Crossing the boundary

Categorization of morphed figures

Mijke O. Hartendorp

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Categorization of morphed figures

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(met een samenvatting in het Nederlands)

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De dingen hebben jou nodig om gezien te kunnen worden.

K. Schippers

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Introduction

Mijke O. Hartendorp

In our daily life, we are surrounded by objects, such as the chair you are sitting on while reading this thesis, the cup of coffee in front of you and your goldfish staring at you from its glass bowl. You need to identify these objects in order to know how to act upon them. Fortunately, the human brain has developed a mechanism, called *categorization*, allowing us to group objects and infer gained knowledge from the particular category. Categorization seems to be a simple mechanism, since it costs us little time to categorize an object, and we make very few mistakes in this process. Despite this seemingly simplicity the mechanism underlying categorization has served as a topic of research for many years. Despite the vast amount of research, many questions remain unanswered. Why is an object assigned to one category, but not to another?

Object Similarity

The shape similarity between two objects (Edelman, 1998) and between an object and an internal representation plays an important role in object categorization (Lamberts, 1995; Medin & Schaffer, 1978; Nosofsky, 1984). This was already stated by Rosch, Mervis, Gray, Johnson and Boyes-Braem in 1976 (p. 384): "To categorize a stimulus means to consider it not only equivalent to other stimuli in the same category but also different from stimuli not in that category". In particular, the shape contour appears to be a valuable source of information to categorize visual objects. The shape contour of an object is defined by concavities and convexities at characteristic locations. According to the Recognition-by-Components theory of Biederman (1987) these concavities and convexities are used to divide an object into *geons*, a definable number of geometric shapes such as cones and cylinders by which an undefinable number of objects can be created. Although a categorization mechanism solely based on geons does not seem plausible (Tarr, Williams, Hayward, & Gauthier, 1998), the information derived from the contour curvature has been found to be useful for explaining object categorization (Hofman & Richards, 1984; Norman, Phillips, & Ross, 2001). For instance, Feldman and Singh (2005) have shown that especially concave information of a shape contour is used to divide objects into parts, while the convex information of a shape contour provides information of the shape of the object's parts themselves (see also De Winter & Wagemans, 2006; Hoffman & Singh, 1997). The intrinsic part structure resulting from the contour curvature based on both the concave and convex information can be used to derive a skeletal representation of the object (Blum, 1973; Blum & Nagel, 1978). For instance, the skeleton model by Feldman and Singh (2006) reduces a shape contour to a simple, but robust skeleton of an object. Using their model, they were able to calculate the skeleton of an object in which each branch represents one part of the object. Because a prior that favoured simple skeletons was included in their model, small violations to the shape contour did not change the skeletal representation of the object. An example of their model is presented in Figure 1.1.

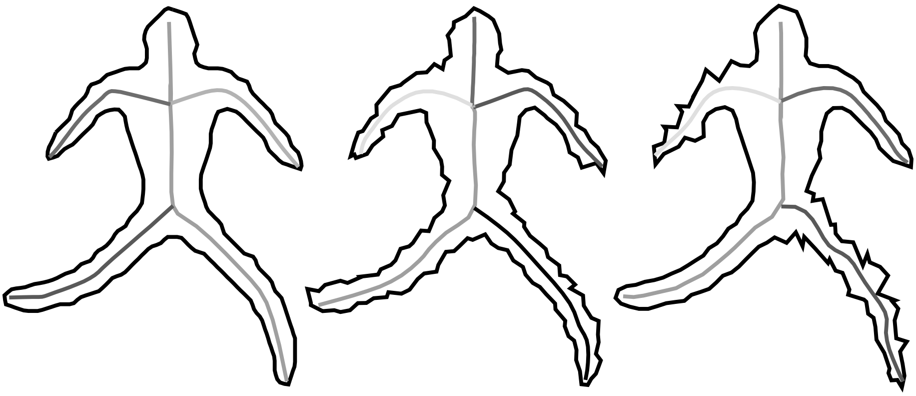

Figure 1.1. The skeletons of three objects as an outcome of the MAP-skeleton model of Feldman and Singh (2006).

This model shows that a skeletal representation of an object stays intact when the shape contour is violated to some extent. However, are we still capable of assigning an object to its original category when the shape contour is changed dramatically? In other words, when do we cross the category boundary and assign the stimulus to another category?

Categorical Perception

One important aspect of categorization is that we do not divide the world into continua, but in discrete categories. As Harnad (2003) wrote "Something either is a bird or it isn't a bird; a penguin is 100% bird, a platypus is 100% not-bird". This discrete classification of entities in our environment is also observed when warping two stimuli into a single stimulus, so-called *morphing*. In 1957, Liberman, Harris, Hoffman and Griffith reported that a continuously changed continuum from the phoneme *ba* into the phoneme *da* was not perceived as a continuous change, but as two discrete categories that showed an abrupt switch from one percept into the other halfway along the continuum. They referred to this phenomenon as *Categorical Perception* (CP). In general, CP is defined by a quantitative measure of discrimination and identification (Macmillan, Kaplan, & Creelman, 1977). First, it is assumed that two stimuli being assigned to the same category are harder to discriminate than two stimuli being assigned to different categories. In addition, it is expected that the difference in discrimination is reflected in the identification: two objects that are harder to discriminate as being different are probably identified as members of the same category, whereas two objects that are easier to discriminate as being different are probably not identified as members of the same category. Despite the fact that the physical differences between the different steps on the morph continuum are equal, we do not perceive these steps as equal, but in a categorical manner, with larger differences observed around the category boundary (Harnad, 1987, 2003). Studies using ERP (event-related potentials) show a similar discrimination pattern as observed using behavioural measurements (Dehaene-Lambertz, 1997; Jacques & Rossion, 2006). For instance, Campanella, Quinet, Bryer, Crommelinck and Guerit (2002) found a larger peak for the N170 when discriminating two between-category stimuli in comparison to discriminating two within-category stimuli. The N170 peak was interpreted to reflect the detection of a visual change.

CP was first thought to be restricted to speech perception (Liberman et al., 1957) leading to the development of the motor theory of speech perception. The general idea behind this theory is that how we hear a phoneme is based on how we pronounce it. Thus, if we cannot produce a particular sound, we are also unable to detect this sound. However, CP was found in a variety of domains, and is therefore not unique to speech perception. For instance, CP was also obtained for colour perception, such as for mixtures of the colours green and blue (Bornstein, 1987; Bornstein & Korda, 1984), and was even found for the colours gold and silver (when varying the reflectance of the colours; Okazawa, Koida, & Komatsu, 2011). A continuous debate in the literature on CP concerns whether the origin of colour CP is innate or linguistic (Harnad, 1987; Özgen & Davies, 2002). Evidence for the innate point of view comes from studies on preverbal children (Franklin & Davies, 2004; Franklin, Drivonikou, Bevis, Davies, Kay, & Regier, 2008). Children at an age at which colour term knowledge was not fully developed yet were tested on a two-alternative forced-choice identification task, in which the sweater of a bear had to be identified as either having the same colour as the sweater of bear A or as bear B (Franklin, Clifford, Williamson, & Davies, 2005). All children identified the colour of the sweaters in a categorical manner, independent of the stage of colour term development of the child, suggesting that CP of colours is not linguistic, but innate. In addition, studies including nonhumans, such as crickets (Wyttenbach, May, & Hoy, 1996) and guinea pigs (McGee, Kraus, King, Nicol, & Carrell, 1996), also suggest that other species besides human beings use a perceptual mechanism similar to CP. Opponents of the innate point of view, on the other hand, advocate that CP of colours is influenced by language. A cross-linguistic study (Roberson, Davies, & Davidoff, 2000) including speakers of English and Berinmo (Papua New Guinea) tested speakers of these populations on their perception of colours on the blue-green continuum. English makes the distinction between blue and green, whereas Berinmo does not. CP was shown by speakers of English, but not by speakers of Berinmo. This finding supports the hypothesis that our linguistic colour term knowledge shapes the way we perceive colours. The debate got a new impulse after the finding by Gilbert and colleagues (Gilbert, Regier, Kay, & Ivry, 2006, 2008) that the categorical effects observed for colour continua were only found for stimuli presented in the right visual field, suggesting that we need language (located in the left hemisphere) to discriminate two colours as belonging to the same category or two distinct categories (but see also Witzel & Gegenfurtner, 2011, and Brown, Lindsey, & Guckes, 2011, who did not find any lateralization effects for CP).

Moreover, CP is not only observed in possible innate entities, such as phonemes, colours and basic emotions (e.g. using morphs of photographs of angry and happy faces; Calder, Young, Perrett, Etcoff, & Rowland, 1996; Etcoff & Magee, 1992; McCullough & Emmorey, 2009, see also Ekman, 1992), but has also been shown for learned categories, such as facial identity (Beale & Keil, 1995) and even for familiar, concrete objects (Newell & Bülthoff, 2002). CP thus seems to be a general phenomenon that can be observed for any kind of stimulus.

Categorical Perception of Objects

Newell and Bülthoff (2002) were one of the first to test CP for concrete objects, such as bottles, lamps and glasses, by conducting a discrimination-identification task. They predicted that CP was particularly found for within-category stimuli (e.g. morphs of a coke bottle and a wine bottle) in contrast to between-category stimuli (e.g. morphs of a bottle and a lamp), since it was presumed that two within-category stimuli show more shape similarity than two between-category stimuli. They interpreted CP as a specific categorization mechanism that enables us to distinguish between similar shapes. This hypothesis was based on previous findings of CP for faces, which can be seen as two within-category stimuli (e.g. the face of Kennedy and the face of Clinton are both members of the category *face*; Beale & Keil, 1995). Indeed, they found CP for all morph continua consisting of two within-category stimuli and for only half of the morph continua consisting of two between-category stimuli. An additional experiment confirmed their prediction that shape similarity was higher for the extreme objects of a morph continuum showing CP than for the extreme objects of a morph continuum showing no CP. This study shows that the shape similarity between the extreme objects plays an important role in observing CP.

In addition, Verstijnen and Wagemans (2004) conducted an identification task using continua consisting only of living objects (e.g. changing an elephant's head to a giraffe's head) or only of nonliving objects (e.g. changing a tent to a triangular piece of cheese). A difference between living and nonliving series was observed, in which living series resembled a pattern of CP more than nonliving series. Since living objects are all members of the same superordinate category (i.e. *animal*), whereas the nonliving objects used in their study stemmed from different superordinate categories (e.g. *sleeping place* and *food*), the shape similarity between the living objects is probably higher than between the nonliving objects. The explanation by Newell and Bülthoff (2002) might also be of relevance here, namely that CP enables us to distinguish between similar shapes.

Wilder, Feldman and Singh (2011) specified that it is particularly the shape skeleton (derived from the contour) of a morphed figure that is used when assigning a morphed object to a category. They compared the outcomes of a classification experiment including morphed objects performed by humans and by a computational model that was based on natural shape statistics (i.e. calculating the skeleton of an object). The outcomes showed great resemblance between human and model performance, supporting their proposal that the shape skeleton of an object plays a crucial role in object categorization. Taken all together, the foregoing clearly suggests that categorization of morphed objects takes place on basis of their shape contours. Understanding more about the role of shape similarity between the two extreme objects of a morph continuum and their intrinsic part structure (i.e. skeleton) might help us to explain the mechanism underlying CP of objects, and indirectly, categorization of objects in general.

Nondominant Object

One aspect of CP that has been underexposed so far is the processing of the nondominant object in a morphed figure. Each morphed figure contains information from both extreme objects, albeit in different proportions for each figure. The dominant object is the nearest extreme object on the morph continuum and the nondominant object is the other extreme object on the morph continuum. Despite the information of the nondominant object in a morphed figure, we prefer to perceive morphed figures as their dominant object. Does this preference also mean that the nervous system only considers the dominant object during the course of the categorization process? In the next chapters this question will be addressed by investigating if the nondominant object is processed (*Chapter 2, 3 and 4*), at what point in time the nondominant object is processed (*Chapter 5*), and at what level the nondominant object is processed (*Chapter 6*). Furthermore, it was investigated whether the (un)certainty in categorization of morphed figures was also reflected in the gaze behaviour (*Chapter 7*). Eventually, the gained knowledge on the processing of the nondominant object can be used to aid in understanding object categorization in general (*Chapter 8*).

In answering these questions, we make use of a stimulus set consisting of black silhouettes of concrete objects (see *Appendix A* and *B*). Below, an example of one morph series used throughout this thesis is presented in Figure 1.2 in which a *car* is morphed into a *turtle*.

Figure 1.2. An example of a morph series, the *Car-Turtle* series.

The percentages below the morph series represent the morphing percentages, not necessarily human perception. The first percentage refers to the percentage *car* in the figure and the second percentage refers to the percentage *turtle*. When the first percentage is higher than the second percentage (e.g. 70%30%) *car* is referred to as the dominant object and *turtle* as the nondominant object. In contrast, when the second percentage is higher than the first one (e.g. 30%70%) *turtle* is referred to as the dominant object and *car as* the nondominant one. In addition, the 50%50% figure has no dominant or nondominant object according to the morphing percentages.

Thesis Outline

Almost all studies examining CP used a forced-choice paradigm (Harnad, 1987; Newell & Bülthoff, 2002). This paradigm includes a phase of discrimination and a phase of identification. The combination of this discrimination-identification paradigm often results in a pattern of categorical perception. However, using a forced-choice paradigm also forces subjects to categorize a morphed figure as either category A or category B. This could have different limitations, such as excluding the possibility that the morphed figure is preferably categorized as object C. In addition, in this forced-choice paradigm one considers category options that might not have been considered otherwise. In *Chapter 2*, we address this issue, by conducting a free-naming experiment in which participants were asked to categorize a morphed figure as any object.

The phenomenon of CP implies that we only perceive one of the two objects interpolated in a morphed figure. A priming experiment by Daelli, van Rijsbergen and Treves (2010), however, has shown that when presenting a morphed figure in a context corresponding to its nondominant object, we tend to shift our categorization to the nondominant category. This indicates that the object not preferably perceived, namely the nondominant object, is processed as well. In a double-naming experiment described in *Chapter 3*, participants were asked to categorize a morphed figure as two objects, again using a free-naming method. In this way, we could investigate whether morphed figures could be interpreted as a second object. It was expected that the first interpretation would replicate the findings of Chapter 2. Our main interest concerned the second interpretation. Are observers able to perceive a second object in a morphed figure, and if they do is this the nondominant object or did morphing of two object shapes give rise to perception of a novel object shape?

As was already mentioned, Daelli and colleagues (2010) have shown that priming affects the categorization of morphed figures: the categorization of a morphed figure was biased towards the identity of the prime. Thus, when a morphed figure was preceded by its dominant extreme object, the figure was more often categorized as its dominant object, and when a morphed figure was preceded by its nondominant extreme object, the figure was more often categorized as its nondominant object. In *Chapter 4*, we were interested whether priming effects differed for type of morph series. In Chapter 2 and 3 (see also Newell & Bülthoff, 2002), CP was observed for some morph series, but not for all. The response pattern shown for cp-series (morph series showing CP) was a consistent pattern in which the morphed figures were preferably categorized as their dominant object. In contrast, the response pattern shown for non-cp-series (morph series showing no CP) was an inconsistent pattern. This inconsistency was caused on the one hand by one preferred third interpretation not originally interpolated in the morphed figure, and on the other hand by a large variety of interpretations, probably caused by great uncertainty how to categorize the morphed figures. As was shown previously, priming has more impact when the stimulus needs more processing, such as degraded stimuli in comparison to undegraded stimuli (De Houwer, Hermans, & Spruyt, 2001). We expected non-cp-series to be affected more by priming than cp-series due to this difference in uncertainty.

Previous findings (Chapter 3 and 4, see also Daelli et al., 2010) support the idea that we do not only process the dominant object, but also the nondominant object interpolated in a morphed figure. However, at what moment during the categorization process do we process the nondominant object? Does this already occur at an early stage during the categorization process, simultaneously with the activation of the dominant object or does the activation of the nondominant object occur at a later stage during the categorization process? We translated these activation moments into the early and late activation account, respectively (*Chapter 5*). To investigate which of these accounts was most applicable, we varied the presentation time of a morphed figure and thereby, the processing time of the figure. Next, the morphed figure needed to be judged on its similarity to one of its extreme figures. We were particularly interested in the similarity to the nondominant extreme figure. If the similarity between a briefly presented morphed figure and its nondominant extreme figure was judged higher than between an extensively presented morphed figure and its nondominant object, support was obtained for the early activation account. In contrast, a reversed pattern supports the late activation account. Since we tested specific hypotheses, a Bayesian model selection approach was applied to find out which hypothesis gained most support from the data.

So far, the nondominant object appeared to be activated during the process of categorization. But to what extent is the nondominant object processed? Do we activate the nondominant object at a perceptual level or also at a semantic level? In other words, do the response candidates, among them the nondominant object, just represent visual information of their shape or do they also represent conceptual information, for example, about the category the response candidate belongs to? In *Chapter 6*, this question is addressed by examining the influence of different types of context. A picture-word interference paradigm was administered in which participants have to name a picture that is superimposed by a word (Glaser & Düngelhoff, 1984; Sailor, Brooks, Bruening, Seiger-Gardner, & Guterman, 2009). For instance, the distractor word *dog* interferes with the naming of a picture of a cat, whereas the word *cat* facilitates naming. We used the picture-word interference paradigm to find out whether the dissociative pattern observed with clear objects, also was observed when using morphed figures. Hence, the distractor words were identical (cat-cat) or semantically related (cat-dog) to either the dominant object or to the nondominant object of a morphed figure. We expected the distractor words related to the dominant object to act similarly to nonmorphed objects. Moreover, we were particularly interested in the conditions in which the distractor word was related to the nondominant object. Thereby, it was examined which distractor words had an impact on the naming process of the morphed figure and hence, to what extent the dominant and nondominant object are processed.

Despite the fact that in general morphed figures are perceived as their dominant object, they still contain information of two objects. This uncertainty in the stimuli might be reflected in the gaze behaviour. In addition, this uncertainty could also be used to investigate whether gaze behaviour was affected by the categorization of a morphed figure or vice versa. It is known from the literature on eye movements that a strong relationship exists between categorization and gaze behaviour: our gaze behaviour can predict what we have seen (Ellis & Stark, 1978; Judd, Durand, & Torralba, 2011). In addition, participants fixate more often on particular features of an object, such as the head of an animal (Kovic, Plunkett, & Westermann, 2009) and the center part of the human face independent of facial orientation (Chelnokova & Laeng, 2011; Sæther, Van Belle, Laeng, Brennen, & Øvervoll, 2009). To examine whether this strong relationship also holds for morphed figures, we conducted a free-naming experiment in *Chapter 7*, in which both the free-naming response and the eye fixations were recorded. We were specifically searching for a correspondence between the response and the feature that was fixated first. To investigate whether the interpretation comes before the eye movement or the eye movement before the interpretation, a priming and cueing experiment was conducted. In the priming experiment, a morphed figure was preceded by a prime word creating an expectation about the upcoming figure. In the cueing experiment, a cue was placed on a critical feature making this critical feature being the first visual input.

In *Chapter 8* (*Summary and Discussion*) the results of the empirical studies on the processing of morphed figures is discussed. The findings are used to paint a broader picture of object categorization in general.

2

Categorical Perception of Morphed Objects Using a Free-Naming Experiment

Mijke O. Hartendorp, Stefan Van der Stigchel, Hollie G. Burnett,
Tjeerd Jellema, Paul H.C. Eilers and Albert Postma (2010).
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Abstract

Morphed figures entail a dominant and nondominant interpretation. Testing perception of morphed objects using forced-choice methods demonstrates that morphed figures are perceived as their dominant interpretation ('categorical perception' (CP)). Using a more natural free-naming response could reveal whether CP is an effect independent of method. In Experiment 1, therefore series of morphed figures were tested for CP using free naming. Half of the morph series were identified as cp-patterns. In Experiment 2, we used forced choice to investigate CP, resulting in an increase of number of cp-series compared to free naming. The overlap between cp-series of Experiment 1 and 2 was small, however. Experiment 3 revealed that higher perceptual similarity between the extremes of the series was strongly related to CP for the free-naming method, in contrast to the forced-choice method. We conclude that the observation of CP depends on the intactness of the intrinsic object structure caused by the morphing procedure.

Introduction

Assigning the entities in our perceptual world to discrete categories enables us to deal effectively with the wealth of information around us. One consequence of perceiving the world in categories is that the gradual merging of one entity into another will be experienced as one discrete percept abruptly switching into the other percept when crossing the category boundary. This phenomenon is known as categorical perception (i.e. CP; Harnad, 2003). Studies on phoneme perception (Liberman, Harris, Hoffman, & Griffith, 1957; Liebenthal, Binder, Spitzer, Possing, & Medler, 2005) and colour perception (Bornstein, 1987; Bornstein & Korda, 1984) have shown that a gradual change from one stimulus into another is indeed not perceived in a continuous fashion, but as an abrupt switch from one percept to the other. For instance, gradually changing the stop consonant *ba* into *da* along a continuum leads to almost 100% *ba* or 100% *da* responses. In other words, what listeners hear seems to change quite abruptly from *ba* into *da* at the moment the merged sound crosses the border of the two categories (Fitch, Miller, & Tallal, 1997).

So far, CP has been mainly examined for elementary features such as tones and colours. This might suggest that CP is primarily due to biological predispositions, because these features are present from birth (Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Franklin, Clifford, Williamson, & Davies, 2005). Interestingly, the study of CP has more recently been extended from single feature dimensions toward higher-order structures, such as faces and facial expressions (Calder, Young, Perrett, Etcoff, & Rowland, 1996; Etcoff & Magee, 1992; McCullough & Emmorey, 2009). For instance, a study on face recognition of famous people (e.g. gradually interpolating Kennedy into Clinton; Beale & Keil, 1995) showed patterns of CP. In line with this, several authors have argued that learned categories can be perceived categorically as well (cf. Goldstone, 1994; Harnad, 1987; Livingston, Andrews, & Harnad, 1998; Newell & Bülthoff, 2002; Verstijnen & Wagemans, 2004).

Newell and Bülthoff (2002) showed CP for familiar objects using a forced-choice paradigm. The stimuli in their study were instances of the same object category (i.e. within-category series), such as *wine bottle* and *coke bottle*, and instances of different object categories (i.e. between-category series), such as *bottle* and *lamp*. Changing each concrete object into another concrete object by small steps of equal interpolation distances resulted in a series of continuously morphed figures. Consequently, all morphed figures contained information of the two categories, with one category always more dominantly present, except for the middle figure of the morph series in which both categories were equally strongly present. Interestingly, Newell and Bülthoff observed a pattern of CP for all within-category series, and for half of the between-category series. In a subsequent experiment comparing the extremes of each morph series on shape, Newell and Bülthoff obtained a positive correlation between shape similarity ratings and degree of CP. They therefore argued that our perceptual recognition system uses CP as a mechanism to distinguish between perceptually similar objects by attending to small differences at the shape level. Hence, within-category series show a stronger pattern of CP than between-category series, because perceptual similarity is generally higher for within-category than for between-category objects (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976).

However, the method Newell and Bülthoff (2002) used in their experiments could have more or less artificially induced the mechanism of CP. The morphed figures were tested by conducting a discrimination-identification task, a well-known method to examine CP (Macmillan, Kaplan, & Creelman, 1977). First, the discrimination task was an ABX task, in which figure X (i.e. one of the morphed figures along a continuum), identical to either figure A or B, had to be discriminated as figure A or B, being two figures along the same morph continuum. Second, in the identification task, all morphed figures had to be identified individually as one of the two extremes of the morph series. As Newell and Bülthoff acknowledged, it is possible that not one of the two extremes, but another category was actually perceived, which could not be reported because of the two-alternative forced-choice response paradigm. Most importantly, participants were forced to choose, even when none of the two categories is recognized in an absolute sense; in such cases, the best strategy seems to choose the most dominant one.

In light of the foregoing, the goal of the current study was to examine to what extent CP of objects also occurs with free-naming or rather should be regarded more as an artefact of the forced-choice method. In the discrimination-identification task (Newell & Bülthoff, 2002), the dominant and nondominant categories (i.e. the extremes of a morph series) were known to the participants. However, in a free-naming task these interpretations are unknown to the participants. As such, in a free-naming situation arguably more continuous interpretation of mixed stimuli is possible. Hence, showing categorical perception even under these circumstances would have a major theoretical impact on how our visual system deals with ambiguous information.

Free-naming could result in one of three response patterns. First, the morphing percentages could directly be reflected in the interpretation patterns, a so-called *pattern of morphing*. In other words, a morphed figure based on 70% of extreme A and 30% of extreme B will be interpreted by 70% of the observers as extreme A and by 30% as extreme B. All category information available in the morphed figure will bear on what observers perceive. Second, the morphed figures could always be perceived as the dominant category (i.e. as the extreme object of which more than 50% was present in the morph): a clear *pattern of CP* should appear. Third, no recognition of either of the two extremes is possible for those figures in which the difference between the dominant and the nondominant category is relatively low (i.e. 70%30% and 60%40%). Hence, when freely naming these figures, observers may generate a great variety of names without a clear pattern (i.e. *no distinct pattern*).

In Experiment 1, the morphed figures were tested for CP using a free-naming method. Each morphed figure was presented individually in random order, and participants were asked to give their interpretation of the object with no restrictions to naming. In Experiment 2, the same morphed figures were tested for CP, but then using a forced-choice method. A comparison between the findings of Experiment 1 and 2 could reveal to what extent this perceptual mechanism is influenced by the method of testing and to what extent CP is a phenomenon applied to the perception of concrete objects. The design of these two experiments was kept similar as much as possible to enable this comparison. If CP is affected by the method of forced-choice, a greater number of series showing CP is expected in Experiment 2 than in Experiment 1. In Experiment 3, we examined the reasons why some series of morphed figures show CP whereas others do not. We looked more closely at different aspects of (visuospatial) perceptual similarity and of general semantic similarity. Moreover, the stimulus material consisted solely of between-category objects for which perceptual similarity might play a different role than for within-category objects.

Defining Categorical Perception

To test morphed objects for CP using a free-naming method, a new set of criteria of CP was necessary. Based on criteria described in earlier studies on CP (Calder et al., 1996; Harnad, 1987), we defined a CP data pattern as a pattern in which each morphed figure along a continuum is interpreted as its dominant interpretation, except for the 50%50% figure for which both interpretations might be given. However, when the nondominant interpretation influenced the interpretation of a morphed figure a pattern of morphing resulted. This means that the morphing percentage was reflected in the answer pattern; thus, a 70%30% morphed figure would be interpreted by 70% of the observers as the dominant interpretation and by 30% as the nondominant interpretation. The four basic response patterns we discriminated are schematically shown in Figure 2.1.

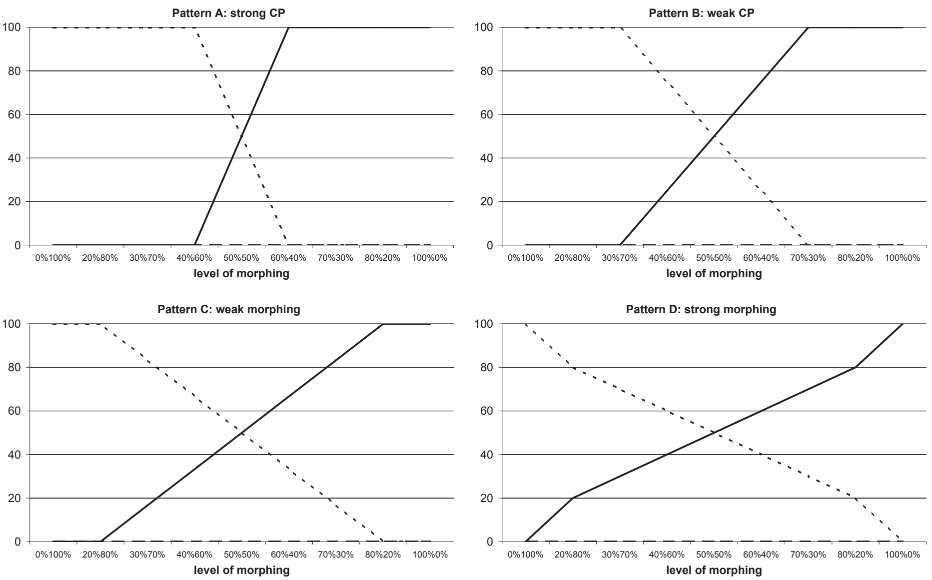

Figure 2.1. Patterns A-D. The x-axis refers to the levels of morphing, the y-axis to the % of responses a certain answer type was shown by the data pattern. The dotted line refers to one extreme; the closed line refers to the other extreme. The dashed line corresponding to the alternative answers is presented for all levels of morphing at a response level of zero.

First, Pattern A reflects *strong categorical perception*. The switch from one interpretation to the other interpretation is between 40%60% to 60%40% for one interpretation (extreme B) and for the other interpretation (extreme A) between 60%40% to 40%60%. Both lines cross one another at 50%50% at a 50% answer level, meaning that 50% of the answers is similar to extreme A and 50% is similar to extreme B. The line for the alternative answers is for all four basic patterns at an answer level of zero at each morphing level. Second, Pattern B of *weak categorical perception* shows a similar pattern to Pattern A, except that the switch moment is shifted from 40%60% to 30%70%. Third, for Pattern C of *weak morphing* all features of the data pattern are similar to the previous two basic patterns, except that the moment of switching is shifted to 20%80%. Last, in the *strong morphing* Pattern D the answer percentages reflect the levels of morphing as described previously (e.g. a 70%30% figure is perceived by 70% of the observers as the dominant interpretation and by 30% as the nondominant one). Patterns A and D were based on an ideal response pattern, which might be found under conditions of forced-choice, but would be highly unlikely under free-response circumstances, because other interpretations besides the dominant and nondominant ones would disrupt it. We could not predict a pattern for the alternative answers because previous studies used forced-choice methods. Therefore, this line was kept at a percentage level of zero. In addition, the moment of switching from one interpretation to the other need not necessarily be the same for each participant. We tried to reduce these individual differences by testing a great number of participants, but this still could affect the moment of switching for a morph series. Therefore, we introduced Patterns B and C, which captured a greater area in which the moment of switching could happen.

Experiment 1

Method

Participants
A total of 83 students from Utrecht University and University College Utrecht participated in this experiment. All were fluent in Dutch. They received a fee for participating. The experiment lasted about 10 minutes.

Materials
Suitable objects were selected from a large set of contour drawings of a wide range of living and non-living objects for which normative identification rates had been established (De Winter & Wagemans, 2004), which in turn were based on the standard set of line drawings by Snodgrass and Vanderwart (1980). In addition, the figure of a man was selected from another stimulus set (Downing, Bray, Rogers, & Childs, 2004).

Morphs (i.e. interpolations) between pairs of objects were made using Sqirlz-Morph software (Xiberpix, version 2.0). In this program, markers were positioned on salient locations of each shape contour, with the same number of markers for the two shapes that would be morphed. The morphing procedure produced linear interpolations between corresponding markers on the two shapes. The interpolation between the markers on a contour shape was decided by (bending) energy minimization (metaphorically the deforming of a thin metal plate). Morphs were made between two living objects (2 pairs out of 15 morph series), two non-living objects (3 pairs out of 15 morph series) and between living and non-living objects (10 pairs out of 15 morph series) (Mehta, Newcombe, & De Haan, 1992). Each morph series consisted of 19 interpolations (5% change). From each complete morph series nine figures were selected: the two extremes (0%100% and 100%0% figures) and the 80%20%, 70%30%, 60%40%, 50%50%, 40%60%, 30%70% and 20%80% figures. In total, fifteen different series were used. Seven out of the 19 interpolations from each series were used to reduce exposure to the same series as much as possible (see Appendix A for a complete overview). Furthermore, all paired extremes were from different (basic-level) categories and most of them from different superordinate categories (Rosch et al., 1976), such as the morph series *Duck-Church*, which are members of the superordinate categories *animal* and *building* respectively. The majority of the objects were seen from profile view, a minority faced forwards (Bernstein & Cooper, 1997). A regular keyboard was used to enter the free-naming responses. The experiment was programmed in Direct RT (Empirisoft, 2006).

Procedure

The experiment consisted of 135 trials (9 figures per morph series x 15 morph series). These were presented randomly, with the restriction that figures of the same series were presented so that they were separated by at least seven items of different series. This randomization was introduced to reduce a learning effect by previously presented figures of the same series. Each figure was presented only once.

At the start of the experiment, participants were instructed to name each target by free-response, which meant they were free to give any answer as long as it was an interpretation of the figure. Three types of answers were possible: answers corresponding to (i) the dominant interpretation, (ii) the nondominant interpretation, or (iii) answers that fitted neither of these (i.e. the alternative answers). Some restrictions were included to prevent too diverging responses, such as answers should exist of one word, and could not be diminutives (e.g. *small shoe*), subordinates (e.g. *sport shoe*) or the name of a brand (e.g. *Nike*).

Participants were given three practice trials, showing 100% figures which were not part of the experimental series, which followed the same procedure as the experimental trials. First, a fixation cross was presented in the middle of the computer screen for 750 ms, followed by the question "*what do you see here?*" (in Dutch). Simultaneously, a target (i.e. one of the nine figures from one of the fifteen morph series) was presented on the screen. Participants were instructed to type their interpretation of the target by using a keyboard placed in front of them. They could view what they were typing at the bottom of the screen (i.e. below the target), and could correct typing errors by using the backspace button. There were no time restrictions to ensure that no missing data would be collected. Trials were separated by a blank screen, the duration of which was determined by the participant by a spacebar press.

Data Analysis

The data matrix was organised by horizontally presenting all targets and vertically presenting all participants. Responses were scored as 0 for one extreme (e.g. *duck* to a target of the *Duck-Church series*), as 1 for the other extreme (e.g. *church* to a target of the *Duck-Church series*), or a score of 2 for alternative answers (e.g. *chimney* or *basket* to a target of the *Duck-Church series*). Nevertheless, re-examination of all alternative responses shifted some responses from the alternative category to one of the extreme categories, because they were a synonym or closely related (semantically or based on appearance) to the dominant or nondominant interpretation, such as *goose* in the *Duck-Church* series. This data matrix was analysed for frequency percentages of answer types per series. The graph of these frequency percentages presented the response patterns for each series separately. These graphs were compared to the graphs of the CP and morphing data patterns described in the Introduction.

It was likely that due to individual differences the data pattern for each morph series would not show such a straightforward pattern as the data patterns of Pattern A to D with an abrupt switch from one percept to another or a strong linear decrease of one of the percepts. These limitations could be dealt with by a statistical model, namely the Birmbaum model, which we used to examine CP. In the next section, *Statistical Model*, a description of this model will be outlined. Based on this model, the steepness and the moment of switching from one percept to another could be measured. By comparing the values of the four data patterns of CP and morphing to the values of the data patterns of the morph series, series could be identified as showing one of the three patterns, namely a cp-pattern, a pattern of morphing or no distinct pattern.

Statistical Model

In the following we refer to the two extreme images as image A and B. When the morphing level is 0% (100%), the pure image A (B) is shown. We assume to model the probability of choosing image B.

A proper model should allow a gradual change and have a parameter for the steepness of the curve in the region of change. The logistic curve is such a model. If $p(0 < p < 1)$ is the probability of choosing image B, and x is the morphing ratio $(0 \leq x \leq 1)$, the model is:

$$\log \frac{p}{1-p} = \alpha(x-\beta)$$

An alternative expression for the same function is:

$$p(x) = \frac{1}{1+\exp[-\alpha(x-\beta)]}$$

The parameter α, which we call the slope, determines the steepness of the curve, while β gives the morphing level for which $p = 0.5$. The latter will be referred to as X50, measuring at which moment at the continuum the switch from one percept to another takes place.

