Moving Beyond Words

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Chapter 6: Mental Simulation of Four Visual Object Properties: Similarities and Differences as Assessed by the Sentence-Picture Verification Task

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Abstract

In the Sentence-Picture Verification (SPV) task, people read sentences in which a particular shape/size/color/orientation of an object is implied. They then indicate for each subsequently presented picture, which either *matches* or *mismatches* the visual information implied in the preceding sentence, whether the object it depicts was mentioned in the sentence. Faster verification times on matching than mismatching trials (i.e., match-advantage) are generally considered supportive to the notion that readers engage in mental simulation during sentence comprehension. The present study advances this work by applying a within-subjects design to the SPV task, enabling us to directly address the strength of and correlation between the match-advantages for the visual object properties shape, size, color, and orientation. Results showed varying match-advantages for shape, size, and color, with color showing the strongest effect, but no match-advantage for orientation. Additionally, shape, size, and color appeared to be significantly correlated, whereas there were no significant correlations with orientation. These findings suggest that the interpretation of match-advantages would benefit from a re-evaluation of the mental simulation account based on a distinction into intrinsic (i.e., shape, size, color) and extrinsic (i.e., orientation) object properties.

In capturing the meaning of text, readers mentally simulate the described situations and events through the reactivation of previously acquired real-world perceptual, motor, and affective experiences (Barsalou, 1999). Retrieving such an experience entails the re-enactment of the neural states from the brain systems that govern perception, action, and emotion which were recruited and stored at the moment the original experience was acquired. Integrating these traces of earlier experiences from multiple perceptual and motor modalities into a mental simulation enables readers to experience the described events as if they are actually part of it (for an overview, see De Koning & van der Schoot, 2013). It follows that, in such an embodied view to language comprehension, the representations involved in understanding sentences are of the same kind as the representations involved in having actual sensory and motor experiences. At present, there are a growing number of studies substantiating the claim that readers indeed activate sensory and motor information in language comprehension (Barsalou, 2008). In this article, we will concentrate on the work that, using the Sentence-Picture Verification (SPV) task, has demonstrated that perceptual information related to an object's shape, size, color, and orientation is activated during sentence comprehension (De Koning, Wassenburg, Bos, & van der Schoot, 2015; Zwaan & Pecher, 2012; for an overview, see Horchak, Giger, Cabral, & Pochwatko, 2014).

In the SPV task, participants read sentences implying a visual property of an object like "The ranger saw the eagle in the nest" (e.g., Engelen, Bouwmeester, de Bruin, & Zwaan, 2011). They then indicate whether or not an image, which depicts the object in such a way that it matches (i.e., an eagle with folded wings) or mismatches (i.e., an eagle with its wings outstretched) the visual property (here: object shape) as implied by the sentence, was mentioned in the sentence. Across numerous studies, readers appear to verify pictures faster when they match rather than mismatch the perceptual information from the preceding sentence. A finding which has been demonstrated for, among other things, multiple visual object properties (i.e., shape, size, color, and orientation) in both children and adults (e.g., De Koning, Wassenburg, Bos, & van der Schoot, 2015; Engelen et al., 2011; Zwaan & Pecher, 2012). This so-called match-advantage is consistent with the idea that readers reactivate previously stored perceptual information from the brain during the processing of sentences and have this information available when verifying subsequently presented pictures, resulting in shorter verification latencies. Conceivably, such findings are typically considered supportive of the general tenet of embodied approaches to language comprehension that mental representations formed during sentence comprehension contain perceptual information (Barsalou, 1999).

