shorter for large objects than for small objects, and whether this was consistent across the three languages. In Study 2, we investigated the mental rotation account using a picture-picture verification task and tested whether verifying if two pictures match in orientation produce a larger match advantage for the large than for the small objects (again using speakers of the three languages). In response to the suggestion of an anonymous reviewer of the preregistration, in Study 3 we used a sentence-picture naming task, similar to Study 1, where participants had to make a vocal response. A picture-naming task was used as it provides a stronger test of the mental simulation hypotheses than the verification task in that it does not call for a comparison between the sentence and the picture.

General Method

To test the plausibility of our hypothesis, we constructed a stimulus set including small manipulable objects (e.g., pen) as well as large non-manipulable objects (e.g., a boat or a missile) and tested it in an initial study. In this initial study, we examined the match advantage for orientation across large and small objects and between three languages:

English, Dutch, and Chinese (see the data and the summary in Electronic Supplementary Material 1). Effects for orientation were found in English but not in Dutch. As per our prediction, the results of a meta-analysis on this initial study showed a significant match advantage for large objects but no match advantage for small objects. In the present study, we built on this initial study regarding the design, materials, and experimental procedure.

Experimental Procedures

Three groups of native speakers (English, Dutch, English) participated in the sentence-picture verification task (Study 1) and the picture-picture verification task (Study 2) in a single experimental session. The sentence-picture naming task (Study 3) took place in a separate experimental session and involved participants from two groups of native speakers (English and Chinese). We used the same design and materials that were employed in the sentence-picture verification task and the picture-picture verification task in our initial study, except that we revised the probe sentences to eliminate the orientation implications of Dutch verbs. Specifically, the initial study yielded two unforeseen issues. First, the Dutch participants surprisingly showed a marginal significant match advantage for small objects. Upon closer inspection of the items in it appeared that some of the Dutch sentences contained verbs implying a particular object orientation. Orientational verbs such as “liggen” (to lie) and “staan” (to stand), provide an additional, and more explicit, clue about the object’s orientation than does the object’s location. Although the use of these verbs is natural in Dutch (in fact more natural than using the less specific “is”), their use in the present experiment undermines the original goal of letting the orientation of the target object be determined by its location (described in a prepositional phrase). It stands to reason that providing an additional orientation cue would increase the size of the match advantage. We addressed this issue in the present study by replacing the orientation verbs with orientation-neutral verbs such as “is”.

In the sentence-picture verification task each experimental session began after six

practice trials. A trial started with a left-justified and vertically centered fixation point for 1000 ms, which was immediately followed by the probe sentence, presented in the same location as the fixation point. Participants pressed the space bar when they had read the sentence. Immediately thereafter a horizontally and vertically centered fixation point appeared for 500 ms, after which the target picture was presented. Participants pressed the “j” key if they thought the depicted object was mentioned in the preceding sentence or the “f” key if they thought the object was not mentioned in the sentence. They were instructed to verify the target picture as quickly and accurately as possible.

The picture-picture verification task was based on the sentence-picture verification task but did not include the test sentences. There were two further exceptions. First, there was only one horizontally and vertically centered fixation point that appeared before the target pictures. Second, the two target pictures appeared next to the fixation point (on both sides) until a response was made or until two seconds had passed.

The picture-naming task, was identical to the sentence-picture verification task except for the mode of responding. Instead of pressing a key on the keyboard, the participant read the object name aloud as quickly as possible within the span of three seconds after the object picture had been presented. Upon completion of the recording, an evaluation screen appeared that presented the object picture and required participants to evaluate their response by using one of four options: “Right”, “Wrong”, “No Response”, and “Recording Failed”. We managed all the tasks in Gorilla.sc (Anwyl-Irvine, Massonnié, Flitton, Kirkham, & Evershed, 2019). All the materials are available in Gorilla Open Materials (see the public link in Appendix A).

Material and Design

A total of 128 pairs of sentences and gray-colored pictures (scaled in 240 x 240 pixels) were used. Sixty-four pairs were the critical items, and the other 64 sentence-picture pairs

were fillers. Sixteen pictures of large objects were obtained from various sources, and the pictures of 16 small objects and 64 fillers were obtained from the standardized stimuli pools (Bonin, Peereman, Malardier, Méot, & Chalard, 2003; Brodeur, Guérard, & Bouras, 2014) and from the internet. The fillers consisted of a sentence accompanied by an unrelated picture. The critical items were created by crossing three within-participant variables: Size (Large vs. Small), Orientation (Horizontal vs. Vertical), and Match (Matching vs. Mismatching of probe sentence and target picture). Of the sixty-four critical items, 32 described large objects and the other 32 described small objects. Object size was determined according to whether the object can be manipulated by a single hand (small) or not and only able to by heavy machinery or force of nature (large). The object terms were the grammatical subject of every critical sentence. The critical sentences implied the object orientations in the form of a prepositional phrase at the end of the sentence. For example, “The pen is on the table” implies a horizontal orientation of the pen, and “The pen is in the container” implies a vertical orientation; “The missile was flying over the sea” implies a horizontal orientation, and “The missile was launched from the submarine” implies a vertical orientation. The sentences were written in Chinese, Dutch, and English respectively. For each critical item, one target picture presenting the horizontal or vertical orientation matched one of the two critical sentences but mismatched the other sentence. For reasons of counterbalancing, we created two stimulus lists wherein each list contained two of the four sentence-picture combinations. Each participant was randomly exposed to only a single horizontal or a vertical picture of a specific target object.

The picture-picture verification task included two within-participant variables: Object size (large vs. small) and match (identical vs. different). All the target objects were presented in the default orientation and had two companions. One companion was the picture presented in the identical orientation, and the other was the picture presented in the different orientation. Each target object was presented twice with its companions in this task. To create “no” responses, in order to balance yes-no responses, 64 filler items which

involved pairs of different objects, which were selected from the stimuli set with the same object size. A total of 256 trials were presented in randomized sequences for the participants.