The logistic model might be applicable if the participants had to make a forced-choice between the two morphed objects. That is not the case for all experiments in the current study: sometimes other descriptions are given. We have to allow for different responses than the dominant and nondominant response. These errors (i.e. alternative responses) are accounted for by Birmbaum's (1968) extension of the logistic model:

$$p(x) = \gamma + (1-\gamma-\delta)\,\frac{1}{1+\exp[-\alpha(x-\beta)]}$$

Here $\gamma(\delta)$ is the expected fraction of errors made at $x = 0 (x = 1)$. As γ and δ are probabilities, their values have to be between 0 and 1. Figure 2.2 shows two examples of the Birmbaum model. It allows s-shaped curves with a variety of ranges, slopes and midpoints. As our results show, this model can give a good fit to our data.

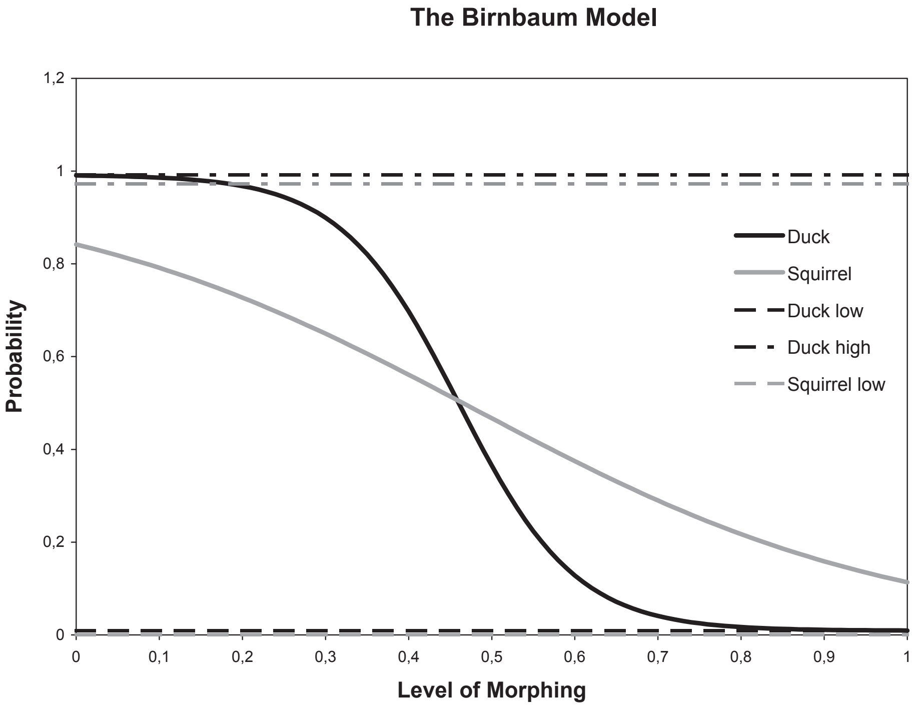

Figure 2.2. The logistic regression based on the Birmbaum model of the interpretation *Duck* (Duck-Church; black) and *Squirrel* (Squirrel-Pram; gray).

To estimate the four parameters, the maximum likelihood method has been used. Let the observations be n triples $(x_i, t_i\, y_i)$, with x_1 the i th morphing level, y_i the number of subjects choosing the 100% image and t_i the size of the sample. The likelihood is proportional to $\prod p(x_i)^{y_i}\ [1 - p(x_i)]^{t_i - y_i}$ and its logarithm is $L = y_i \log p(x_i) + (t_i - y_i) \log[1 - p(x_i)]$. Given the data L is a function of the four parameters α, β, γ and δ, and we have to find values for them that maximize the log-likelihood.

Estimating parameters for the Birmbaum model by maximum likelihood can only be done by numerical optimization. We could not find easily accessible software for this task, so we developed a specialized spreadsheet for Microsoft Excel. One of the so-called add-ons for Excel is the Solver. It is a powerful routine for (constrained) numerical optimization. In our experience this is a reliable and robust solution, if reasonable starting estimates for the parameters are provided. These are easily found. Our default set is $\alpha = 10$, $\beta = 0.5$ and $\gamma = \delta = 0$.

One of the parameters, the slope α, lacks the clear intuitive meaning of the other three. To express it in more familiar terms, we compute the "gap" $G = 4(1 - \gamma - \delta)/\alpha$.

The gap is a measure to calculate the abruptness of the switch from one percept to the other. This formula follows from the following geometric construction (see also Figure 2.3). The tangent line to the curve at the midpoint β is constructed (it has slope $\alpha/4$). This line is intersected with horizontal lines at levels γ and $1-\delta$. The intersections occur at morphing ratios x' (left) and x'' (right). The distance between them is the *gap*: $G = x'' - x'$.

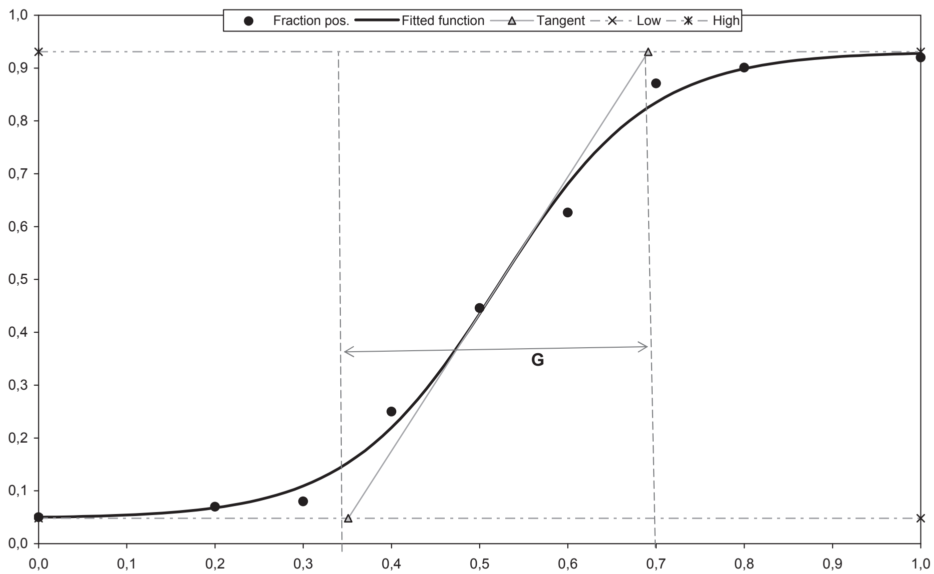

Figure 2.3. From the model parameters we compute what we call the "gap". It is indicated by an arrow, marked G, in the figure. The tangent line to the curve is extended to the point where it crosses the 0% level; this defines the left end of the gap. Similarly, the point where the tangent line crosses the 100% level defines the right end of the gap.

Data Patterns

Due to alternative responses and individual differences an ideal pattern of CP (Pattern A, strong CP) might not be observed, but if G is small enough it is possible to speak of an approximation of CP. This means that the observed G of the data pattern of one interpretation (either A or B) of a morph series should be similar or in-between the observed G for Pattern A of strong CP and Pattern B of weak CP (i.e. $0.04 \leq G \leq 0.24$). In addition, the X50 should be as close as possible to 0.50 (i.e. at the middle of the continuum), but at least in-between 0.40 and 0.60 (i.e. $0.40 < X50 < 0.60$). Furthermore, a data pattern could also fit the basic patterns of morphing, meaning that G should fit or be in-between the G of Pattern C of weak morphing and Pattern D of strong morphing (i.e. 0.39 ≤ G ≤ 0.71). Again, X50 should be near to the midpoint (i.e. 0.40 < X50 < 0.60). Both interpretations of a morph series should fit both assumptions of either the cp-patterns or morphing-patterns to be identified as patterns of CP or morphing respectively. If one or both of the interpretations of a morph series did not fit these restrictions, a series was labelled as no distinct pattern.

Results

Tables were created for each individual target (i.e. 135 tables) showing the percentages for the three types of answers. Next, the answer types were presented in a graph; each graph included three lines representing the percentage an answer type was chosen for all nine targets in a morph series (i.e. 0%100%, 20%80%, 30%70%, 40%60%, 50%50%, 60%40%, 70%30%, 80%20% and 100%0% figures). Such a graph was created for all 15 morph series (see Figure 2.4 for the graphs of four series representative for the dataset).

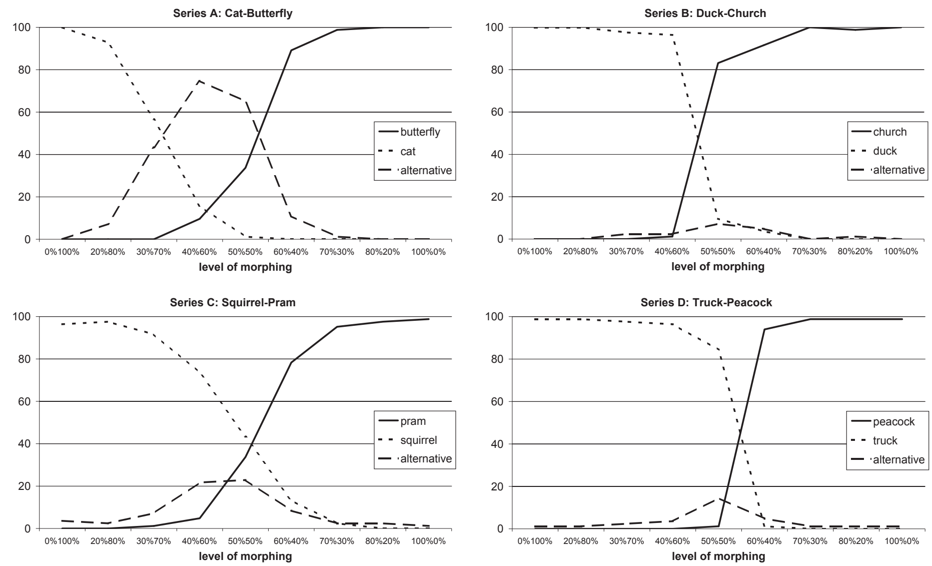

Figure 2.4. Four examples of data patterns of morph series. The nine levels of morphing are presented on the x-axis, the percentage that a certain answer was given is presented on the y-axis going from 0% to 100% of all responses. The dotted lines refer to the first category name of the series name (e.g. Duck for Duck-Church), the closed lines to the second category name of the series name (e.g. Church for Duck-Church), and the dashed lines to the alternative answers. Morph series B (Duck-Church) and D (Truck-Peacock) were labelled as CP, while series A (Cat-Butterfly) and C (Squirrel-Pram) were labelled as no distinct pattern.

Based on these graphs, the Gap and X50 were calculated for each series separately using the Birmbaum model. These values were matched to the Delta Gap and X50 values of the basic Patterns of CP and Morphing to see which series showed a cp-pattern, a pattern of morphing or no distinct pattern. In Table 2.1, the Gap and X50 values of all series are presented, including the variance measure representing the goodness-of-fit of the estimated curve to the observed data. Here, this measure of fit is the *deviance*. It is defined as two times the difference between the "saturated log-likelihood" and the model log-likelihood. The saturated log-likelihood is obtained if the observed fractions are filled in for the binomial log-likelihood, instead of the probabilities obtained from the model.

Table 2.1. Separate presentation of Delta Gap and X50 values for both interpretations of all morph series obtained in Experiment 1. Delta Gap1 and X50_1 refer to the first series name (e.g. Delta Gap1 for Truck-Peacock refers to Truck) and Delta Gap2 and X50_2 refer to the second name of a series (e.g. Delta Gap2 for Truck-Peacock refers to Peacock). All bold scores fit the cp-restrictions. A series being labelled as CP needs to have both series names being bold. If not, series were labelled as no distinct pattern. If a series name is underlined, this series name was labelled as morphing; however, none of the series parts was identified as a pattern of morphing. The series are presented in alphabetic order. The last two columns represent the variance measures (Deviance_1 and Deviance_2) of the fit of the estimated curve of the observed data.

Morph Series	Delta Gap1	X50_1	Delta Gap2	X50_2	Deviance_1	Deviance_2
Arm-Banana	0.46	0.53	0.32	0.67	24.1	8.8
Bear-**Bow**	0.22	0.40	0.22	0.48	17.7	13.8
Bell-Kettle	0.16	0.51	0.32	0.73	5.4	14.1
Cat-**Butterfly**	0.18	0.32	0.17	0.52	1.1	4.6
Crocodile-Airplane	0.23	0.44	0.21	0.51	29.8	9.8
Dog-Gorilla	0.21	0.42	0.22	0.42	6.3	7.3
Duck-Church	0.07	0.46	0.07	0.47	12.6	18.4
Guitar-Sea Lion	0.12	0.52	0.08	0.54	9.0	3.2
Gun-Rabbit	0.22	0.46	0.20	0.69	15.1	13.3
Hat-Bird	0.35	0.45	0.41	0.58	15.3	8.2
Heart-Apple	0.17	0.43	0.19	0.47	36.5	26.5
Man-Lamp	0.36	0.52	0.27	0.59	3.2	8.1
Squirrel-**Pram**	0.25	0.48	0.19	0.54	2.3	0.7
Truck-Peacock	0.06	0.53	0.05	0.56	1.5	0.0
Turtle-Car	0.18	0.56	0.18	0.56	6.4	6.4

In conclusion, based on our definitions of CP seven morph series out of fifteen were regarded as categorically perceived. These were the series *Truck-Peacock, Duck-Church, Guitar-Sea Lion, Heart-Apple, Turtle-Car, Crocodile-Airplane* and *Dog-Gorilla,* presented in order of strong CP to weak CP. The remaining eight morph series, *Squirrel-*

Pram, Bear-Bow, Gun-Rabbit, Cat-Butterfly, Man-Lamp, Bell-Kettle, Hat-Bird and *Arm-Banana*, were interpreted as showing no distinct pattern. None of the series evolved in a pattern of morphing.

The distinction between cp-series and non-cp-series should also be reflected in the pattern of alternative responses; it was expected that a stronger increase of alternative responses would be observed for the non-cp-series than the cp-series. A sum of the number of alternative responses for each series on each morphing level reflected by percentages showed that a stronger increase of alternative responses was indeed obtained with increase of morphing level for the non-cp-series compared to the cp-series. This was statistically supported by the significant main effect of *CP* (cp-series and non-cp-series), $F(1,13) = 17.44$ and $p = .001$, and by the significant interaction effect between *CP* (cp-series and non-cp-series) and *Morphing* (from 100%0% to 0%100%) on the percentage alternative responses, $F(8,104) = 2.83$, $p < .01$. The stronger increase of alternative responses for the non-cp-series compared to the cp-series is graphically presented in Figure 2.5.

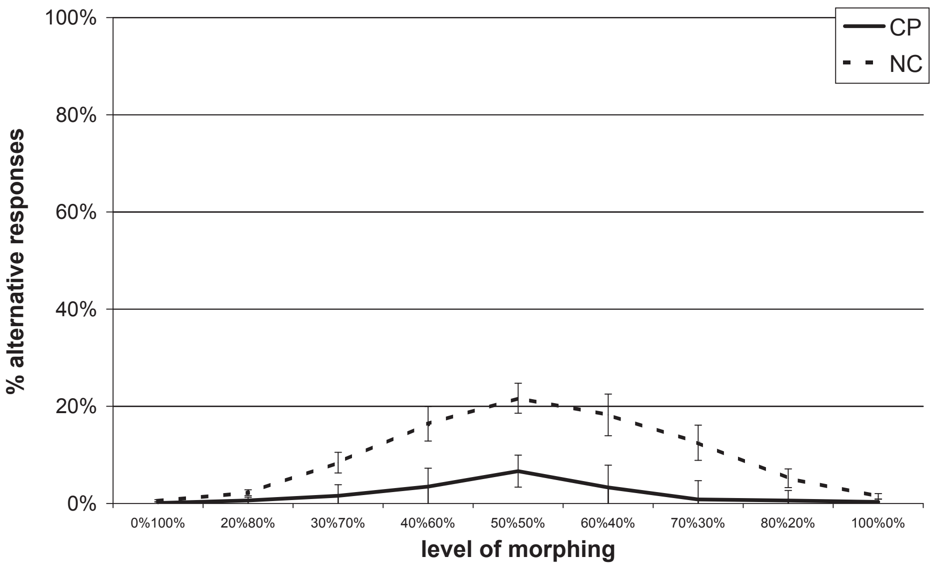

Figure 2.5. The mean percentage alternative responses reported for the cp-series (CP) and non-cp-series (NC) in Experiment 1, with the different levels of morphing on the x-axis and the percentage of alternative responses on the y-axis.

The described pattern of alternative responses suggests that the 50%50% figures for the non-cp-series are difficult to recognize and therefore result in a great number of alternative responses. One might think that this great number of alternative responses, in particular for the indefinable 50%50% figures of non-cp-series, would affect the steepness of the slope for a non-cp-series to such an extent that a pattern of CP is by forehand already impossible. We evaluated whether a free-naming pattern with a score of 0 for the 40%60% and 50%50% figure (indicating a score of 100 for the alternative responses) and a score of 100 for the 60%40% figure would lead to no distinct pattern. However, this pattern still resulted in a cp-pattern, with naturally a X50 shifted towards the right (X50 = 0.56) and a Delta Gap still fitting the cp-criteria (G = 0.04).

Discussion

Morphed figures were individually presented and were labelled using free-naming. Patterns of CP of concrete objects were previously reported by Newell and Bülthoff (2002), but were found under conditions of forced-choice. Interestingly, the current findings showed that CP also occurs for concrete objects when using a free-naming method. In total, seven out of fifteen series were categorically perceived. Notably, the remaining eight series showed no fit with either the patterns of CP or patterns of morphing. The findings of Experiment 1 provide more support that CP can be found for morphed figures of concrete objects as well. Subsequently, we examined whether the method used has different influences on CP by conducting a forced-choice experiment in Experiment 2.

Experiment 2

Method

Participants

Forty-four students from Utrecht University participated in this experiment. None of them participated in Experiment 1. The experiment lasted about 10 minutes and participants received a fee or course credits for their contribution.

Materials

All 135 figures used as stimulus materials in Experiment 1 (i.e. morphed figures and extremes) functioned as stimulus materials in this experiment. The black silhouettes were presented on a white background. The response possibilities were printed in black in font type *Courier New* and font size 24. The stimuli were displayed on a 17-inch monitor using E-Prime (Psychology Software Tools Inc., version 1.1) in a nonlit room. The viewing distance to the monitor was approximately 60 cm. Participants used a stimulus-response box (SR-box) to enter their responses.

Procedure

Participants were asked to identify each morphed figure by choosing between two response possibilities. These possibilities were always similar to the dominant and nondominant interpretation of that particular object. For example, a figure from the series *Duck-Church* was always accompanied by the two response possibilities *duck* and *church*. Each trial started with a fixation cross (+) presented at the middle of the screen for 1000 ms. Next, the plus sign was replaced by a target (one of the figures from the stimulus material set) with a maximum of 10 seconds. Simultaneously to the presentation of the target two words appeared on the screen below the figure at the left and right of the screen. These were the two response possibilities. Participants responded by pressing either the left button on a stimulus response box (SR box) if they thought the word on the left side of the screen corresponded most to the target or the right button of the SR box if they thought the right word corresponded most to the target. The moment a button was pressed the target and response words disappeared and the next trial initiated. Because our main interest was the identification of the objects, no time restrictions were included, except for the maximum of 10 seconds. By putting time pressure on responding, the chance of errors would increase, which would mean a loss of data. Furthermore, participants were instructed that this experiment was about their interpretation of the figures, and thus no correct or incorrect responses could be given. All figures were presented randomly, with the restriction that no two figures of the same series were presented sequentially.

Data Analysis

The data were presented in a data matrix with all figures at the horizontal axis and all participants at the vertical axis. Each response was scored as either 0 or 1 referring to both interpretations of a series. For example, responses to a figure of the *Duck-Church* series were coded as 0 if they corresponded to *duck* and 1 to *church*. Because of the forced-choice method, no alternative responses were registered. This data matrix was used to measure the frequency percentages of a particular response. The graphs resulting from these frequency percentages presented the response patterns for each series separately.

Results

Of all data, 0.07% (4 out of 5940 trials) was excluded due to responses slower than 10 seconds. Subsequently, the data were analysed in the same way as in Experiment 1, except for the fact that instead of three types of answers (i.e. dominant, nondominant and alternative responses), two answer types were analyzed (i.e. dominant and nondominant responses). Using the Birmbaum Model, a curve with the best fit was calculated from which the Delta Gap and X50 could be inferred for each series separately. These values were compared to the values of the four data patterns of CP and of morphing. It was found that nine series out of fifteen showed a pattern of CP, while the remaining six series showed no distinct pattern (see Table 2.2).

Table 2.2. The Delta Gap and X50 for all morph series tested in Experiment 2. When the name of a series is bold, this indicates that the Delta Gap and X50 of that series fit the cp-restrictions. The series are presented in alphabetic order. The last column presents the variance measure (Deviance) of the fitted function on the observed data.

Morph Series	Delta Gap	X50	Deviance
Arm-Banana	0.28	0.43	11.3
Bear-Bow	0.20	0.53	10.1
Bell-Kettle	0.25	0.39	29.8
Cat-Butterfly	0.03	0.59	12.3
Crocodile-Airplane	0.27	0.57	11.8
Dog-Gorilla	0.24	0.62	7.5
Duck-Church	0.07	0.57	9.2
Guitar-Sea Lion	0.12	0.47	13.4
Gun-Rabbit	0.13	0.46	2.0
Hat-Bird	0.34	0.44	33.1
Heart-Apple	0.26	0.58	17.9
Man-Lamp	0.19	0.48	12.6
Squirrel-Pram	0.18	0.49	12.8
Truck-Peacock	0.16	0.44	0.0
Turtle-Car	0.12	0.44	10.3

The cp-series found in the forced-choice naming task were in order of strongest categorical to weakest categorical *Guitar-Sea Lion*, *Squirrel-Pram*, *Gun-Rabbit*, *Man-Lamp*, *Duck-Church*, *Cat-Butterfly*, *Bear-Bow*, *Turtle-Car* and *Truck-Peacock*. The series showing no distinct pattern presented in an order of least non-categorical to most non-categorical were *Crocodile-Airplane*, *Arm-Banana*, *Heart-Apple*, *Hat-Bird*, *Bell-Kettle* and *Dog-Gorilla*. None of the series showed a pattern of morphing.

Discussion

In this experiment, morphed figures were tested for patterns of categorical perception using a forced-choice method in which participants were forced to identify a morphed figure as its dominant or nondominant interpretation. The response patterns were analysed using the Birmbaum model. It was found that nine out of fifteen morph series showed a pattern of CP. The remaining six showed no distinct pattern, and no morph series showed a pattern of morphing. The lack of CP for these six series was caused for two series by an early switch in percept instead of a switch halfway the continuum. The remaining four non-cp-series showed a pattern that was not linear enough to fit the criteria of a pattern of morphing and not discrete enough to fit a pattern of CP. Despite the fact that not all series showed CP, these data suggest that a majority of the morph series used in this study was perceived categorically.

Experiment 3

In Experiment 1 and 2, the observation of CP for familiar objects was confirmed. Not all morph series showed a pattern of CP, however. Furthermore, not all series showed the same pattern for both methods. From these findings the question is raised why some series are perceived categorically and others not.

Notably, the different effects the morph series had on CP could not be explained by image differences on pixel-level (i.e. we calculated the luminance differences between all figures of a morph series and compared these pixel differences between the cp-series and non-cp-series). In other words, some series showed a larger increase in difference in number of pixels between extreme and morphed figure than other series, but this difference in changes was not consistently larger for either cp-series or non-cp-series. Moreover, Newell and Bülthoff (2002) argued that whether a series shows CP or not depends on the strength of perceptual similarity between the extremes. They reported a positive correlation between CP and similarity in shape. Therefore in the current experiment, we examined whether our dataset supported this claim. Similarity was assessed for a number of features; we distinguished perceptual similarity into subdivisions of shape (i.e. referring mainly to general contours), number of parts and intrinsic part structure (Rosielle & Cooper, 2001). Moreover a number of studies (Biederman, 1987; Biederman & Gerhardstein, 1995) have suggested categorization is often component-based; therefore, number of parts and intrinsic part structure could be valuable additions to investigate perceptual similarity. Things which look the same are also often connected in other respects, such as in meaning and general semantics (Rosch et al., 1976). We therefore also compared the semantic similarity ratings, and finally the phonological similarity ratings between the categorical and the non-categorical series. Because the division of cp-series and non-cp-series was different for the free-naming and forced-choice experiment, we ran two analyses to find out whether perceptual similarity plays an important role for one or both methods.

Method

Participants

Twenty students from Utrecht University participated in Experiment 3. The experiment lasted about 20 minutes, and the students were paid a fee or course credit for their participation. All participants had normal or corrected-to-normal vision. All participants had Dutch as their native language. None of them had participated in Experiment 1 and 2.

Materials

The stimuli that were used were the extremes (100%0% and 0%100%) of each morph series tested in Experiment 1 and 2. The stimuli were presented on a computer using E-Prime (Psychology Software Tools Inc., version 1.1) in a nonlit room. Participants used a standard keyboard to enter their responses.

Procedure

The experiment contained five blocks in which the two extremes were compared on five different aspects: shape, semantics, phonology, number of parts and intrinsic part structure. The five aspects were always presented in the order as reported here, which was based on an increase in difficulty. Within each block, trials were presented in a new random order for each participant.

The presentation of the experimental trials was the following: at the top of the screen the question *How strong is the similarity between the two figures in…?* was presented in Dutch. The dots were replaced by the aspect investigated in that particular block. In the middle of the screen the two extremes of a morph series were presented next to one another. A rating scale from one to seven was presented at the bottom of the screen with at the left end the word *weak* and at the right end the word *strong*. Participants were instructed to enter a number from one to seven. They were encouraged to use the entire range of the rating scale. Participants viewed what they were typing below the rating scale. When participants agreed on their response, they pressed the enter button to continue to the next trial. Alternatively, they could use the backspace button to correct it. Participants were given ample time to respond to each trial.

Each block was preceded by instructions about the particular aspect examined. For instance, participants were presented with three examples to illustrate what the idea was behind comparing shape. The first example was always a written example; for instance, a *warning triangle* and a *wedge of cake* imply high similarity in shape, but a *warning triangle* and a *traffic light* do not. Next, participants were presented with a good example followed by a bad example. For these illustrations, silhouette figures were used which were also based on the line drawings of Snodgrass and Vanderwart (1980), but none was similar to the silhouette figures used in the experimental trials. For example in the shape block, *bottle* and *candle* were used as a good example and *camel* and *boat* were used as a bad example.

Data Analysis

Two groups were created: categorical series (cp-series), consisting of the categorically perceived series, and non-categorical series (non-cp-series), consisting of the non-categorically perceived series. The division of the 15 morph series in these two groups varied for Experiment 1 and 2. These two groups were compared for their similarity ratings on five different aspects: shape, semantics, phonology, number of parts and intrinsic part structure.

Results

First, an overall correlation test was performed to investigate possible correlation patterns between the different aspects. A priori, one might expect that the three aspects concerning perceptual similarity (*Shape*, *Number of Parts* and *Intrinsic Part Structure*) were correlated. It was found that *Number of Parts* and *Intrinsic Part Structure* were the only two aspects that were significantly correlated (r = .670, p = .001). This meant that the similarity ratings on most aspects were not influenced by similarity ratings on other aspects, except for *Number of Parts* and *Intrinsic Part Structure*. An object containing a certain number of parts might have a fixed way in which it is structured. For example, an object with five parts could contain one component in the middle and four components around this center part, which might underlie the observed correlation between *Number of Parts* and *Intrinsic Part Structure*.

Subsequently, the two groups of cp-series and non-cp-series were compared for each aspect separately running Analyses of Variance using Repeated Measures in a 2x5 within-subject design. The variables *Categorical Perception* (cp-series and non-cp-series) and *Aspect* (shape, number of parts, intrinsic part structure, semantics and phonology) were used as within-subject variables. Significant effects found at an alpha-level of .05 were investigated further by conducting Bonferroni post-hoc comparisons.

The main effect of *Aspect* was significant $F(4,76) = 67.21$, $p < .001$. Post-hoc comparisons showed that almost all aspects differed significantly, $F(4,16) = 29.68$, $p < .001$, except for the aspects of *Number of Parts* and *Intrinsic Part Structure* and for the aspects of *Semantics* and *Phonology*. The highest similarity ratings were assigned to the aspect of *Number of Parts* followed by *Intrinsic Part Structure*, *Shape, Semantics* and *Phonology*. The effect of *Aspect* was similar for the cp- and non-cp-series of the forced-choice and the free-naming experiment, because this effect was independent of CP.

The main effect of *Categorical Perception* and the interaction effect between *Categorical Perception* and *Aspect* are, due to a difference in the division of cp-series and non-cp-series, reported separately for the free-naming experiment and the forced-choice experiment.

Free-Naming Division cp-Series and Non-cp-Series

We compared the cp-series to the non-cp-series based on the findings of the free-naming experiment. The main effect of *Categorical Perception* was significant, $F(1,19) = 36.49$, $p < .001$, with higher similarity ratings for the cp-series than for the non-cp-series. Furthermore, the interaction effect of *Categorical Perception* and *Aspect* was also significant, $F(4,76) = 28.94$, $p < .001$. Bonferroni comparisons revealed that the aspects on perceptual similarity all showed higher ratings for the cp-series in comparison to the non-cp-series, $F_{shape}(1,19) = 8.06$, $p = .010$, $F_{parts}(1,19) = 33.91$, $p < .001$, $F_{structure}(1,19) = 55.98$, $p < .001$, while the non-cp-series showed higher similarity ratings on the aspect of *Phonology* than the cp-series, $F_{phonology}(1,19) = 9.79$, $p < .01$, and did not differ from one another on the aspect of *Semantics*, $F_{semantics}(1,19) = 0.30$, $p > .05$. In Figure 2.6, the means and standard errors for the free-naming as well as the forced-choice distinction of the cp-series and non-cp-series on the five different aspects of similarity are presented graphically.

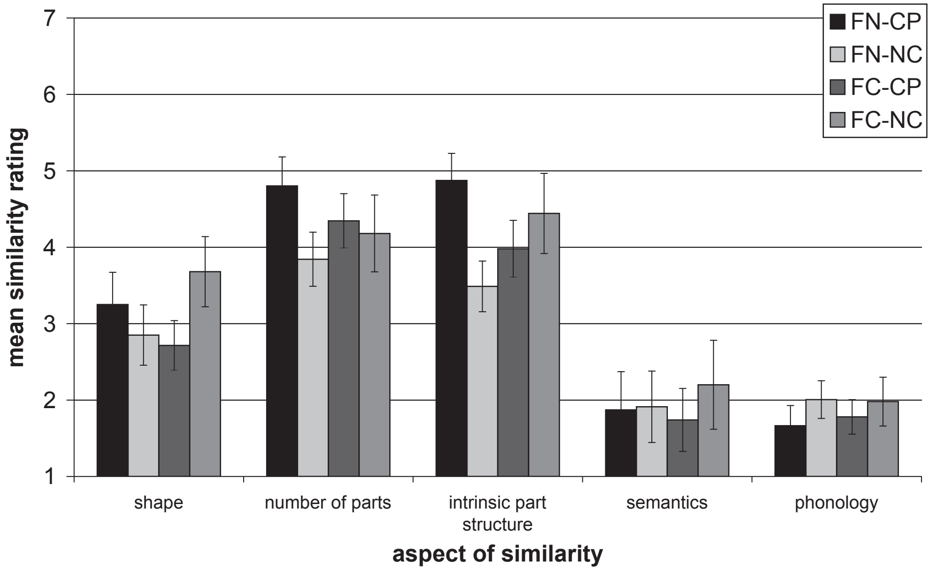

Figure 2.6. The means and standard errors for all five aspects of similarity, with the black bar and the light grey bar representing the cp-series and non-cp-series of the free-naming experiment, and the dark grey bar and the grey bar representing the cp-series and non-cp-series of the forced-choice experiment. On the x-axis the five aspects of similarity are outlined. The y-axis represents the rating scale from 1 to 7 with an increase in similarity rating.

The finding that the extremes of cp-series were rated more perceptually similar than the extremes of non-cp-series suggests that CP and perceptual similarity might be positively correlated. Therefore, we ran a regression in which the morph series were ordered from least categorical to most categorical in an ordinal way using z-scores based on the two Delta Gap and two X50 values of each morph series. The regression including the three aspects of perceptual similarity was not significant, $F(3,11) = 1.74$, $p = .217$, $R^2 = .321$. This means that no significant relation was found between strength of CP and amount of similarity on any of the aspects ($r_{shape} = .058$, $p = .836$; $r_{parts} = -.387$, $p = .154$; $r_{structure} = -.459$, $p = .085$; $r_{semantics} = .197$, $p = .482$; $r_{phonology} = .256$, $p = .357$). Importantly, the Analysis of Variance apparently showed clear differences for cp-series versus non-cp-series.

Forced-Choice Division Cp-series and Non-cp-series

We found opposite patterns for the results of the ANOVA with *Categorical Perception* and *Aspect* as within-subject variables based on the forced-choice division of cp-series and non-cp-series in comparison to the analysis of the free-naming division. The main effect of *Categorical Perception* was significant, $F(1,19) = 61.69$, $p < .001$. Unexpectedly, the extremes of the non-cp-series were rated more similar than the extremes of the cp-series. The interaction between *Categorical Perception* and *Aspect* was also significant, $F(4,76) = 8.83$, $p < .001$. Conducting pairwise comparisons (Bonferroni corrected), the aspects of *Shape,* $F(1,19) = 123.02$, $p < .001$, *Intrinsic Part Structure,* $F(1,19) = 5.48$, $p < .05$ and *Semantics,* $F(1,19) = 54.32$, $p < .001$, differed significantly for the cp-series and non-cp-series with higher similarity ratings assigned to the extremes of the non-cp-series than the cp-series. The aspects of *Number of Parts* and *Phonology* were not significantly different between the cp-series and non-cp-series.

Discussion

In Experiment 3, the two extremes of all fifteen morph series used in Experiment 1 and 2 were tested for their similarity on different aspects: shape, number of parts, intrinsic part structure, semantics and phonology. The similarity ratings for each aspect were compared between the cp-series and non-cp-series for the two different divisions found under conditions of free-naming and forced-choice. The two methods showed diverging data patterns of similarity ratings between cp-series and non-cp-series. For the free-naming distinction, the three aspects of perceptual similarity all showed higher similarity ratings for the cp-series in comparison to the non-cp-series, but a linear relation between order of CP and degree of perceptual similarity was not found, possibly due to the order of series from most categorical to least categorical which was somewhat arbitrarily chosen. In contrast, for the forced-choice division, the perceptual similarity aspects of shape and intrinsic part structure showed higher similarity ratings for the non-cp-series than for the cp-series. In addition, the aspect of number of parts was not different for the two types of series. Noteworthy, the group of cp-series consists of more series than the group of non-cp-series as a result of the forced-choice experiment (nine cp-series to six non-cp-series), while the distribution of the cp-series and non-cp-series as a result of the free-naming experiment is more or less equal (seven cp-series to eight non-cp-series). The skewed distribution of cp- and non-cp-series by the forced-choice method might have biased the findings of the analyses on the relation between perceptual similarity and CP.