Whilst the findings derived from all of the SPV task studies so far seem straightforward, zooming in on these findings shows a less clear and less consistent pattern of results. Whereas these variations could actually be existent representing real differences in mental simulation between different visual object properties, they could also just be the result of differences in characteristics of the sentence-picture verification task used in different studies. For example, studies differed in whether (line-)drawings (e.g., Stanfield & Zwaan, 2001) or real photographs (e.g., Engelen et al., 2011) were presented as pictures. In addition, the pictures used in prior studies inevitably varied in visual appearance such as their style and colorization. Also, these studies varied in the populations that were studied (children, Engelen et al., 2011; psychology students, Zwaan et al., 2002; older adults, Zwaan & Pecher, 2012) and the settings in which they were tested (e.g., online platforms, Zwaan & Pecher, 2012; lab cubicles, Zwaan et al., 2001; school classrooms, Bos, De Koning, Wassenbrug, & van der Schoot, 2016; Engelen et al., 2011). Moreover, at present, the often implicit assumption articulated by Zwaan and Pecher (2012) that "If comprehenders perform mental simulations [for one visual dimension], then other visual dimensions should also be simulated (p. 2)" has only received circumstantial support given that a direct comparison between visual object properties has yet to be made. Stronger support for this assumption would be obtained if prior results on each of these individual visual object properties could be replicated in such a direct comparison. Based on these considerations, the present study employed, as far as we know for the first time, a within-subjects design to the SPV task so as to investigate the mental simulation of the visual object properties shape, size, color, and orientation during sentence comprehension. This within-subjects design enables us to address at least two aspects related to the mental simulation of these visual object properties that research using the SPV task so far has not been able to answer.

First of all, it offers the possibility to take a look at the fact that across studies employing the SPV task, the magnitude of the match-advantages appears to vary from one visual property to the other. A relatively large and robust match-advantage (averaged over studies approximately 63 ms, see Zwaan & Pecher, 2012) is typically reported for studies involving the mental simulation of object shape (e.g., Rommers, Meyer, & Huettig, 2012; Zwaan, Stanfield, & Yaxley, 2002; for a more elaborated discussion, see Zwaan & Pecher, 2012). Recently De Koning, Wassenburg, Bos, and van der Schoot (2015) have reported a match-advantage for the mental simulation of object size which was of comparable magnitude (61 ms for children and 69 ms for adults). Also for object color large match-advantages have been reported (averaged over studies approximately 121 ms, see Zwaan & Pecher, 2012), although it could be questioned to what extent the color effect is robust given that the opposite pattern of results, a mismatch-advantage, has also been observed (Connell, 2007). Nevertheless, Zwaan and Pecher (2012) have argued that future studies are more likely to show match-advantages for object color rather than mismatch-advantages. For object orientation, however, much lower match-advantages are reported across studies (38 ms, see Zwaan & Pecher, 2012). Importantly, there are even studies that fail to find a match-advantage for orientation at all (e.g., Rommers et al., 2013).

Although these findings suggest clear differences in the reported match-advantages for each of the visual object properties, to the best of our knowledge, no study has yet attempted to actually test this assumption directly. Studies have typically focused on just a single visual object property at the time (e.g., Connell, 2007; Zwaan et al., 2002), have intermixed different visual object properties (i.e., shape and orientation) in one SPV task (e.g., Engelen et al., 2011), or if more than one visual object property was investigated in a study have treated them as between-subjects factors in different sentence-picture verification tasks (Zwaan & Pecher, 2012). Hence, empirical evidence is yet inconclusive about the relative magnitude of the match-advantages of different visual object properties observed in previous studies. By applying a within-subjects design in the present study, we aim to clarify this issue by directly comparing the magnitude of the match-advantages for each of the four examined visual object properties (i.e., shape, size, color, orientation).

Interestingly, embodied accounts of language comprehension do not seem to make any predictions that would lead one to hypothesize differential match-advantages depending on the visual property (i.e., shape, size, color, orientation) that is studied. An approach that could provide some more guidance in this respect is to consider the kind of visual object property. Shape, size, and color are intrinsic visual properties of an object meaning that they are properties an object has of itself regardless of other things, like its relation with other objects, and thus are invariant. Instead, orientation is an extrinsic visual property in that it is not inherent to an object, but rather varies depending on aspects like the observer (e.g., rotating his/her head or not), the particular condition of observation (e.g., looking straight ahead while standing upright or when lying on your side), or the way an object is positioned (e.g., holding a sword upright or directing it at someone in front of you) (Borghi, Caligiori, & Scorolli, 2010; Scorolli & Borghi, 2008). It is important to realize that such variations in the orientation of an object do not change the object itself, but only how the object is held or perceived. Applying this intrinsic-extrinsic distinction to the previously reported match-advantage findings learns that both intrinsic and extrinsic properties are sensitive to sentence context, but that the extrinsic visual object property (i.e., orientation) shows the least favorable results. The three intrinsic visual object properties (i.e., shape, size, color) all show more positive results as well as appear somewhat more comparable in terms of the magnitude of the match-advantage. This is particularly the case for shape and size, which show a striking resemblance. Following this line of thinking, it could be argued that match-advantages vary depending on whether sentences contain an intrinsic or extrinsic visual object property. Therefore, the present study examines the extent to which the distinction between extrinsic and intrinsic properties is useful in helping us to explain the observed differences in the magnitude of the match-advantages. More precisely, it examines whether, as suggested by previous literature (e.g., Rommers et al., 2013; Zwaan & Pecher, 2012), the match-advantage is smallest, or even non-existent, for extrinsic properties (i.e., orientation) as compared to intrinsic properties (i.e., shape, size, color).