Study 1: Sentence-Picture Verification

The first aim of this study was to test the hypothesis that the match advantage for orientation items is larger for the large objects than for the small objects. The second aim was to test whether there were similar results across the languages Chinese, Dutch, and English. Earlier studies had found effects for English but not for Dutch stimuli. Chinese had not been tested to our knowledge. We modified some items for our Chinese participants. Whisk was replaced by chopsticks. Although a whisk is a common kitchen utensil for English and Dutch participants, it is unfamiliar to Chinese participants. Four large objects, i.e. drawbridge, wine barrel, steel barrel, and bottle were also deemed unfamiliar to Chinese participants. We revised the Chinese sentences describing these objects to make them comprehensible for Chinese participants.

To foreshadow, with regard to the second hypothesis the results of the Dutch participants deviated from those of the English and Chinese participants. We suspected that language-specific knowledge might have affected Dutch participants' performance. Therefore, we collected additional data in a group of Dutch native speakers, but fluent in English, who were presented with the English version of the sentence-picture verification task.¹ This additional data collection followed the preregistered data collection plan but was not preregistered in itself.

Methods

Sampling plan

We used G*Power (Faul, Erdfelder, Buchner, & Lang, 2009) to estimate the expected

¹ This idea was suggested to us by Richard Morey in an informal conversation.

effect size and sample size based on a one-tailed t -test in terms of 0.05 significance level and 80% ~ 90% power. According to the preregistered plan,² we conducted a sequential analysis based on Bayes Factors estimations along with the data collection (Morey, Rouder, Love, & Marwick, 2015; Schönbrodt, Wagenmakers, Zehetleitner, & Perugini, 2017). We decided to use $BF_{10} = 10$ as the criterion to stop data collection for two reasons: (1) The collective evidence (De Koning et al., 2017a; Zwaan & Pecher, 2012) moderately supports the mental simulation of object orientation, $BF_{10} = 20.944$; (2) a BF_{10} between 10 and 30 implies strong evidence (Jeffreys, 1961). For each participant group (i.e., language), we computed a Bayesian t -test on the data of the sentence-picture verification task after each set of 40 participants. If the resulting BF was smaller than 10, we continued data collection with the next 40 participants. Once one of the match advantages had BF_{10} beyond 10, data collection for that group ended. For each group, data collection continued until BF_{10} beyond 10 or when the predetermined maximum of 160 participants was reached.

Participants

This study recruited native speakers of English, Chinese, and Dutch. English speaking participants were recruited via Prolific Academic, Chinese participants from Bounty Workers, and Dutch participants from the Erasmus University Rotterdam psychology participant pool.³ The age range of English and Chinese participants was 18-40 years, and the age range of Dutch participants was 18-30 years.

Pre-Analysis Processing

After data collection, we first removed the data from participants who did not

² The permanent link for access to the preregistered plan is <https://osf.io/4z9my/>

³ In January 2019, Prolific Academic had 136 eligible Dutch participants and 344 eligible Chinese participants. The Chinese participants were from various Asian countries where people usually intermix Traditional and Simple Chinese. Taiwanese are used to read Traditional Chinese. Therefore, we decided to use Bounty Workers (<https://bountyworkers.net/>) for recruiting participants as many registered participants are native Taiwanese speakers.

complete the task or had no correct responses for at least one condition from the dataset.

This resulted in removal of 22 (out of 104) participants from the English sample, 24 (out of 117) participants from the Chinese sample, 8 (out of 121) from Dutch sample, and 22 (out of 121) participants from the Dutch sample doing the English task.

Results

Overall Accuracy of Verification and Comprehension

Table 1 summarizes the average accuracy on the sentence-picture verification task and the inter-trial comprehension task for each language group. A between-participant analysis of variance shows that there was a significant difference among the groups in the verification task, $F(3, 459) = 14.04$, $MSE = 148.36$, $p < .001$, $\hat{\eta}_p^2 = .084$, and in the comprehension task, $F(3, 459) = 8.44$, $MSE = 185.90$, $p < .001$, $\hat{\eta}_p^2 = .052$.

(Insert Table 1 about here)

Specifically, Dutch participants had a higher accuracy on the sentence-picture verification task than did the Chinese and English participants. Additionally, the Dutch participants' comprehension responses were more accurate than those of English and Chinese participants. Based on this, we excluded participants in the English and Chinese groups who had accuracy scores $< 75\%$ and 70% respectively. For the Dutch group, participants whose accuracy was $< 80\%$ were excluded. The remaining dataset contained data of 82 English participants, 93 Chinese participants, 113 Dutch participants, and 104 Dutch participants doing the English task.

Sequential Analysis of Verification Response Times

We conducted the preregistered sequential analyses on the response time data of sentence-picture verification by language group. The results showed that the English and Chinese samples met the preregistered criterion of $BF_{10} > 10$ at half the preregistered

maximum sample size. Figure 1 illustrates the sequential analysis of each group separately for large and small objects.

(Insert Figure 1 about here)

Verification Responses by Conditions

Table 2 summarizes the mean reaction times and accuracy percentages as a function of language group, objects size, and match. In addition to Dutch participants, English and Chinese participants showed match advantages on the mean reaction times. Chinese participants performed worse than the other participants.

(Insert Table 2 about here)

We conducted three sets of statistical analyses as per the preregistered plans. They were (1) a three-way mixed analysis of variance with language group as between participants factor, and object size and match as within-subject factors; (2) a meta-analysis of the match advantage across language groups and object size; (3) a linear mixed-effect models with participants and items as intercepts. Because we ultimately completed two English studies, there were four language groups in each analysis.