Furthermore, phonological similarity was quite low in absolute sense (i.e. a score between 1 and 2 on a rating scale of 1 to 7), indicating that the sound pattern of object names does not affect the way they are visually perceived. This implication was reinforced by the fact that the low similarity effect on the aspect of phonology could not be due to variability in the names used for rating the objects on their phonological similarity: 91% of the participants used the same names for the objects. Moreover, semantic similarity ratings were also low for both types of groups suggesting that the general meaning of an object category does not contribute to the categorical perception of a morphed figure.

General Discussion

The goal of this study was to explore whether higher-level visual constructs such as morphed objects are perceived and interpreted in a continuous fashion or more categorically. We obtained support for CP of concrete objects in Experiment 1 and 2 by showing that CP not only occurs under circumstances of forced-choice, but also under circumstances of free-naming. These results extend the findings by Newell and Bülthoff (2002) who also found CP for familiar objects.

Notably, the free-naming and forced-choice experiment showed differences in which particular series were identified as yielding CP[1]. Four series that showed strong CP in the free-naming experiment also had a strong cp-pattern in the forced-choice experiment. However, five series that were perceived categorically using forced-choice were not perceived categorically in the free-naming experiment. The latter finding illustrates that forced-choice methodology evokes more CP. Most importantly, three series that were labelled as non-cp-series in the forced-choice experiment were perceived categorically under conditions of free-naming. We may consider two reasons for this latter difference. One concerns the fact that in the free-naming experiment participants were not restricted to two options only, but also could give an alternative response. The other reason for the limited overlap in cp-series between the two experiments could be that in a forced-choice task, one is presented with both response options, while in a free-naming experiment one has to retrieve the answer oneself. Both reasons make that free-naming resembles a more natural method (Malt & Sloman, 2007) to identify objects under circumstances of perceptual uncertainty.

As was implied by Newell and Bülthoff (2002), CP might be a mechanism to discriminate especially between perceptually similar objects, in particular objects from the same (basic-level) category. In Experiment 3, we confirmed this hypothesis for the free-naming distinction of cp-series and non-cp-series: extremes of series labelled as categorically perceived were rated as more perceptually similar than extremes of series labelled as non-categorically perceived, even though the stimulus materials consisted

1 We acknowledge that labelling a series as CP or non-CP is slightly arbitrary and is an example of dichotomous categorization itself. However, we argue that our distinction is defendable; CP is a well-described phenomenon in the literature from which we have inferred conservative criteria which a series should fulfil before being labelled as a cp-series.

only of between-category objects. In contrast, the effect observed for the forced-choice distinction of cp- and non-cp-series showed a higher similarity rating for the non-cp-series than the cp-series. Notably, this result might be biased by the skewed distribution of number of cp-series and non-cp-series (i.e. nine versus six respectively). The current results therefore show that perceptual similarity indeed plays an important role in categorizing morphed figures, but only in more natural circumstances, such as free-naming. Interestingly, Newell and Bülthoff found a positive correlation between perceptual similarity and amount of categorical perception, despite the fact that they used a forced-choice method. It has to be noted that the forced-choice method they used did not rely on stored concepts; participants were asked to choose between two images, instead of words like the current experiment. Therefore, participants in the study of Newell and Bülthoff could have visually compared the images to the morphed figure. This discrepancy might explain the differences between the two studies.

The foregoing findings appear to form a rather elegant illustration of a recent Bayesian model of Feldman and Singh (2006), in particular for the relation between CP and perceptual similarity. This model is used to compute the so-called optimal skeletal representation of an object (i.e. MAP skeleton). A shape skeleton represents an object in the simplest, generative manner by translating an object into branches and subbranches each representing a component of that object. By this method a unique skeletal representation can be derived for each object. If two extremes are judged as perceptually similar, they probably have closely-related skeletons. By morphing perceptually similar extremes, their skeletal representations will change with small steps. Because of the robustness to small changes, a skeletal representation will keep its unique appearance until the category boundary is reached (at which the skeleton will adopt characteristics of the other extreme's skeleton). In Experiment 3 and in particular for the division of cp- and non-cp-series by the free-naming experiment, we found that perceptual similarity ratings were highest for cp-series on the aspect of intrinsic part structure. This assumption provides support for objects being categorized by their skeletal representation, because the intrinsic part structure seems to have much in common with the model of shape skeleton. This model also explains why perceptually dissimilar extremes would not show a pattern of CP. The skeletal representation of these extremes varies to a great extent, enhancing the opportunity to form a new, distinctly different skeleton within a morphing series. This new skeletal representation might resemble a third category or a new unknown (i.e. yet undefined) category. Moreover, studies on changes to an object, such as rotation

(Wallis & Bülthoff, 2001) and different viewpoints (Newell & Bülthoff, 2002; Newell & Findlay, 1997), reported that these changes did not affect categorization of the objects. Again we may speculate that this is because the skeleton frame is preserved throughout these changes.

Based on the association between perceptual similarity and CP, we argue that it is the intrinsic part structure of a morphed figure that is probably used to categorize an object. If two perceptually similar objects are morphed, this intrinsic part structure is less distorted than when two perceptually dissimilar objects are morphed. These small distortions caused by perceptually similar objects might result in still recognizing the morphed figure as a member of the same category as its dominant extreme.

The latter speculations also fit the general assumption that categorization is based on similarity (Edelman, 1995; Edelman, 1998; Hahn & Ramscar, 2001; Hampton, Estes, & Simmons, 2005; Rosch et al., 1976). Morphed figures at the first half of a continuum share enough features to be categorized as the same object. However, halfway the continuum these features have changed so much that they no longer will fit the characteristics of that particular category. Thus, figures at one half of the continuum could have been identified on basis of their similarities, while figures halfway the continuum could be identified differently on basis of their lack in similarities.

Notably, what makes morphed figures unique is the combination of two extremes. Although the dominant one is perceived in many of the series, it would be interesting to investigate to what extent the nondominant interpretation has any effect on the visual processing of morphed figures. This could be examined by investigating influences of top-down information by conducting a priming experiment in which a prime congruent to the nondominant interpretation preceding a morphed figure could affect interpretation of the morphed figure or not. Moreover, a priming experiment may crystallize the underlying mechanism of CP further.

Conclusion

Support of categorical perception of objects was provided by showing patterns of CP under conditions of forced-choice and free-naming. In the free-naming experiment half of the series fitted the pattern of CP. This may be due to perceptual similarity between the extremes of a morph series; high ratings on perceptual similarity were strongly associated with categorically perceived series. Moreover, the series that showed a cp-pattern in the free-naming experiment did not necessarily show a cp-pattern in the forced-choice experiment. The distinction between cp-series and non-cp-series resulting from the forced-choice experiment could not be explained by perceptual similarity. We would like to argue that free-naming is a more natural way of investigating CP (see also Malt & Sloman, 2007).

Since we found CP in the current study for concrete objects, we would like to argue that the phenomenon of CP is not limited to biological predispositions. CP shares many characteristics to the general process of categorization by assigning figures to the same category when they share many features, but assigning them to different categories when they share few or none features. It might be the strength of violations to the intrinsic part structure caused by the morphing procedure that makes a morph series being perceived categorically or not. A similar process might be underlying categorization in general. Therefore, CP probably is a submechanism of categorization which specifically deals with perceptual uncertainty by focusing on visual features of an object to fit it into a category.

3

The Absoluteness of Categorical Perception: One or Two Interpretations?

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Abstract

Categorical perception (CP) refers to the phenomenon that a continuous change of one object into another is perceived categorically instead of continuously. In the current study, we examined the absoluteness of CP: Does CP mean that we completely block out alternative interpretations or can we come up with more perceptual interpretations when encouraged to? In a double-naming experiment, participants were asked to give two interpretations of a morphed figure. When a second interpretation was given, a distinction was made between responses corresponding to the nondominant object and those corresponding to another alternative. Analysing the first responses resulted in some morph series showing CP (cp-series) and others not (non-cp-series), replicating the findings of Hartendorp et al. (2010). Second responses were particularly absent for figures in which the dominant figure was strongly represented. When the dominant figure was less strongly represented, an increase of nondominant interpretations was observed for cp-series, whereas an increase of alternative interpretations was observed for non-cp-series. In conclusion, we argue that CP is not absolute; the nondominant object is also processed when interpreting a morphed figure. These findings are discussed in terms of violations to the intrinsic part structure of the original figures when they are morphed.

Introduction

When we perceive an object in daily life, it is often immediately assigned to a category. This categorization process enables us to deal with the uncountable number of objects that we are exposed to. Even in case of uncertainty, we still often end up with a single interpretation. A strong example of perceptual uncertainty is a morphed stimulus. This is a stimulus resulting from two clearly identifiable stimuli that are interpolated in small steps. Therefore, each morphed stimulus contains information from both interpolated stimuli (i.e. extreme objects). Morphed stimuli are in most cases preferred to be categorized as the stimulus that is most dominantly present in the morphed figure (i.e. dominant object) (Harnad, 1987). Interestingly, this preference may continue over various morphing levels, i.e. the categorization pattern of a morph continuum shows an abrupt switch in perception halfway along the morph continuum. The abrupt switch in perception from one interpretation into another is termed *categorical perception* (CP: Harnad, 1987; 2003). This switch is not only observed in the way observers explicitly categorize the items but also in the discrimination responses: morphed stimuli are judged as more similar when they are assigned to the same category (i.e. within-category stimuli) than when they are assigned to different categories (i.e. between-category stimuli) (Macmillan, Kaplan, & Creelman, 1977; see also Gillebert, Op de Beeck, Panis, & Wagemans, 2009).

CP has been reported for many different types of stimuli, such as phonemes (Liberman, Harris, Hoffman, & Griffith, 1957; Liebenthal, Binder, Spitzer, Possing, & Medler, 2005), colours (Bornstein, 1987; Bornstein & Korda, 1984) and facial expressions (Calder, Young, Perrett, Etcoff, & Rowland, 1996; Etcoff & Magee, 1992; McCullough & Emmorey, 2009), but also for learned categories such as facial identities (Beale & Keil, 1995) and familiar objects (Gillebert et al., 2009; Hartendorp, Van der Stigchel, Burnett, Jellema, Eilers, & Postma, 2010; Newell & Bülthoff, 2002; Verstijnen & Wagemans, 2004). In addition, electrophysiological data also suggest a CP pattern (Dehaene-Lambertz, 1997; Jacques & Rossion, 2006). For instance, in a same-different task (Campanella, Quinet, Bryer, Crommelinck, & Guerit, 2002) it was found that the peak of the N170 was larger for two morphed stimuli that were behaviourally assigned to different categories than for two morphed stimuli that were behaviourally assigned to the same category. The N170 peak is interpreted as the degree of repetition priming: A small peak indicates no change or a small change in the visual input, whereas a large peak indicates a large change. Thus the differences between the two within-category stimuli were less noticeable than the differences between two between-category stimuli.

On the basis of the foregoing, CP seems to be a wide-observed phenomenon, deeply grounded in human perception. As such, one could expect that observers typically reach only a single interpretation and stick to this interpretation over the various levels of morphing. Alternatively, it is possible that multiple interpretations are available but only the strongest will reach the level of an overt categorization response. Therefore, the aim of the current study was to investigate the absoluteness of CP: Does the preference of categorizing a morphed figure according to a single interpretation also mean that we only perceive one object? In other words, are we able to recognize a second object in a morphed figure besides the dominant object? And if we are capable of recognizing a second object in a morphed figure, is this the nondominant object or another object? Previous research has provided evidence that CP might not be a strictly absolute process. Daelli, van Rijsbergen and Treves (2010) showed that a prime corresponding to the nondominant object could affect the identification of a morphed figure in the direction of its nondominant object (and the same accounted for a prime corresponding to the dominant object, guiding identification in the direction of the dominant object). These priming effects imply that besides the dominant interpretation also the nondominant interpretation is activated. Whether this only happens as a result of priming is unknown yet.

CP is commonly investigated using morphed stimuli (Etcoff & Magee, 1992; Harnad, 1987; Liebenthal et al., 2005; but see also Rosielle & Cooper, 2001). However, morphing two stimuli does not always result in CP, as was shown by Newell and Bülthoff (2002) and Hartendorp and colleagues (2010) who tested whether CP was found for interpolated, familiar objects. Newell and Bülthoff used a forced-choice paradigm in which each morphed figure had to be identified as either object A or object B. A morphed figure consisting of 60% of object A and 40% of object B (i.e. 60%40% figure) has object A as its *dominant* object and object B as its *nondominant* object. Results showed that some morphed object pairs (i.e. morph series) showed a pattern of CP (i.e. cp-series) due to the preference of identifying these figures as their dominant object, whereas other morphed object pairs did not show a pattern of CP (i.e. non-cp-series). These findings suggest that observers do not have the strong preference to identify a morphed figure of a non-cp-series as its dominant object, whereas they do have this preference for cp-series. Since the paradigm was a forced-choice one, an alternative explanation for this behaviour could be that observers were uncertain about how to categorize a morphed figure of a non-cp-series and therefore chose the nondominant option instead of the dominant option. To this end, Hartendorp and colleagues conducted a free-naming experiment in which it was shown that figures from non-cp-series were not necessarily categorized as the nondominant object, but often as an alternative object (i.e. neither the dominant nor the nondominant object)[2].

In the present study, it was investigated whether CP means that we completely block out alternative interpretations or whether we can come up with more interpretations than the dominant one. The most straightforward and simplest way to test the absoluteness of CP is just by asking participants to interpret the morphed figures in two ways in a so-called double-naming experiment. To simulate categorization of morphed figures under natural circumstances as much as possible (Malt & Sloman, 2007; see also Hartendorp et al., 2010; Ross & Murphy, 1996), a double free-naming response method was used. Due to the free naming one possibility is that observers are not able to recognize a second interpretation in a morphed figure. If participants are able to come up with only a single interpretation of the morphed figures even when asked to give more interpretations, this would confirm the absoluteness of CP. In case of two interpretations, the precise pattern of given responses is most interesting. We expected more absoluteness for cp-series than for non-cp-series since the perceptual certainty for cp-series is higher than for non-cp-series (i.e. cp-series show a more consistent response pattern than non-cp-series when just one interpretation has to be given; cf. Hartendorp et al., 2010). Furthermore, the morphed figures differed in levels of morphing, which also creates differences in perceptual certainty: we expected morphed figures in which the dominant object is strongly represented (e.g. 80%20% and 70%30% figures) to be more often interpreted as just one object, whereas morphed figures in which the dominant and nondominant object are (about) equally represented (e.g. 60%40% and 50%50% figures) to be more often interpreted as two objects.

Experiment

Method

Participants

Forty-five students participated (thirty female, fifteen male). Their age ranged from 18 to 28 years old. They participated for free or course credits. The experiment lasted about half an hour.

2 The distinction between cp-series and non-cp-series was not only found in a free-naming experiment, but was confirmed by a study (unpublished) in which the similarity between an extreme figure and a morphed figure had to be judged. The so-called switch size (cf. Hartendorp et al., 2011) was larger for cp-series than for non-cp-series.

Stimuli

Morphed figures were created from black silhouette objects (filled line drawings) that were presented on a white background. These silhouette objects were selected from a large set of contour drawings of a wide range of living and nonliving objects for which normative identification rates had been established (De Winter & Wagemans, 2004; Wagemans, De Winter, Op de Beeck, Ploeger, Beckers, & Vanroose, 2008), which in turn were derived from a set of line drawings validated by Snodgrass and Vanderwart (1980). Additionally, one figure (i.e. the *man* figure) was selected from a set of contour drawings by Downing, Bray, Rogers and Childs (2004). Pairs of silhouette objects were interpolated in steps of 5% change using Sqirlz-Morph software (Xiberpix, version 2.0), resulting in morph series consisting of 19 interpolations and two extremes (cf. Hartendorp et al. (2010) for a description of the morphing procedure). All paired extremes were from different (basic-level) categories and most of them from different superordinate categories (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). From each complete morph series seven figures were selected: the 80%20%, 70%30%, 60%40%, 50%50%, 40%60%, 30%70% and 20%80% figures (approximately 4.29° x 3.34°, 7 cm x 9 cm). To reduce exposure to the same series as much as possible, only seven out of the 19 interpolations from each series were included as stimulus materials. Equivalent morphing levels were collapsed, since we assumed that response patterns would not differ in general for the two equivalent figures. The morphing levels were reduced from seven levels to four levels with the 80%20% morphing level containing the 80%20% and 20%80% figures, the 70%30% morphing level containing the 70%30% and 30%70% figures, the 60%40% morphing level containing the 60%40% and 40%60% figures and the 50%50% morphing level containing just the 50%50% figures. In total, fifteen different series were used (see Appendix A for a complete overview). The stimuli were displayed on two computer screens attached to one computer using E-Prime (Psychology Software Tools Inc., version 1.1) of which the output was the same for both computer screens, one viewed by the participant and one by the experimenter. Participants used a stimulus-response box (SR-box) to enter their responses for recordings of reaction time and the experimenter used a regular keyboard to rate the responses of the participants. The lower part of the participant's screen was covered to prevent the participant from viewing the response codes. The experimenter used the response codes for rating. The rating procedure is explained in the next section, *Coding Procedure*. In addition, sixty line drawings derived from the Snodgrass and Vanderwart stimulus set were selected. Half of these line drawings corresponded to the thirty extreme figures of the tested morph series. The other half consisted of line drawings of other randomly selected objects to present participants with a wide range of objects that could be visible in the experimental stimuli. The line drawing of the man-figure came from Wikimedia.org.

Procedure

Participants were asked to orally give two interpretations for each stimulus that was presented. The stimuli differed in level of morphing (80%20%, 70%30%, 60%40% and 50%50% figures) and were from different morph series. A total of 105 trials were tested (15 morph series x 7 morphed figures per series). The free-naming method was used to collect the interpretations of each morphed figure. Observers were free to provide any object name suitable to the figure and were asked to respond with 'nothing' when they were unable to interpret the figure. In previous free-naming experiments some variability in responding was observed (Hartendorp et al., 2010; Wagemans et al., 2008). Since we asked participants to give two interpretations for each morphed figure, we were expecting more variability in responding, particularly for the second response. To reduce the variability in responding as much as possible, participants were exposed in advance to line drawings of the extreme figures of the experimental morph series accompanied by their object name. To reduce a priming effect as much as possible we used the original line drawings on which the back silhouettes were based instead of the actual black silhouettes. Furthermore, we added thirty randomly selected line drawings from the same stimulus set and we informed participants that these sixty figures could be reflected in the experimental stimuli. Subsequently, the instructions continued with mentioning that multiple interpretations could be recognized in the pictures encouraging participants to come up with two interpretations. They were not informed about the morphing itself. The instructions ended by five practice trials which followed the same sequence as the experimental trials, except that the targets were nonmorphed black silhouettes and from nonexperimental series. Each experimental trial started with a fixation cross presented for 1000 milliseconds followed by a morphed figure. As soon as participants recognized the stimulus as an object, they pressed the left button on the SR-box and simultaneously said out loud their first interpretation of the object. The morphed figure stayed on the screen until a second interpretation was given by pressing the right button and again saying simultaneously their interpretation out loud. After the second button press, the morphed figure disappeared and a blank screen was viewed by the participant. The trials were presented randomly with the restriction that a following trial contained a target of another morph series.

Coding Procedure

The two responses of each trial were categorized by the experimenter by inserting a code referring to the two responses (1 = dominant object, 2 = nondominant object, 3 = alternative object or, 4 = *nothing*). A possible code could be 12 if the first response was the dominant object and the second response the nondominant object. In case of a 50%50% figure there are no dominant and nondominant interpretations. Therefore, if both responses included both interpretations of a morphed figure, the order in which the responses were given did not matter. They were always interpreted as a dominant-nondominant response combination. In addition, if one of the responses for a 50%50% figure was an alternative response, no matter which of the two interpretations was the other response, the two responses were interpreted as a dominant-alternative response combination or as an alternative-dominant response combination (depending on whether the alternative response was the first or the second response) and never as a nondominant-alternative or as an alternative-nondominant response combination. The same accounted for the response combinations including a 'nothing' response. Because both interpretations could count as dominant (or nondominant) object, more response combinations are assigned to particular response groups in contrast to the other levels of morphing. Nevertheless, our main interest concerned the differences between types of morph series (see also the section *Categorical Perception* for more details on this topic) and between different response combinations within the different morphing levels. However, some caution was needed when interpreting the results between morphing levels.

Based on our previous experience with free naming (Hartendorp et al., 2010), we know that it could happen that a synonym or semantically closely related word was used as interpretation instead of the object names provided with the line drawings; some of these interpretations were accepted as dominant or nondominant interpretation. For example, the words *lizard* and *salamande*r were coded as correct interpretations for *crocodile*, *pheasant* and *turkey* for *peacock* and *seal* and *walrus* for *sea lion*. The exposure to these animals in daily life is too low to expect participants to recognize this specific object in the black silhouettes. In contrast, generalizations of words, such as *bird* for *duck* and *rodent* for *rabbit*, were not accepted as correct interpretations and were therefore labelled as alternative responses.

Results

A total of 4725 trials were recorded of which 4.3% was discarded, because participants did not respond within 10 seconds or because a technical error occurred. First of all, the first responses (R1s) were analysed to divide the morph series into cp-series and non-cp-series (i.e. series showing categorical perception and not showing categorical perception, respectively). Next, the second responses (R2s) were analysed to investigate in which conditions a second interpretation could be given and more specifically, what kind of interpretation was given.

Categorical Perception

To make the distinction between morph series as being categorically perceived or not, the same formula was applied as used in our previous free-naming experiment (Hartendorp et al., 2010). This method has proven to detect categorical perception among data collected using free naming. Since we used the same stimuli in the current experiment as the ones in the previous free-naming experiment, we could have adopted the findings on CP from the previous study. However, we decided to test whether the previous distinction between morph series into cp-series and non-cp-series could be replicated by the current findings. This would strengthen the findings of CP for objects in general and for the current stimulus set in particular.

The first responses were used to detect whether a series showed CP or not. CP was tested for each morph series separately. For example, R1s for the *Arm-Banana* morph series were labelled as *arm* response, *banana* response or as alternative response (including nonresponses). The frequencies of *arm* and *banana* responses for each morphed figure were used to calculate whether the *Arm-Banana* series showed CP or not. To do so, we conducted a logistic regression on both response types providing us with a slope of the response pattern. Thus, the slope was measured for the *arm* responses and for the *banana* responses separately. Drawing a straight line through the slope crossing the x-axis at the top and the bottom of the graph, the width of the area between the point at which the line crossed the top x-axis and the point at which the line crossed the bottom x-axis can be calculated. This area is here referred to as the *Delta Gap*. The smaller the Delta Gap (the narrower the area on the x-axis), the steeper the slope was, the more abrupt the switch from one percept into another. In other words, the smaller the Delta Gap, the higher the chance was of finding CP. We decided that a Delta Gap smaller than 0.24 was indicating CP. In addition, to label a morph series as showing CP, both responses (e.g. *arm* responses and *banana* responses) should fulfil this Delta Gap criterion. Furthermore, we do not only consider the switch itself as an important aspect of the definition of CP, but also the position along the continuum where this switch takes place (i.e. "moment"). Therefore, the number of participants that gave a particular response (e.g. *arm* response) halfway along the morph continuum (i.e. 50%50% morphing level) was used to express the moment of switching for that particular response; the moment of switching was expressed in *X50* (the closer the X50 to 0.50, the more the moment of switching was halfway along the morph continuum). To fulfil our CP criterion, both response types should besides a Delta Gap smaller than 0.24 also have a value on the X50 between 0.40 and 0.60. A complete and detailed description of the formula to detect CP is described in Hartendorp et al. (2010). In Appendix C, the values of the Delta Gaps and X50s are presented as obtained in the current study. Here, we will just sum up our conclusions based on the Delta Gaps and X50s.

Five morph series showed a pattern of CP. In alphabetic order, these were: *Duck-Church, Guitar-Sea Lion, Heart-Apple, Truck-Peacock* and *Turtle-Car*. For two morph series, *Crocodile-Airplane* and *Dog-Gorilla*, the previously obtained pattern of CP could not be replicated in the current study. However, these two series were already close to the border of showing CP in the previous experiment (Hartendorp et al., 2010). This time they were close to the border again, but on the opposite side of the border (the non-cp side). These are probably 'weak' cp-series that are sensitive to individual differences. More importantly, the five series showing CP in the current study also showed a strong pattern of CP in the previous experiment. Therefore, we can conclude that CP is replicated for these morph series. Besides the five morph series that showed CP in the current study, the remaining ten morph series showed no CP. If we take the five morph series that showed the weakest non-cp-pattern (based on the values of the Delta Gap and X50) these were the same series as the ones showing the weakest non-cp-pattern in the previous study. In alphabetic order, these were the series: *Arm-Banana, Bell-Kettle, Gun-Rabbit, Hat-Bird* and *Man-Lamp*. In further analyses, the five series showing CP in the current study will be referred to as cp-series. The five 'weakest' series showing no CP in the current study will be referred to as non-cp-series. The discussion of our results will mainly focus on the differences between these two types of morph series. Nevertheless, the five remaining series, namely the five 'strongest' non-cp-series (here referred to as in-between series) were also taken into account when analysing the data.

Responses

The observers' responses resulted in a combination of two responses. For instance, having the dominant object as the first response (R1) and the nondominant object as the second response (R2) is combined into a dominant-nondominant response. The percentages that each response combination was observed are presented in Table 3.1.

Table 3.1. Percentages of all observers' responses. Each cell refers to a different combination of first response type and second response type. The combinations dominant-dominant and nondominant-nondominant were not possible, because this would mean that the second response was a repetition of the first response. The last column and the last row contain the sum of the percentages for that particular response type.

response 2 / response 1	dominant	nondominant	alternative	nothing	sum
dominant	-	14.04	26.34	38.24	78.62
nondominant	2.87	-	1.95	1.77	6.59
alternative	2.96	1.15	4.36	3.12	11.59
nothing	0.02	0.00	0.00	3.18	3.21
Sum	5.86	15.19	32.64	46.31	100.00

First of all, it can be noticed that the occurrence of the dominant-nothing response (38%) is relatively high compared to the other response combinations. This implies that in many cases, observers could only recognize the dominant object in a morphed figure, though they were asked to give two interpretations. As we will see later, this finding is strongly related to the dominance of one of the morphed objects. Nevertheless, in many cases observers recognized another object in a morphed figure besides the dominant object (46% in total: 29% dominant-alternative response combinations and 17% dominant-nondominant response combinations). Notably, since many nonresponses were registered, this indicates that the presentation of the line drawings before the experiment had not fully guided participants' stimulus interpretations. In addition, despite the pre-exposure to the line drawings, participants still came up with other responses than the two objects interpolated into the morphed figures.

The above-mentioned percentages do not take the difference between morph series into account. In Figure 3.1, the response patterns of the first and second response are presented separately for two cp-series and two non-cp-series. A first inspection of these graphs already indicates differences between cp-series and non-cp-series.

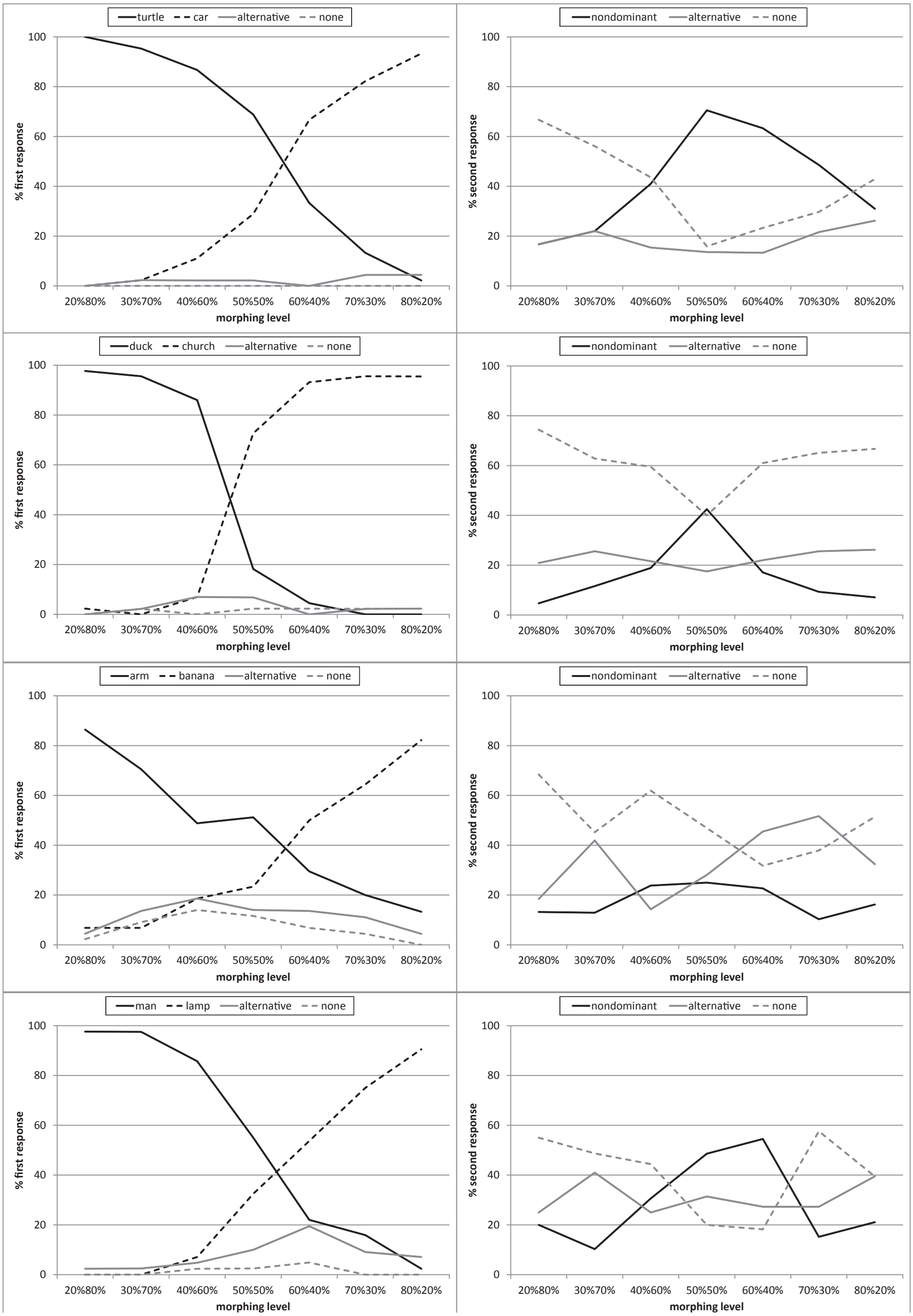

Figure 3.1. Response graphs of four morph series, *Turtle-Car, Duck-Church, Arm-Banana* and *Man-Lamp,* presented on each row, respectively. The first two are cp-series, the latter two non-cp-series. The left column presents the response percentages of the first response, the right column of the second response (with the restriction that the second response was preceded by the dominant response).

Two Analyses of Variance Repeated Measures (ANOVAs) were performed with *Morphing* (80%20%, 70%30%, 60%40% and 50%50% figures) and *Series* (cp-series (i.e. five series showing CP), non-cp-series (i.e. five series that were most 'non-CP') and in-between series (i.e. five series that were still non-CP, but close to the CP-border)) as within-subject variables. Significant effects at an alpha-level of .05 were analysed further by conducting Bonferroni corrected posthoc comparisons.

The first ANOVA was conducted to test whether differences were observed for the percentage of double responses in contrast to single responses. The dependent variable was the percentage of double responses (dominant-nothing responses received score 0 and dominant-nondominant and dominant-alternative responses received score 1). First, the main effect of *Morphing* was significant, $F(3,129) = 42.02$ and $p < .001$ and partial $\eta^2 = 0.49$. Posthoc comparisons revealed that all morphing levels differed significantly from each other on the percentage that a second response was given, with a linear increase in percentage from 80%20% to 50%50% level. In other words, an increase of uncertainty made it more likely that a second interpretation besides the dominant one was generated. Second, the main effect of *Series* was significant, $F(2,86) = 5.34$ and $p < .01$ and partial $\eta^2 = 0.11$. Posthoc comparisons showed that the percentage of trials in which a second response was given was about equal for cp-series and non-cp-series, but was significantly higher for in-between series. This finding is unexpected, but might be explained by the undetermined status of the in-between status. Since our main focus is on the distinction cp/non-cp, we did not further analyse this finding. Last, the interaction effect of *Morphing* and *Series* was significant, $F(6,258) = 2.42$ and $p < .05$ and partial $\eta^2 = 0.05$. Posthoc comparisons showed that for the different morphing levels, the cp-series and non-cp-series only differed for the 50%50% figures with a higher percentage of second responses for the cp-series than for the non-cp-series. However, since both interpretations of a morph series were coded as 'dominant' response in case of a 50%50% figure, whereas only one of the two objects was coded as dominant for the other levels of morphing we will not adhere too much weight on this difference between cp-series and non-cp-series for the 50%50% morphing level. In addition, the percentage of a second response was higher for in-between series than for cp-series and non-cp-series for the 70%30% and 60%40% morphing level. Notably, the effect size of the interaction effect was very small, reducing the importance of these differences greatly. Therefore, we can say that with increase of morphing level (i.e. more to the middle of the morph continuum) the number of second responses increased, but this increase was not substantially different between the different types of morph series.

The second ANOVA was conducted to test whether differences were observed in the percentage of nondominant responses in comparison to alternative responses. The same within-subject variables were used as in the previous analysis. The dependent variable was the percentage of nondominant responses (dominant-nondominant responses received score 1 and dominant-alternative responses received score 0). The degrees of freedom were smaller than in the previous analysis, because not all participants generated a second interpretation for all items. The main effect of *Morphing* was significant, $F(3,75) = 15.83$ and $p < .001$ and partial $\eta^2 = 0.39$. The differences in response pattern between morphing levels revealed by posthoc comparisons were not very pronounced. Two neighbouring morphing levels were not significantly different in percentages of nondominant responses (and thus also not in alternative responses), but were different from non-neighbouring levels. Overall, the general response pattern on the morphing levels showed an increase in percentage, albeit a weak increase, suggesting that an increase of morphing level (from 80%20% to 50%50%) was accompanied by an increase of nondominant responses. The main effect of *Series* was also significant, $F(2,50) = 30.93$ and $p < .001$ and partial $\eta^2 = 0.55$, with a significantly higher score for the cp-series (50.4%) than for the non-cp-series (21.4%) and in-between series (23.4%), indicating that more nondominant responses were recorded for the cp-series in comparison to the non-cp-series and in-between series, or vice versa, more alternative response for the non-cp-series and in-between series in comparison to the cp-series. Moreover, the non-cp-series and in-between series did not differ in percentage of nondominant responses as second response. Notably, both non-cp-series and in-between series were indicated as showing no CP (but in-between series showed 'weaker' patterns of no CP). Therefore, finding no CP does not only mean that the dominant object is not consistently observed, it also indicates that it is more difficult to recognize the nondominant object in contrast to cp-series. The interaction effect of *Morphing* and *Series* was not significant, $F(6,150) = 1.47$ and $p > .15$ and partial $\eta^2 = 0.06$, suggesting that the pattern observed for the different types of morph series (cp-series showed a higher percentage of nondominant responses than non-cp-series and in-between series) was the same for all morphing levels.