A second, yet unexplored, aspect the within-subjects design enables us to investigate is whether a participant who is mentally simulating one visual object property (e.g. shape) while reading, is also mentally simulating other visual object properties (e.g., orientation). Addressing this issue moves beyond getting insight into whether or not each of the visual object properties alone is mentally simulated as it primarily targets the stability of an individual's reliance on mental representations over all of the visual object properties. Assuming that an individual consistently engages in mental simulation irrespective of which visual object property is involved, then all visual object properties should elicit a similar match-advantage on the sentence-picture verification task, and more importantly, we would expect these effects to be correlated. Such a finding would provide direct support for the assumption derived from embodied theories of language comprehension that mental simulation is the common underlying mechanism involved in the comprehension of sentences implying visual properties (e.g., shape, size) of objects (Barsalou, 1999; Zwaan & Pecher, 2012). This would be a valuable contribution to the literature as so far this assumption has at best only received indirect support. That is, the empirical findings on the SPV task discussed above are often considered sufficient to be interpreted in a way suggestive of a common mental simulation mechanism that underlies sentence comprehension for the different visual object properties.

Importantly, we also should consider the possibility that a pattern of findings emerges which is inconsistent with this idea. Under this view, only for some, or even none, of the visual object properties correlations between match-effects would be observed. For instance, reverting to the intrinsic-extrinsic distinction alluded to earlier, one could envision a scenario in which there are significant correlations among the intrinsic visual object properties (i.e., shape, size, color) but no correlations between each or all of the intrinsic visual object properties with the extrinsic visual object property (i.e., orientation). This, then, would be indicative of a common underlying mechanism (i.e., mental simulation) for intrinsic visual object properties that is to a greater or lesser extent different from the mechanism involved for extrinsic visual object properties. One possibility worth mentioning in this regard is that, in the SPV task, irrespective of the context in which an extrinsic visual object property is described (e.g., screw [in the wall/in the ceiling]) exactly the same object (i.e., the object itself does not change) is involved and that this object is associated with the same knowledge schema (e.g., metal, sharp, construction, screwdriver). In verifying the depicted image, readers might engage in mental rotation of the image depending on what information they gained from the sentence context. In contrast, for intrinsic visual object properties verifying a matching (e.g., picture of a white bear following the sentence "He saw a bear at the North pole") or mismatching (e.g., picture of a brown bear following the sentence "He saw a bear at the North pole") picture involves a different object which is associated with a (partly) different semantic network (for a similar suggestion, see Zwaan & Pecher, 2012). For example, a polar bear typically is more strongly associated with concepts like snow, cold, white, ice, whereas a regular brown bear is typically associated with concepts like wood/tree, honey, and nuts. Obviously, sentence context influences which of these are activated and thus whether or not an extra processing step (in case of a mismatch, to another semantic network) is needed to accurately verify the depicted image. That this possibility of different processing mechanisms is not as unlikely as it may seem, becomes clear when we move beyond the SPV task and consider the literature in adjacent fields of research. For example, by now several studies have shown that for object manipulation the grasp component of a movement is influenced by intrinsic object properties, whereas the reaching component of a movement is influenced by extrinsic object properties, suggesting that different processes are associated with intrinsic and extrinsic object properties (Gentilucci, Chieffi, Scarpa, & Castiello, 1992; Jeannerod, 1981; Jeannerod, Arbib, Rizzolatti, & Sakata, 1995). The within-subjects design in the SPV task employed in the present study provides a first step to investigate whether or not all examined (intrinsic and extrinsic) visual object properties share a common underlying mechanism, which from an embodied view to language comprehension is assumed to be mental simulation.