Three-Way Mixed ANOVA

The preregistered mixed ANOVA on the verification times showed that, at a significance level of $< .05$, there were main effects of language group, $F(3, 383) = 12.14$, $MSE = 84,138.96$, $p < .001$, $\hat{\eta}_p^2 = .087$; object size $F(1, 383) = 216.50$, $MSE = 6,053.32$, $p < .001$, $\hat{\eta}_p^2 = .361$; and match advantage $F(1, 383) = 13.40$, $MSE = 6,166.75$, $p < .001$, $\hat{\eta}_p^2 = .034$. The main effects of object size and match advantage were consistent with our preregistered prediction. The main effect of language group was also beyond the significance level, but requires further exploration in light of the interactions. The interaction between object size and language group shows that Chinese participants required more time to verify

the large objects than did the other groups, $F(3, 383) = 4.24$, $MSE = 6,053.32$, $p = .006$, $\hat{\eta}_p^2 = .032$. There also was a significant interaction between language group and match, $F(3, 383) = 2.90$, $MSE = 6,166.75$, $p = .035$, $\hat{\eta}_p^2 = .022$. The interaction between object size and match advantage was not significant, $F < 1$. Also, the three-way interaction of language group with match and object size was not significant, $F(3, 383) = 0.89$, $MSE = 5,892.41$, $p = .448$, $\hat{\eta}_p^2 = .007$.

A three-way mixed ANOVA on the accuracy scores showed significant main effects of language group, $F(3, 383) = 20.76$, $MSE = 3,621.59$, $p < .001$, $\hat{\eta}_p^2 = .140$, and match $F(1, 383) = 63.55$, $MSE = 951.25$, $p < .001$, $\hat{\eta}_p^2 = .142$. Unlike the response time data, the accuracy scores showed no effect of object size, $F(1, 383) = 0.29$, $MSE = 629.80$, $p = .592$, $\hat{\eta}_p^2 = .001$. Consistent with the verification times, the interaction of object size and language group indicated that Chinese participants made more errors for the large objects than did the other language groups, $F(3, 383) = 8.08$, $MSE = 629.80$, $p < .001$, $\hat{\eta}_p^2 = .060$. The interaction of language group and match advantage also indicates that Chinese participants made more errors for the mismatching object orientation, $F(3, 383) = 27.63$, $MSE = 951.25$, $p < .001$, $\hat{\eta}_p^2 = .178$. This analysis indicated no interaction of orientation and match and no three-way interaction, $F_s < 1$.

Meta-analysis on the match advantage

Following the preregistered analysis plan, we compared the match advantages across language groups. The meta-analysis shows that the English group showed the largest effect size for large objects, $M = 29.13$, 95% CI [10.48 , 47.78], while the Chinese group had the largest effect size for small objects, $M = 37.09$, 95% CI [11.18 , 62.99]. Additionally, as planned we tested if the effect size of large objects is larger than that of small objects. The meta-analysis showed a match advantage for large objects, $M = 16.54$, 95% CI [3.1 , 29.97], but a null effect for small objects, $M = 8.53$, 95% CI [-4.2 , 21.27]. Figure 2 shows the results of this meta-analysis in a forest plot.

(Insert Figure 2 about here)

The preregistered hypothesis for this study predicted that object size should moderate the orientation match advantage. To test this hypothesis we conducted a moderator analysis on the effect size of match advantage as the dependent measurement, language groups as the independent variable, and object size as the moderator. We ran this analysis without and with the heterogeneous residuals. By the analysis without the heterogeneous residuals, the coefficient for the object size was estimated $b = -8.09$ ($SE = 9.42$) and was above the preregistered significance level, $p = 0.39$. The analysis with the heterogeneous residuals returned the similar result: the estimated coefficient was $b = -8.01$ ($SE = 9.45$) and was above the preregistered significance level, $p = 0.40$.

Linear mixed-effect model on the verification times

The preregistered analysis plan aimed to explore the interactions of the three fixed effects (language group, object size, and matching of sentence and object). We decided to use the model including the trial sequence and the correlation of trial sequence and items based on the lowest Akaike information criterion (Akaike, 1974; Burnham & Anderson, 2010). Appendix B summarizes the selection of models.

Table 3 summarizes the fixed effects in the linear mixed-effect model. The mixed-effect model shows main effects of matching and language group below the preregistered significance level of $p < .05$, but the main effect of object size and all the interactions were not significant. The mixed-effect model did not show an interaction of match advantage and object size or language as did ANOVA and meta analysis. Table 4 summarizes the coefficients of random effects in the linear model based on the suggestion of Barr, Levy, Scheepers, and Tily (2013). The variances of random effects were critical for controlling the Type 1 error and the statistical power.

(Insert Table 3 about here)

(Insert Table 4 about here)

Study 2: Picture-Picture Verification

The aim of Study 2 was to examine the mental rotation hypothesis. We assumed that large, non-manipulable objects require longer rotation times than small, manipulable objects. Therefore, we predicted that participants would take more time to verify larger objects that are presented in different orientations.

Method

Participants. Same as in Study 1.

Results

The analysis includes data from participants who had high accuracy (English: >75%, Chinese: >70%, Dutch: >80%) in the sentence-picture verification task. Table 5 summarizes the descriptive statistics as a function of language group, object size, and match. Each language group showed a longer mean reaction time and a lower accuracy for large objects. Participants made faster and more accurate responses for object pairs presented in the same orientation, especially for large objects.