Discussion

The goal of the current study was to investigate the absoluteness of categorical perception (CP: Harnad, 1987; Hartendorp et al., 2010; Newell & Bülthoff, 2002). In a double-naming experiment, participants were asked to give two interpretations for a morphed figure. The stimuli varied in amount of uncertainty: more perceptual uncertainty was indicated for non-cp-series than for cp-series, since cp-series are known to be more consistently interpreted than non-cp-series (Hartendorp et al., 2010). In addition, figures at different levels of morphing also varied in perceptual uncertainty, with figures more to the middle of the morph continuum inducing more perceptual uncertainty than figures more to the end of the continuum. The responses in the double-naming task were combinations of dominant, nondominant, alternative responses and non-responses.

First of all, we wanted to know whether participants were able to interpret a morphed figure as another object than just the dominant object. Results showed that participants were able to do so in about half of the trials. In turn, the stimulus was categorized as an alternative object in two-third of these trials, and as the nondominant object in one-third of these trials. This shows that CP is not absolute. If that had been the case, the percentage single responses should have been much higher and at least have formed the majority. One might argue that the double responses are simply a consequence of task demands, since participants were explicitly asked to give two responses. However, we emphasized during the instruction phase that if a participant was not able to recognize a second object in the stimulus, he/she should answer with 'nothing' as a response, so discouraging random naming. This is also what we observed in about forty percent of the trials in which participants could only come up with a single interpretation.

A closer examination revealed that with increasing morphing level, the number of double responses also increased. Significantly more double responses were given for 60%40% and 50%50% figures than for 80%20% and 70%30% figures. Importantly, this increase in double responses with increase of morphing level was observed for both the cp-series and the non-cp-series, indicating that the ability to give two interpretations was only affected by level of morphing and not by type of morph series. Moreover, the fact that in particular morphed figures at a lower level of morphing less often evoked a second interpretation further counters the idea that generation of two options simply follows from the particular task demands. In contrast, the degree of perceptual uncertainty seems most important (see also Murphy & Ross, 2010).

While no overall difference between cp-series and non-cp-series was observed, a specific qualitative difference was obtained: whereas figures of cp-series were more often interpreted as their nondominant object as a second response, morphed figures of non-cp-series were more often interpreted as an alternative object as a second response. Figures of cp-series especially at a higher level of morphing cause the consideration of more than one response option, and therefore the inference can be made that CP is not absolute. The inconsistent response pattern observed for non-cp-series for as well as the first and the second response confirms the larger degree of perceptual uncertainty previously observed for non-cp-series (Hartendorp et al., 2010). If CP is not found for a morph series, it is also harder to detect the nondominant object in a morphed figure.

On basis of the foregoing, we propose that response competition might be underlying the categorization process of morphed figures. Murphy and Ross (2010) have shown that many options are considered consciously when someone is exposed to uncertain information. In their study, participants were asked to assign uncertain visual input to a category choosing from four categories. Before the decision was made, they were asked explicitly to write down the probability that the visual input belonged to each category. Results showed that participants considered and weighed different categories, but finally chose the most likely one. This suggests competition between response options. Theories on object categorization are in line with this suggestion (Bar, 2003; Panis, Vangeneugden, & Wagemans, 2008). However, response competition is mostly described as an unconscious process. We show here that the latent processes during object categorization can also become conscious under the right circumstances. In case of perceptual uncertainty, the competition between response options is strong since more response options are probable candidates. Hence a response option that has lost the competition in the first place can exceed the threshold in a second round. In a previous study, we have shown that the similarity between a morphed figure and its nondominant extreme object increased with increase of processing time of the morphed figure (Hartendorp, Van der Stigchel, Wagemans, Klugkist, & Postma, 2012). This is consistent with the current findings: More processing of the visual input is necessary to increase the probability of the nondominant object becoming a possible interpretation.

Why is the nondominant response alternative more readily available in cp-series than in non-cp-series? In other words, why is the nondominant object a stronger response candidate for figures of cp-series than for figures of non-cp-series? We speculate that this difference in second response might have to do with the extent of violation to the intrinsic part structure of a morphed figure (Blum & Nagel, 1978; Rosielle & Cooper, 2001). Using a Bayesian model, Feldman and Singh (2006) calculated the skeleton (i.e. intrinsic part structure) of a visual object that represents the object in a simplistic manner. They showed that this skeleton is resistant against some violations to the contour shape from which the skeleton is deduced. It has been shown before (Hartendorp et al., 2010; Newell & Bülthoff, 2002) that the extreme objects of cp-series were rated as more similar in intrinsic part structure than extreme objects of non-cp-series. If you take two objects showing similarity in their intrinsic part structure, morphing the two contour shapes results in a morphed figure of which the skeletons of both interpolated objects are less violated than morphing two objects that show less similarity in intrinsic part structure. Due to smaller violations, the skeleton of a morphed figure of a cp-series resembles the skeleton of its dominant and nondominant object more than the skeleton of a figure of a non-cp-series. Since the resemblance is larger for figures of cp-series than for figures of non-cp-series, it is easier for us to recognize both the dominant and nondominant object in a morphed figure of a cp-series than of a non-cp-series. This is also what the data shows: more dominant responses on R1 and more nondominant responses on R2 for the cp-series in contrast to the non-cp-series.

Taken together, the preference of categorizing a morphed figure according to a single interpretation does not necessarily mean that we only perceive one interpretation. Only figures at a lower level of morphing were particularly categorized as just a single interpretation. Figures at a higher level of morphing were often responded to as two interpretations. Surprisingly, it was observed that interpreting a morphed figure as its nondominant object was most often found for figures belonging to cp-series. Interpreting a morphed figure as an alternative object was mostly observed for figures belonging to non-cp-series. Because we are able to recognize another object in a morphed figure besides the dominant one, we conclude that CP is not absolute. We argue that response competition might be underlying the categorization of all morphed figures, but only with increase of perceptual uncertainty other response options than the dominant object become strong enough to exceed the categorization threshold. The activation of response options may be based on the intrinsic part structure of the visual object; morphing two perceptually similar objects keeps their intrinsic part structure relatively intact making it possible to recognize both objects in a morphed figure.

4

CP or not CP: The Effects of Priming on Categorical Perception

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Abstract

Categorical perception (CP) is a well-investigated phenomenon: a continuous change of one stimulus into another is not perceived continuously, but is perceived categorically with an abrupt switch from one percept to the other at the category boundary. CP is found for almost any type of stimulus. In case of objects, it has been found that some morph continua result in CP (cp-series), whereas others do not (non-cp-series). The difference in categorization between cp-series and non-cp-series might have been caused by a difference in perceptual uncertainty, and therefore might have its impact on the influence of context on the categorization of these objects. In the current study, therefore, we conducted a priming experiment in which a morphed figure was preceded by either a prime word corresponding to its dominant object, its nondominant object or an unrelated object. Overall, faster responses were found for the dominant prime and slower responses for the nondominant prime. In addition, faster reaction times and more dominant responses were observed for cp-series than for non-cp-series. The effects of priming, however, were not different for cp-series and non-cp-series. Therefore, we conclude that both the dominant and nondominant object are processed in figures of both cp-series and non-cp-series suggesting response competition between these two response options. However, the strength of these two response options varies between cp-series and non-cp-series.

Introduction

Categorical perception (CP; Harnad, 1987) is a well-investigated phenomenon: changing one stimulus with small, equal steps into another stimulus is not perceived as a continuous change, but as two discrete categories. A broad range of types of stimuli have been shown to be perceived categorically, such as phonemes (Liberman, Harris, Hoffman, & Griffith, 1957; Liebenthal, Binder, Spitzer, Possing, & Medler, 2005), colours (Bornstein, 1987; Bornstein & Korda, 1984; Okazawa, Koida, & Komatsu, 2011), facial expressions (Calder, Young, Perrett, Etcoff, & Rowland, 1996; Etcoff & Magee, 1992; McCullough & Emmorey, 2009), facial identities (Beale & Keil, 1995) and familiar objects (Gillebert, Op de Beeck, Panis, & Wagemans, 2009; Hartendorp, Van der Stigchel, Burnett, Jellema, Eilers, & Postma, 2010; Newell & Bülthoff, 2002; Verstijnen & Wagemans, 2004). The widespread nature of CP is reflected by the fact that this useful tool is not only observed in human beings, but was even observed in crickets (Wyttenbach, May, & Hoy, 1996).

Because CP is found across different species and for different types of stimuli, it seems a useful strategy to deal with the great variation in sensory information (Harnad, 2003; Wyttenbach et al., 1996). We would, therefore, expect to find CP for almost any kind of stimulus interpolation. However, this is not true for all morphed combinations. For instance, morphing a happy face to a surprised face does not consistently result in CP (Etcoff & Magee, 1992). Recently, the extension of CP to familiar objects did also not lead automatically to the observation of CP. In a study by Newell and Bülthoff (2002), 3D familiar objects were interpolated, resulting in so-called morph series. About two-third of the morph series showed CP, the other series did not. In addition, Hartendorp and colleagues (2010) extended these findings by conducting a free-naming experiment. They reported similar results: some morph series showed CP (i.e. cp-series), whereas others did not (i.e. non-cp-series).

The difference between morph series in showing CP or not expresses a difference in categorization certainty that is reflected in the consistency of the response pattern. The certainty in categorization is larger for figures of cp-series than of non-cp-series. In a free-naming experiment by Hartendorp et al. (2010) most non-cp-series showed a great variation in responses (e.g. morphing a banana into an arm led not only to the responses *banana* and *arm*, but also to irrelevant responses such as *sock* and *branch*), whereas the variation of responses to figures of cp-series was limited to the object names of the two extreme objects (e.g. morphing a car into a turtle led only to the responses *car* and *turtle*). The difference in categorization certainty might be influenced differently by priming. As we know from the literature, priming degraded stimuli causes shorter reaction times than priming clear, undegraded stimuli (De Houwer, Hermans, & Spruyt, 2001). Moreover, Jemel, Pisani, Calabria, Crommelinck and Bruyer (2003) conducted a repetition priming experiment using intact faces as primes and Mooney faces as ambiguous targets. Mooney faces are two-tone black-and-white pictures of faces and nonfaces, which are used to investigate face detection. They have shown that priming Mooney faces with the same face decreased reaction time and the error rate in a face recognition task in contrast to priming with a different face when this concerned a familiar face, whereas a reversed pattern was found for unfamiliar faces. They explain this difference as a difference in having a stored concept of the familiar faces, but not yet of the unfamiliar faces.

Studies using morphed figures have shown effects of priming on both the interpretation and the reaction time. First, Huart, Corneille and Becquart (2005) have shown a strong bias to categorize a gender ambiguous face (a male face morphed with a female face) as male or female when preceded by the name 'Jean' or 'Marie', respectively. In addition, Daelli, van Rijsbergen and Treves (2010) primed morphed stimuli of familiar objects by a picture of one of the extreme objects of a morph series and found a bias in responding towards the identity of the prime. Hartendorp, Van der Stigchel and Postma (under review) have tested the effects of distractor words on the categorization of simultaneously presented morphed figures using free naming. They found faster reaction times for morphed figures presented with a distractor word corresponding to the dominant object of the morphed figure and an interference effect for distractor words corresponding to the nondominant object. These studies suggest that the categorization of morphed figures can be biased by a prime. However, none of these studies has incorporated the difference between cp-series and non-cp-series. On the one hand, we might expect stronger effects of priming on non-cp-series than on cp-series, since categorization of non-cp-series is more variable than cp-series and therefore harder. This difference in categorization would resemble the difference in degradation of the stimuli used by De Houwer et al. (2001). On the other hand, non-cp might also indicate that it is hard to match the visual input to stored concepts, since it is hard to interpret a figure of a non-cp-series reflected in the great variation of responses to figures of non-cp-series. Therefore, priming could also have a larger impact on figures of cp-series than on figures of non-cp-series, following the findings of Jemel et al. (2003) who showed a facilitation effect for faces that could easily be matched to a stored concept and an interference effect for (unfamiliar) faces that could not be matched to a stored concept.

In the current study, the effects of priming on the categorization of morphed figures of cp-series and non-cp-series were investigated. Morphed figures were preceded by a dominant prime (i.e. name of the dominant object), a nondominant prime (i.e. name of the nondominant object) or an unrelated prime. For example, a 70%30% figure of the *Duck-Church* series, in which the duck is the dominant object and the church the nondominant object, the dominant prime word was *duck*, the nondominant prime word was *church* and the unrelated prime word was *car*. The latter was included to have a baseline to which the priming effects of the dominant and nondominant prime could be compared. Participants were presented with a two alternative forced-choice response which always was a combination of the name of the dominant and nondominant object of the morphed figure. Notably, the extreme objects used in the current study were all familiar objects.

Experiment

Methods

Participants

Twenty students from Utrecht University participated in this experiment. Their age ranged from 18 to 27 years. Participants were paid 6 Euros or one course credit for their contribution. The experiment lasted approximately 45 minutes.

Materials

Morphed figures were created from black silhouette objects (filled line drawings) that were presented on a white background. These silhouette objects were selected from a large set of contour drawings of a wide range of living and nonliving objects for which normative identification rates had been established (De Winter & Wagemans, 2004; Wagemans, De Winter, Op de Beeck, Ploeger, Beckers, & Vanroose, 2008), which in turn were derived from a set of line drawings validated by Snodgrass and Vanderwart (1980). Additionally, one figure (i.e. the *man* figure) was selected from a set of contour drawings by Downing, Bray, Rogers and Childs (2004). Pairs of silhouette objects were interpolated in steps of 5% change using Sqirlz-Morph software (Xiberpix, version 2.0), resulting in morph series consisting of 19 interpolations and two extremes (cf. Hartendorp et al. (2010) for a description of the morphing procedure). All paired extremes were from different (basic-level) categories and most of them from different superordinate categories (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). From each complete morph series six figures were selected: the 80%20%, 70%30%, 60%40%, 40%60%, 30%70% and 20%80% figures (approximately 4.29° x 3.34°, 7 cm x 9 cm). To reduce exposure to the same series as much as possible, only six out of the 19 interpolations from each series were included as stimulus materials. The labels used for the different morphing levels were reduced to three levels: 80%20% (including 80%20% and 20%80% figures), 70%30% (including 70%30% and 30%70% figures) and 60%40% (including 60%40% and 40%60% figures). All of these morphed figures have a dominant and a nondominant object. For example, the dominant object of the 60%40% figure of the *Duck-Church* series is *duck* and the nondominant object is *church*. The dominance and morphing percentages are based on the morphing procedure, not necessarily on human perception. In total, fifteen morph series were used. Seven out of these fifteen morph series were labelled as cp-series and the remaining eight as non-cp-series, based on the findings of Hartendorp and colleagues (2010). This distinction between morph series was predicated upon the abruptness of change in percept and additionally, the moment along the morph continuum that this change in percept took place. Morph series showing an abrupt switch halfway along their morph continuum were labelled as cp-series, morph series not fulfilling these criteria were labelled as non-cp-series (see Appendix A for a complete overview of the stimulus set). The experiment was programmed in E-Prime (version 1.1, Psychological Software Tools), using a Stimulus-Response box (SR-box) including eight response buttons of which only the outer two were used for registration of the responses and reaction times.

Procedure

In the current priming experiment, fifteen morph series were tested from which six morphed figures were selected. Each morphed figure was presented four times, preceded by a dominant prime word corresponding to the dominant object name of the morphed figure, by a nondominant prime word corresponding to the nondominant object name of the morphed figure, and twice by a different unrelated prime word corresponding to one of the object names of the other experimental morph series. For instance, the morphed figure consisting of 70% church and 30% duck was preceded by the dominant prime *church*, the nondominant prime *duck* and the unrelated primes *car* and *lamp*. Each run consisted of 360 experimental trials (15 morph series x 6 morphed figures x 4 prime words) which were presented randomly with the restriction that no trial was followed immediately by a trial containing a target of the same morph series. A two alternative forced-choice (2AFC) paradigm was used to test the priming effects on the categorization of morphed figures. An experimental trial had the following sequence. First, participants viewed a fixation cross on a computer screen that disappeared after 1500 milliseconds (ms). Next, a prime word was presented in the center of the screen. After 500 ms this word was replaced by a blank screen for 700 ms. Subsequently, the target picture appeared (i.e. morphed figure). Simultaneously, two response options were presented at the bottom of the screen, one at the left corner of the screen and the other at the right corner. The response options were always the dominant and nondominant object name of the target, although participants were not informed about this relation between target and response options. Participants were instructed to passively view the prime word and subsequently to respond to the target as quickly and accurately as possible by pressing either the most left button on the SR-box for the left response or the most right button for the right response. At the moment they pressed a button, the next trial started. When participants did not respond within 2500 ms no response was registered and the experiment would continue with the next trial. This sequence was repeated until all 360 experimental trials were presented. After 120 and 240 trials a self-timed break was inserted. The experiment was conducted in Dutch meaning that the instructions, prime words and response options were all in Dutch. To ensure participants would understand the task, participants were given four practice trials before the experiment started. These trials followed the same procedure as the experimental trials, except that the target figures were nonexperimental black silhouettes that were not morphed. The prime was an unrelated word to the figure, and the response options were the correct interpretation of the figure and an unrelated word, but different from the prime word.

Results

From all responses, 0.4% was recorded as no response, meaning that in these trials participants did not respond within the time restriction of 2500 ms. Furthermore, three morph series, namely *Bird-Hat*, *Dog-Gorilla* and *Kettle-Bell*, were excluded from further analyses, since about half of the responses to targets of these series were the nondominant response (against about 10% nondominant response to trials containing targets of other morph series) and showed reaction times which were exceeding the grand mean substantially. After excluding the no responses and the data of the three morph series, further analyses were based on 5737 trials. From this dataset, 8.4% were nondominant responses; the remaining responses were dominant responses. For analysing the response preferences (RP) both dominant and nondominant responses were included. For analysing the reaction times in ms (RT), only the dominant responses were included.

Response Preferences

To examine whether participants perceived morphed figures as their dominant or nondominant interpretation, both the dominant and nondominant responses were used. A score of 1 referred to the dominant interpretation and a score of 0 to the nondominant interpretation. This means that a mean score closer to 1 indicated a stronger preference for the dominant interpretation than a mean score closer to 0. The mean scores for the response preferences are presented in Table 4.1.

Table 4.1. The mean RP in proportions per condition and their standard error of the mean in brackets. Each column contains the RPs for the different levels of morphing. Each row contains the RPs for the different priming conditions, with the first three rows representing the RPs for the cp-series and the last three rows for the non-cp-series.

series	priming	80%20%	70%30%	60%40%
cp	dominant	0.97 (0.01)	0.94 (0.02)	0.92 (0.01)
	nondominant	0.93 (0.02)	0.96 (0.02)	0.88 (0.02)
	unrelated	0.95 (0.01)	0.95 (0.01)	0.90 (0.02)
non-cp	dominant	0.95 (0.01)	0.90 (0.02)	0.88 (0.02)
	nondominant	0.94 (0.02)	0.89 (0.02)	0.86 (0.03)
	unrelated	0.93 (0.02)	0.93 (0.01)	0.83 (0.02)

Repeated Measures ANOVAs were performed with *Series* (cp-series and non-cp-series: *cp* and *nc*, respectively), *Morphing* (80%20%, 70%30% and 60%40% figures: *8020*, *7030* and *6040*, respectively) and *Priming* (dominant, nondominant and unrelated prime words: *dom*, *non* and *unr*, respectively) as within-subject variables. Significant differences at an alpha-level of .05 were investigated further by posthoc comparisons that were Bonferroni corrected.

First, the main effect of *Series* was significant, $F\ (1,19) = 18.08$ and $p < .001$ and $\eta^2 = 0.49$, $M_{cp} = 0.93$ and $SE_{cp} = 0.01$, $M_{nc} = 0.90$ and $SE_{nc} = 0.01$, showing that figures of cp-series were more often interpreted as their dominant object than figures of non-cp-series. This confirms our distinction made between cp-series and non-cp-series. Second, the main effect of *Morphing* was also significant, $F(2,38) = 27.33$ and $p < .001$ and $\eta^2 = 0.59$, $M_{8020} = 0.94$ and $SE_{8020} = 0.01$, $M_{7030} = 0.93$ and $SE_{7030} = 0.01$, $M_{6040} = 0.88$ and $SE_{6040} = 0.01$. Posthoc comparisons revealed that more dominant response were generated for the 80%20% and 70%30% figures than for the 60%40% figures. In other words, more nondominant response were generated for the 60%40% figures in comparison to the 80%20% and 70%30% figures. Third, the main effect of *Priming* was not significant, $F(2,38) = 1.68$ and $p > .15$ and $\eta^2 = 0.08$, $M_{dom} = 0.93$ and $SE_{dom} = 0.01$, $M_{unr} = 0.91$ and $SE_{unr} = 0.01$, $M_{non} = 0.91$ and $SE_{non} = 0.01$. This implies that a prime did not influence the categorization of a morphed figure. Furthermore, none of the interactions showed a significant effect, $F_{series*morphing}(2,38) = 1.90$ and $p > .15$ and $\eta^2 = 0.09$, $F_{series*priming}(2,38) = 0.31$ and $p > .70$ and $\eta^2 = 0.02$, $F_{morphing*priming}(4,76) = 1.69$ and $p > .15$ and $\eta^2 = 0.08$, $F_{series*morphing*priming}(4,76) = 1.60$ and $p > .15$ and $\eta^2 = 0.08$. The absence of any interaction suggests that the influence of the prime did not differ for morphing level or type of morph series.

Reaction Times

The reaction times (RTs) reflect the time necessary to categorize a morphed figure. Only the dominant response preferences were used to analyse the RTs. The mean RTs in millisecond=ds (ms) are presented in Table 4.2.

Table 4.2. The mean RT in ms per condition and their standard error of the mean in brackets. Each column contains the RTs for the different levels of morphing. Each row contains the RTs for the different priming conditions, with the first three rows representing the RTs for the cp-series and the last three rows for the non-cp-series.

series	priming	80%20%	70%30%	60%40%
cp	dominant	794 (33)	887 (38)	934 (37)
	unrelated	871 (31)	908 (37)	997 (33)
	nondominant	896 (35)	913 (34)	1015 (39)
non-cp	dominant	875 (35)	940 (40)	1010 (51)
	unrelated	897 (34)	983 (34)	1099 (46)
	nondominant	960 (33)	1022 (38)	1133 (47)

The same analyses were conducted as was previously done for the response preferences. Thus, Repeated Measures ANOVAs were performed with *Series* (cp-series and non-cp-series), *Morphing* (80%20%, 70%30% and 60%40% figures) and *Priming* (dominant, nondominant and unrelated prime words) as within-subject variables. Significant differences at an alpha-level of .05 were investigated further by posthoc comparisons that were Bonferroni corrected.

First, the main effect of *Series* was significant, $F(1,19) = 58.74$ and $p < .001$ and $\eta^2 = 0.76$, $M_{cp} = 913$ and $SE_{cp} = 32$, $M_{nc} = 991$ and $SE_{nc} = 37$, showing that figures of cp-series were categorized faster as their dominant object than figures of non-cp-series. Second, the main effect of *Morphing* was also significant, $F(2,38) = 89.51$ and $p < .001$ and $\eta^2 = 0.83$, $M_{8020} = 882$ and $SE_{8020} = 31$, $M_{7030} = 942$ and $SE_{7030} = 34$, $M_{6040} = 1031$ and $SE_{6040} = 38$. Posthoc comparisons revealed that all morphing levels differed significantly from another, with fastest RTs for the 80%20% figures, followed by the 70%30% figures and slowest RTs were observed for the 60%40% figures. Third, the main effect of *Priming* was significant, $F(2,38) = 25.74$ and $p < .001$ and $\eta^2 = 0.58$, $M_{dom} = 907$ and $SE_{dom} = 36$, $M_{unr} = 959$ and $SE_{unr} = 33$, $M_{non} = 990$ and $SE_{non} = 35$. This result is presented graphically in Figure 4.1.

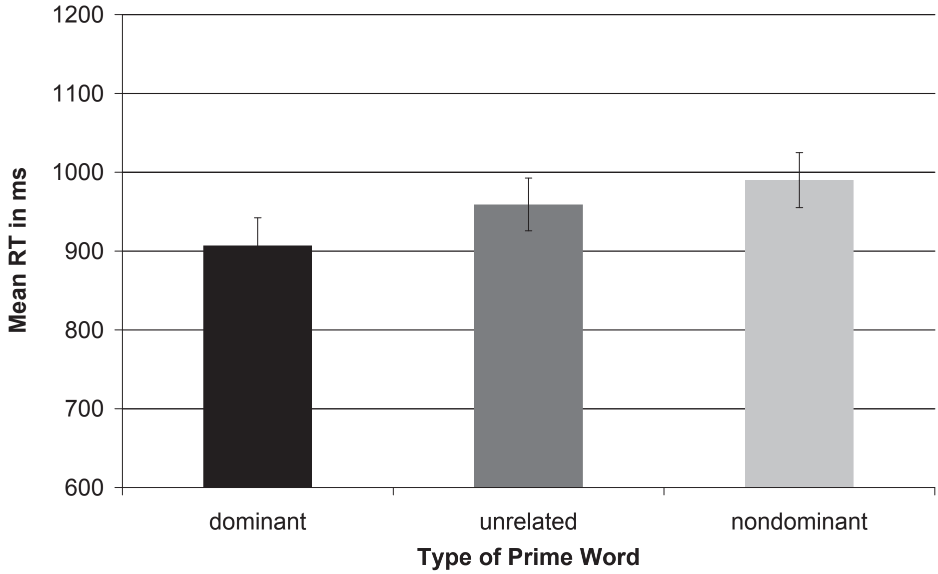

Figure 4.1. The mean RT in ms for the different priming conditions. For example, a 70%30% church-duck figure has *church* as a dominant prime, *car* as an unrelated prime and *duck* as a nondominant prime.

Posthoc comparisons showed that a facilitation effect was observed for the dominant prime with respect to the unrelated and nondominant prime and an interference effect for the nondominant prime with respect to the unrelated and dominant prime. This shows that a dominant prime speeds up the process of categorizing a morphed figure as its dominant object and a nondominant prime slows down the same process. Again, none of the interactions showed a significant effect, $F_{series*morphing}(2,38) = 2.06$ and $p > .10$ and $\eta^2 = 0.10$, $F_{series*priming}(2,38) = 1.41$ and $p > .25$ and $\eta^2 = 0.07$, $F_{morphing*priming}(4,76) = 1.94$ and $p > .10$ and $\eta^2 = 0.09$, $F_{series*morphing*priming}(4,76) = 1.45$ and $p > .20$ and $\eta^2 = 0.07$. The absence of any interaction suggests that the influence of the prime on RT did not differ for morphing level or type of morph series. The interaction effect of *Series*Priming* is presented graphically in Figure 4.2, since this effect concerns our main question.

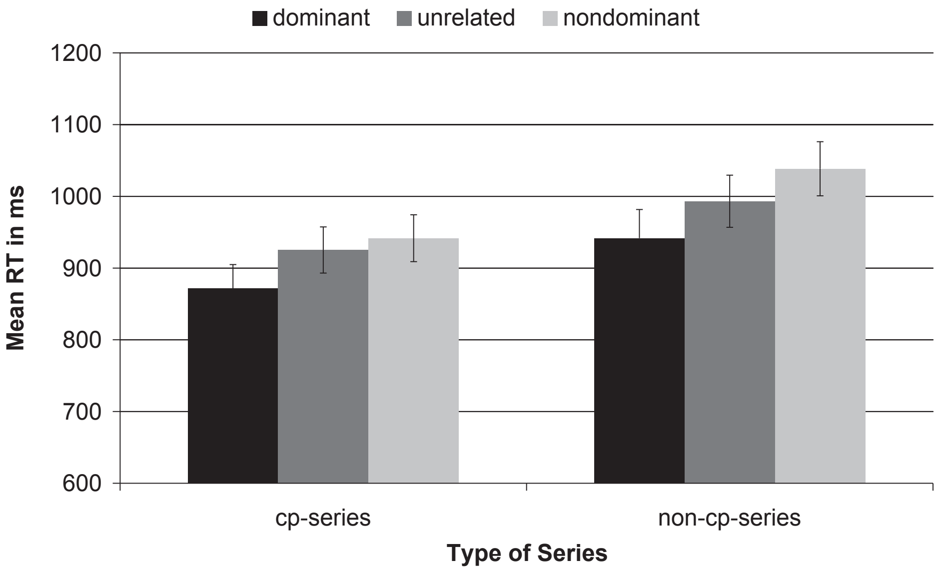

Figure 4.2. The mean RT in ms for the different priming conditions presented separately for the different types of series, namely cp-series and non-cp-series. The black bars reflect the mean RTs for the dominant priming condition, the dark grey bars the unrelated priming condition and the light grey bars the nondominant priming condition.

4

Discussion

In the current study, the effects of priming on the categorization of morphed figures were investigated taking the distinction between types of morph series into account (Hartendorp et al., 2010; Newell & Bülthoff, 2002). A 2AFC priming experiment was conducted in which participants had to categorize a morphed figure as either its dominant or nondominant object. The morphed figures were preceded by a prime word that corresponded to the dominant object name, the nondominant object name or an unrelated object name. In addition, morphed figures belonged either to cp-series or non-cp-series. The response preference and the reaction time were recorded.

As was expected on basis of the findings by Hartendorp et al. (2010), more dominant responses were recorded for figures of cp-series than for figures of non-cp-series. In addition, these dominant responses were also given at a faster rate for figures of cp-series compared to figures of non-cp-series. These findings reflect an overall difference in categorization between cp-series and non-cp-series: it is easier to recognize the dominant object in a morphed figure of a cp-series than in a non-cp-series. Of main interest here were the effects of priming. A dominant prime facilitated categorizing a morphed figure as its dominant object and a nondominant prime interfered with categorizing a morphed figure as its dominant object both with respect to the unrelated prime. These results support the findings of previous studies (Daelli et al., 2010; Hartendorp et al., under review; Huart et al., 2005) in which also priming effects on the categorization of morphed figures by both the dominant and nondominant prime were reported.

One could argue that the observed priming effects were due to response priming. This type of priming is observed when the prime word directs the responding itself, not necessarily the encoding of the target. In a pilot experiment, we controlled for response priming by using not only the combination of a dominant and nondominant object name as response options, but also a dominant and an unrelated object name as response options. An effect of response priming was not found: the unrelated response was not more often chosen when the target was preceded by the same unrelated prime word. This implies that participants did not choose the nondominant response option as their interpretation of the morphed figure simply because the response option was similar to the prime word. Assuming that response priming is not an issue here, we chose to use only the dominant and nondominant object names as response options in the current study to reduce the number of trials and therefore the exposure to the same morphed figures (diminishing learning effects as much as possible).

Importantly, no difference in priming was observed between cp-series and non-cp-series. Categorization of morphed figures of both types of morph series was influenced by the dominant and nondominant prime in a similar way: facilitation by the dominant prime and interference by the nondominant prime. This indicates that both the dominant and nondominant object are processed to some extent, independent of type of morph series. However, the difference in reaction time and response preference between cp-series and non-cp-series across priming conditions suggests that the dominant and nondominant object are processed to a larger extent in figures of cp-series than in figures of non-cp-series. Besides type of morph series, the level of morphing was varied, also producing a difference in difficulty to categorize. The more the figure contained information of both objects, the more often the figure was categorized as its nondominant object and the more time was needed to respond. Again, no differences in priming were found for the different levels of morphing. The finding that degraded stimuli were more affected by priming than undegraded stimuli (De Houwer et al., 2001) does not seem to be applicable here, though our stimuli also differed in difficulty of categorization. The previously observed priming effect might only concern visible uncertainty, and not necessarily uncertainty in interpretation. Furthermore, the facilitation effect found across all morphed figures suggests that the morphed figures in general could be matched to a stored concept (Jemel et al., 2003), though matching took more time in case of non-cp-series than cp-series.

Both the dominant and nondominant prime affected the categorization process of morphed figures, independent of type of morph series and level of morphing. This suggests that both the dominant and nondominant object within a morphed figure is processed simultaneously. We argue that response completion might be underlying the process of categorization. When trying to interpret a morphed figure, both the dominant and nondominant object are seriously considered as possible interpretations of the visual input, until, as happens in the majority of trials, a final conclusion is reached in the form of the dominant interpretation. Hence, a dominant prime would reduce competition between possible interpretations and the nondominant prime would enhance competition. This reduction and reinforcement of response competition is indeed reflected by our results: shorter reaction times in the dominant priming conditions and longer reaction times in the nondominant priming conditions, both in relation to the unrelated priming conditions.

Panis, Vangeneugden and Wagemans (2008) adopted the continuous flow model of information processing of Eriksen and Schultz (1979) to explain performance during the categorization of morphed figures. This model includes three processes that together explain their observed findings. The first process is response activation, the second response priming and the third response competition. A similar idea on object categorization was proposed by Bar (2003): during a first stage, a coarse, blurred image based on low-spatial frequencies activates a number of response candidates. It is likely that a coarse image of a morphed figure will activate both objects interpolated in a morphed figure. In the following stage, more specific information about the stimulus is conveyed (Sugase, Yamane, Ueno, & Kawano, 1999), resulting in gradually accumulated activation of certain responses (or exclusion of inactivated ones, cf. Graboi & Lisman, 2003). If a particular response is accumulated sufficiently, a threshold of categorization will be reached and an overt response will be triggered. Many exemplar-based models (Lamberts, 1995; Medin & Schaffer, 1978; Nosofsky, 1984) include the matching between the visual input and stored exemplar concepts or, in terms of Bar, response candidates. However, Bar (see also Panis et al., 2008) suggests that competition between suitable candidates can be influenced by priming, which will increase activation of one of the response candidates when primed by a concept similar to one of the response candidates. With respect to the present findings, one may infer that both the dominant and nondominant object were activated as possible response candidates. A stronger activation of the dominant object makes it more likely that the dominant interpretation will exceed the threshold of categorization more quickly. However, activation of the nondominant interpretation will be reinforced by the nondominant prime. This increase of activation results in more response competition between the dominant and nondominant response candidate, which translates in an increase of reaction time.

Overall, the foregoing suggests a gradual accumulation of evidence for the correct object categorization resulting in response competition. This accumulation of evidence can be hampered by activation of another probable candidate, namely the nondominant object. In conclusion, we argue that the reported priming effects support the idea that processing of a morphed figure activates both objects interpolated into a morphed figure. However, it should be mentioned that although the dominant and nondominant objects are possible response options, they are stronger response options when processing figures of cp-series than figures of non-cp-series. This difference in strength might have to do with the difference in perceptual uncertainty. Information of both objects is processed in the morphed figures of non-cp-series, and therefore, can be reinforced by priming, but other response options are also strong candidates and perhaps even stronger candidates than the dominant object, as is reflected in the inconsistent response pattern observed in previous experiments (Hartendorp et al., 2010).

5

The Activation of Alternative Response Candidates: When Do Doubts Kick in?

Mijke O. Hartendorp, Stefan Van der Stigchel, Johan Wagemans, Irene Klugkist and Albert Postma (2012).
Acta Psychologica, *139*, 38-45.

Abstract

In the current study, we investigated at which moment during visual object categorization alternative interpretations are most strongly activated. According to an *early activation account*, we are uncertain about how to interpret the visual information early in the categorization process. This uncertainty will vanish over time and therefore, the number of possible response candidates decreases over time. According to a *late activation account*, the visual information is categorized quickly, but after extensive viewing alternative interpretations become more strongly activated. Therefore, the number of possible response candidates increases over time. To increase perceptual uncertainty we used morphed figures composed of a dominant and nondominant object. The similarity rating between morphed figures and their nondominant object was taken as indicator for the activation of the nondominant response candidate: high similarity indicates that the nondominant object is relatively strongly activated as an alternative response candidate. Presentation times were varied in order to distinguish between the early and late activation account. Using a Bayesian model selection approach, we found support for the late activation account, but not for the early activation account. It thus seems that in a late stage of the categorization process the influence of the nondominant response candidate is strongest.