Taken together, the present study aimed to provide novel insights into the mental simulation of visual object properties during sentence comprehension by taking a within-subjects design approach to the SPV task. In this study, participants thus completed a sentence-picture verification task four times, one for each of the visual object properties shape, size, color, and orientation. Our first interest was to investigate the yet untested suggestion that the magnitude of the match-advantages differs depending on the visual object property involved. Based on previous empirical work, we may expect intrinsic visual object properties (i.e., shape, size, color) to show significantly stronger match-advantages than extrinsic visual object properties (i.e., orientation). A second aim of this study was to examine whether the match-advantages for the four visual object properties would show a correlation, and thus be indicative of a shared processing mechanism (i.e., mental simulation). Although embodied accounts of language comprehension would expect this to be the case, for reasons mentioned earlier, we anticipated that there may only be significant correlations among the visual object properties shape, size, and color. This is motivated by the fact that these visual object properties are intrinsic properties, whereas orientation is an extrinsic visual object property for which the verification decisions presumably invoke a different processing mechanism (i.e., mental rotation).

Method

Participants

The participants were 169 university students recruited from different educational programs of a large Dutch university. Consistent with biased gender ratios in these programs, there were 125 woman and 44 men, with an average age of 20.97 years (*SD* = 2.19 years). The participants provided written consent indicating that they voluntarily took part in the experiment. Participants received course credit for their participation. All participants participated in a counterbalanced within-subjects design with the factors Visual Property, consisting of four levels (i.e., shape, orientation, color, size), and Matching, consisting of two levels (i.e., match vs. mismatch), both of which are discussed in more detail below.

Materials

Sentence-Picture Verification Task

In the Sentence-Picture Verification (SPV) task, readers read a sentence implying a visual property of an object (e.g., shape, orientation) and subsequently had to indicate whether or not the object shown in a subsequently presented picture was mentioned in the sentence. In this study, four SPV tasks were used, each targeting a different visual property for an object: shape, orientation, color, and size. These tasks were based on the original experimental sentence and picture stimuli that have been used to study the object properties shape, orientation, color, and size developed by Zwaan et al. (2002), Stanfield and Zwaan (2001), Connell (2007), and De Koning, Wassenburg, Bos and van der Schoot (2015) respectively. Where appropriate, we translated items into Dutch, rephrased sentences, and constructed new items (for example, the color task developed by Connell (2007) contained only half as much items as the other SPV tasks). An example of each, as used in the current study, is provided in Table 1.

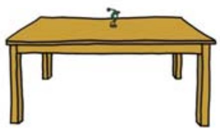
In all four SPV tasks, a set of experimental sentences (presented in Dutch) and pictures were used. Sentences all were of the format "Subject-Verb-Object-Adverb" (e.g., The cook saw the egg in the skillet). For the experimental sentences, there were always two versions that only differed in the visual property of the object that it implied. For example, the sentence "The man saw the eagle in the sky" suggests a different shape of the critical object than the sentence "The man saw the eagle in the nest". Participants read one of the two versions of each sentence and subsequently saw a picture that either matched or mismatched the visual property implied in the sentence (see Table 1). All pictures were colored drawings made by a qualified draftsman and were scaled to occupy a square of approximately 15x15 cm on the computer screen. This ensured that all pictures were comparable on aspects like style, brightness, color use, and size. Importantly, each picture only showed the critical object, except for the pictures in the SPV task involving implied object size where the critical object was always presented on the same table (see Table 1). As determining object size requires contextual cues, this table provided a necessary reference point which enabled participants to "read off" an object's size directly (De Koning, Wassenburg, Bos, & van der Schoot, 2015). The SPV tasks involving the visual object properties color, orientation, and shape, contained 24 experimental sentence-picture items, whereas for the SPV task involving implied size, there were 28 experimental sentence-picture items.