(Insert Table 5 about here)

Three-way ANOVA

Consistent with the preregistered plan, we conducted a mixed ANOVA on the correct reaction times as a function of language group, object size, and match. This analysis showed significant main effects of language group, $F(3, 457) = 7.32$, $MSE = 28,383.87$, $p < .001$, $\hat{\eta}_p^2 = .046$; object size, $F(1, 457) = 411.90$, $MSE = 870.22$, $p < .001$, $\hat{\eta}_p^2 = .474$; and match, $F(1, 457) = 1,208.09$, $MSE = 854.53$, $p < .001$, $\hat{\eta}_p^2 = .726$. Of more importance to our hypotheses, the interaction between object size and match was significant, $F(1, 457) = 46.16$,

$MSE = 673.50$, $p < .001$, $\hat{\eta}_p^2 = .092$. This interaction indicated that the verification time was longer for large objects (55 ms) than for small objects (39 ms). Additionally, the interaction between language group and object size was not significant, $F(3, 457) = 1.37$, $MSE = 870.22$, $p = .252$, $\hat{\eta}_p^2 = .009$, nor was there a significant interaction between language group and match, $F(3, 457) = 5.77$, $MSE = 854.53$, $p = .001$, $\hat{\eta}_p^2 = .036$. The non-significant interactions suggest that human perception of object size and orientation generalizes across the three languages.

The mixed ANOVA on the accuracy scores shows significant main effects of object size, $F(1, 457) = 729.85$, $MSE = 26.26$, $p < .001$, $\hat{\eta}_p^2 = .615$, and match, $F(1, 457) = 646.19$, $MSE = 45.65$, $p < .001$, $\hat{\eta}_p^2 = .586$. Unlike the analysis of response times, the main effect of language group was not significant, $F(3, 457) = 1.26$, $MSE = 117.05$, $p = .289$, $\hat{\eta}_p^2 = .008$. Consistent with the reaction time analysis, the analysis of response accuracy showed a significant interaction of object size and match, $F(1, 457) = 929.43$, $MSE = 22.55$, $p < .001$, $\hat{\eta}_p^2 = .670$. This interaction indicated that participants made more errors for the large objects presented in different orientations. The other interactions were above the predefined significance level of .05.

Meta-analysis on the verification times

Along with the preregistered hypothesis for the first study, this study investigated whether object size moderates the mental rotation of target objects. We conducted the moderator analysis on the effect size of match as the dependent measurement, language groups as the independent variable, and object size as the moderator. We ran this analysis without and with the heterogeneous residuals. In the analysis without the heterogeneous residuals, the coefficient for the object size was estimated $b = -16.38$ ($SE = 4.89$ and was below the preregistered significance level, $z = -3.35$, $p = .001$). The analysis with the heterogeneous residuals returned a similar result: the estimated coefficient was $b = -16.42$ ($SE = 4.89$ and was below the preregistered significance level, $z = -3.36$, $p = .001$).

Mixed-effect model

As in Study 1, we decided to use a model including the trial sequence as the intercept and the correlation of trial sequence and participants as the best fitting model. Table 3 summarizes the coefficients of the fixed effects. In addition to the main effects of match, object size, and languages, this mixed-effect model confirmed the larger effect of match for the large objects, $\beta = 93.14$, $t = 3.67$, $p < .01$. This model also indicates that there was an interaction between match and language, indicating a larger effect for Dutch participants in comparison with Chinese participants, $\beta = 59.65$, $t = 2.65$, $p < .01$.

Study 3: Naming Study

Similar to Study 1, the aims of Study 3 were to test whether there was a larger match advantage for large than for small orientation item, and whether this was similar across languages. Study 3 focused on the language groups that showed the orientation effects in Study 1: English and Chinese. If the match advantage obtained in Study 1 is found in this study as well, this would provide corroborating evidence that mental simulations are performed when processing large objects.

Method

Procedure

The procedure was similar to that in Study 1 except that participants spoke the object name of the target picture aloud instead of pressing a response key. Before participants commenced with the experiment, they tested their audio recording function on a calibration page. In each practice and experimental trial, participants named the object aloud within 3 seconds. The Gorilla website, which was used for presenting the stimuli, stored each vocal response in mp3 format. Then, participants verified their voice response with four options: “Right,” “Wrong,” “No Response,” and “Recording Failed.” After half of the filler trials, participants completed comprehension questions about the probe sentences, which were used

to check whether participants were reading these sentences for meaning. As for the sentence-picture verification task, the participants filled in the post-survey about this study at the end.

Naming Latency Coding

The sound files were archived in mp3 format in mono channel and 128 kbit/second. We extracted the naming latency of each voice response in two phases. In the first phase, we used the Praat (Boersma, 2001) script to successfully determine the naming latency of sound files without noise.⁴ In the second phase, we checked the participants' evaluation of their own recordings. Fifteen English participants indicated that more than 50% of their responses "Failed Recording," but it appeared that these sound files contained accurate recordings of participants' voice in the trials nonetheless. Ten Chinese participants' sound files included background noise. The noise caused the Praat script to calculate incorrect naming latencies. Prior to the data analysis, we reset the 15 English participants' evaluations, and we manually coded the 10 Chinese participants' naming latencies.

Participants

English and Chinese participants from the same participant pools as in Study 1 (English: ProA; Chinese: BW) participated. Thirty-two participants whose responses contained over 50% of unrecognizable sounds and who were not native speakers were removed from the data set. The data analysis included the responses of 76 English participants and 87 Chinese participants.

Results

Table 6 summarizes the mean reaction times and accuracy from the participants. Both English and Chinese participants showed a weak match disadvantage in the picture-naming

⁴ We thank David Feinberg of McMaster University for providing assistance and suggestions for extracting the naming latencies. See the contact of Feinberg's laboratory at <https://osf.io/jc2hk/>

task, and they required a longer time to read the large objects than the small objects. The preregistered plan addressed the exploratory goals for the analysis of picture-naming responses. There was a significant difference between large objects and small objects in a mixed ANOVA with language, object size, and match as factors. We compared the responses to large objects and small objects by using a mixed-effect model approach.