Introduction

We tend to assign categories to the various visual stimuli that catch our eye. Categorization is very profitable because it enables us to deal with the uncountable number of objects in a solid and efficient way. There are various circumstances, however, in which the visual input is not clear or rich enough to allow successful and rapid categorization. When information is limited or ambiguous, multiple alternatives will arise and compete for categorization. Doubting to which category an object belongs could have negative consequences. For instance when an object approaches us from the sky, it is important to decide quickly whether this is a rock or a leaf. In other situations, it might be helpful to assign an object to another category than the one first available. For example, if a dark object covered with mud lies on the pavement, it might be advantageous to think of this as not just a leaf but also as a money billet.

The activation of and competition between possible response options is often included in models on object recognition (Bar, 2003; Gerlach, Law, & Paulson, 2004; Graboi & Lisman, 2003; Panis, Vangeneugden, & Wagemans, 2008). It is proposed that the activation of response candidates takes place by a quick and global process, and the matching of these candidates to the visual input by a more slow and local process leading to response competition. This competition might be stronger when concerning more uncertain information. In addition, previous research has also shown that often more than one interpretation is generated when dealing with uncertain information. For instance, it was demonstrated that the interpretation of an ambiguous figure (e.g. daughter/mother-in-law figure) alternates from one category to another (see Long & Toppino (2004) for a review on alternations of ambiguous figures). In addition, Murphy and Ross (2010) reported that if uncertain information needs to be categorized, more than one category is weighed consciously, although the most likely category (the one with the highest probability) is selected as the final interpretation of the visual input.

From these findings the question rises at which moment in the process of categorization an alternative interpretation is most strongly activated. We propose two accounts. The *early activation account* states that at an early stage in the categorization process we hesitate about the interpretation of an object. It takes time to fully process the visual input, causing uncertainty that leads to activation of more response candidates. With increase of exposure time, the number of response candidates will decrease (Graboi & Lisman, 2003). A similar idea is suggested by Lamberts and Freeman (1999: Experiment 2), who proposed that it takes time to process the features (i.e. dimensions) of an object. They showed that with a short presentation of an object, not all features were processed yet causing uncertainty to which category an object belongs. In contrast, the *late activation account* states that we categorize an object quickly, but that extensive viewing of an object can change the category to which the object was previously assigned. Therefore, at a late stage in the categorization process we hesitate about the interpretation of an object leading to activation of more response candidates with increase of exposure time. A similar idea follows from studies on ambiguous figures. With extensive viewing, the interpretation of an ambiguous figure changed from one category into another (i.e. adaptation, neural fatigue, satiation, competition, search for novelty). Importantly, the first interpretation was made quickly, but the change in interpretation from one category to another happened only after some seconds expired (Gomez, Argandona, Solier, Angulo, Vazquez, 1995; Leopold & Logothetis, 1996; Long & Toppino, 2004; Pöppel, 1997).

The aim of the current study was to unravel whether the early or the late activation account is most plausible. The early and late activation accounts differ in the moment during the categorization process at which alternative response candidates are most strongly activated. Alternative response candidates are response options that are members of other categories that show (perceptual) similarity to the actual category of the visual input (Bar, 2003; Lamberts, 1995; Malt, Ross, & Murphy, 1995; Medin & Schaffer 1978; Murphy & Ross, 2010; Nosofsky, 1984; Panis et al., 2008). For instance, if you see a yellow, curved object, you will categorize this object as a *banana*. However, the category *boomerang* might be one of the alternative response candidates. The critical question is at what moment in time the influence of alternative response candidates on the categorization process is strongest.

To create uncertain information to test the two accounts, we used morphed figures, which were created by interpolating two objects with small steps. Interestingly, morphed figures are preferably categorized as their dominant object (i.e. nearest end extreme object on the morph continuum), a phenomenon known as categorical perception (i.e. CP: Harnad, 1987; Hartendorp, Van der Stigchel, Burnett, Jellema, Eilers, & Postma, 2010; Newell & Bülthoff, 2002; Verstijnen & Wagemans, 2004). For instance, a morphed figure consisting of 80% of object A (dominant object) and 20% of object B (nondominant object), i.e. 80%20% figure, is preferably categorized as object A. In addition, a 20%80% figure is preferably categorized as object B. Categorical perception results in an abrupt switch in categorization halfway the morph continuum. Importantly, it was recently demonstrated (Hartendorp, Van der Stigchel, Wagemans, & Postma, submitted) that nondominant interpretations of morphed figures may be evoked when asking for two possible interpretations instead of the usual single response option. This suggests partial availability of the nondominant response candidate (see also Daelli, van Rijsbergen, & Treves, 2010).

The amount of activation of the nondominant response candidate can be investigated by asking observers to compare a morphed figure to either its dominant or nondominant object on (perceptual) similarity, because perceptual similarity between objects plays a crucial role in the categorization process (Edelman, 1998; Lamberts & Freeman, 1999; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976): similar objects are assigned to the same category, whereas dissimilar objects are assigned to different categories, as was already proposed by Höffding in 1891. Therefore, the stronger the reported similarity between a morphed figure and its nondominant object, the more the nondominant response candidate is activated in the process of categorizing a morphed figure. Taking the previous example, if the yellow, curved object is compared to a boomerang at the moment the alternative response candidate (e.g. boomerang) is strongly activated, we expect the similarity between the yellow, curved object and a boomerang to be higher than at the moment the alternative response candidate is less activated. Thus, investigating the similarity between a morphed figure and its dominant and nondominant object informs us to what extent the nondominant object is activated as an alternative response candidate.

In the current study, we examined how the morphed figures of different morph series were judged on perceptual similarity to their dominant and nondominant object. Participants were asked to judge the similarity between a morphed figure and an extreme figure that could either be the dominant object of the morphed figure, the nondominant object of the morphed figure or an extreme figure of another morph series. To investigate the moment of activation of the nondominant response candidate during the categorization process the presentation time of the morphed figure was varied from a brief presentation time (50 ms) to an extended presentation time (3000 ms). If the similarity between a morphed figure and its nondominant object appeared to be higher for the brief presentation time compared to the extended presentation time, support is found for the early activation account. In contrast, if the similarity between a morphed figure and its nondominant object appeared to be higher for the extended presentation time compared to the brief presentation time, support is found for the late activation account.

We examined whether the similarity between a morphed figure and its nondominant object increased or decreased over time by looking at the *switch size* of the similarity patterns across the different timing conditions (see Figure 5.1 for different switch sizes).

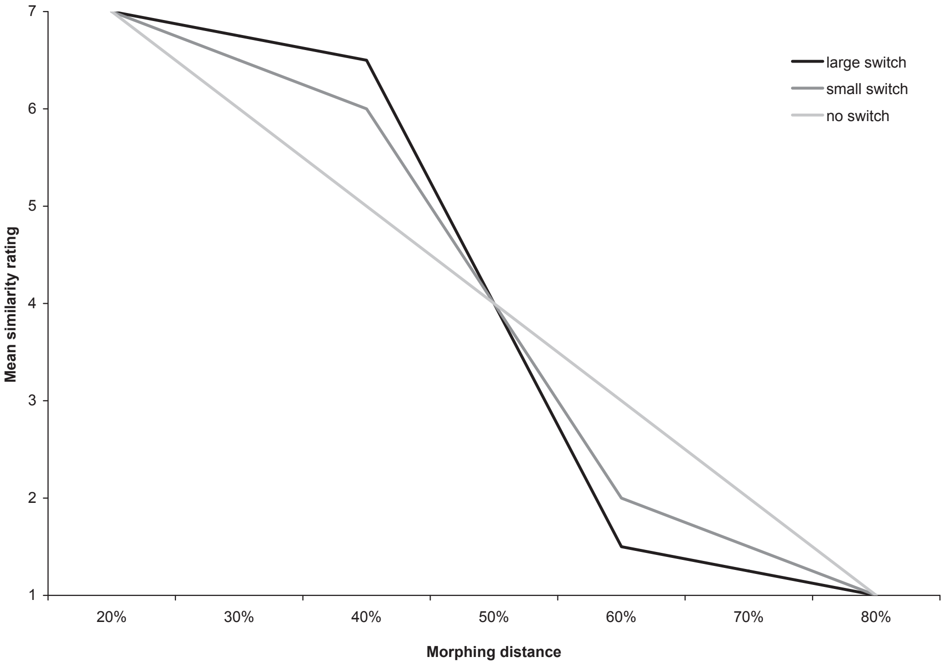

Figure 5.1. An example to illustrate the difference between three similarity patterns of which one shows a large switch, one shows a small switch and one shows no switch. The morphing distances between the morphed figure and the (related) extreme figure are presented on the x-axis. The mean similarity rating on a rating scale from one to seven is presented on the y-axis. All lines show a linear decrease in similarity rating across morphing distance, but only the black line and the dark gray line show a switch indicated by a stronger decrease in similarity rating from 40% to 60% morphing distance compared to the decrease in similarity rating from 20% to 40% and from 60% to 80%. In addition, the difference in decrease is larger for the black line than for the dark gray line (i.e. a larger switch for the black line).

With the switch size we refer to the decrease in similarity along the morph continuum. One would expect a linear decrease of similarity when the morphed figure moves further away from the extreme figure (e.g. less similarity between a 60%40% figure and a 100%0% figure than between a 70%30% and a 100%0% figure). However, we know from the literature on CP that the similarity pattern does not show a continuous linear decrease, but an abrupt switch hallway the morph continuum (cf. discrimination tasks: Harnad, 1987). A larger switch size (i.e. a more abrupt switch) implies a stronger activation of the dominant response candidate (i.e. more similarity between a morphed figure and its dominant object), whereas a smaller switch size (i.e. a less abrupt switch) implies more activation of the nondominant response candidate (i.e. more similarity between morphed figure and its nondominant object). See also the section *3.2. The Switch* for more explanation.

In addition, the blank interval between a morphed figure and its extreme figure was varied from a short interval (300 ms) to a long interval (3000 ms), to examine whether the nondominant response candidate could be kept active despite absence of visual stimulation or that the nondominant response candidate would fade away over time. In case of the latter, we expect to observe higher similarity between a morphed figure and its nondominant object for the short interval and lower similarity between a morphed figure and its nondominant object for the long interval.

The data were analyzed by Bayesian model selection using the Bayes factor (Kass & Raftery, 1995). For the type of hypotheses formulated in this research we used the approach introduced by Klugkist and colleagues (Hoijtink, Klugkist, & Boelen, 2008; Klugkist, Laudy, & Hoijtink, 2005; Mulder, Hoijtink, & Klugkist, 2010). With this approach, specific expectations are translated into equalities and inequalities between the means of the different experimental conditions (e.g. the similarity rating of condition 1 is *larger than* condition 2), making this statistical method a confirmative one in contrast to traditional methods, such as null-hypothesis testing in which only no difference or a difference between the conditions can be detected and not necessarily a specific difference between the conditions.

Experiment

Method

Participants

Ninety students from Utrecht University participated in this experiment. The participants were equally divided over the six different between-subjects timing conditions, leading to fifteen participants in each timing condition. Depending on the condition, the experiment lasted about 30 minutes in the short timing conditions to 45 minutes in the long timing conditions. The participants received 6 Euros or one course credit for their contribution.

Materials

Suitable objects were selected from a large set of contour drawings of a wide range of living and nonliving objects for which normative identification rates had been established (De Winter & Wagemans, 2004), which in turn were derived from a set of line drawings validated by Snodgrass and Vanderwart (1980). Additionally, one figure (i.e. the *man* figure) was selected from a set of contour drawings by Downing, Bray, Rogers and Childs (2004). The interior of the contour drawings was filled with black resulting in silhouette objects. Pairs of silhouette objects were interpolated in steps of 5% change using Sqirlz-Morph software (Xiberpix, version 2.0), resulting in morph series consisting of 19 interpolations and two extreme figures (cf. Hartendorp et al. (2010) for a description of the morphing procedure). All paired extreme figures were from different (basic-level) categories and most of them from different superordinate categories (Rosch et al., 1976). From each complete morph series nine figures were selected: the 100%0%, 80%20%, 70%30%, 60%40%, 50%50%, 40%60%, 30%70%, 20%80% and 0%100% figures (approximately 4.29° x 3.34°, 7 cm x 9 cm) for use in the current study. The 100%0% and 0%100% figures are referred to as the extreme figures, the remaining seven figures (from 80%20% to 20%80%) are referred to as morphed figures. It was decided to select only seven out of the 19 interpolations from each series to reduce exposure to the same series as much as possible. In total, fifteen different series were used (see Appendix A for a complete overview). The black silhouettes were presented on a white background using E-Prime (Psychology Software Tools Inc., version 1.1). Participants used a regular keyboard to enter their similarity ratings.

Procedure

Participants were asked to rate the perceptual similarity, and in particular the similarity in intrinsic part structure, between two sequentially presented targets on a seven-point rating scale. The exact instructions were: *It is your job to tell how strong the similarity in structure of the parts is between the two pictures* (in Dutch). Intrinsic part structure has previously shown to be an important aspect underlying categorization of objects in general (Biederman, 1987; De Winter & Wagemans, 2006; Feldman & Singh, 2006; Hoffman & Singh, 1997; Rosielle & Cooper, 2001) and categorization of morphed figures in particular (Hartendorp et al., 2010). In the instructions, an explanation was provided of our definition of intrinsic part structure (i.e. spatial relation of the parts of an object) making use of an example of a bookcase and a snowman: both have a vertical piled up structure of the object's parts and therefore should be rated as showing strong similarity in intrinsic part structure. In contrast, the comparison of a bookcase and a sweater illustrated a weak example of similarity in intrinsic part structure with the explanation that a sweater has a more horizontal structure of the object's parts. The targets were always a combination of a morphed figure presented first, followed by a blank interval and next by an extreme figure. We are aware of the different effects of stimulus order on similarity ratings (Op de Beeck, Wagemans, & Vogels, 2003), namely that prototypicality might cause an asymmetry (e.g. 99 is judged as being more similar to 100 than 100 to 99). Since we kept the stimulus order and the instructions the same for all timing conditions, we controlled for possible order effects. The figures were presented at the center of the screen. The relation between the morphed figure and extreme figure was of different natures; this relation could be unrelated (i.e. the two targets were from different morph series) or could be related (i.e. the two targets were from the same morph series). Furthermore, the morphing distance between morphed figure and extreme figure was varied. For instance, the morphing distance was 20% when the morphed figure was an 80%20% figure and the extreme figure a 100%0% figure, but was also 20% when the morphed figure was 20%80% and the extreme figure 0%100%. The morphing distance could be 20% to 80% with steps of 10% resulting in seven different morphing distances. Each morphed figure was presented three times: once with its related 100%0% figure, once with its related 0%100% figure, and once with an unrelated extreme figure. An experimental run consisted of 315 trials based on 15 morph series x 7 morphed figures x 3 different extreme figures. The duration of the viewing time of a morphed figure and the blank interval in-between morphed figure and extreme figure were varied between participants. The presentation time of a morphed figure could be short (50 milliseconds (ms)), medium (300 ms) or long (3000 ms). The blank interval could either be short (300 ms) or long (3000 ms). Combining the different presentation times of the morphed figure and the different interval durations resulted in six timing conditions, with the presentation time of the morphed figure presented first and the interval duration second: short-short (50 ms - 300 ms), medium-short (300 ms - 300 ms), long-short (3000 ms – 300 ms), short-long (50 ms – 3000 ms), medium-long (300 ms – 3000 ms) and long-long (3000 ms – 3000 ms). The participants were instructed in advance about the sequential presentation of the stimuli. Each experimental trial followed a sequence of a fixation cross that was replaced after 1000 milliseconds by a morphed figure that stayed on the screen depending on the timing condition the participant was assigned to. Next, a blank interval was presented of which the duration also depended on the timing condition to which the participant was assigned. Subsequently, an extreme figure appeared that was presented until the participant making use of the keyboard entered a response. The response consisted of a number from 1 to 7 indicating the similarity between the two targets according to the participant, with 1 referring to no similarity and 7 to very strong similarity. There were no time restrictions for responding. Participants were reinforced to use the whole rating scale and informed that we were interested in their interpretation: there were no correct or incorrect responses. The moment participants filled in their response, a blank screen appeared for 1000 milliseconds after which the following trail started. When 105 trials were completed, a self-timed break was included.

Data Analysis

Bayesian Model Selection Approach

To evaluate which hypothesis gained the most support, a Bayesian model selection approach was used (Hoijtink et al., 2008; Klugkist et al., 2005; Mulder et al., 2010). Specific constraints between the different conditions enable a direct and confirmative comparison between the different hypotheses. Instead of rejecting the null-hypothesis or finding a significant interaction effect, this method calculates which hypothesis is most supported by the data. Each informative hypothesis is evaluated against a basic model, the unconstrained model (Hypothesis unconstrained: Hunc), in which no constraints are imposed on the means (comparable to the alternative hypothesis in case of null-hypothesis testing). A Bayes factor (BF) informs us about the support the informative hypothesis receives from the data in comparison to the unconstrained model. If BF is above 1 the informative hypothesis is more supported by the data than the unconstrained model. Furthermore, the larger the resulting BF, the stronger the evidence is for that hypothesis. This method makes it possible to test more than one hypothesis; the one that ends up with the largest (and above 1) BF will be the one that has the strongest support by the data. The analyses in this article are performed using the free software package BIEMS that can be downloaded from www.fss.uu.nl/ms/informativehypotheses. The full technical explanation is provided in two papers of Mulder and collaborators (Mulder, Klugkist, Van der Schoot, Meeus, Selfhout, & Hoijtink, 2009; Mulder et al., 2010).

The Switch

To investigate the activation of the nondominant response candidate, we compared the size of the switch observed in the similarity pattern between the different timing conditions. To explain what we mean with *the switch*, the morph series *turtle-car* (see Figure 2) is used as an illustration. In a categorization task (Hartendorp et al., 2010), the 80%20%, 70%30% and 60%40% figures (first % refers to percentage *turtle* and second % to percentage *car*) are categorized as *turtle* (their dominant object). The 40%60%, 30%70% and 20%80% figures are categorized as *car*. Assuming that similar objects are categorized similarly and dissimilar objects differently, it is expected that the 80%20 %, 70%30% and 60%40% figures are rated as very similar to a turtle, since they are all categorized as *turtle*. In addition, the 40%60%, 30%70% and 20%80% figures are likely to be rated as very similar to a car, since they are all categorized as *car*. Moreover, the 40%60%, 30%70% and 20%80% figures are probably rated as less similar to a turtle than to a car, since they are not categorized as *turtle*. If we plot the similarity ratings of the morphed figures when compared to a turtle, a switch is observed halfway the morph continuum as is presented in Figure 1.

In short, if morphed figures are categorized as their dominant object we expect to find a large switch in their similarity pattern when compared to one of both extreme figures. However, if the morphed figures are categorized as another object besides the dominant object (e.g. activation of the nondominant object), we expect to observe a decrease in the size of the switch in the similarity pattern.

Informative Hypotheses

In the current analysis, the growth and decline of the switch size between the different timing conditions was investigated. To investigate the activation accounts, our main interest concerned the related condition in which the similarity between a morphed figure and its dominant and nondominant object was examined. However, to ensure that the unrelated condition was of no influence, the informative hypothesis H1 was tested stating that the similarity ratings between a morphed figure and a related extreme figure should be higher across all morphing distances than the similarity ratings between a morphed figure and an unrelated extreme figure. If the BF of H1 was larger than one, this assumption was supported by the data (otherwise, in case the assumption was not met, the BF should be smaller than one).

Before we investigated the differences in switch size between the different timing conditions, we first examined whether a switch was present in the different timing conditions. We tested in H2A whether the conditions for the short presentation time of the morphed figures (short-short and short-long) showed a switch. Next, in H2B we tested whether the conditions for the medium presentation time of the morphed figures (medium-short and medium-long) showed a switch. Subsequently, in H2C it was tested whether the conditions for the long presentation time of the morphed figures (long-short and long-long) showed a switch.

The following step was to examine whether more support was found for the early or the late activation account by comparing the switch sizes of the different timing conditions. The early activation account was represented by H3A, in which the largest switch was expected for the conditions with the long presentation time of the morphed figures (long-short and long-long), followed by the medium presentation time conditions (medium-short and medium-long), and the smallest switch was expected for the short presentation time conditions (short-short and short-long). In contrast, H3B represented the late activation account in which the largest switch was expected for the conditions with the short presentation time of the morphed figures (short-short and short-long), followed by the medium presentation time conditions (medium-short and medium-long), and the smallest switch was expected for the long presentation time conditions (long-short and long-long).

Subsequently, to examine whether the nondominant response candidate could be kept active during absence of visual stimulation, the blank interval in-between morphed figure and extreme figure was varied (a short interval and a long interval). Two informative hypotheses were constructed. First, by H4A a larger switch was predicted for the long interval conditions (short-long, medium-long and long-long) than for the short interval conditions (short-short, medium-short and long-short). Second, in H4B it was predicted that a larger switch would be observed for the short interval conditions (short-short, medium-short and long-short) in contrast to the long interval conditions (short-long, medium-long and long-long). In case of the latter (a larger switch for the short interval than for the long interval), it is suggested that either the nondominant response candidate becomes more active over time or more likely, and that the dominant response candidate will lose strength over time. However, if support is found for H4A (a larger switch for the long interval in comparison to the short interval), this suggests that the nondominant response candidate is more active during the short interval than during the long interval, but the dominant response candidate will not lose activation strength over time. Some informative hypotheses, from H3A to H4B, are presented in an abstract manner in Figure 5.2.

The (in)equality constraints for all informative hypotheses are presented per hypothesis in Appendix D.

Results

First, the similarity ratings were calculated. These ratings were divided into the within-subject variables *Relation* between morphed figure and extreme figure (morphed and extreme figure were related when they belonged to the same morph series and unrelated when they belonged to different morph series) and *Morphing Distance* between morphed figure and extreme figure (the morphing distance could be 20%, 30%, 40%, 50%, 60%, 70% and 80%). In addition, the between-subject variables *Presentation Time* of morphed figure (short, medium and long presentation time: 50 ms, 300 ms and 3000 ms, respectively) and *Interval Duration* (short and long interval: 300 ms and 3000 ms, respectively) were included in the design. This resulted in 84 different conditions (2 relations x 7 morphing distances x 3 presentation times x 2 interval durations). For each condition, the mean similarity ratings per participant were measured. The mean similarity ratings are presented graphically in Figure 5.3 and 5.4, with Figure 5.3 representing the three presentation times of the morphed figures for the related and unrelated condition and with Figure 5.4 representing the two interval durations for the related and unrelated condition. The rating scale of the similarity in intrinsic part structure was from 1 to 7 with 1 referring to no similarity and 7 to strong similarity. Thus, a higher mean similarity rating implied more similarity between morphed figure and extreme figure.

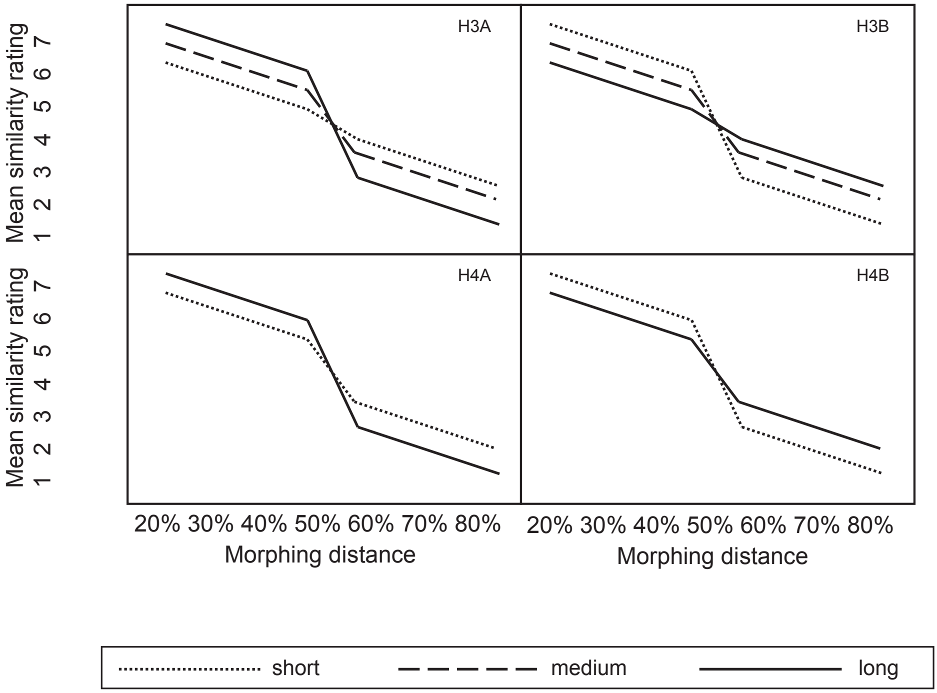

Figure 5.2. The four graphs represent the informative hypotheses H3A to H4B in an abstract manner. The graph at the left top represents H3A (early activation account): the dotted line refers to a short presentation time of the morphed figures (small switch), the dashed line to a medium presentation time (medium switch) and the closed line to a long presentation time (large switch). The graph at the right top represents H3B (late activation account): the dotted line refers to a short presentation time of the morphed figures (large switch), the dashed line to a medium presentation time (medium switch) and the closed line to a long presentation time (small switch). The graph at the left bottom represents H4A: the dotted line refers to a short duration of the interval (small switch) and the closed line refers to a long duration of the interval (large switch). The graph at the right bottom represents H4B: the dotted line refers to a short duration of the interval (large switch) and the closed line to a long duration of the interval (small switch).

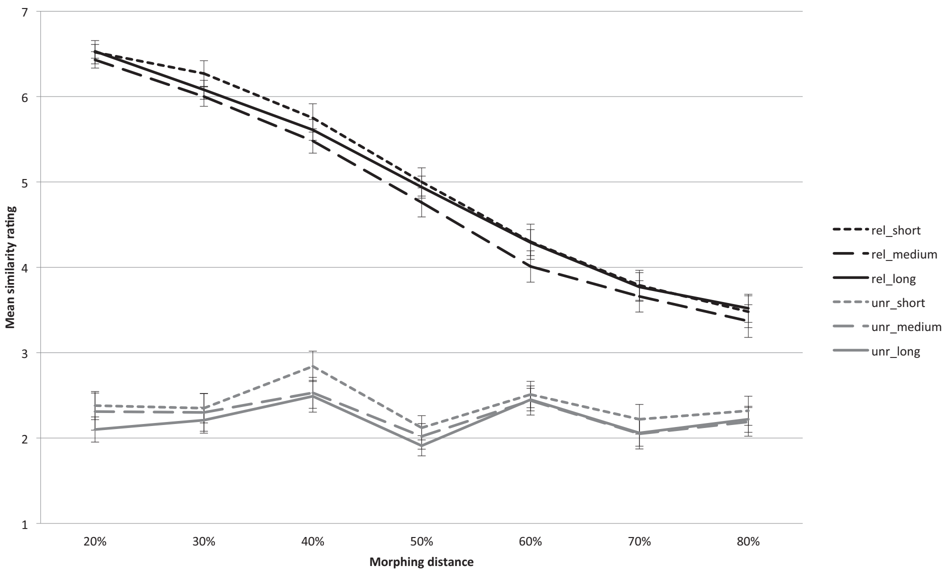

Figure 5.3. The mean similarity ratings and their standard error for the different presentation times of the morphed figures (short, medium, long; 50, 300, 3000 ms, respectively) with the distinction whether the extreme figure was related (rel) or unrelated (unr) to the morphed figure. The morphing distance between morphed figure and extreme figure is presented on the x-axis. The mean similarity rating on a rating scale from one to seven is presented on the y-axis. The black lines represent the related condition and the gray lines the unrelated condition. The dotted lines represent the short presentation time condition, the dashed lines represent the medium presentation time condition and the closed lines represent the long presentation time condition.

The informative hypothesis H1 was tested against the unconstrained model (Hunc), BF = 1.11E+09. Since much support was found for this hypothesis (BF > 1), one can assume that the similarity ratings in the related condition were higher than the similarity ratings in the unrelated condition across all morphing distances. Subsequently, the three timing conditions for the presentation time of the morphed figures were tested for showing a switch or not. All three hypotheses were tested against Hunc, H2A: BF = 3.697, H2B: BF = 3.705 and H2C: BF = 3.301, indicating that all three timing conditions (short, medium, large) showed a switch in their data pattern. Since all three timing conditions showed the switch, we could test which condition showed the largest switch size. Therefore, the two hypotheses concerning the early and late activation account were tested, H3A and H3B, respectively. H3A was tested against Hunc, BF = 0.292. Since the BF of H3A is smaller than one, no support is gained from

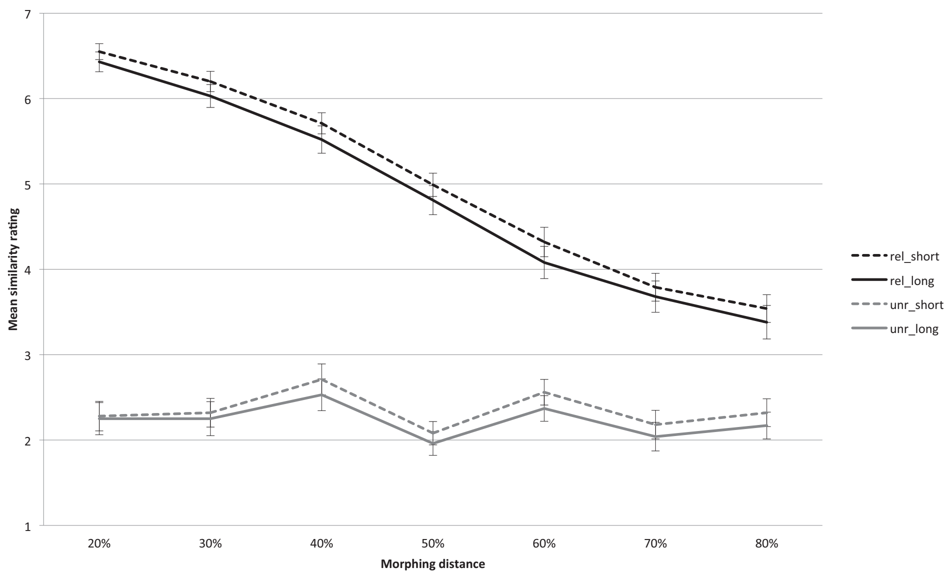

Figure 5.4. The mean similarity ratings and their standard error for the different interval durations (short, long; 300, 3000 ms, respectively) with the distinction whether the extreme figure was related (rel) or unrelated (unr) to the morphed figure. The morphing distance between morphed figure and extreme figure is presented on the x-axis. The mean similarity rating on a rating scale from one to seven is presented on the y-axis. The black lines represent the related condition and the gray lines represent the unrelated condition. The dotted lines represent the short presentation time condition and the dashed lines represent the long presentation time condition.

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the data for the early activation account. Second, H3B was tested against Hunc, BF = 2.423. The BF is larger than one, indicating that the data provided support for the late activation account.

To find out whether varying the interval duration had an effect on the size of the switch, H4A with a larger switch for the long interval in comparison to the short interval and H4B with a larger switch for the short interval in comparison to the long interval were tested. First, H4A was tested against Hunc, BF = 1.267. Next, H4B was tested against Hunc, BF = 0.787. We conclude that varying the length of the interval had an effect on the size of the switch with a larger switch for the long interval (3000 ms) than for the short interval (300 ms). This finding suggests that the nondominant response candidate was more active during the short interval than during the long interval, and that the dominant response candidate stayed equally active with increase of interval duration.

Discussion

In this experiment, similarity between two sequentially presented stimuli had to be judged. The first stimulus was always a morphed figure and the second stimulus was always an extreme figure (i.e. nonmorphed figure). The extreme figure corresponded to either the dominant object of the morphed figure, to the nondominant object of the morphed figure or to an object that was completely unrelated to the morphed figure. In between the first and the second stimulus a blank interval appeared. The presentation time of the morphed figure and the duration of the blank interval were varied between participants. Participants were asked to rate the similarity in intrinsic part structure between the morphed figure and the extreme figure on a seven-point rating scale. The similarity ratings were analyzed making use of the Bayesian model selection approach (Hoijtink et al., 2008; Klugkist et al., 2005; Mulder et al., 2010). This method compares specific hypotheses to find out which of these hypotheses gains most support from the data. Since we were looking for subtle differences between the different timing conditions, this approach appeared to be a perfect method to test our hypotheses. The first informative hypothesis H1 tested whether the related extreme figures were always judged as more similar to the morphed figures than the unrelated extreme figures to ensure that the rating of similarity worked sufficiently. Strong support was found for this hypothesis, indicating that participants noticed the difference in similarity between extreme figures that were related to the morphed figure (being the dominant or nondominant object of a morphed figure) and extreme figures that were unrelated to the morphed figure.

We used the switch size observed in the similarity pattern to examine at which moment during the categorization process the nondominant object became a stronger response candidate. All three timing conditions showed the switch. The next step was to compare the size of the switches between the different timing conditions. When the activation of the nondominant object as an alternative response candidate increased, the similarity between a morphed figure and its nondominant extreme figure should increase as well, resulting in a decrease of the switch size. The increase of activation of the nondominant response candidate may occur in an early stage of the categorization process, supporting the early activation account, or in a late stage, supporting the late activation account. Both activation accounts imply that more information is processed with longer exposure to the visual input. However, the early activation account suggests that more information leads to more certainty about which response candidate should be selected (see also Lamberts & Freeman, 1999). In contrast, the late activation account indicates that more information leads to generating another response candidate besides the preferred response candidate (see also Long & Toppino, 2004). We found support for the late activation account and not for the early activation account. Stronger similarity between a morphed figure and its nondominant object emerged when a morphed figure was presented for a longer period than when it was presented only briefly. We can infer from these findings that activation of the nondominant object is strongest at a later stage of the categorization process.

We also varied the duration of the interval between the presentation of the morphed figure and the extreme figure. The influence of interval duration informs us whether the nondominant response candidate increased over time or whether its activation decreases over time. Again, we used the switch size to test whether the similarity between morphed figure and its nondominant extreme figure stayed the same for both interval durations. We found support for the latter: a larger switch was observed for the long interval (i.e. less activation of the nondominant response candidate) compared to the short interval. The activation of the nondominant response candidate decreased over time when the stimulus was no longer visible. Moreover, the increase of switch size with increase of interval duration also informs us that the similarity between a morphed figure and its dominant object did not drop when the morphed figure was no longer presented. Hence, we infer that the activation of the dominant response candidate did not lose much strength during the absence of visual stimulation.

We have asked participants to compare the two stimuli for similarity in intrinsic part structure, an aspect of similarity that shows much overlap to the idea of an object's skeleton that is based on the global contour shape of an object (Feldman & Singh, 2006). Wilder, Feldman and Singh (2011) have suggested that in particularly a skeletal representation of a morphed figure is used to assign a morphed figure to its dominant object's category. In their study, it was shown that we already subtract the skeleton of an object in a very early stage of the categorization process. In our study, a similar process might be underlying the similarity process between a morphed figure and its dominant object. This quick and global processing particularly involves the dominant object. The similarity comparison between a morphed figure and its nondominant object, however, might rely on other information than the skeletal representation of an object. A possible explanation for this difference could be found in the literature on holistic and analytical processing of visual information. Supporters of this idea of object perception argue that with brief presentation an object is processed in a holistic (configural) manner, while extensive presentation causes analytical processing of an object (Schwarzer, Huber, & Dümmler, 2005; Ward

& Scott, 1987; but see also Lamberts, 1995). The present results suggest that initial, holistic processing leads to activation of particularly the dominant interpretation of a morphed figure. Extensive viewing of the same morphed figure may allow processing of the specific features of the object. This analytical processing makes it possible to recognize the nondominant object in the morphed figure as well (see also Torfs, Panis, & Wagemans (2010) for the effects of exposure time on object categorization). More support for first processing an object in a holistic manner and subsequently in an analytical manner is provided by Op de Beeck, Torfs and Wagemans (2008). They have found different neural correlates for shape envelope (i.e. global shape processing, or in other words, holistic processing) and shape features (i.e. local shape processing, or in other words, analytical processing): activity in area V3 was stronger correlated with perceived similarity between objects on shape envelope, whereas activity in area LOC (lateral occipital complex) was stronger correlated with perceived similarity between objects on shape features.