For each SPV task, we created four experimental lists by crossing the two versions of experimental sentences and the two versions of pictures, using a Latin Square design. As a result, each list included one of the four possible sentence-picture combinations for an object. Each participant saw just one of these lists per SPV task that he or she completed. Across the four lists, all item combinations were used equally often. On each list, half (i.e., 12) of the experimental sentence-picture items matched whereas the other half (i.e., 12) mismatched on the visual property of interest. As the answer to the 24 experimental items always required a yes-response, an equal number of filler items were added to balance responses. Filler items consisted of a sentence which had the same amount of words as the experimental sentences which was followed by a picture unrelated to the critical object mentioned in the sentence. Filler items thus always required a no-response.

Procedure

All four SPV tasks were administered individually in a single session in a quiet cubicle in the university's lab facility. The order of presentation of the SPV tasks was counterbalanced across the participants to diminish unwanted serial order effects (e.g., fatigue, improved performance due to experience with the task). Participants were instructed to read each sentence at their own pace and to indicate as fast and

Table 1
Examples of sentence-picture pairs (match and mismatch) used for each visual object property

Visual property	*Sentence-picture combinations*	
Orientation	 The handyman put the drill against the wall (match) / ceiling (mismatch)	 The handyman put the drill against the wall (mismatch) / ceiling (match)
Color	 The girl licked the ice cream with chocolate (match) / vanilla (mismatch) flavor	 The girl licked the ice cream with chocolate (mismatch) / vanilla (match) flavor
Size	 The man saw the sculpture in the windowsill (match) / garden (mismatch)	 The man saw the sculpture in the windowsill (mismatch) / garden (match)
Shape	 The chef took the egg out of the skillet (match) / box (mismatch)	 The chef took the egg out of the skillet (match) / box (mismatch)

accurate as possible whether or not the depicted object had been mentioned in the sentence. Upon the first encounter of each SPV task, participants were presented with a few practice trials. Next, the experimental and filler trials were presented in a random order. Each trial started with a horizontally and vertically centered sentence on the computer screen, displayed in a black 24-point Courier New Bold font against a white background. Participants pressed the spacebar when they had understood the sentence, after which a 500 ms fixation cross appeared, followed by a picture. Participants indicated whether the pictured object was mentioned in the preceding sentence or not by pressing the keys on the keyboard marked by a green sticker (yes-response) and a red sticker (no-response). After having worked through all four SPV tasks, participants were thanked for participating and they left the room. The whole experiment lasted approximately 40 minutes.

Results

Data trimming consisted of removing all reaction times (RT) slower than 300 ms and faster than 3000 ms (Connell, 2007), and all responses that were more than 2.5 standard deviations from the participant's mean reaction time in the relevant condition. This resulted in removal of less than 5% of the data in all SPV tasks (color: 4.14%; shape: 3.20%; orientation: 2.52%; size: 4.18%). In line with the procedure used by Zwaan and Pecher (2012), data of participants with an accuracy score of .80 or lower were left out of our analyses as such unusually low accuracy scores on this task are considered to not accurately reflect the cognitive processes the task aims to target. For RT analyses, incorrect responses were eliminated. First of all, we aimed to test whether the match-advantage in the SPV task differs between visual properties (i.e., size, shape, color, and orientation). Therefore, we conducted a 4 (Visual Property: shape, color, orientation, size) × 2 (Matching: match vs. mismatch) within-subject repeated measures ANOVA. Interestingly, we obtained a significant interaction effect between Visual Property and Matching ($F(3,363) = 10.01$, $p < .001$, $\eta_p^2 = .08$). As can be seen in Figure 1, the reaction time patterns on the different SPV tasks differed from each other as a function of the visual property implied in the SPV task. Although the main effect for Matching seems to suggest that overall matching sentence-picture trials were responded to faster than mismatching sentence-picture trials ($F(1,121) = 26.57$, $p < .001$, $\eta_p^2 = .18$) this was only the case for SPV tasks involving size, shape and color and not for the SPV task involving orientation. The match-advantage was the largest for the visual property color (ΔRT = 88 ms, $t(138) = -5.69$, $p < .001$, $\eta_p^2 = .17$), followed by shape (Δ RT = 39 ms, $t(159) = -3.42$, $p < .001$, $\eta_p^2 = .07$), size (Δ RT = 24 ms, $t(148) = -2.31$, $p = .02$, $\eta_p^2 = .04$), and orientation (Δ RT = 7 ms, $t(166) = -.92$, $p = .36$, $\eta_p^2 = .005$). Additionally, post hoc contrast analysis comparing intrinsic visual properties (i.e., shape, size, color) on the one hand and extrinsic visual properties (i.e., orientation) on the other hand showed a significant interaction effect between Visual Property (intrinsic vs. extrinsic) and Matching (match vs. mismatch), ($F(1,121) = 17.83$, $p < .001$, $\eta_p^2 = .13$), indicating that SPV tasks involving intrinsic visual properties showed a match-advantage whereas the SPV task involving extrinsic visual properties did not. These findings suggest that obtaining a match-advantage in the SPV task is influenced by, among other things, the nature (i.e., intrinsic vs. extrinsic) of the visual object property. These effects occurred despite the fact that there was a main effect for Visual Property ($F(3,633) = 67.45$, $p < .001$, $\eta_p^2 = .36$), indicating that overall reaction times on the color and size task were higher than those on the shape and orientation tasks (see Figure 1).