(Insert Table 6 about here)

Three-Way Mixed ANOVA on the naming latency

The analysis on naming latencies yielded a significant main effect of object size, $F(1, 138) = 166.84$, $MSE = 8,399.33$, $p < .001$, $\hat{\eta}_p^2 = .547$. All other main effects and interactions had $p > .1$ and $\hat{\eta}_p^2 < .005$.

Linear mixed-effect model

The fixed effect of object size was the only coefficient beyond the preregistered significance level of $p < .05$. The confidence intervals of naming times indicated that large objects require more time for pronunciation, $M = 973.91$, 95% CI [904.45, 1,042.78], than small objects, $M = 833.28$, 95% CI [780.43, 886.14]. Table 3 and Table 4 summarize the coefficients of the fixed effects and random effects.

Discussion

We set out to investigate to what extent inconsistent findings previously reported for the mental simulation of object orientation are related to the size of objects. In addition, we examined whether our findings would generalize across languages (Chinese, Dutch, and English). We conducted three pre-registered studies in which we manipulated the size of objects to be either small or large. Participants made verification judgments (Studies 1 and 2) or named the depicted objects (Study 3). We hypothesized that a larger match advantage would be obtained for large objects than for small objects. We performed a confirmatory test

on the verification task (based on earlier research using this task) and explored the effects in the picture-naming task. Additionally, we hypothesized that the match advantage should be similar across languages. Moreover, we tested a mental rotation account predicting that large and non-manipulable objects should take longer to mentally rotate than small and manipulable objects, which would result in a smaller match advantage for small objects than for large ones. In the following discussion, we separate conclusions about our confirmatory analyses from exploratory analyses and comments.

Confirmatory analyses

Our first preregistered hypothesis was that the orientation effect should be larger for large than for small objects. Contrary to this hypothesis, the preregistered mixed ANOVA showed a null interaction of object size and object orientation in the sentence-picture verification task. The meta-analysis on the sentence-picture verification times (Study 1) showed that while there was a larger match advantage for large than for small objects, the difference between these meta-analytic effects was not significant (See Study 1 Result, Meta-analysis on the match advantage).

The meta-analysis suggests that the pattern is more complex than we assumed. We will discuss this in the exploratory section of this discussion. Additionally, contrary to the sentence-picture verification experiment (Study 1), the picture-picture verification experiment (Study 2) did show the predicted interaction between object size and match. Thus, without a sentence context, pictures of large objects do yield a larger orientation effect than do pictures of small objects.

To summarize, the evidence regarding our first preregistered hypotheses is mixed. Only the task that is the most purely visual (Study 2) shows the predicted interaction between size and orientation but the lack of such an interaction in the language-based task (Study 1) suggests that object size cannot be used to explain the relatively small size of the orientation

effect relative to other perceptual features such as color, actual object size (*per se*), or shape.

Our second hypothesis pertains to the generalizability of the orientation effect across languages, specifically in the picture-sentence verification task, as this is what was used in virtually all previous studies. Although the meta-analysis of the Study 1 results shows a main effect of match, the pattern of orientation effects differed across languages in a rather complex manner. The interaction itself is not very strong ($p = .035$) and object size is not a moderator in the meta-analysis.

As a supplement to our first hypothesis, we investigated in Study 2 whether differences could be found in picture verification times for large and small objects in an attempt to examine the role of mental rotation in the orientation effect. The mixed ANOVA showed longer verification times for larger objects as we predicted. Also the meta-analysis indicated that object size moderated the verification times to target pictures. This suggests that mental rotation is a mental process that participants engage in during a picture-picture verification task.

Exploratory analyses

As the meta-analysis of Study 1 shows, there was an effect of orientation across languages and object size. This extends the original finding by Stanfield and Zwaan (2001). Nevertheless, the meta-analytic effect is small (12 ms) and considerably smaller than the original effect of 44 ms or the Zwaan and Pecher (2012) replication of 35 ms. Importantly, the present study is not a direct replication. First, different materials were used. Second three language groups were included. However, even if one takes only the native English speakers, the effect (across large and small objects) is 15 ms. The match advantage for the Chinese participants is 35 ms. The Dutch participants showed no orientation effect when the stimuli were presented in Dutch (2 ms across large and small objects). This is consistent with earlier findings by Rommers et al. (2013) and De Koning et al. (2017a), who also tested

the orientation effect using Dutch stimuli.

Combined with earlier findings, a pattern seems to be arising. In English, a small but reliable match advantage is found. In Dutch, however, no effect is found, while in Chinese a larger effect is found than in either English or Dutch (in the present study). As alluded to earlier, the lack of an effect in Dutch might be due to the nature of the stimuli. In Dutch it is common, at least according to the second and third authors' intuitions as native speakers of Dutch, to use a verb that describes the orientation of an object when describing the location of that object. Thus, *Het boek staat op de plank* (*The book stands on the shelf*) is more common than *Het boek is op de plank* (*The book is on the shelf*). It is possible that the lack of an orientation verb in our stimulus sentences has thrown our Dutch speakers off in that it violated their expectations. It is conceivable that Dutch speakers are used to using the orientation verb as the primary source of information on how to represent the orientation of an object rather than relying on the prepositional phrase to infer the object's orientation from, as was necessitated by our stimuli. Perhaps the lack of an orientation effect in Dutch is due to the relative unusualness of our Dutch stimulus sentences.