In the beginning of this article, we sketched a situation in daily life in which activation of alternative response candidates can be convenient at an early stage of the categorization process as well as at a late stage (i.e. is an object a leaf, a rock approaching you from the sky, or a money billet lying on the pavement). We have found support for the late activation account. This suggests that in a late stage of the categorization process the influence of alternative response candidates is strongest. Thus, observers are capable of distracting the most important aspects of the object in order to reach a solid decision, and as such can avoid being hit by a falling rock. Nevertheless, they are also still flexible enough to consider other interpretations after extensive viewing. Thus they will not miss out the money billet, though initially they thought it was a leaf.

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To What Extent Do We Process the Nondominant Object in a Morphed Figure? Evidence from a Picture-Word Interference Task

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Abstract

To investigate to what extent response candidates are processed during visual object categorization, a picture-word interference task was conducted in which the effects of different types of distractor words on object naming were examined. Distractor words were related to either the dominant or the nondominant object in a morphed figure. We assume both the dominant and nondominant object to be response candidates during response competition. The distractor words were identical (dog-dog), semantically related (cow-dog) or unrelated (spoon-dog) to the dominant or nondominant object. It was found that in relation to the dominant object in a morphed figure identical distractors facilitated naming, whereas semantically related distractors caused interference. Moreover, in relation to the nondominant object identical words interfered with naming, while semantically related words only interfered with naming when they were part of the response set. Therefore, identical words primarily influenced the activation of the nondominant response candidate, whereas semantically related words only did so under restricted conditions. We conclude that the selected response candidate (i.e. the dominant object) will reach the semantic level, whereas the other response candidates (e.g. the nondominant object) are only processed up to the perceptual level.

Introduction

To understand the process of visual object categorization, it is important to gain insight in the stages *before* an overt response is given. Several theoretical models (Bar, 2003; Lamberts, 1995; Malt, Ross, & Murphy, 1995; Medin & Schaffer, 1978; Nosofsky, 1984; Panis, Vangeneugden, & Wagemans, 2008) have proposed that multiple interpretations are activated when categorizing objects. For instance, the neurological model by Bar suggests that a number of response candidates are activated from the stored concepts that show shape similarity to the visual input. The response candidate with the strongest match to the visual input wins the competition for categorization. Because the matching concerns only shape similarity between visual input and stored concepts, the perceptual information of the response candidates should at least be activated. It is unclear, however, whether other information associated with the activated response candidates, such as category membership and associations, is coactivated. Therefore, the goal of the current study was to investigate up to what level the response candidates are activated during response competition. Are they just activated at a perceptual level, or also at a semantic level? For instance, when the visual input shows shape similarity to the concept *dog*, does the response candidate representing the concept *dog* only contain perceptual information about the concept *dog* (e.g. *snout, four legs, tail*) or also semantic information (e.g. *animal, cat, bone*)?

As has been demonstrated by many priming studies (Balcetis & Dale, 2007; Bar & Biederman, 1998; Bugelski & Alampay, 1961; Dell'Acqua & Grainger, 1999; Goolkasian, 1987; Jemel, Pisani, Calabria, Crommelinck, & Bruyer, 2003; Leeper, 1935; Palmer, 1975), presenting the visual input in a related context facilitates selection of a particular response candidate. The primes affect the categorization process by reducing the time necessary to categorize the visual object and even by changing the interpretation of the visual input towards the preceded context. The above-mentioned priming studies showed that the categorization process is not only affected by repetition priming (dog-dog), but can also be influenced by semantic priming (cow-dog). However, it remains to be determined whether context influences only the selected response candidate or non-selected response candidates as well.

Additional evidence that context has an effect on the categorization process comes from picture-word interference tasks. In these tasks, it has been revealed that the naming of pictures was influenced by superimposed words semantically related (also referred to as semantic-coordinate) to the picture (Glaser & Düngelhoff, 1984; Sailor, Brooks, Bruening, Seiger-Gardner, & Guterman, 2009). For example, the semantically related distractor word *cow* slows down the naming of a picture of a dog, because they belong to the same semantic category (i.e. *animal*), whereas the identical distractor word *dog* facilitates naming of the picture of a dog. Notably, the interference effect observed in the picture-word interference tasks is opposite to the facilitation effect found in priming tasks. This difference can be explained by the fact that in a picture-word interference task picture and word are presented simultaneously, whereas in a priming task the prime precedes the picture. Additionally, the advantage of a picture-word interference task with respect to a priming task is that repetitive and semantic information result in a dissociative pattern: Facilitation when the word is identical to the name of the object in the picture and interference when the word is semantically related to the object in the picture. The effects of different kinds of contextual information have been tested in picture-word interference tasks. Besides distractor words that belonged to the same category as the picture (semantic information: cow-dog), words were also tested that showed a strong association to the picture, but did not belong to the same category (associative information: bone-dog). Here we only tested semantic information and not associative information, because associative information facilitates the naming process (Alario, Segui, & Ferrand, 2000; La Heij, Dirkx, & Kramer, 1990) and hence, does not show a dissociative pattern to repetitive information.

To investigate to what degree repetitive and semantic information influence the activation of response candidates, we need visual stimuli that activate a known set of response candidates. Ideal stimuli are, therefore, morphed figures, because they allow at least two interpretations, namely an interpretation corresponding to the *dominant object* and an interpretation corresponding to the *nondominant object*. For instance, when morphing a *car* into a *turtle*, an 80%20% figure consists of 80% *car* (dominant object) and 20% *turtle* (nondominant object), whereas a 40%60% figure consists of 40% *car* (nondominant object) and 60% *turtle* (dominant object). It is important to note that the percentages reflect only morphing percentages, that is, they do not necessarily reflect human perception. Morphed figures are often categorized as their dominant object (i.e. categorical perception: Beale & Keil, 1995; Bornstein & Korda, 1984; Harnad, 1987; Hartendorp, Van der Stigchel, Burnett, Jellema, Eilers, & Postma, 2010; McCullough & Emmorey, 2009; Newell & Bülthoff, 2002). Hence, we may consider the dominant object as the *preferred response candidate* (final output, response candidate that has won the response competition). It is likely that the nondominant object is one of the *alternative response candidates* (the response candidates that have lost the response competition), if any, since a morphed figure also contains visual information from the nondominant object. This assumption has been reinforced by a recent finding of Daelli, van Rijsbergen and Treves (2010; see also Hartendorp, Van der Stigchel, Wagemans, & Postma, submitted). They have shown that the categorization of morphed figures changed when a morphed figure was preceded by its nondominant object, suggesting that the nondominant object is indeed one of the response candidates.

We conducted a picture-word interference task in which the distractor words were identical, semantically related or unrelated to the dominant and nondominant object of a morphed figure to investigate which type of context has an effect on the activation of the nondominant response candidate. For example, if the morphed figure is a 70%30% figure of the *Car-Turtle* series, the identical words will be *car* and *turtle*, the semantically related words *train* and *frog*, and the unrelated words *hammer* and *suitcase* for the dominant and nondominant object, respectively. We used identical words to examine the influence of repetitive context on the categorization process (dog-dog) and the semantically related words examined the influence of semantic context on the categorization process (cow-dog). The unrelated words functioned as a baseline to which the effects of the identical and semantically related words could be compared. Earlier research showed that the preferred response candidate is the dominant object (Harnad, 1987; McCullough & Emmorey, 2009; Verstijnen & Wagemans, 2004), so we expected the distractor words related to the dominant object to have similar effects on the categorization process as the effects reported in previous picture-word interference tasks (Glaser & Düngelhoff, 1984; Sailor et al., 2009). In other words, dominant identical words should facilitate naming of a morphed figure and dominant semantically related words should interfere with naming. Most importantly, the distractor words related to the nondominant object of a morphed figure directly revealed to what extent the alternative response candidates were activated. If the alternative response candidates, e.g. the nondominant object, are only represented at a perceptual level, we would expect only nondominant identical words to interfere with naming. However, if the alternative response candidates, e.g. the nondominant object, also contain semantic information, we might anticipate the nondominant semantically related words to have an effect on naming as well. Two picture-word interference tasks were conducted. In Experiment 1, only the identical words showed membership to the response set. The semantically related and unrelated words did not. In Experiment 2, we controlled for possible response set effects (La Heij, 1988) by using a stimulus set in which all distractor words showed membership to the response set.

Experiment 1

Method

Participants

Thirty female students (M age in years = 22.5 years, SD age in years = 5.4) from Utrecht University participated in this experiment and received 3 Euros or a course credit for their contribution. The experiment lasted about half an hour.

Materials

Morphed figures were created from black silhouette objects (filled line drawings) that were presented on a white background. These silhouette objects were selected from a large set of contour drawings of a wide range of living and nonliving objects for which normative identification rates had been established (De Winter & Wagemans, 2004; Wagemans, De Winter, Op de Beeck, Ploeger, Beckers, & Vanroose, 2008), which in turn were derived from an earlier set of line drawings validated by Snodgrass and Vanderwart (1980). Additionally, one figure (i.e. the *man* figure) was selected from a set of contour drawings by Downing, Bray, Rogers and Childs (2004). Pairs of silhouette objects were interpolated in steps of 5% change using Sqirlz-Morph software (Xiberpix, version 2.0), resulting in morph series consisting of 19 interpolations and two extremes, the 100% figures (cf. Hartendorp et al. (2010) for a description of the morphing procedure). All paired extremes were from different (basic-level) categories and most of them from different superordinate categories (for an explanation of different levels of categorization see Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). From each complete morph series six morphed figures were selected: the 80%20%, 70%30%, 60%40%, 40%60%, 30%70% and 20%80% figures (approximately 4.29° x 3.34°, 7 cm x 9 cm). To reduce exposure to the same series as much as possible, only six out of the 19 interpolations from each series were included as stimulus materials. Equivalent morphing levels were collapsed, since we assumed that response patterns would not differ in general for the two equivalent figures. The morphing levels were reduced from six levels to three levels, namely to the 80%20%, 70%30% and 60%40% morphing level, with the 80%20% morphing level containing the 80%20% and 20%80% figures, the 70%30% morphing level containing the 70%30% and 30%70% figures, and the 60%40% morphing level containing the 60%40% and 40%60% figures. In total, nine different morph series were used (see Appendix A for the stimulus materials).

The distractor words followed a number of restrictions. First, the identical words were similar to the basic-level name (Rosch et al., 1976) of the objects interpolated in the morphed figures. Second, the semantically related words referred to objects that belonged to the same category as the interpolated objects in a morphed figure. However, they were required not to be strongly associated to the target object, because the impact of associative primes differs from purely semantic primes (Alario et al., 2000; La Heij et al., 1990). This was tested by a pilot experiment in which 20 participants were asked to rate the strength of association between two words on a scale from one to seven (1 refers to no association and 7 to a very strong association). For instance, the word *duck* was compared to the presumably associatively related word *pond*, to the presumably semantically related, but not associatively related word *bee* and to the presumably unrelated word *sweater*. The associative strength score average was highest for the associative pairs (M = 5.67 and SD = 0.76), followed by the semantically related pairs (M = 3.87 and SD = 1.21) and eventually by the unrelated pairs (M = 1.45 and SD = 0.32), $t_{associative\text{-}semantic}(19) = 9.05$ and $p < .001$, $t_{associative\text{-}unrelated}(19) = 27.20$ and $p < .001$, $t_{semantic\text{-}unrelated}(19) = 10.13$ and $p < .001$. Third, a semantically related distractor word and its target's object name had to start with a different first letter and had to consist of approximately the same number of syllables ($M_{identical}$ = 1.89 and $SD_{identical}$ = 0.83, $M_{semantic}$ = 1.50 and $SD_{semantic}$ = 0.51, $M_{unrelated}$ = 1.56 and $SD_{unrelated}$ = 0.62) and letters ($M_{identical}$ = 6.50 and $SD_{identical}$ = 2.50, $M_{semantic}$ = 5.50 and $SD_{semantic}$ = 1.65, $M_{unrelated}$ = 5.11 and $SD_{unrelated}$ = 1.64). Fourth, the eighteen unrelated words were restricted to be unrelated to all objects interpolated in the morphed figures, meaning that they should not belong to the same category and should have no (strong) association to any one of the presented objects. Unrelated words were always combined in random order with the figures from the morph series to ensure that participants did not learn a predictable connection between an unrelated distractor word and the figures of a particular morph series (see Appendix E for all distractor words). The unrelated words are assigned to either the dominant or nondominant conditions making it possible to compare the identical and semantically related conditions within a dominance type to the unrelated condition. The stimuli were displayed using E-Prime (Psychology Software Tools Inc., version 1.1). Participants used a voicekey for responding and the experimenter used a stimulus-response box for rating the participants' response as either a dominant response, a nondominant response, an alternative response, or as a voicekey error.

Procedure

In this picture-word interference task, participants were asked to name a picture that was superimposed by a Dutch distractor word printed in red. The picture was always a morphed figure. The distractor word was related to the dominant or nondominant object of a morphed figure. Furthermore, the distractor word was identical, semantically related or unrelated to the target. For example, for a morphed figure consisting of 70% church (dominant object) and 30% duck (nondominant object), the identical words were *church* and *duck*, the semantically related words were *palace* and *bee*, and the unrelated words could be *newspaper* and *key*. An experimental run consisted of 324 experimental trials (9 morph series x 6 morphed figures x 6 distractor words). In advance, participants were familiarized with the pictures and their correct object names. These were the 100% figures (the extremes) that were used for the interpolation of the morph series. They were presented successively with their object name printed below the figure. Subsequently, participants were instructed to name the pictures as quickly and accurately as possible using the voicekey and to ignore the distractor word. Next, eight practice trials were presented containing nonexperimental stimuli that followed the same sequence as the experimental trials. First, a fixation cross was presented on the center of the screen for 1500 milliseconds (ms). Subsequently, the target picture was presented (morphed figure) superimposed by a distractor word for a maximum of 2000 ms. The display cleared when a response was triggered. Next, the experimenter rated the verbal response of the participant, after which the next trial started. The target picture and distractor word were presented simultaneously (i.e. SOA 0), because in most studies a semantic interference effect was observed using an SOA close or equal to zero (Bloem & La Heij, 2003; La Heij et al., 1990; Mädebach, Oppermann, Hantsch, Curda, & Jescheniak, 2011; Sailor et al., 2009).

Results

From all responses, 91.2% was recorded as dominant responses (see Table 6.1 for the mean percentage dominant responses for each condition), 5.0% as nondominant responses (see Table 6.2 for the mean percentage nondominant responses for each condition), 2.2% as alternative responses and 1.7% as voicekey errors. The reaction times (RTs) in ms were analysed including only the dominant responses. The mean RT observed for the different conditions are presented in Table 6.3 for the participant means and in Table 6.4 for the item means. In addition, the trials with a RT below 200 ms (0.3%) or above 3 standard deviations of the mean RT per participant (0.7%) were discarded from further analyses.

Table 6.1. Mean percentage dominant responses and their standard error of the mean in brackets (also expressed in percentages) across participants for all conditions. The columns represent the different morphing levels and the rows represent the different distractor word types. The first column refers to whether the distractor word is related to the dominant or nondominant object of the morphed figure and the second column refers to the type of relation between the distractor word and one of the objects in a morphed figure.

			Morphing	
dominance	**relation**	**80%20%**	**70%30%**	**60%40%**
dominant	identical	97.0 (0.6)	96.4 (0.7)	92.6 (1.1)
	unrelated	95.5 (0.9)	92.5 (1.2)	86.5 (1.6)
	semantic	95.5 (1.2)	93.6 (1.5)	85.7 (1.6)
nondominant	identical	93.9 (1.0)	88.1 (1.7)	78.1 (1.8)
	unrelated	95.6 (1.2)	91.2 (1.4)	84.4 (1.7)
	semantic	93.5 (1.1)	93.9 (1.2)	86.9 (1.5)

Table 6.2. Mean percentage nondominant responses and their standard error of the mean in brackets (also expressed in percentages) across participants for all conditions. See the subscription of Table 6.1 for an explanation of the headings.

			Morphing	
dominance	**relation**	**80%20%**	**70%30%**	**60%40%**
dominant	identical	0.2 (0.2)	2.1 (0.5)	5.6 (0.9)
	unrelated	1.5 (0.5)	2.7 (0.6)	9.6 (1.3)
	semantic	0.9 (0.4)	3.4 (0.7)	8.3 (1.2)
nondominant	identical	1.9 (0.6)	6.7 (1.4)	17.4 (1.5)
	unrelated	1.3 (0.5)	3.7 (0.7)	10.3 (1.4)
	semantic	2.1 (0.5)	2.5 (0.6)	9.4 (1.2)

Table 6.3. Mean RT in ms of the dominant responses and their standard error of the mean in brackets (also expressed in ms) across participants for each condition. See the subscription of Table 6.1 for an explanation of the headings.

Participant Means (F_1)			**Morphing**	
dominance	**Relation**	**80%20%**	**70%30%**	**60%40%**
dominant	Identical	663 (14)	680 (16)	717 (17)
	Unrelated	776 (17)	790 (17)	811 (15)
	Semantic	796 (18)	835 (19)	855 (21)
nondominant	Identical	800 (17)	812 (20)	861 (20)
	Unrelated	768 (17)	790 (15)	845 (21)
	Semantic	769 (16)	788 (15)	842 (20)

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Table 6.4. Mean RT in ms of the dominant responses and their standard error of the mean in brackets (also expressed in ms) across item for each condition. See the subscription of Table 6.1 for an explanation of the headings.

Item Means (F_2) dominance	**Relation**	**Morphing** 80%20%	70%30%	60%40%
dominant	Identical	661 (9)	679 (12)	718 (18)
	Unrelated	775 (10)	792 (18)	813 (15)
	Semantic	798 (15)	834 (16)	849 (17)
nondominant	Identical	803 (26)	813 (27)	868 (24)
	Unrelated	769 (16)	790 (12)	849 (20)
	Semantic	769 (14)	788 (14)	847 (18)

Repeated Measures ANOVAs were performed with *Morphing* (three levels: 80%20%, 70%30% and 60%40% figures), *Dominance* (two levels: distractor word was related to dominant or nondominant object) and *Relation* (three levels: distractor word was identical, semantically related and unrelated) as within-subject variables for the participant means F_1 and as within-series variables for the item means F_2. Bonferroni corrected posthoc comparisons were performed for significant effects at an alpha-level of .05.

The main effect of *Morphing* was significant, $F_1(2,58) = 70.10$, $p < .001$, partial $\eta^2 = .71$ and $F_2(2,16) = 103.77$, $p < .001$, partial $\eta^2 = .93$. All morphing levels differed significantly from each other, with fastest RTs for 80%20% figures, followed by 70%30% figures and slowest RTs for 60%40% figures.

The main effect of *Dominance* was significant, $F_1(1,29) = 58.12$, $p < .001$, partial $\eta^2 = .67$ and $F_2(1,8) = 59.56$, $p < .001$, partial $\eta^2 = .88$. Dominant distractor words resulted in faster RTs than nondominant distractor words.

The main effect of *Relation* was significant, $F_1(2,58) = 50.53$, $p < .001$, partial $\eta^2 = .64$ and $F_2(2,16) = 22.93$, $p < .001$, partial $\eta^2 = .74$. The RTs in the identical condition were shorter than in the semantically related and unrelated condition. The semantically related and unrelated words differed significantly for the participant means, with longer RTs obtained for the semantically related condition than for the unrelated condition. The latter did not differ significantly for the item means, though a marginal effect ($p = .08$) was revealed by the posthoc comparisons, showing a similar trend as was found for the participant means.

The interaction effect of *Morphing* and *Dominance* was significant, $F_1(2,58) = 3.80$, $p < .05$, partial $\eta^2 = .12$ and $F_2(2,16) = 6.99$, $p < .01$, partial $\eta^2 = .47$. Despite the fact that all conditions differed significantly from one another according to the posthoc comparisons, this significant interaction effect is probably caused by the fact that the linear increase of RT from 80%20% to 70%30% and next to 60%40% morphing level observed for figures superimposed by a dominant distractor word was not observed for figures superimposed by a nondominant distractor word. For the nondominant distractor words, a steeper increase of RT is observed from 70%30% to 60%40% morphing level than from 80%20% to 70%30%. However, it should be noticed that the effect size of this interaction effect is quite small, reducing the impact of this finding.

The interaction of *Morphing* and *Relation* was not significant, $F_1(4,116) = 0.56$, $p > .65$, partial $\eta^2 = .02$ and $F_2(4,32) = 0.48$, $p > .70$, partial $\eta^2 = .06$. This means that the effects reported above for the different relations between distractor words and morphed figure were not significantly different for the different levels of morphing.

Most importantly, the interaction effect of *Relation* and *Dominance* was also significant, $F_1(2,58) = 120.15$, $p < .001$, partial $\eta^2 = .81$ and $F_2(2,16) = 49.67$, $p < .001$, partial $\eta^2 = .86$. For the dominant distractor words, the identical words facilitated the naming of a morphed figure compared to the unrelated words ($p < .001$), while the semantically related words interfered with the naming of a morphed figure ($p < .01$). For the nondominant distractor words, an interference effect was observed for the identical words compared to the semantically related ($p < .001$) and unrelated words ($p < .05$). The semantically related and unrelated words did not differ ($p = .60$). Moreover, this difference was only found for the participant means. Although the RTs for the item means showed a similar pattern (longer RTs for the nondominant identical words in contrast to the nondominant semantically related and unrelated words), these conditions did not differ significantly ($p = .48$ and $p = .56$, respectively). The absence of a significant difference might be due to the small number of morph series. In Figure 6.1, this interaction effect is presented for the participant means.

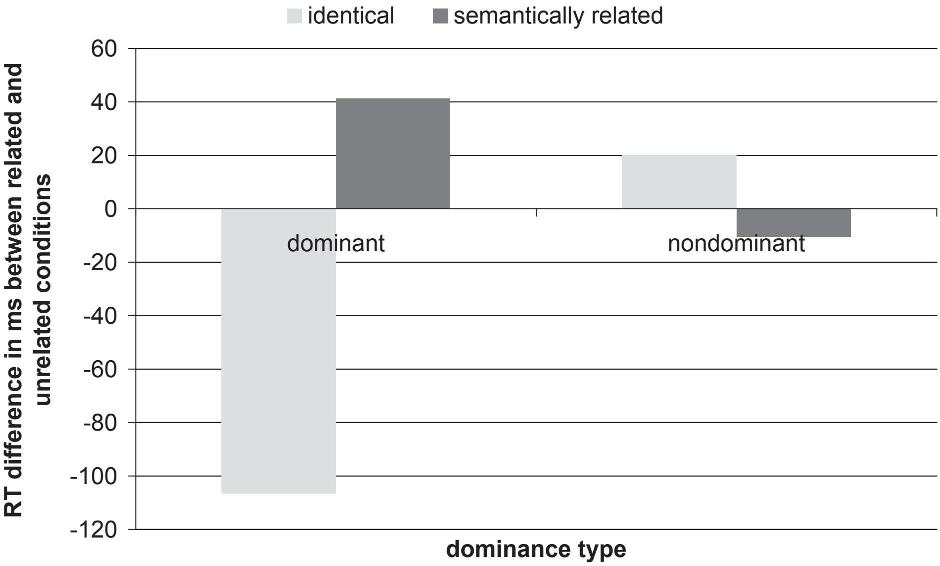

Figure 6.1. The differences in RT in ms between the related conditions and the unrelated condition for the interaction effect of *Relation* and *Dominance*. The mean RT of the unrelated condition is subtracted from the mean RT of the related condition. Thus, a positive bar indicates longer RTs for the related condition compared to the unrelated condition, whereas a negative bar indicates shorter RTs for the related condition compared to the unrelated condition. The related condition is either the identical condition (light grey bars; e.g. the distractor word *duck* for a morphed figure of the morph series *Duck-Church*) or the semantically related condition (dark grey bars; e.g. the distractor word *bee* for a morphed figure of the morph series *Duck-Church*). The related conditions are presented separately for the distractor words that are related to the dominant object (left two bars; e.g. the distractor word *duck* for the 70%30% figure of the *Duck-Church* morph series) and to the nondominant object of a morphed figure (right two bars; e.g. the distractor word *church* for the 70%30% figure of the *Duck-Church* morph series).

The three-way interaction of *Morphing*, *Dominance* and *Relation* was not significant, $F_1(4,116) = 0.96$, $p > .40$, partial $\eta^2 = .03$ and $F_2(4,32) = 0.56$, $p > .65$, partial $\eta^2 = .07$. This suggests that the significant differences observed for the two-way interaction between *Dominance* and *Relation* did not differ for the different levels of morphing.

Discussion

In the current experiment, a picture-word interference task was conducted in which the level of morphing of morphed figures was varied. In addition, distractor words were presented that were identical, semantically related or unrelated to either the dominant or the nondominant object in the morphed figure. The response latencies of the dominant responses were computed both over participants and over items. In general, the results of the item means were similar to those of the participant means, although not all effects that were significant for the participant means were significant for the item means. This lack of significance is probably due to the small number of morph series in our experiment. Although one expects items to be processed similarly, items will always differ. The variability between items plays a larger role when using a relatively small set size in comparison to a larger set size (see also La Heij & van den Hof (1995) who studied the effects of set size in a picture-word interference paradigm). Moreover, we found the following results: First of all, an increase of morphing level (from 80%20% to 60%40%) meant also an increase in response time. This corresponds to the idea that an increase of morphing level causes an increase of uncertainty that is expressed in longer response latencies. Furthermore, the distractor words related to the dominant object caused faster response times than the ones related to the nondominant object. This is probably due to the stronger presence of the dominant object in a morphed figure than the nondominant object leading also to more influence of the distractor words related to the dominant object than related to the nondominant object. In addition, the identical words facilitated the naming process, whereas the semantically related words induced interference. The reported interaction between *Dominance* and *Morphing* was caused by a larger difference in reaction time between the 70%30% and 60%40% condition for the distractor words related to the nondominant object than for the distractor words related to the dominant object. This suggests that the nondominant object in a morphed figure is more strongly present in the 60%40% figure than in the 70%30% figure. As a consequence, distractor words related to the nondominant object have a greater impact on the naming process when they concern a figure at a 60%40% morphing level than at another morphing level. This might be explained by the increased perceptual uncertainty, leaving more space for interference (see also De Houwer, Hermans, & Spruyt, 2001). Most interestingly, an interaction was found between *Dominance* and *Relation*. For the distractor words related to the dominant object of a morphed figure, a facilitation effect was shown for the identical words and an interference effect for the semantically related words. Moreover, the distractor words related to the nondominant object showed a different effect on the naming latencies. The identical words interfered with the naming of the morphed figure, whereas semantically related words had no effect on the naming process. This suggests that the naming process of a morphed figure as its dominant object is facilitated by distractor words identical to the dominant object and is disturbed by distractor words semantically related to the dominant object. In contrast, the naming process is only affected by a nondominant distractor word when it is identical to the nondominant object.

Experiment 2

The context effects reported in Experiment 1, in particular the lack of semantic interference in the nondominant semantically related condition, might have been due to the fact that the semantically related words were not members of the response set, whereas the identical words always were part of the response set. As La Heij (1988; see also La Heij, 1990; Levelt, Roelofs, & Meyer, 1999; Roelofs, 1992, 2001; but see also Caramazza & Costa, 2000, 2001) has shown, unrelated words that belong to the response set interfered more with naming than unrelated words that did not belong to the response set. This might have to do with the difference in strength of lexical activation between distractor words that are produced and repeated due to their response set membership and distractor words that are not produced and not repeated due to their nonmembership to the response set. In Experiment 2, therefore, in order to control for this effect we only used distractor words that were also part of the response set.

Method

Participants

Twenty-three students from Utrecht University participated in the current experiment. These were all different participants than the participants who volunteered for Experiment 1. Three of them were excluded from further analyses; two of them were nonnative speakers of Dutch and one of them did not respond within the restricted presentation time of a target (2000 ms) in about 30% of the trials. The experiment lasted about half an hour and participants received 3 Euros or a course credit for their contribution.

Materials

To control for possible response set effects (La Heij, 1988), only distractor words were used in the present experiment that were also object names of the extreme objects (100% figures) of the other experimental morph series. Due to the criterion that all distractor words should be part of the response set, extreme objects of the morph series used in the current experiment functioned both as semantically related and unrelated words. This means that other morph series were selected than the ones in Experiment 1, since the extreme objects of those morph series were not semantically related to any extreme object of the other experimental morph series. Pairs of morph series were selected of which the extremes were semantically related to one another.

For example, the *Car-Turtle* series was coupled to the *Peacock-Truck* series: *car* and *truck* were both members of the category *vehicle*, and *turtle* and *peacock* were both members of the category *animal*. Four pairs of morph series were selected, (*Car-Turtle* and *Peacock-Truck*, *Airplane-Crocodile* and *Pram-Squirrel*, *Arm-Banana* and *Apple-Heart*, *Bell-Kettle* and *Lamp-Man*). In addition, the unrelated distractor words belonged to the extreme objects that were not semantically related to the morph series in question (the morph series *Arm-Banana, Apple-Heart*, *Bell-Kettle* and *Lamp-Man* functioned as unrelated words for the series *Car-Turtle*, *Peacock-Truck*, *Airplane-Crocodile* and *Pram-Squirrel*, and vice versa). The pairs *Bell-Kettle* and *Lamp-Man* were not semantically related to each other, but were added to balance the distribution of unrelated words. Trials containing a morphed figure of one of these series were therefore not taken into account when analysing the data.

Procedure

The instructions and procedure in the current experiment were similar to the instructions and procedure of Experiment 1, except for the morph series and, therefore, the object pictures that were presented during the familiarization phase. Furthermore, an experimental run now consisted of 288 trials instead of 324 trials due to the reduction in number of morph series from nine to eight. This also meant that after 96 trials (instead of 108) a self-timed break was included.

Results

From all responses, 89.8% was recorded as dominant responses, 5.1% as nondominant responses, 1.5% as alternative responses and 3.6% as voicekey errors. The reaction times (RTs) in ms were analysed including only the dominant responses and excluding the trials containing a figure of one of the series *Bell-Kettle* and *Lamp*-Man. The trials with an RT below 200 ms (0.5%) and above 3 standard deviations of the mean RT (RT>1539; 1.7%) were discarded from further analyses. The mean RT found for the different conditions are presented in Table 6.5 for the participant means and in Table 6.6 for the item means.

Table 6.5. Mean RT in ms of the dominant responses and their standard error of the mean in brackets (also expressed in ms) across participants for each condition. See the subscription of Table 6.1 for an explanation of the headings.

Participant Means (F_1) dominance	**Relation**	**Morphing** 80%20%	70%30%	60%40%
dominant	Identical	707 (27)	722 (24)	798 (27)
	Unrelated	824 (20)	813 (23)	842 (29)
	Semantic	833 (20)	842 (23)	883 (27)
nondominant	Identical	835 (25)	849 (20)	927 (22)
	Unrelated	796 (24)	838 (24)	847 (23)
	Semantic	823 (23)	861 (24)	887 (27)

Table 6.6. Mean RT in ms of the dominant responses and their standard error of the mean in brackets (also expressed in ms) across items for each condition. See the subscription of Table 6.1 for an explanation of the headings.

Item Means (F_2) dominance	**Relation**	**Morphing** 80%20%	70%30%	60%40%
dominant	Identical	705 (9)	719 (13)	792 (17)
	Unrelated	822 (33)	813 (27)	842 (15)
	Semantic	834 (27)	838 (22)	889 (24)
nondominant	Identical	834 (20)	852 (23)	935 (31)
	Unrelated	797 (16)	840 (24)	851 (33)
	Semantic	826 (24)	862 (33)	887 (8)

The same analyses were performed as in Experiment 1. Repeated Measures ANOVAs were performed with *Morphing* (80%20%, 70%30% and 60%40% figures), *Dominance* (word related to dominant or nondominant object) and *Relation* (identical, semantically related and unrelated) as within-subject variables for the participants means F_1 and as within-series variables for the item means F_2. Subsequently, Bonferroni corrected posthoc comparisons were conducted for significant effects at an alpha-level of .05.

All three main effects were significant. First, the main effect of *Morphing* was significant, $F_1(2,38) = 33.29$, $p < .001$, partial $\eta^2 = .64$ and $F_2(2,10) = 34.55$, $p < .001$, partial $\eta^2 = .87$. All three levels differed significantly for the participant means with shortest RTs for the 80%20% figures, followed by the 70%30% figures and the longest RTs were observed for the 60%40% figures. For the item means, the RTs observed for the 80%20% figures and 70%30% figures were marginally different ($p = .07$), but were significantly shorter than the RTs for the 60%40% figures. The increase in RT with increasing morphing level was observed for both types of means.

Furthermore, the main effect of *Dominance* was also significant, $F_1(1,19) = 57.23$, $p < .001$, partial $\eta^2 = .75$ and $F_2(1,5) = 36.17$, $p < .01$, partial $\eta^2 = .88$. When distractor words were related to the dominant object of the morphed figure, RTs were shorter than when distractor words were related to the nondominant object for both the participant and the item means.

The main effect of *Relation* was also significant, $F_1(2,38) = 40.88$, $p < .001$, partial $\eta^2 = .68$ and $F_2(2,10) = 15.69$, $p < .01$, partial $\eta^2 = .76$. For both types of means, the RTs for the identical conditions were shorter than the RTs for the unrelated and semantically related conditions. In addition, the RTs for the semantically related condition were significantly longer than the RTs for the unrelated condition for the participant means, but not for the item means.

The interaction between *Morphing* and *Dominance* was not significant, $F_1(2,38) = 1.64$, $p > .20$, partial $\eta^2 = .08$ and $F_2(2,10) = 2.86$, $p > .10$, partial $\eta^2 = .36$. The absence of a significant effect indicates that the increase in RT observed for higher morphing levels was not different for distractor words related to the dominant or nondominant object of a morphed figure.

The interaction effect of *Morphing* and *Relation* was significant, $F_1(4,76) = 3.66$, $p < .01$, partial $\eta^2 = .16$ and $F_2(4,20) = 3.34$, $p < .05$, partial $\eta^2 = .40$. For the 80%20% and 70%30% levels of morphing, the RTs were shortest for the identical condition and longest for the semantically related condition, whereas for the 60%40% morphing level the shortest RTs were found for the unrelated condition, though the RTs for the identical condition were still shorter than for the semantically related condition.

The interaction effect of *Dominance* and *Relation* was also significant, $F_1(2,38) = 42.05$, $p < .001$, partial $\eta^2 = .69$ and $F_2(2,10) = 17.17$, $p < .01$, partial $\eta^2 = .77$. Posthoc comparisons revealed that the participant and item means in the dominant conditions showed a similar pattern to the main effect of *Relation* in that shorter RTs were observed in the identical condition and longer RTs in the semantically related condition. More interestingly, the distractor words related to the nondominant object showed longer RTs in the identical and semantically related conditions in comparison to the unrelated condition for the participant means ($p < .001$ and $p < .05$, respectively). These differences were not observed for the item means ($p = .14$ and $p = .08$, respectively), though the response latencies reflected a similar trend as obtained for the participant means. This means that naming was slowed down by identical and semantically related words related to the nondominant object. The absence of any effect for the item means is probably due to the small number of morph series used in the current analyses.