A second issue we wanted to investigate is the strength of the relationship between the visual properties shape, color, orientation, and size. If all of these visual properties share a common underlying mechanism, the performance on the four SPV tasks implying these visual object properties are expected to be correlated. To test this hypothesis, we first calculated the effect size (i.e., match-advantage) for each visual object property (Zwaan & Pecher, 2012). The effect size was calculated as the difference between the reaction time on mismatch items and match items divided by the pooled standard deviation.

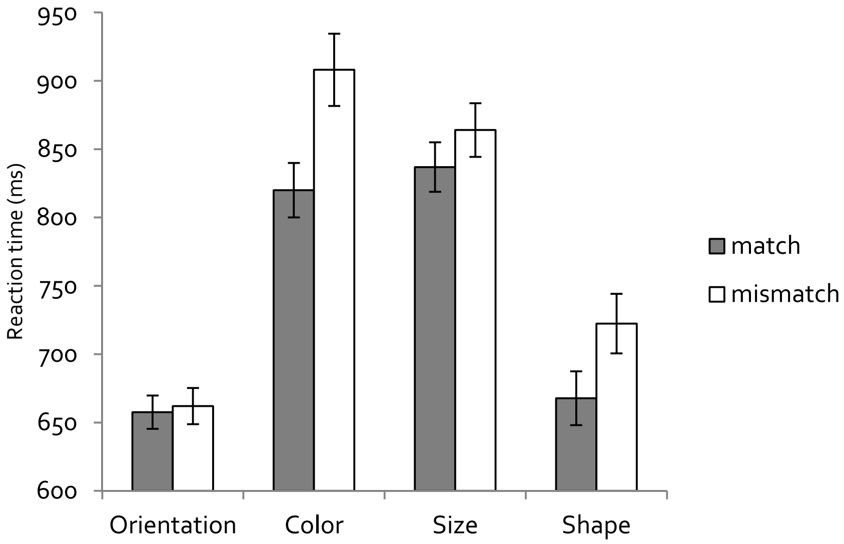


Figure 1. Mean reaction times in milliseconds (+ SE) for the four visual object properties of the SPV task in the match and mismatch conditions

Next, a correlation analysis was conducted on each of these SPV tasks effect sizes. As shown in Table 2, the correlation between the visual object properties shape and size was significant, as well as the correlations between the visual object properties size and color, and the correlation between the visual object property shape and color.

However, we found no significant correlation between the object property orientation and any of the other visual object properties. So, 3 out of 4 visual object properties appeared to be significantly correlated. Consistent with the reaction time analyses, the significant correlations included the visual object properties size, shape, and color but not orientation. In other words, there was a significant correlation among the intrinsic visual properties and these did not correlate with the only visual object property that is extrinsic in nature. Taken together, these results only partially support the hypothesis of a common underlying mechanism involved in perceptually simulating the visual properties of objects in the SPV task.