There are two aspects of our data that are consistent with this tentative explanation. First, as noted before, in our pilot study we obtained an effect in a Dutch-Dutch sample for small objects. When we checked the stimuli, we noticed that there were many stimulus sentences with an orientation verb. These sentences were constructed by a Dutch research assistant, who had translated these sentences from English examples. It is telling that the research assistant automatically used orientation verbs when translating from sentences without an orientation verb. Apparently, the assistant thought this was the best translation rather than using a more literal one using the orientation-neutral *is* which was deliberately used in the original study by Stanfield and Zwaan (2001) precisely because of this characteristic. Moreover, we obtained an orientation effect with these sentences containing orientation verbs. Thus, the lack of an orientation effect in Dutch sentences might be

629 attributed to the absence of orientation verbs.

630 The meta-analytic data provide a second hint that is consistent with this idea. When
631 tested in English, the Dutch participants showed a pattern that is somewhere between
632 English and Dutch data, at least with regard to the large objects. The Dutch-Dutch sample
633 has an orientation effect of 1 ms while the English sample has 29 ms. The Dutch-English
634 sample has a difference of 13 ms. To be sure, this analysis is highly speculative (hence its
635 presence in a section titled “exploratory analyses”) but it points at avenues for further
636 research.

637 The Chinese sample shows the largest effects of the three language groups and is, in
638 fact, the only sample showing an effect for small objects. We are not sure why this is the
639 case. One thing to note, however, is that, as we noted earlier, this sample shows by far the
640 largest variability in response times. One plausible factor is that many Taiwanese
641 participants were likely not as experienced as English and Dutch participants in on-line
642 psychological experiments. Nevertheless, even though the Chinese data showed the largest
643 variability in this study, our best-fitting mixed-effect model did not show a significant
644 interaction between language group and match advantage.

645 A further observation concerns the putative role of mental rotation in the various tasks.
646 The meta-analysis for Study 1 suggests that object size did not moderate the match
647 advantage of object orientation, although we found significant match advantages of large
648 objects in English and a match advantage of small objects in Chinese. On the other hand,
649 the meta-analysis for Study 2 indicates that object size indeed moderated the mental
650 rotation speed of objects. These results demonstrate that the mental rotation hypothesis
651 provides a better account for the perception task (i.e., picture-picture verification) than for
652 the reading task (i.e., sentence-picture verification). The preregistered hypothesis was
653 supported only by the results from the picture-picture verification task. The results suggest
654 that mental rotation might play a role in the picture-picture verification task but not in the

655 sentence-picture verification task. Hence, the present study does not confirm De Koning et
656 al.'s (2017a) suggestion that the failure to find an orientation effect in a sentence-picture
657 verification task might be due to participant's engagement in mental rotation processes
658 where a mismatched orientation is quickly transformed into an orientation that matches the
659 object as described in the sentence.

660 According to our preregistered plan, the findings of the sentence-picture naming task
661 (Study 3) provide clues to explore theoretical and methodological issues beyond the
662 confirmatory analysis. Our picture-naming task showed a main effect of object size but null
663 effect of object orientation. This result speaks to the theoretical distinction between extrinsic
664 and intrinsic properties (Scorolli, 2014). Embodied cognition researchers have classified
665 object orientation as an extrinsic property and object size as an intrinsic property (e.g., De
666 Koning et al., 2017a). This classification depends on the assumption that simulating an
667 intrinsic property requires only the visual system, whereas simulating extrinsic property
668 requires the visual and motor systems. The finding that supports this distinction is that
669 English readers, in feature-generation tasks, provided more intrinsic property than extrinsic
670 property of target objects (McRae, Cree, Seidenberg, & McNorgan, 2005; Wu & Barsalou,
671 2009). One account to be examined is that the object name would sufficiently initiate the
672 simulation of extrinsic property. Simulating intrinsic property, on the other hand, would
673 require the understanding of sentence context.

674 It is premature to claim our findings support the theoretical distinction between
675 extrinsic and intrinsic property, but our analysis provides clues for further research. One
676 potential topic is to isolate the distinction between extrinsic and intrinsic properties. In the
677 study which measured two kinds of object property, an orthogonal manipulation of
678 properties would be the appropriate method. Take object size and orientation as an example.
679 Researchers could test the target picture "rocket" in four scenarios: large object and vertical
680 "The rocket that will carry the satellite has been placed on the launching platform"; large

object and horizontal “The rocket that is being transferred to the base will carry the satellite”; small object and vertical “In that diorama, a rocket has been placed on the launching platform”; small object and vertical “The rocket on that table will be placed in the diorama on the launching platform”. With a number of sentence-picture sets like in this example, researchers could examine if there is an interaction between size and orientation and evaluate to which extent sentence context influenced the retrieval of object names.

Conclusions

In this preregistered report, we tested two hypotheses about the orientation effect in the sentence-picture verification task. The first hypothesis was that the match advantage should be larger for large non-manipulable objects than for small manipulable objects. The second hypothesis was that this effect should generalize across the languages we tested, Chinese, Dutch, and English. Neither hypothesis was supported by the data. Although the match effect was optically larger for large objects than for small objects, there was no significant interaction between object size and match. Therefore, we cannot conclude that object manipulability is a factor in the orientation effect and that the fact that the orientation effect is typically smaller than the effects for shape, color, and size is due to manipulability. Contrary to our second hypothesis, the orientation effect did vary across languages. The effect was largest in Chinese, smaller in English, and absent in Dutch.

In exploratory analyses, we attempted to explain all of our findings and suggest a design to explore further theoretical questions. We tentatively explain the lack of an orientation effect in Dutch by noting that the experimental sentences are somewhat unusual in Dutch, as compared to English. A future (preregistered) experiment could examine this idea further. These results suggest the orientation effect may not always be as straightforward as researchers think to generalize effects from one language to other languages and from one task to other tasks.