The three-way interaction *Morphing*, *Dominance* and *Relation* was not significant, $F_1(4,76) = 0.72$, $p > .55$, partial $\eta^2 = .04$ and $F_2(4,20) = 0.36$, $p > .80$, partial $\eta^2 = .07$. The interaction effect found for *Dominance* and *Relation* therefore did not differ for the different levels of morphing.

Discussion

In this experiment, a picture-word interference task was conducted in which all distractor words were part of the response set in order to control for possible response set effects. The results were very similar to the results observed in Experiment 1, except for the interaction effect between *Dominance* and *Relation*. We therefore replicated the context effects of Experiment 1: Dominant identical words again induced facilitation, whereas the dominant semantically related words again induced interference of the naming process. In contrast, the distractor words related to the nondominant object diverged from the results of Experiment 1. Although the nondominant identical words still induced interference, the nondominant semantically related words now also induced interference in relation to unrelated words, instead of having no effect on the naming process. Clearly, inclusion in the response set indeed increases the likelihood of finding semantic interference, as was already suggested by Roelofs (2001). This difference in results between the two experiments will be discussed further in the *General Discussion*.

General Discussion

The aim of the current study was to investigate to what extent response candidates are activated during visual object categorization. Response candidates might be activated up to a perceptual level but also up to a semantic level. With the former we mean that only visual information is available and the activation of response candidates takes place on basis of their perceptual similarity to the visual input. Semantic information concerns the category an object belongs to (i.e. semantic-category or semantic-coordinate) and might also become available during activation stage of response candidate. If not, then visual categorization is purely perceptual. We conducted two picture-word interference experiments to investigate whether repetitive (dog-dog) and semantic context (cow-dog) interfered with the processing of a morphed figure. Participants were asked to name a morphed figure and to ignore the superimposed distractor word. The word was related to either the dominant or the nondominant object of a morphed figure. This relation between morphed figure and distractor word was identical, semantically related or unrelated. In Experiment 1, the semantically related and unrelated words were not part of the response set. In Experiment 2, the effects of response set membership were examined by using only distractor words that were all part of the response set.

The distractor words related to the dominant object affected the response latencies similarly as has been reported previously by other picture-word interference studies (Glaser & Düngelhoff, 1984; Sailor et al., 2009). On the one hand, the naming of a morphed figure as its dominant object was facilitated by a distractor word that was identical to the dominant object of a morphed figure, and on the other hand, the naming was slowed by a distractor word that was semantically related to the dominant object. This is in line with the general finding from picture-word interference studies that the naming process is facilitated by identical words (dog-dog) and disturbed by semantically related words (cow-dog). The latter finding suggests that during the naming process, information about other members of the same category is also activated. This is consistent with spreading activation accounts (e.g. Levelt et al. 1999; Roelofs, 1992; Starreveld & La Heij, 1996). According to these accounts, both the picture and the word activate their own lexical representation that will compete for verbal response production. However, the picture will also activate (semantically) related lexical representations, such as other animal names. A semantically related lexical representation will therefore not only be activated by the word that is shown but also by the spreading activation generated by the picture, making the lexical representation of the distractor word a serious competitor for naming. As a consequence, the response latencies will increase due to the elevated competition between the lexical representations.

However, the picture-word interference tasks use clearly identifiable objects which cannot reveal whether semantic information is only activated for the preferred response candidate or also for alternative response candidates. In our study, the influence of distractor words related to the nondominant object gave further insight into the level of activation of the alternative response candidates, i.e. nondominant response candidates. In Experiment 1, we found that distractor words related to the nondominant object also interfered with the naming of a morphed figure as its dominant object, but only when a distractor word was identical to the nondominant object, and not when it was semantically related to the nondominant object. These findings support the idea that the activation of alternative response candidates can be increased by repetitive context causing more response competition between the preferred and alternative response candidates. However, the absence of an effect by the semantically related nondominant distractor words indicates that the response competition is not influenced by the semantic context. In other words, response candidates are represented at a perceptual level and not at a semantic level.

One might argue that the absence of semantic interference for nondominant distractor words may be due to response set membership. In Experiment 1, identical words were always members of the response set, whereas the semantically related and unrelated words were not. Roelofs (2001; see also La Heij, 1988; Levelt et al., 1999; Roelofs, 1992) for instance, showed that semantic interference was only found when the response set was small and repeated over trials. This way, the response set and its related lexical nodes were kept active in short-term memory. Hence, interference might be induced by nondominant semantically related words if they are members of the response set. In Experiment 2, therefore, the semantically related words were made part of the response set. We found that the nondominant semantically related words indeed caused interference of the naming process. This finding, however, cannot be fully ascribed to the difference in response set membership between Experiment 1 and 2, because we also obtained semantic interference when the distractor words were not part of the response set (Experiment 1). In addition, others have also found semantic interference when the response set did not contain all distractor words (Caramazza & Costa, 2000, 2001). Nevertheless, the difference in short-term memory load between the two experiments might have played a role in the observed differences in semantic interference; in Experiment 2, the lexical nodes corresponding to all distractor words may be activated at the lexical level due to the small and repeated response set (i.e. sixteen distractor words) and not only the selected one.

An on-going debate within the literature describing the picture-word interference effect concerns the locus of interference. Some argue that semantic knowledge is already coactivated in an earlier stage of the naming process (Dell'Acqua, Job, Peressotti, & Pascali, 2007; Starreveld & La Heij, 1996; Roelofs, 1992), whereas others argue that this kind of information interferes with the naming process after a response is selected (Bloem & La Heij, 2003; Bloem, van den Boogaard, & La Heij, 2004; Levelt, 1989), or even at the final stage of the production process where only one output can be articulated at a time (Mahon, Costa, Peterson, Vargas, & Caramazza, 2007). The conceptual selection model or CSM by Bloem and colleagues (Bloem & La Heij, 2003; Bloem et al., 2004) seems most in accordance with the present findings. In their model, the picture and word are first represented at a conceptual level. Only the selected concepts will reach the next stage, the lexical level. At this level, spreading activation takes place leading to interference when the distractor word is semantically related to the picture.

We have shown that identical words related to both the dominant and nondominant object induced the naming process by facilitation or interference, respectively. From these findings we can infer that despite the fact that the majority of the responses were the dominant interpretation, both the dominant and nondominant object are activated up to the perceptual level (i.e. conceptual level according to Bloem & La Heij, 2003; Bloem et al., 2004). Moreover, after one of the activated response candidates is selected, this concept will be processed up to a next level where semantic information plays a part (i.e. the lexical level according to Bloem & La Heij, 2003; Bloem et al., 2004). This is also indicated by the semantic interference induced by distractor words semantically related to the dominant object. However, the nondominant object did not automatically reach this level. It only occurred under restricted paradigm conditions in which all distractor words were also members of the response set. Bloem and colleagues have dealt with a similar problem by incorporating 'task input' as a factor in their model. Differences in task instructions (e.g. a semantically related word induces interference when instructed to name the picture at its basic level, and the same word induces facilitation when instructed to name the picture at its superordinate level) may lead to processing of distractor words at different levels during the naming process. The effects of response set membership when taking into account a 'task input' factor might provide an explanation for the differences between the two experiments.

Furthermore, it was observed that the level of morphing also influenced the naming process. Clearly, the more information a figure contained regarding the nondominant object, the longer the response latencies were. This suggests that the response competition between the dominant and nondominant response candidate was enhanced with increased morphing level, assuming that longer latencies indicate more response competition. Alternatively, one might argue that it is the increase in uncertainty causing the longer response latencies instead of the enhancement of the activation of the nondominant response candidate. Uncertainty, in this case, refers to having difficulties recognizing any object in the visual input. However, we should note that there was a considerable increase in the number of nondominant responses for the higher morphing levels. If it had been just overall uncertainty, we would have expected an overall increase of alternative responses and not specifically an increase of nondominant responses.

Based on our findings, we conclude that semantic information is probably not activated during the response competition stage, but only begins to play a role once a response candidate has been selected. This idea is in accordance with Bar's explanation of object recognition. Bar (2003) proposed that semantic knowledge is added to a concept at a post-recognition stage. Moreover, object identification was suggested to be an unfolding process (Yee, Huffstetler, & Thompson-Schill, 2011) in which the perceptual features are processed first and during a later stage the abstract features (i.e. the function of an object, or in our words, semantic information) are processed. Our results subscribe to this generally held tenet. Notably, the model by Bloem and colleagues (Bloem & La Heij, 2003; Bloem et al., 2004) proposes semantic *facilitation* at the perceptual level (i.e. conceptual level). The current findings contradict that part of the model, because we found that semantic information only affects the selected response candidate, thus at the semantic level (i.e. lexical level). Further research should reveal whether other types of information related to the nondominant object might interfere with the categorization process of morphed figures.

7

The Relation between Gaze Behaviour and Categorization: Does Where We Look Determine What We See?

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Abstract

When categorizing an object, we fixate our eyes on informative parts of the object. In the current study, morphed figures were used to investigate whether the interpretation of such unclear objects is reflected in the eye movement pattern. The morphed figures were created by interpolating two concrete objects. The intermediate steps represent figures that contain properties of both objects, but in different proportions. Three experiments were conducted to investigate the relation between categorization and gaze behaviour. In all three experiments, free-naming responses and eye movements were recorded simultaneously. The first experiment showed that there is a strong relation between the interpretation and the fixated part of the figure. The next question concerned whether gaze patterns drive categorization or vice versa. In the second experiment, morphed figures were preceded by a prime word. A priming effect on categorization was found, but not on gaze behaviour. In the third experiment, a cue directed the observer's gaze to a particular location on the morphed figure. Interestingly, the cueing experiment showed a cueing effect not only on gaze behaviour but also on categorization. Taken together, these findings suggest that where we look affects how we interpret an ambiguous visual stimulus.

Introduction

The eyes are the entrance to the external visual world. In particular the foveal area of our retina provides us with sharp and detailed information. Therefore, if we examine someone's scan path we can register which information is focussed on and is important for the interpretation of the visual input. Decades ago, the relation between categorization and gaze behaviour was already observed by Ellis and Stark (1978). They detected a correspondence between interpreting the Necker cube as facing leftwards or rightwards and the specific line of the cube which was fixated. In addition, Yarbus (1967) reported that when his participant was exploring a human face, the eyes, nose and mouth were important features of the face which were fixated. More recently, gaze patterns were examined for faces viewed from different viewpoints (Chelnokova & Laeng, 2011; Sæther, Van Belle, Laeng, Brennen, & Øvervoll, 2009). Interestingly, the centre part of the human face that was most frequently fixated when presented in frontal view was also most frequently fixated when the viewpoint was changed. The head and eyes of animate objects are important aspects to which our eyes are drawn (Cerf, Frady, & Koch, 2009; Drewes, Trommershäuser, & Gegenfurtner, 2011; Judd, Durand, & Torralba, 2011; Kovic, Plunkett, & Westermann, 2009).

Kovic and colleagues (2009) investigated the relation between categorization and gaze behaviour by examining the effect of mental representations on the gaze behaviour of animate objects. The object (e.g. picture of a cat) that had to be scanned was preceded by a sentence that could either be "look at the picture", "what's this?" or "look at the cat". The latter reinforces the activation of a mental representation of a cat before the picture of a cat is presented. This mental representation could guide participants towards focusing on cat-specific features, whereas the other two questions leave them in ignorance of what to expect. No differences in scan paths were observed between the different conditions. This suggests that the gaze behaviour was not directly affected by the expectation activated by the previously presented word. Moreover, in a study by Georgiades and Harris (1997), the dominance of an ambiguous figure (wife/mother-in-law figure) was influenced by placing a cue at a critical feature. If the cue was placed near the position of the 'wife's eye' a tendency was reported to interpret the figure more often as the wife than as the mother-in-law. They showed that the feature that was looked at can affect the interpretation of the visual input. The opposite pattern observed in these two studies seems counterintuitive, because expectations of the upcoming event play an important role in our gaze behaviour (Hunnius & Bekkering, 2010; Land, Mennie, & Rusted, 1999). For instance, when making tea, the eyes are directed to the location important for the next step in executing the action (Land et al., 1999). One possible explanation of the absence of a priming effect against the presence of a cueing effect might be the difference in stimulus materials. In the study by Kovic and colleagues clear and unambiguous pictures were used, while in the study by Georgiades and Harris an ambiguous stimulus was used. The difference in ambiguity might have different effects on categorization and could, therefore, also have different effects on gaze behaviour.

In a study by Judd and colleagues (2011), the strength of the relation between categorization and gaze behaviour was further explored by varying the resolution of photographs of scenes. They showed that fixation locations registered for low-resolution images predict fixation locations found for high-resolution images. Despite the fact that some images were presented at a very low resolution, the pattern of fixation locations was still comparable to the ones found for the high-resolution images. The predictability of the low-resolution images of the scan path of the high-resolution images indicates that the uncertainty caused by the low-resolution of the image still makes that observers fixate on the same locations of the scene: the relation between categorization and gaze behaviour therefore seems to be strong which is also apparent under visually uncertain circumstances.

In the current study, we investigated the direction of the relation between categorization and gaze behaviour using ambiguous stimuli: does categorization directs gaze behaviour or does gaze behaviour directs categorization? The stimulus set consisted of so-called morphed figures, stimuli created by changing one object into another object with small linear steps. The intermediate steps represent figures that contain properties of both objects, but all in different proportions. Using morphed figures makes it possible to examine whether the uncertainty in categorization is also reflected in the gaze behaviour (Experiment 1). In addition, by manipulating either the categorization or the gaze behaviour of the morphed figures new insights are provided on how they influence one another (Experiment 2 and 3, respectively).

Experiment 1

In the current experiment, it was examined whether categorizing individually presented morphed figures also yields a correspondence in the interpretation of a morphed figure and the fixation pattern. This relation was tested by conducting a free-naming experiment in which response and eye fixations were recorded simultaneously. The scan paths obtained for the extreme figures of a morph series (nonmorphed figures) were used to identify the regions of interest, such as the head of an animal. The frequency of trials in which the free-naming response corresponded to the fixated area was contrasted to the frequency of trials in which they did not correspond. A higher frequency of the former in comparison to the latter confirms the existence of a relation between the categorization and the gaze behaviour obtained for morphed figures.

Methods

Subjects

Twenty-one students of Utrecht University and Hogeschool Utrecht participated in this experiment (5 male and 16 female; *M* = 23.8 years old, *SD* = 3.8 years). The experiment lasted about thirty minutes and participants received 6 Euros or one course credit for their contribution.

Materials

Morphed figures were created from black silhouette objects that were presented on a white background. Pairs of silhouette objects were interpolated in steps of 5% change using Sqirlz-Morph software (Xiberpix, version 2.0), resulting in morph series consisting of 19 interpolations and two extremes (cf. Hartendorp, Van der Stigchel, Burnett, Jellema, Eilers, & Postma (2010) for a description of the morphing procedure). From each complete morph series nine figures were selected: the 100%0%, 80%20%, 70%30%, 60%40%, 50%50%, 40%60%, 30%70%, 20%80% and 0%100% figures (approximately 4.29° x 3.34°, 7 cm x 9 cm). To reduce exposure to the same series as much as possible, only seven out of the 19 interpolations from each series were included as stimulus materials. Thirty morph series were used in the current experiment. Fifteen morph series were similar to the ones used in Hartendorp et al. (2010), here referred to as the *original dataset*. The original dataset was selected from a large set of contour drawings of a wide range of living and nonliving objects for which normative identification rates had been established (De Winter & Wagemans, 2004; Wagemans, De Winter, Op de Beeck, Ploeger, Beckers, & Vanroose, 2008), which in turn were derived from a set of line drawings validated by Snodgrass and Vanderwart (1980). Additionally, one figure (i.e. the *man* figure) was selected from a set of contour drawings by Downing, Bray, Rogers and Childs (2004). The remaining fifteen morph series, here referred to as the *new dataset*, consisted of extreme objects that had the same object name as the extreme objects in the original dataset. For instance, if we take one of the fifteen original morph series *Arm-Banana*, a new morph series was constructed by also interpolating a figure of an arm and a banana, but with different images of an arm and a banana than the ones used in the original dataset. The extreme figures of the new dataset were selected from Flickr (www.flickr.com), a website storing over more than five billion photos. The photos were restricted to be mostly covered by the object we were looking for and to have a high resolution. The selected photos were transformed into black silhouette objects presented on a white background using Adobe Photoshop CS (8.0, Adobe Systems, 2003). To validate the identification of the new black silhouettes, a verification task was conducted. In this task, twenty participants (different subjects than the ones tested in the current experiment) were asked to verify whether an object name and a subsequently presented picture (black silhouette) corresponded to one another. Only pictures were used for interpolation for which the corresponding word was easily verified as the correct object name of a picture. The reason for using extreme figures that were examples of the same categories as the extreme figures of the original dataset was to generalize eye movement patterns for different examples of the same category. Great overlap in gaze behaviour was observed. In Figure 7.1, a number of examples of extreme figures of morph series are presented in which this overlap is clearly visible. For instance, independent of car type, we move our eyes to the location where the driver's window should be. A complete overview of all thirty morph series can be found in Appendix A and B.

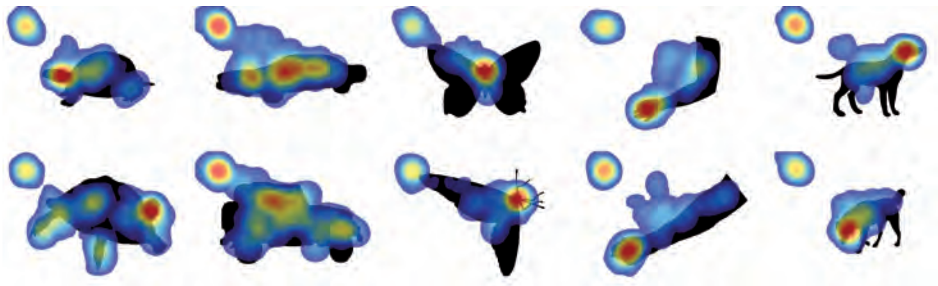


Figure 7.1. Heatmap examples of extreme figures of morph series. The upper row includes stimuli from the so-called original dataset, and the lower row from the so-called new dataset. The blob in the left top corner reflects the location of the fixation cross where observers started their scan path in a majority of the trials.

Apparatus

The stimuli were simultaneously presented on two separate displays. One display was used for presentation to the participant, the other to the experimenter. The experiment was designed using E-Prime (Psychology Software Tools Inc., version 1.2) and the additional TET package (TET: Tobii Eye Tracking, version 1.0.3.0). A voicekey was used to end stimulus presentation when triggered by a sound cue (e.g.

participant's response) and a Stimulus Response box (SR-box) was used to register the type of response. The eye tracker used was a Tobii 1750. For calibration of the Tobii eye tracker the Tobii software ClearView (version 2.7.1) was applied. Calibration of the participant's eyes was conducted prior to the experiment and was repeated after every 90 experimental trials.

Procedure

Participants were asked to interpret a single figure by means of a free-naming response. Although no specific time restrictions were included participants were instructed to respond as quickly as possible. Responses were registered by the voicekey. Participants were told to speak loudly and clearly and to avoid sounds like sighing and smacking, since the voicekey was sensitive to any kind of sound. In addition, their response could be any interpretation as long as their response consisted of one word. We informed them that there were no correct or incorrect responses; we were just interested in their interpretation. The figures were presented randomly with the restriction that a subsequent trial should contain a figure of another morph series. Participants were first asked to fixate for 1000 ms on a fixation cross in the top left corner of the screen. Subsequently, a figure of one of the morph series appeared at the centre of the screen. The figure stayed on the screen until the participant's response triggered the voicekey, after which the figure disappeared immediately. At the same time the eye movements were recorded. The recording of the eye movements started after the fixation cross disappeared and ended when the voicekey was triggered. After the figure disappeared, the experimenter coded the response (see section *Responses* for an explanation of the coding procedure of the responses). Next, the following trial started. An experimental run consisted of 270 trials (30 morph series x 9 figures per series). Prior to the experimental run, four practice trials were included that followed the same sequence as an experimental trial, though the stimulus was an extreme figure not included in the experiment.

Data Analysis

Eye Fixations

To test whether there is a relation between how we categorize an object and what we look at, we first had to decide which regions of an object are of our interest, so-called regions of interest (ROIs). As we know from the literature on gaze behaviour, many objects have a preferred feature what we look at while categorizing the object. For instance, we have a strong tendency to fixate on the head of an animal (Kovic et al., 2009). In addition, we prefer to look at the centre part of a human face independent of the orientation of the face (Sæther et al., 2009). We visualized gaze patterns by creating a heatmap of the eye fixations during the categorization process of an object. A heatmap is a graphical representation of the most frequently fixated areas of an image by using a colour gradient overlay. This colour gradient indicates the average viewing pattern. Red tones indicate the most frequently scanned spots of the image, whereas blue tones indicate lower fixation rates. The heatmaps of the extreme figures of the tested morph series (100%0% and 0%100% figures) were used to determine the ROIs corresponding to a particular interpretation of the series. We were interested whether the heatmap of a morphed figure matched the heatmap of one of its extreme figures. Each ROI covers a particular area of the visual display in which each pixel can be expressed in an xy-coordinate. In addition, the eye fixations are expressed in an xy-coordinate. Thus, if the xy-coordinate of the eye fixation falls within the range of xy-coordinates of the specified ROI, this eye fixation is interpreted as falling within a particular ROI. As an illustration, the heatmaps and their ROIs of the *Arm-Banana* series are presented in Figure 7.2.

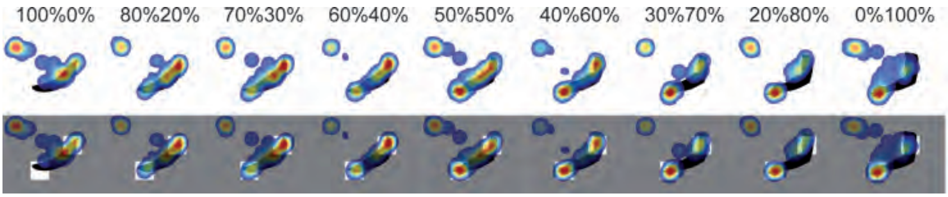


Figure 7.2. Heatmaps of the *Arm-Banana* series across all participants and across all responses. The upper row presents the heatmaps for each figure separately. The lower row presents the same heatmaps covered by the filter used to define the ROIs of the *Arm-Banana* series.

It was observed that the heatmap of the 100% *arm* has a ROI located at the position of the hand of the arm. If we demarcate this ROI by placing a square on top of this position, a particular area consisting of a number of xy-coordinates is created referred to as the ROI *arm*. The ROI *arm* and ROI *banana* had the same size (this holds for all series), but were placed on different locations of the visual display with the restriction that they should not have any overlap. The area of the visual display that was not occupied by either ROI *arm* or ROI *banana* is referred to as *outside ROIs*. The next step was to match the xy-coordinates of the eye fixations of a morphed figure to the xy-coordinates of the ROI *arm*. If they match, the eye fixation was labeled as ROI *arm*. Here, we were particularly interested in the ROI of the first fixation. Notably, in the current experiment, with the first fixation we actually mean the second fixation, because we expect the actual first fixation to be still on the position of the fixation cross. Therefore, the actual first fixation will be referred to as the *start fixation* and the actual second fixation as the *first fixation*. The morph series in which the ROIs showed overlap (e.g. morph series *Heart-Apple*) were deleted from further analyses, because eye fixations falling within this ROI could not be defined as falling either in one ROI or another ROI. Eventually, ten out of thirty morph series appeared to show overlap in their ROIs, and were, therefore, discarded.

Responses

The verbal responses were coded by the experimenter as either the object name of one extreme of the morph series, as the object name of the other extreme of the morph series, as an alternative object name (not the object name of one of the extreme figures of the morph series), or as a voicekey error. The latter was registered when the voicekey was triggered by another sound than the participant's response. For example, the response *banana* was coded as 1, the response *arm* as 2, the response *branch* as 3 and a sigh as 4. Due to the free-naming method, it is likely that participants would respond with a word other than the object names provided with the line drawings (Snodgrass & Vanderwart, 1980). On basis of the free-naming responses from a previous free-naming experiment partly using the same stimulus set (Hartendorp et al., 2010), the group of equivalent names was created which all referred to the same (verbal) category. For example, the words lizard and salamander were coded as correct interpretations for crocodile, pheasant and turkey for peacock and seal and walrus for sea lion. The exposure to these animals in daily life is too low to expect participants to recognize this specific object in the black silhouettes. In contrast, generalizations of words, such as bird for duck and rodent for rabbit, were not accepted as correct interpretations and were therefore labeled as alternative responses.

Fixations and Responses

An inspection of the heatmaps recorded for a morph series (see Figure 2) suggests a shift in the centre of gravity of the eye fixations halfway along the morph continuum from one region of interest (e.g. top right corner: ROI *banana*) to the other region of interest (e.g. bottom left corner: ROI *arm*). If these heatmaps are separated for type of response (e.g. heatmaps for *banana* responses and for *arm* responses), a distinct pattern is observable with a preference for the region of interest that fits the type of response, as is shown in Figure 7.3. The heatmaps of the morphed figures that were interpreted as a banana show a centre of gravity of the eye fixations at the top right corner (at the location of the banana stem) and the heatmaps of the figures interpreted as an arm show a centre of gravity of the eye fixations at the left bottom corner (at the location of the hand).

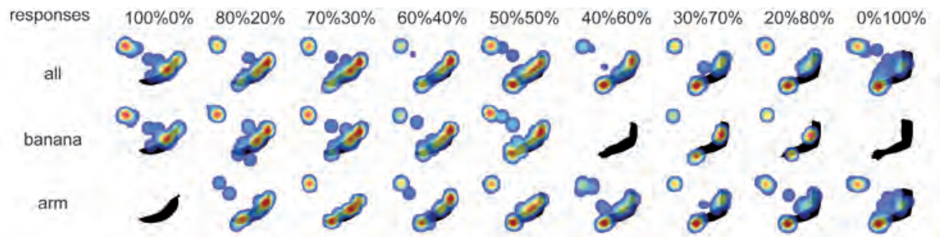


Figure 7.3. Heatmaps of the *Arm-Banana* series across all participants. The first row presents the heatmaps for all responses, the second row for the *banana* responses, and the third row for the *arm* responses.

The strength of the relation between gaze behaviour and the interpretation of the morphed figures was tested here by calculating the degree of correspondence between the eye fixations and the responses. First, it was tested whether looking at a particular ROI results in a corresponding response (i.e. *Response in relation to Region of Interest*). If the response corresponded to the ROI of the first fixation, this response was labeled as *equal* (ROI and response are equal). If the response did not correspond to the ROI of the first fixation, but corresponded to the ROI of the other extreme figure of the morph series, this response was labeled as *opposite*. If the response was an alternative interpretation, this response was labeled as *other*. The relation between categorization and gaze behaviour was also inspected from a response point of view: when we have given a particular response, did we also look at the corresponding ROI? Therefore, the ROI of the first fixation was compared to the response that was given (i.e. *Region of Interest in relation to Response*). If the ROI of the first fixation corresponded to the response, this ROI was labeled as *equal*. If the ROI of the first fixation did not correspond to the response, but was the other ROI of the morphed figure, this ROI was labeled as *opposite*. If the first fixation fell outside the ROIs this trial was labeled as *other*. A relation between the categorization and the gaze behaviour of morphed figures was ascertained when more *equal* trials (responses and ROIs) than *opposite* and *other* trials were observed.

Results

In total, the verbal responses and eye movement patterns were collected for 5670 trials (270 trials per experimental run x 21 subjects). First of all, from these trials, all trials containing a 100%0% and 0%100% figure as target were excluded since they were used to determine the ROIs (Regions of Interest). Subsequently, ten out of thirty morph series were excluded based on our restriction that the two ROIs of a morph series should show no overlap, leaving us with twenty morph series. Furthermore, all trials with a reaction time (RT) below 200 ms and above 10000 ms were discarded. To give a verbal response based on the visual input takes at least 200 ms, and it was expected that participants would be able to interpret a figure within 10000 ms, otherwise wild guessing might have taken place. In addition, all trials that were registered as voicekey errors or as missing gaze data (i.e. actual first fixations missing) were also discarded from further analyses, eventually leaving us with 2650 trials. The responses could either be one of the two interpretations (85.5%) or could be an alternative interpretation (14.5%).

The start fixation could be in one of the two ROIs (21.8%) or outside these two ROIs (78.2%). These percentages reflect the experimental paradigm, as participants started their gaze behaviour at the top left corner of the screen where the fixation cross was located. Therefore, our main interest was focussed on the first fixation and not on the start fixation, since the first fixation indicated where participants looked at *first* after they started from the location of the fixation cross. These fixations could fall in one of the two ROIs (61.5%), outside these ROIs (32.3%), or could not be recorded when only the start fixation was made during a trial (6.2%). The mean RT of these trials was 1414 ms (SD = 1124 ms) and the average number of fixations that were made per trial was 3.9 (SD = 3.3).

The relation between fixated ROI and response was examined. The number of trials in which the location that was fixated corresponded to the response (*equal* trials: e.g. *fixation of ROI arm* and *arm* response) was compared to the number of trials in which the response was the opposite response (*opposite* trials: e.g. *fixation of ROI arm* and *banana* response) and to the number of trials in which the response was an alternative response (*other* trials: e.g. *fixation of ROI arm* and *sock* response) or in which the fixated location was outside one of the ROIs (*other* trials: *outside ROIs* and *arm* response). A higher frequency of *equal* trials in comparison to *opposite* and *other* trials confirms a relation between categorization and gaze behaviour. First, we tested *Response in relation to Region of Interest* by conducting a chi-square test on the distribution of *equal, opposite* and *other* trials, $X^2(2) = 6.70E2$ and $p < .001$. Next, paired samples t-tests were conducted to test the difference in distribution between conditions, $t_{equal\text{-}opposite}(20) = 15.22$ and $p < .001$, $t_{equal\text{-}other}(20) = 20.85$ and $p < .001$, $t_{opposite\text{-}other}(20) = 5.18$ and $p < .001$. This means that there are far more *equal* trials than *opposite* and *other* trials, and more *opposite* than *other* trials as can be seen in Figure 7.4.

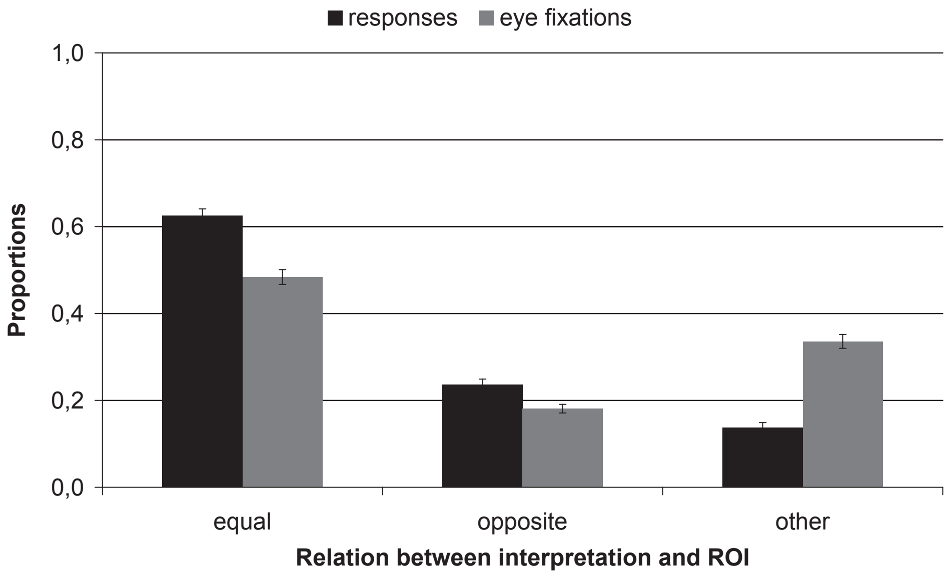


Figure 7.4. The occurence of different types of trials (equal, opposite and other) expressed in proportions observed in Experiment 1. The black bars refer to the proportion of trials in which a particular response was given in relation to the region of interest (ROI) of the first fixation. For instance, when presented with a morphed figure of the *Arm-Banana* series, if the first fixation was in the *ROI arm* the response *arm* was labeled as *equal,* the response *banana* as *opposite* and the response *sock* as *other*. The grey bars express the proportion of trials in which the first fixation was in a particular ROI in relation to the response that was given. For instance, when presented with a morphed figure of the *Arm-Banana* series, if the response was *arm* the first fixation falling within the *ROI arm* was labeled as *equal*, the first fixation falling within the *ROI banana* was labeled as *opposite* and the first fixation falling outside the *arm* and *banana* ROI was labeled as *other*.

In about 20% of the trials, the start fixation was already in one of the two ROIs. This could have biased the observed relation between categorization and gaze behaviour that was based on the first fixation. To control for this bias, the same analyses were conducted, but only including trials in which the start fixation fell within the region of the fixation cross. About 66% of the trials suited this criterion. Indeed, the strong relation between categorization and gaze behaviour was also found for these trials, $X^2(2) = 4.14E2$ and $p < .001$. Paired samples t-tests showed that the frequency of *equal* trials ($M = 0.60$ and $SE = 0.02$) was higher than the frequency of *opposite* trials ($M = 0.26$ and $SE = 0.02$), which in their turn was higher than the frequency of *other* trials ($M = 0.14$ and $SE = 0.01$), $t_{equal\text{-}opposite}(20) = 11.30$ and $p < .001$, $t_{equal\text{-}other}(20) = 18.59$ and $p < .001$, $t_{opposite\text{-}other}(20) = 5.68$ and $p < .001$.

Second, we tested *Region of Interest in relation to Response* by conducting a chi-square test on the distribution of *equal, opposite* and *other* trials, $X^2(2) = 2.93E2$ and $p < .001$. Next, paired samples t-tests were conducted to further investigate the bias in the distribution, $t_{equal\text{-}opposite}(20) = 13.39$ and $p < .001$, $t_{equal\text{-}other}(20) = 4.57$ and $p < .001$, $t_{opposite\text{-}other}(20) = -7.49$ and $p < .001$. These results show that there are much more *equal* trials than *opposite* and *other* trials, and that there are more *other* than *opposite* trials. The difference between this analysis and the first one is caused by the difference in *other* trials. From all responses, only a small amount was an alternative response (the other responses corresponded to the object name of the two extreme figures of a morph series), whereas the number of trials in which an area was fixated outside one of the ROIs was larger. In Figure 4, the distribution of the frequencies of *equal*, *opposite* and *other* trials of the two analyses are presented graphically.

Subsequently, the mean reaction times (RTs) of the responses were analysed to examine whether participants categorized a morphed figure faster when the ROI of the first fixation corresponded to the response than when they did not correspond. A Repeated Measures ANOVA was conducted with *Relation between response and ROI fixated* (*equal, opposite, other*) as within-subject variable, $F(2,40) = 47.35$ and $p < .001$. A Bonferroni corrected posthoc comparison showed that all three levels differed significantly from one other at an alpha-level of .05, with the shortest RTs for *equal* trials ($M = 1171$ ms and $SE = 50$ ms), followed by *opposite* trials ($M = 1412$ ms and $SE = 112$ ms) and the longest RTs were observed for *other* trials ($M = 2510$ ms and $SE = 222$ ms). These findings show that when a participant looked at a particular ROI and subsequently responded correspondingly to this ROI, participants were faster than when someone's first fixation was in a ROI that did not correspond to the response of that trial.