Table 2
Correlations between the effect sizes of the four visual object properties

	1.	2.	3.	4.
1. Orientation	1	-.04	.05	.13
2. Color		1	.23**	.16*
3. Size			1	.36**
4. Shape				1

** $p < .01$, * $p < .05$

Discussion

This study applied a within-subjects design to the SPV task in order to address two yet unresolved issues regarding the mental simulation of the visual object properties shape, size, color, and orientation. First, we directly investigated whether, as suggested by prior research, the match-advantages for these visual object properties actually show a distinct pattern of findings. Second, to investigate whether all four visual properties share a common underlying mechanism, we examined whether there is a correlation among the match-advantages of the four visual object properties. For both of these aspects, we used the distinction between intrinsic (i.e., shape, size, and color) and extrinsic (i.e., orientation) visual properties as a potential source for possible variations.

The results of this study provide direct evidence that some visual object properties show stronger match-advantages than others. This confirms our presumption derived from prior (between-subject) SPV task studies (e.g., De Koning, Wassenburg, Bos, & van der Schoot, 2015; Stanfield & Zwaan, 2002; Zwaan & Pecher, 2012), and indicates that differences in the match-advantages of the four visual object properties exist independent of variations in stimuli, settings, and populations. In fact, we used a set of stimuli that was carefully constructed so that the stimuli were as comparable as possible. For example, all pictures were drawn by a professional draftsman to ensure that across SPV tasks there were no differences in terms of the pictures' appearance (e.g., style, brightness, color use). Together, this adds to the suggestion that match-advantage differences are most likely due to the extent to which readers engage in mental simulation.

In particular, our findings demonstrate the expected variations in the match-advantages for the visual object properties shape, size, and color. Of these, color showed the strongest match-advantage, which is consistent with the findings previously reported by Zwaan and Pecher (2012). Using a larger set of color stimuli than prior studies, our study now puts the balance on three strong match-advantages against one mismatch-advantage for color (Connell, 2007). This indicates that the color effect does not appear as weak and unstable as initially thought (also see Zwaan & Pecher, 2012). It is unclear from the present study, however, to what extent the fact that overall participants responded slower to the pictures on this task, may have contributed to this strong match-advantage of color. Shape and size showed comparable match-advantages, with shape exhibiting a slightly stronger effect. This finding provides direct evidence for De Koning et al. (2015) suggestion that a close correspondence exists between these two visual object properties. Interestingly, this pattern showed up even though overall participants took longer to verify the pictures on the size task. Our findings suggest that it does not matter for obtaining a match-advantage that an extra object (i.e., a table on which the critical object was displayed to "read off" objet size directly) was presented; it only seemed to take somewhat longer to obtain such an effect as two objects rather than one had to be dealt with when verifying the pictures. Whilst these findings together are in line with our expectations, the match-advantages obtained in our study are somewhat smaller than those in previous studies. One possible reason for this is that, in contrast to previous SPV task studies, the present study employed a within-subjects design in which each participant completed four SPV tasks each targeting another visual object property instead of having to complete just one SPV task. Consistent with this, Zwaan and Pecher (2012) reported that match-advantages did not disappear as participants completed multiple SPV tasks (in a between-subject design), but it did reduce the strength of the match-advantage.

Importantly, our findings thus demonstrate a match-advantage, of varying strength, for all three intrinsic visual object properties. Instead, as anticipated, the only extrinsic visual object property investigated in this study, orientation, did not show such a match-advantage. This finding is not surprising as we consider that findings on the orientation effect appear weak and not very consistent (e.g., Zwaan, 2014). Whereas some researchers (e.g., Zwaan & Pecher, 2012) have found a match-advantage, albeit a small one compared to other visual object properties, others (e.g., Rommers et al., 2013) have failed to obtain a match-advantage for orientation. Such divergent findings are typically explained by arguing that failures to replicate the orientation effect are due to slight deviations from Zwaan et al.'s (2001) original orientation experiment and thus do not allow for meaningful comparisons (Zwaan, 2014). However, the fact that our study contained four SPV tasks which all followed exactly the same procedures and were comparable in the design of the stimuli enables us to make straightforward comparisons between match-advantages on the SPV tasks. So, it does not seem likely that the failure to find an orientation effect in our study emanates from differences between SPV tasks. Rather, the present findings more likely fit the idea put forward in the Introduction that the match-advantage is sensitive to the kind of visual object property (i.e., intrinsic vs. extrinsic) that should be mentally simulated when reading a sentence.