We should note that there are several limitations to our approach. First, we explored the cognitive aspects of simulating object orientation and size in terms of specific tasks, namely the sentence-picture verification task (our primary experiment), the picture-picture verification task, and the sentence-picture naming task. These tasks did not show similar patterns of results, suggesting that the results are to some extent task-specific. The sentence-picture verification task, our primary task, showed the most complex pattern of results, which we have tried to explain above. The sentence-picture naming task showed mainly null results. We are not sure whether this is due to the fact that we collected the naming data online or simply to the fact that the picture-naming task may not be sensitive enough to detect an orientation effect, given that the orientation effect is small to begin with, and naming effects tend to be smaller than verification effects (Zwaan, 2014). The picture-picture verification task showed the clearest results. This is perhaps not surprising given that it is the only language-independent task and does not rely on inferential (or knowledge-activation) processes. The fact that this task showed an interaction between object size and the match advantage might have to do with the size of the depicted objects but could also yield to a more mundane explanation, for example that the pictures depicting the larger objects had more visual features to be verified than the pictures depicting the small objects.

The current study set out to investigate key issues that have been unexplored in embodied cognition research (see Ostarek & Huettig, 2019). Although not fully conclusive, our results point to two aspects that could help advance research and theorizing regarding the mental simulation of object properties. First, we made an attempt to investigate whether and how variation in the characteristics of objects (i.e., size) within one object property (i.e., orientation) impacts the mental simulation of objects. Second, we investigated whether the mental simulation of object orientation is language independent. Our findings suggest that differences exist in mental simulation across languages, which is important to take into account when predicting, comparing or interpreting mental simulation findings from various

languages. Together, the findings of this study provide a first step in furthering our understanding of the mental simulation of object properties and hopefully inspire other researchers to contribute to further developments. Along this line, Chen et al. (2018) are currently assessing the replicability of the match advantage of object orientation in more than 14 languages. These and other initiatives can build on our findings to explore novel questions and further refine theories of mental simulation in language comprehension.

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Table 1

Average accuracy (in %) on the sentence-picture verification task and comprehension task (standard errors in parentheses).

Group	Verification	Comprehension
Chinese	83.05(1.17)	70.35(1.46)
Dutch-Dutch	93.06(0.7)	77.71(0.9)
Dutch-English	89.02(1.12)	78.26(1.14)
English	86.75(1.5)	74.43(1.55)

Table 2

Averaged reaction times and error percentages (in parentheses) of the sentence-picture verification task.

Groups	Object Size	Matching	Mean RT	Accuracy Percentage
Chinese(N = 93)	Large	N	828.23(24.80)	219.35(7.57)
		Y	799.19(19.14)	264.31(4.14)
	Small	N	765.30(23.19)	239.31(7.59)
		Y	728.21(19.91)	266.94(4.12)
Dutch(N = 113)	Large	N	726.96(13.69)	278.60(2.28)
		Y	725.65(15.21)	277.27(2.22)
	Small	N	651.81(11.47)	278.43(2.07)
		Y	649.53(12.44)	276.60(2.08)
English(N = 99)	Large	N	690.47(14.02)	271.59(2.41)
		Y	677.56(13.68)	280.87(2.17)
	Small	N	646.17(12.80)	267.42(3.08)
		Y	641.75(13.10)	274.05(2.48)
*Dutch(N = 82)	Large	N	722.27(18.49)	271.19(3.82)
		Y	693.14(15.09)	281.02(2.45)
	Small	N	656.77(14.92)	270.73(4.46)
		Y	655.26(15.57)	276.22(3.95)

Note:

Standard errors of RT and Accuracy are in the parentheses.

* Dutch participants who joined the English study

Table 3

Fixed Effects of Critical Variables: Sentence-Picture Verification Task and Picture-Picture Verification Task

	Sentence-Picture Verification		Picture-Picture Verification		Sentence-Picture Naming	
	Estimate (Std. Error)	t value	Estimate (Std. Error)	t value	Estimate (Std. Error)	t value
Intercept	972.03(69.93)	13.9***	831.49(20.84)	39.91***	968.77(30.64)	31.61***
Trial	-4.49(0.17)	-26.07***	-0.17(0.04)	-4.2***	-0.71(0.36)	-1.96
Group	-85.3(20.4)	-4.18***	-	-2.94**	-4.24(36.07)	-0.12
(English)			64.29(21.86)			
Group	-	-2.6**	-44.7(21.2)	-2.11*		
(Dutch ¹)	51.48(19.77)					
Group	-	-3.04**	-	-4.22***		
(Dutch ²)	64.92(21.36)		92.57(21.91)			
Object Size	-	-0.69	-	-4.99***	-	-5.65***
	65.29(95.13)		112.44(22.55)		133.56(23.62)	
Matching ³	-27.89(9.35)	-2.98**	-	-8.95***	-	-0.76
			161.31(18.03)		10.49(13.75)	
Object Size:	-3.37(12.98)	-0.26	93.14(25.38)	3.67***	15.47(19.29)	0.8
Matching ³						
Group	15.53(12.83)	1.21	-	-2.24*	-	-0.5
(English):			44.44(19.82)		10.04(19.99)	
Small Size						
Group	-	-1.36	11.36(19.56)	0.58		
(Dutch ¹):	16.88(12.41)					
Small Size						
Group	-4.91(13.39)	-0.37	39.84(16.08)	2.48*		
(Dutch ²):						
Small Size						
Group	11.31(12.56)	0.9	36.95(22.87)	1.62	-	-0.74
(English):					14.92(20.04)	
Matching ³						
Group	22.6(12.19)	1.85	59.65(22.51)	2.65**		
(Dutch ¹):						
Matching ³						
Group	-2.37(13.13)	-0.18	67.51(18.76)	3.6***		
(Dutch ²):						
Matching ³						
Group	13.14(17.63)	0.75	41.81(33.2)	1.26	18.95(28.23)	0.67
(English):						
Small Size:						
Matching ³						
Group	2.42(17.07)	0.14	-	-1.06		
(Dutch ¹):			34.28(32.33)			
Small Size:						
Matching ³						
Group	32.74(18.42)	1.78	-	-1.51		
(Dutch ²):			39.72(26.31)			
Small Size:						
Matching ³						