The findings following from the correlation analyses are in line with this interpretation. Specifically, significant correlations were found between all of the three intrinsic visual object properties (i.e., shape, size, color); the extrinsic visual object property orientation appeared not to be significantly correlated with any of the intrinsic visual object properties. So, our study shows that a reader who mentally simulates the shape implied in a sentence, as evidenced by a match-advantage, also mentally simulates the size and color implied in a sentence, but does not necessarily, or at least to a lesser extent, mentally simulate an object's orientation as implied in a sentence. Obviously, this seems to challenge the theoretical stance adopted in previous SPV task studies, which assumes that mental simulation represents the core common underlying mechanism involved in processing both the intrinsic and extrinsic visual object properties investigated in this study (e.g., Horchak et al., 2014; Zwaan & Pecher, 2012). Our findings suggest that it would advance the interpretation of match-advantages if distinctions were made between the effects obtained for intrinsic visual object properties and those obtained for extrinsic ones. Following up on this, we suspect readers to engage in a similar processing mechanism, presumably mental simulations, when reading a sentence implying an object's shape, size, or color (i.e., intrinsic object properties). In this view, match-advantages are believed to arise from a relatively larger overlap between activated brain patterns resulting from (re-)enacting perceptual information of the described situation and seeing the object picture (Barsalou, 2008). Based on the intrinsic-extrinsic distinction and its associated rationale provided in the Introduction, we assume that for matching trials the part of the semantic network that is activated by an object with the particular shape/size/color implied in the sentence appears to be consistent with that needed to accurately verify the picture. Rather, for mismatching trials at least part of the semantic network that is activated does not overlap with the information required to adequately verify the picture. Having this information available may interfere with the verification process, resulting in longer verification latencies in the mismatch condition. Presumably, these processes together contribute to the match-advantage for intrinsic visual object properties.

Importantly, based on our study, there is reason to assume that representing extrinsic visual object properties (i.e., orientation) implied in a sentence relies less, if at all, on mental simulations. We speculatively attribute our finding that the extrinsic property orientation is the only visual object property that "falls out" to the fact that readers relied on a processing mode in which mental rotation was involved. We assert that to make a verification decision, readers try to map the presented picture to the visual-spatial mental image they created from the object described in the sentence. Depending on the extent to which the implied and pictured orientation of an object match, readers (have to) engage in a ninety-degree mental rotation of the object so as to let it correspond to the presented picture. The time needed to be able to make a decision about whether the orientation in the sentence and picture match likely changes accordingly. That this appears to be a fast process can be derived from the observation that overall verification times on orientation items were short, which presumably relates to the fact that the object itself does not change in the match and mismatch conditions. In this sense, sentence context appears to have less of an influence on the verification process of an extrinsic property such as orientation than it has on intrinsic properties. Whether the above suggestions adequately account for the match-advantage differences found between intrinsic and extrinsic visual object properties in the SPV task remains to be examined in future research, for example by studies that more directly address the processing mechanisms involved in this task.

In conclusion, this study demonstrates that, consistent with our predictions, different kinds of visual object properties (intrinsic/extrinsic) have somewhat different effects in a SPV task. The three intrinsic visual object properties shape, size, and color all showed clear match-advantages, with color showing the strongest effect, followed by shape and size which exhibited more or less comparable effects. The extrinsic visual object properties orientation, however, did not show a significant match-advantage. Moreover, we found significant correlations among the intrinsic visual object properties and these did not correlate with the extrinsic visual property orientation. These findings suggest that the distinction between intrinsic and extrinsic visual object properties might be helpful to explain the variations in the reported match-advantages and provides a useful supplement to the mental simulation account. Importantly, more research is required to substantiate this claim and to clarify whether other processing mechanisms are responsible for the fact that some visual object properties (shape, size, color) are strongly activated during language comprehension, while others (orientation) are not. This study provides a starting point from which such endeavors can be further explored.