* p < .05, ** p < .01, *** p < .001

¹ Dutch participants who finished the Dutch study

² Dutch participants who finished the English study

³ Matching of sentence and picture (Study 1,3) and target objects (Study 2)

Table 4

Random Effects in Sentence-Picture Verification Task and Picture-Picture Verification Task

Term	Sentence-Picture Verification		Picture-Picture Verification		Sentence-Picture Naming	
	Variance	Corr.	Variance	Corr.	Variance	Corr.
Participant (Intercept)	34931.03	NA	22441.47	NA	62029.52	NA
Participant: Trial	8.16	-0.76	0.22	-0.55	NA	NA
Item (Intercept)	73845.79	NA	2311.71	NA	5945.33	NA
Residual	50671.09	NA	26228.04	NA	122131.56	NA

Table 5

Averaged reaction times and error percentages (in parentheses) of the picture-picture verification task.

Groups	Object Size	Matching	Mean RT	Accuracy Percentage
Chinese(N = 116)	Large	FALSE	674.96(9.48)	83.22(0.77)
		TRUE	614.90(7.72)	96.90(0.57)
	Small	FALSE	633.33(9.03)	95.69(0.60)
		TRUE	596.54(9.09)	96.55(0.61)
Dutch(N = 121)	Large	FALSE	650.00(8.37)	82.23(0.81)
		TRUE	603.66(7.53)	96.26(0.39)
	Small	FALSE	619.18(7.38)	95.27(0.44)
		TRUE	586.37(6.92)	96.07(0.38)
English(N = 120)	Large	FALSE	638.01(8.22)	80.60(1.14)
		TRUE	584.15(7.67)	96.25(0.47)
	Small	FALSE	603.57(7.60)	94.09(0.93)
		TRUE	565.45(6.90)	96.20(0.43)
*Dutch(N = 104)	Large	FALSE	695.01(9.60)	81.61(1.02)
		TRUE	632.74(8.49)	97.33(0.47)
	Small	FALSE	657.27(8.82)	95.46(0.74)
		TRUE	608.26(7.84)	96.72(0.44)

Note:

Standard errors of RT and Accuracy are in the parentheses.

* Dutch participants who joined the English study

Table 6

Averaged reaction times and accuracy percentages of the sentence-picture naming task.

Groups	Object Size	Matching	Mean RT	Accuracy Percentage
Chinese(N = 87)	Large	N	912.59(23.36)	93.97(0.81)
		Y	907.11(21.58)	94.25(0.79)
	Small	N	800.38(17.93)	97.70(0.54)
		Y	815.43(20.43)	97.41(0.65)
English(N = 76)	Large	N	873.08(37.85)	95.48(0.95)
		Y	877.94(32.85)	96.13(0.97)
	Small	N	771.28(31.79)	96.38(0.89)
		Y	801.32(27.47)	96.63(0.90)

Note:

Standard errors of RT and Accuracy are in the parentheses.

Figure 1. Bayesian sequential analysis of Sentence-picture verification response times. Note. Eng: English group; Chi: Chinese group; NL-Dut: Dutch group, Dutch study; NL-Eng: Dutch group, English study; L: Large objects; S: Small objects; I: Included low-accuracy data; E: Excluded low-accuracy data

Figure 2. Meta-analysis on the mean differences of match advantages.

Appendix A

Guideline for replication and reproduction

856 Researchers who are planning to replicate the studies can download the experimental scripts,
857 sentence sheets, and picture files from the open materials repository (permanent link:
858 <https://gorilla.sc/openmaterials/39336>).

859 The data files and analytical scripts are accessible in this project repository (
860 <https://osf.io/auzjk/>). Readers who want to reproduce the data analysis can at first
861 download the files in this repository. In the guideline file `datafile_guide.md`(packaged in
862 `includes.zip`), we summarized the content of files to reproduce the data analysis of this
863 project.

864 Considered the massive numbers and volume of voice files, we packaged the recorded
865 voice of English and Chinese participants in `Study3_voice.7z` with Praat script. This file is
866 available in this project repository (direct access link: <https://osf.io/sc59e/>).

Appendix B

Selections of Mixed-Effect Models

The mixed-effect models in each study considered inclusion of trial sequence and the constituents of random effects. There were four types of models, and each included the three fixed effects (language groups, object size, and matching setting) and the two random effects (participants, target objects). In each study we evaluated the fitness of four types of models: (a) The model does not include the trial sequence as the intercept; (b) The model includes the trial sequence as the intercept; (c) The model includes the trial sequence as the intercept and the correlation of trial sequence and participants; (d) The model includes the trial sequence as the intercept and the correlation of trial sequence and items. Table B1 summarizes the statistical information of each model. Model (c) had the smallest AIC in each study.

Table B1

Statistical information of mixed-effect models

Study	Model	Degree of Freedom	AIC
Sentence-Picture Verification	a	19	307,588.56
	b	20	305,454.49
	c	22	305,093.07
	d	22	305,464.32
Picture-Picture Verification	a	19	171,204.32
	b	20	171,169.64
	c	22	171,145.05
	d	22	171,119.18
Sentence-Picture Naming	a	11	146,054.77
	b	12	146,048.33
	c	14	145,887.37
	d	14	146,052.12