All previous results were analysed across all morphing levels. An increase of morphing level (from 80%20% to 50%50% figures) also indicates an increase of uncertainty. This increase of uncertainty might be reflected in the gaze behaviour pattern. A Repeated Measures ANOVA was conducted with *Relation between response and ROI fixated* (*equal, opposite, other*) and *Level of morphing* (*80%20%, 70%30%, 60%40%* and *50%50%*) as within-subject variables. A main effect of *Relation* was found, $F(2,40) = 171.22$ and $p < .001$. Bonferroni corrected posthoc comparisons showed, as before, that most trials fell in the equal category, followed by *opposite* trials and finally by *other* trials. The main effect of *Morphing* could not be calculated, since the proportional occurrence of the four levels of morphing was similar across trials. Most interestingly, a significant interaction effect of *Relation*Morphing* was observed, $F(6,102) = 16.02$ and $p < .001$. Bonferroni corrected posthoc comparisons revealed that the 80%20% and 70%30% morphing levels showed a similar pattern to the overall effect of *Relation*. The

60%40% morphing level showed a higher frequency of *equal* trials, but the frequency of *opposite* and *other* trials was similar. Last, the 50%50% morphing level showed that there were more *equal* trials compared to *other* trials. However, the frequency of *equal* and *opposite* trials and *opposite* and *other* trials did not differ significantly. This finding suggests that the response pattern for the 50%50% figures was not directly related to the ROI of the first fixation. The distributions of *equal*, *opposite* and *other* trials for the different levels of morphing are presented in Figure 7.5.

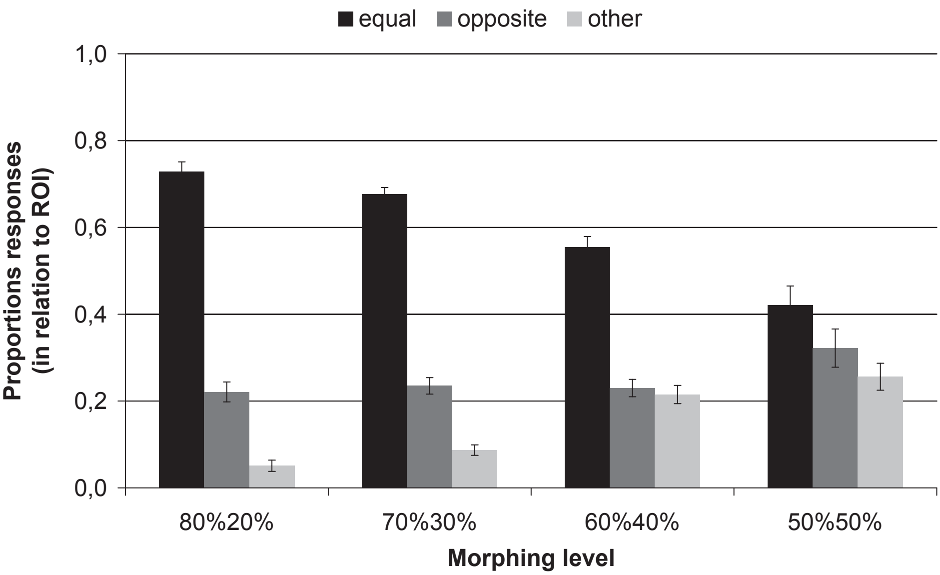


Figure 7.5. The proportions of *equal*, *opposite* and *other* trials for the different levels of morphing (80%20%, 70%30%, 60%40% and 50%50%). The black bars represent the proportions of trials in which the response corresponded to the ROI of the first fixation. The dark grey bars represent the proportions of trials in which the response was opposite to the ROI of the first fixation, and the light grey bars represent the proportions of trials in which the response was an alternative interpretation.

Discussion

In the current experiment, we examined whether there is a relation between categorization and gaze behaviour of morphed figures using free naming. In particular, we looked at the frequency of trials in which the ROI of the first fixation corresponded to the response. For example, we were interested in the number of trials in which the first fixation during target presentation fell in the ROI *arm* and was interpreted as *arm*. A strong relation was observed expressed by a higher frequency of trials in which response and ROI of the first fixation corresponded to one another in comparison to the frequency of trials in which they did not correspond. In addition, analysing the reaction times showed that when the response corresponded to the ROI of the first fixation, categorization of the morphed figures was faster than when they did not correspond. These analyses were all conducted across morphing levels. Trials containing 80%20% and 70%30% figures showed a similar pattern to the overall pattern, meaning that more *equal* trials were observed, followed by *opposite* trails and the *other* trials were the least observed. Trials containing 60%40% and 50%50% figures showed a trend corresponding to the overall pattern, albeit that trials containing 60%40% and 50%50% figures showed no significant difference in frequency between *opposite* and *other* trials and trials containing 50%50% figures showed also no significant difference between *equal* and *opposite* trials. This suggests that an increase of uncertainty weakens, though maintains, the relation between categorization and gaze behaviour.

Experiment 2

In this experiment, it was investigated whether the interpretation of an object directs the participant's eyes to a particular feature of the object using a priming paradigm. Each morphed figure was preceded by a prime word that corresponded to one of the two figures interpolated in the morphed figure or corresponded to one of the extreme figures of another morph series.

Methods

Subjects

Twenty students of Utrecht University and Hogeschool Utrecht participated in this experiment (9 male and 11 female; M = 23.4 years old, SD = 2.2 years). They had not participated in Experiment 1. Two of them were not included in the data analyses, since in about one-third of the trials no gaze data was recorded. The experiment lasted about twenty-five minutes and participants received 3 Euros or a course credit for their contribution.

Materials

Only ten out of the thirty morph series used in Experiment 1 were selected for use in the current experiment. We limited our selection to only morph series of the original dataset, since we used prime words in the current experiment that corresponded to the object names of the extreme figures of the morph series. This means that if we would use series of the original as well as the new dataset which both were based on extreme figures with the same object name, there would be an overlap in prime words. In Appendix A, the morph series used in the current experiment are marked by an asterisk. The prime words were the Dutch object names of the extreme figures. For example, a figure of the *Arm-Banana* series was preceded by the prime word *arm* (in Dutch *arm)*, by the prime word *banana* (in Dutch *banaan)* or by an unrelated prime word, which was an object name of one of the extreme figures of another morph series (e.g. *church*; in Dutch *kerk*).

Procedure

The instructions were similar to those in Experiment 1, except that participants were instructed that after the fixation cross a briefly presented word appeared that they could ignore. This word (i.e. prime word) was presented in black letters at the same position as the fixation cross, namely in the top left corner of the display. The prime word was presented for 100 ms after which a blank interval of 250 ms followed. Next, a figure was presented at the centre of the screen that had to be named using free naming. The remainder of the procedure was similar to the procedure of Experiment 1. An experimental run consisted of 270 trials (10 morph series x 9 figures x 3 prime words).

Results

In the current experiment, the verbal responses and eye movement patterns from 4860 trials (270 trials per experimental run x 18 subjects) were recorded. The trials with a RT below 200 ms and above 10000 ms and the trials that were registered as voicekey errors or as missing gaze data were discarded from further analyses, leaving us with 4709 trials. The responses could either be one of the two interpretations (92.3%) or could be an alternative interpretation (7.7%). The start fixations could fall in one of two ROIs (52.8%) or outside these ROIs (47.2%). The first fixations could fall in one of the two ROIs (64.3%), outside these ROIs (22.2%), or could not be recorded when only one fixation was made during a trial (13.4%). The mean RT of these 4709 trials was 1016 ms (SD = 635 ms) and the average number of fixations that were made per trial was 3.0 (SD = 1.7).

To investigate whether the prime had an effect on either the response or the first fixation, these two effects were tested separately. First, the type of response was compared to the type of prime, resulting in *equal*, *opposite* and *unrelated* trials.

For instance, if the response was *arm*, the prime word could either be *arm* (*equal*), *banana* (*opposite*) or *church* (*unrelated*). The distribution of *equal*, *opposite* and *unrelated* trials was tested by a chi-square test, $X^2(2) = 11.07$ and $p < .01$. In Figure 7.6, the distribution of the *equal*, *opposite* and *unrelated* trials is presented graphically. To investigate the bias of the distribution further, paired samples t-tests were conducted, $t_{equal\text{-}opposite}(17) = 4.87$ and $p < .001$, $t_{equal\text{-}other}(17) = 4.38$ and $p < .001$, $t_{opposite\text{-}other}(17) = -4.16$ and $p < .01$. These results show that there were more *equal* trials than *unrelated* trials, and more *unrelated* than *opposite* trials. Thus, prime word indeed influenced the response.

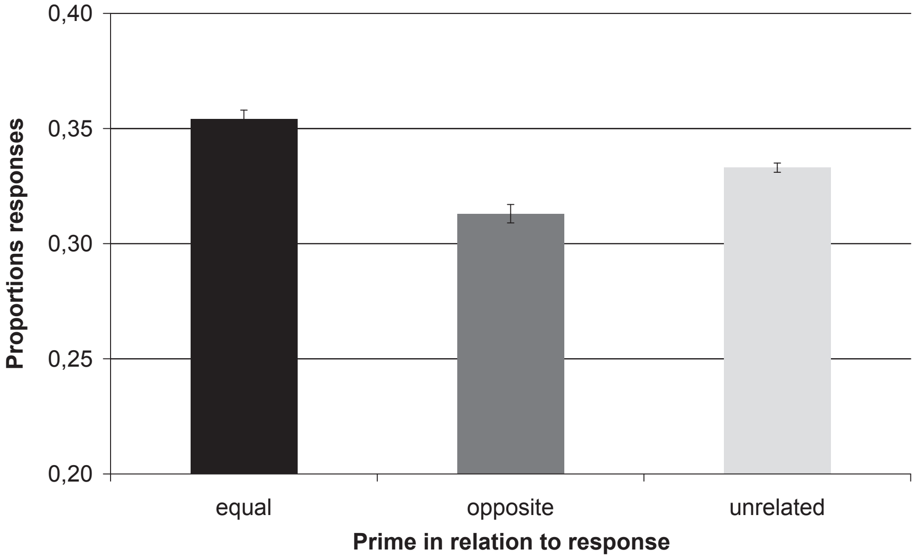


Figure 7.6. The proportions a particular response was given in relation to the prime. For instance, if the response to a target of the *Arm-Banana* series was *arm*, the trial was labeled as *equal* when preceded by the prime word *arm* was labeled as *opposite* when preceded by the prime word *banana,* and was labeled as *unrelated* when preceded by the prime word *church*.

In addition, it was tested whether the priming effect was also found for the time necessary to categorize a morphed figure by comparing the RTs for the different relations between prime and response. A Repeated Measures ANOVA was conducted with *Relation between prime and response* (*equal, opposite* and *unrelated*) as within-subject variable, $F(2,34) = 16.38$ and $p < .001$. Bonferroni corrected posthoc comparisons showed that the fastest RTs were observed for the *equal* trials ($M = 891$ ms and $SE = 40$ ms) compared to the *opposite* ($M = 991$ ms and $SE = 49$ ms) and *unrelated* trials ($M = 994$ ms and $SE = 43$ ms). The latter two did not differ significantly. This finding shows that participants were faster in categorizing a morphed figure when their response was similar to the prime word.

Second, the ROI of the first fixation was compared to the type of prime, resulting in *equal, opposite* and *unrelated* trials. The distribution of *equal*, *opposite* and *unrelated* trials was tested by a chi-square test, $X^2(2) = 0.75$ and $p > .65$. In Figure 7.7, the distribution of the *equal*, *opposite* and *unrelated* trials is presented graphically. Although the distribution of *equal*, *opposite* and *unrelated* trials shows a similar pattern to the distribution of priming effects on responses, no significant difference was reported. This implies that priming had no effect on where the first eye movement was made to.

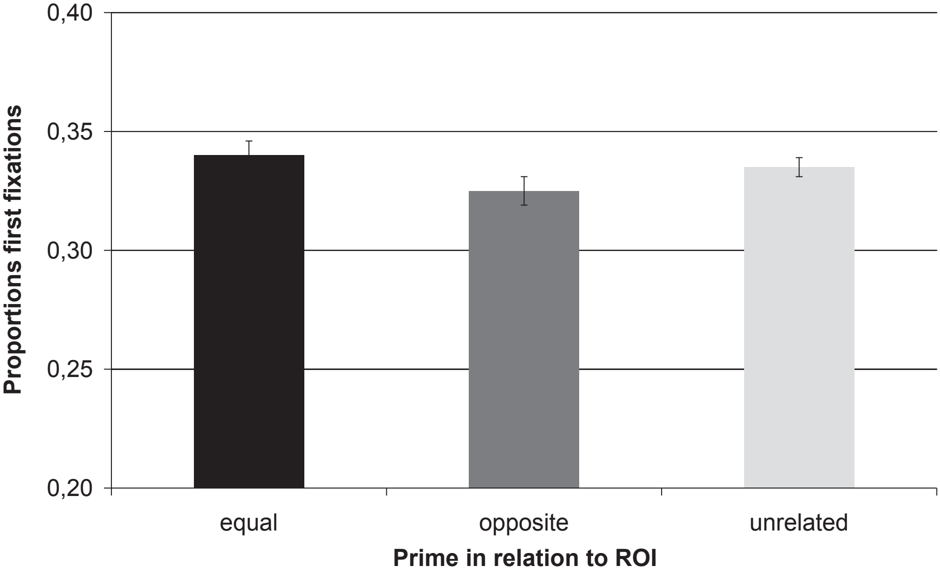


Figure 7.7. The proportions of first fixations that fell into a particular ROI in relation to the prime. For instance, if the first fixation made when presented to a target of the *Arm-Banana* series was in the ROI *arm*, when preceded by the prime word *turlte* this trial was labeled as *equal*, when preceded by the prime word *banana* this trial was labeled as *opposite* and when preceded by the prime word *church* this trial was labeled as *unrelated*.

Notably, the percentage of the start fixations that fell into one of two ROIs was much higher than expected (more than 50%), assuming that observers did not start their gaze pattern in the top left corner at the location of the fixation cross. Consequently, the prime word that was presented in the top left corner might not have been perceived by the participants. If we select only the trials in which the start fixation fell in the region around the prime word (N=539 trials), we might find an effect of priming on the first fixation. This was not the case, $X^2(2) = 0.16$ and $p > .90$. Again, this indicates that priming has no effect on gaze behaviour.

In addition, it was tested whether the relation between prime word and ROI of the first fixation influenced the time necessary to categorize a morphed figure. A Repeated Measures ANOVA was conducted with *Relation between prime word and ROI* (*equal, opposite* and *unrelated*) as within-subject variable, $F(2,34) = 7.81$ and $p < .01$. Bonferroni corrected posthoc comparisons showed that e*qual* trials ($M = 980$ ms and $SE = 47$ ms) and *opposite* trials ($M = 1026$ ms and $SE = 47$ ms) did not differ in RT and *opposite* trials and *other* trials ($M = 1095$ ms and $SE = 53$ ms) did also not differ in RT. Only *equal* trials and *other* trials differed in RT.

To investigate whether priming had a different effect on morphing level, we conducted two Repeated Measures ANOVAs. First, a Repeated Measures ANOVA was conducted with *Relation between prime and response* (*equal, opposite, unrelated*) and *Level of morphing* (*80%20%, 70%30%, 60%40%* and *50%50%*) as within-subject variables. As was expected, the main effect of *Relation* was significant, $F(2,34) = 20.43$ and $p < .001$, showing a similar pattern as reported above. The interaction effect of *Relation*Morphing* was not significant, $F(6,102) = 2.14$ and $p > .05$. Second, a Repeated Measures ANOVA was conducted with *Relation between prime and ROI* (*equal, opposite, unrelated*) and *Level of morphing* (*80%20%, 70%30%, 60%40%* and *50%50%*) as within-subject variables, $F(6,102) = 1.35$ and $p > .05$. As was expected, the main effect of *Relation* was not significant, $F(2,34) = 2.41$ and $p > .05$, replicating the findings of the analysis across morphing level. The interaction effect of *Relation*Morphing* was not significant, $F(6,102) = 1.35$ and $p > .05$. Both analyses show that there were no different priming effects found for the different levels of morphing.

Discussion

In the present experiment, the effect of priming on the categorization and gaze behaviour of morphed figures was investigated. The prime word was either similar to the name of one of the two extremes of the morph series to which the morphed figure belonged or was the name of an extreme of one of the other morph series. First, a priming effect on categorization was shown for both the response itself and the reaction time necessary to categorize the target. More *equal* trials and less *opposite* trials were observed with respect to the frequency of *unrelated* trials. This implies that the prime word biased the interpretation of the figures towards the prime word when the prime word corresponded to one of the extremes of the morph series of the target. Furthermore, when the response was equivalent to the prime word, categorization of the targets was faster than when the response was different from the prime word. These findings suggest that the prime word was processed and influenced the categorization of the figures. Nevertheless, an effect of priming on the gaze behaviour (i.e. first fixation) was not found. Since we have found an effect of priming on the response, but not on the first fixation, it is suggested that priming affects the categorization process at a later stage than at the start of target presentation. This point will be discussed further in the General Discussion of this article.

Experiment 3

In this cueing experiment, it was investigated whether the feature that the eyes fixate on directs the interpretation of the object. Each morphed figure was preceded by a cue at the location of a critical feature of one of the extreme figures interpolated in the morphed figure (such as the head of an animal).

Methods

Subjects
Twenty students of Utrecht University and Hogeschool Utrecht participated in this experiment (5 male and 15 female; M = 22.6 years old, SD = 2.8 years). They had not participated in Experiment 1 and 2. The experiment lasted about fifteen minutes and participants received 3 Euros or a course credit for their contribution.

Materials
In the current experiment, the same stimuli were used as described in the stimulus section in Experiment 2.

Procedure
The procedure of the current experiment was similar to the procedure of Experiment 2, except that the prime word was a cue. The cue was a plus sign that was presented for 250 ms, right after the presentation of the fixation cross. Immediately after the presentation of the cue a figure was presented at the centre of the screen. The cue was presented at the centre of the corresponding ROI of extreme figure A or extreme figure B of the morph series in question. For instance, if the ROI *arm* is positioned where the hand of the arm is, the cue (i.e. a plus sign) is placed in the middle of this ROI. Participants were instructed explicitly to look at the cue when it appeared. Each figure was presented twice, once preceded by the cue corresponding to the ROI of

extreme figure A and once of extreme figure B. An experimental run consisted of 180 experimental trials (10 morph series x 9 figures x 2 cues).

Results

In the current experiment, the verbal responses and eye movement patterns from 3600 trials (180 trials per experimental run x 20 subjects) were recorded. The trials with a RT below 200 ms and above 10000 ms and the trials that were registered as voicekey errors or as missing gaze data were discarded from further analyses. In addition, the instruction was to look at the cue. Therefore, we only used the trials in which the start fixation fell within the ROI of the cue (80.7%), leaving us eventually with 2709 trials. From these trials, the responses could either be one of the two interpretations (88.7%) or could be an alternative interpretation (11.3%). Furthermore, the first fixations could fall in one of the two ROIs (64.7%), outside these ROIs (26.7%), or could not be recorded when only one fixation was made during a trial (8.6%). The mean RT of these 2709 trials was 1161 ms (SD = 941 ms) and the average number of fixations that were made per trial was 3.2 (SD = 1.7).

In the current experiment, it was analysed whether starting the viewing pattern in the ROI where the cue was presented affected the response. Therefore, the relation between cue and response was investigated. This relation could either be *equal, opposite* or other. For instance, if the cue was presented in the ROI *arm*, the sequentially presented figure of the *Arm-Banana* series could be responded to as *arm* that was labeled as an *equal* trial, as *banana* that was labeled as an *opposite* trial, or as an alternative interpretation (e.g. *sock*) that was labeled as an *other* trial. The distribution of *equal*, *opposite* and *unrelated* trials was analysed by a chi-square test, $X^2(2) = 5.95E2$ and $p < .001$. In Figure 7.8, the distribution of the *equal*, *opposite* and *other* trials is presented graphically. To further investigate the bias of the distribution, paired samples t-tests were conducted, $t_{equal\text{-}opposite}(19) = 1.75$ and $p > .05$, $t_{equal\text{-}other}(19) = 26.26$ and $p < .001$, $t_{opposite\text{-}other}(19) = 23.90$ and $p < .001$. These results indicate that the significant effect of the chi-square test was caused by the higher frequencies of *equal* and *opposite* trials in comparison to the low frequency of *other* trials. This suggests that cue has no effect on the response, since there are about the same number of *equal* trials as *opposite* trials.

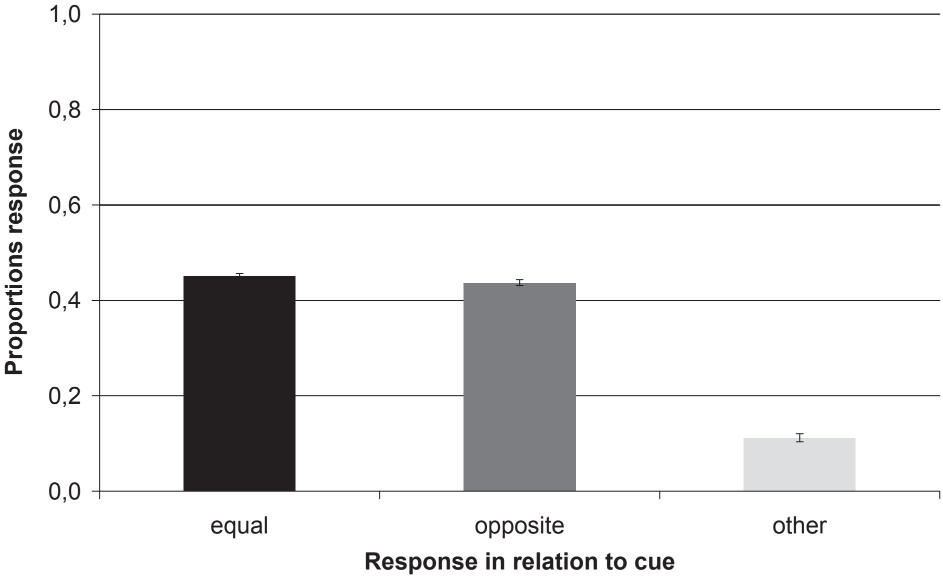


Figure 7.8. The proportions a particular response was given in relation to the cue preceding the target. For instance, if the cue was presented in the *ROI arm* followed by a figure of the *Arm-Banana* series, the response *arm* was labeled as *equal,* the response *banana* was labeled as *opposite*, and an alternative interpretation (e.g. *sock*) was labeled as *other*.

However, this absence of cueing effect might be due to the fact that in some trials the start fixation is shorter than the actual cue duration; the moment the figure appears, participants are no longer fixating at the position of the ROI emphasized by the cue. Note that the cue was presented for 250 ms after which the figure was presented immediately. We, therefore, conducted two analyses similar to the previous one, but then only containing trials in which the start fixation was shorter than 250 ms (57.4%) or longer than 250 ms (42.6%). First, the distribution of *equal*, *opposite* and *unrelated* trials for the short start fixations was tested by a chi-square test, $X^2(2) = 3.98E2$ and $p < .001$. To investigate the bias of the distribution further, paired samples t-tests were conducted, $t_{equal\text{-}opposite}(19) = -8.30$ and $p < .001$, $t_{equal\text{-}other}(19) = 12.47$ and $p < .001$, $t_{opposite\text{-}other}(19) = 22.90$ and $p < .001$. These findings show that there are more *opposite* trials than *equal* trials and more *equal* trials than *other* trials. Second, the distribution of *equal*, *opposite* and *unrelated* trials for the long start fixations was tested by a chi-square test, $X^2(2) = 3.78E2$ and $p < .001$. To investigate the bias of the distribution further, paired samples t-tests were conducted, $t_{equal\text{-}opposite}(19) = 9.04$ and $p < .001$, $t_{equal\text{-}other}(19) = 17.91$ and $p < .001$, $t_{opposite\text{-}other}(19) = 11.30$ and $p < .001$. In contrast to the analysis on the short start fixations, these results show that there are more *equal* trials than *opposite* trials and more *opposite* trials than *other* trials. In Figure 7.9, the distributions of the *equal*, *opposite* and *other* trials for both the short start fixations and the long start fixations analyses are presented graphically. Taken together, when someone still fixates at the position of the cue when the target appears, the visual information present at the ROI of the cue influences the interpretation of the figure. This shows that which visual information comes in first actually affects the interpretation of the visual input.

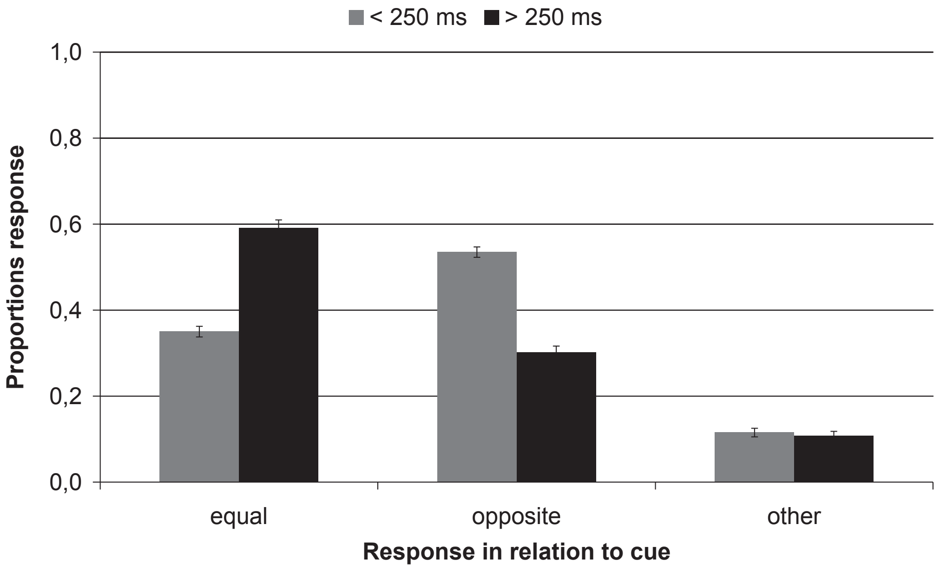


Figure 7.9. The proportions a particular response was given in relation to the cue preceding the target. The grey bars represent the trials in which the first fixation was shorter than 250 ms and the black bars represent the trials in which the first fixation was longer than 250 ms. On the x-axis the different types of trials are presented with *equal* referring to trials in which the response corresponds to the ROI of the cue, *opposite* to trials in which the response is opposite to the ROI of the cue, and *other* to trials in which the response is an alternative interpretation independent of the cue.

Subsequently, it was examined whether the different cues had an effect on the time necessary to categorize a figure. Only the trials in which the start fixation was longer than 250 ms in the ROI of the cue were taken into account. A Repeated Measures ANOVA was conducted with *Relation between cue and response* (*equal, opposite* and *other)* as within-subject variable, $F(2,38) = 14.21$ and $p < .001$. Bonferroni corrected posthoc comparisons showed that *equal* trials ($M = 1223$ ms and $SE = 71$ ms) and *opposite* trials ($M = 1113$ ms and $SE = 50$ ms) did not differ in RTs, but both of them showed shorter RTs than the RTs observed for the *other* trials ($M = 1710$ ms and $SE = 153$ ms). This analysis shows that the starting point of the gaze behaviour had no effect on the reaction time when the response was the object name of one of the two extremes of the figure. However, the reaction time increased strongly when an alternative interpretation was provided.

Last, the effects of cueing on morphing level was examined by conducting a Repeated Measures ANOVA with *Relation between cue and response* (*equal, opposite* and *other*) and *Level of morphing* (*80%20%, 70%30%, 60%40%* and *50%50%*) as within subject variables using only the trials in which the start fixation was longer than 250 ms in the ROI of the cue. As was expected, a significant main effect of *Relation* was found, $F(2,38) = 92.14$ and $p < .001$, showing a similar pattern as was reported earlier. The interaction effect of *Relation*Morphing* was also significant, $F(6,114) = 7.17$ and $p < .001$. Bonferroni corrected posthoc comparisons showed that the 80%20%, 70%30% and 60%40% morphing levels showed a similar pattern to the pattern observed across all morphing levels (more *equal* trials than *opposite* trials, and more *opposite* trials than *other* trials). However, the 50%50% morphing level showed no differences in frequency of *equal*, *opposite* and *other* trials. This result shows that when the target was a 50%50% figure, cueing had no effect at all on the response.

Discussion

In this experiment, the effect of cueing on the categorization and gaze behaviour of morphed figures was investigated. Each target was preceded by a cue (a plus sign) that was located at the centre part of one of the two ROIs of the target. In about 80% of the trials, the start fixation fell in the ROI of the cue. The remaining trials were discarded from further analyses. Subsequently, we investigated whether the cue affected the response. At first, it seemed like cueing had no effect on the interpretation of the target: The frequency of *equal* and *opposite* trials was the same. However, when we analysed the trials in which the eyes were still fixating on the location of the cue while the target appeared, we did find an effect of cueing on the response: When the start fixation was still at the location where the cue was presented at the moment the figure appeared, more *equal* trials than *opposite* and *other* trials were reported. This indicates that the feature of the target to which the eyes were directed by the cue biased the response towards the interpretation corresponding to the ROI indicated by the cue. Moreover, an evaluation of the effect of cueing on morphing level showed that trials containing 80%20%, 70%30% and 60%40% figures resulted in a similar pattern as the overall pattern. However, the 50%50% figures diverged from the overall pattern. The effect of cueing on categorization disappeared when the target was a 50%50% figure. Thus, cueing had an effect on the response as long as the target contained more information of one of the two objects.

General Discussion

In the current study, we investigated whether there is a relation between where observers look and how they interpret a morphed figure. In Experiment 1, it was shown that when the first fixation was in a particular region of interest (e.g. ROI *arm)*, in a majority of the trials the free-naming response corresponded to this region of interest (e.g. response *arm*), and vice versa. In addition, this finding was reinforced by shorter reaction times that were found for the trials in which the region of interest of the first fixation corresponded to the response. The strong relation between categorization and gaze behaviour observed previously (Cerf et al., 2009; Chelnokova & Laeng, 2011; Drewes et al., 2011; Judd et al., 2011; Kovic et al., 2009; Sæther et al., 2009) was also confirmed in the current study in which morphed figures were used as visual stimuli. This relation can be explained in two ways. First, observers can already form an expectation based on global, peripheral information, and subsequently direct their eyes towards a region of interest for verification of this expectation. Second, the eyes fixate on a particular feature. When this region contains valuable information about the visual input, categorization is easier and faster.

To distinguish between these two explanations of what is affecting the relation between categorization and gaze behaviour, we manipulated these two aspects. In Experiment 2, it was tested whether having an expectation of the object's interpretation would have an influence on which region of interest was fixated first. Each figure was preceded by a prime word that corresponded to one of the two objects or was unrelated to the target. The categorization was indeed influenced by the prime words, showing a bias towards the prime word. This effect was reinforced by the shorter reaction times observed for the trials in which the response corresponded to the prime word. Despite the fact that priming had an effect on the speed and the response itself, this priming effect was not observed for the gaze behaviour. These findings indicate that having an expectation about the subsequently presented visual object affects categorization, but does not affect gaze behaviour. Subsequently, in Experiment 3, it was investigated whether fixating on a particular region of interest influenced the interpretation of a morphed figure. Each figure was preceded by a cue presented at the location of one of the two regions of interest of the figure (e.g. at the centre of ROI *arm* or at the centre of ROI *banana*). In this way, the visual input seen first is the information present in the region of interest at the location of the cue. We found that the cue biased the interpretation of the figure towards a response corresponding to the region of interest of the cue. In other words, those visual features fixated first directly influenced the interpretation of the morphed figure.

Our findings resemble those by Kovic and colleagues (2009) and Georgiades and Harris (1997): In contrast to expectation, cueing has a clear effect on categorization. Whereas these previous studies used unambiguous figures and ambiguous faces, we now show for the first time that the strong correspondence in how a visual object is interpreted and which feature is fixated first is also observed for morphed figures. Therefore, the strong relation between categorization and gaze behaviour can be generalized to a great variety of visual stimuli. Based on the perceptual uncertainty of morphed figures expressed in the longer reaction times and greater variability in verbal responses one might not expect a strong relation between the final interpretation of a morphed figure and the feature first fixated. On the contrary, we have shown that where an observer fixates first seems to be a strong indicator of how the morphed figure will be interpreted.

Moreover, the categorization of a morphed figure can be influenced by the gaze behaviour, while the gaze behaviour cannot directly be influenced by the categorization of a morphed figure: where the observer fixates influences how the visual object is interpreted, not the other way around. In many studies on object recognition and even on scene perception, it was observed that particular features of objects (such as faces of humans and animals) were preferably fixated (Cerf et al., 2009; Crouzet, Kirchner, & Thorpe, 2010; Kovic et al., 2009; Thorpe, Fizet, & Marlot, 1996, see also Schütz, Braun, & Gegenfurtner (2011) for a review). However, it is still unknown what makes the eyes move towards these specific features. Our experiments have shown that the gaze is not just expectancy based using the eyes as a verification method; the visual input itself plays an important role in the process to come to a final interpretation.

The contradiction of finding a priming effect on the response, but not on the first fixation, might be explained by the fact that priming took place at a basic level. A recent study by Poncet, Reddy and Fabre-Thorpe (2012) showed that categorization of peripherally presented animate and manmade objects is categorized at the superordinate level (i.e. animal and vehicle) twice as fast than at the basic level (i.e. dog and car). They explained this difference by the level of information processing. Categorization at a superordinate level takes place at a more global information processing level, whereas categorization at a basic level needs more detailed, local information processing. Many studies support the idea that global information is processed more quickly than local information (Bar, 2003; Fei-Fei, Iyer, Koch, & Perona, 2007; Greene & Oliva, 200; Schwarzer, Huber, & Dümmler, 2005). The prime words in our experiment were at the basic level, and therefore might have only affected the categorization process when arrived at the detailed, basic-level information processing. Perhaps a prime at the superordinate level would have affected the first fixation.

The findings discussed so far were all analysed across morphing levels. If we take morphing level into account, however, differences were observed. In particular, the 50%50% figures diverged from the other levels of morphing. This effect might be due to the categorization of these specific figures. The literature on the categorization of morphed objects (Harnad, 1987; Hartendorp et al., 2010; Newell & Bülthoff, 2002; Verstijnen & Wagemans, 2004) describes that morphed stimuli are perceived categorically (i.e. categorical perception). This means that morphed figures at one half of the morph continuum are categorized as their nearest end extreme. For instance, a 60%40% *arm-banana* figure is preferably categorized as *arm*, whereas a 40%60% *arm-banana* figure is preferably categorized as *banana*. However, the categorization of the 50%50% figure is more variable. This uncertainty in categorization is reflected by more inconsistency between observers in their gaze behaviour. Nevertheless, a relation between categorization and gaze behaviour was still observed, albeit a weaker one than the relation obtained for the figures at other levels of morphing. A decrease in predictive value of gaze behaviour was also observed by Judd and others (2011) when the resolution of the image decreased. We argue that the relation between categorization and gaze behaviour is very strong, but when the categorization is less consistent, the gaze behaviour is also less consistent.

In summary, the current study has shown that the strong relation between categorization and gaze behaviour was also found for morphed figures. The origin of this relation was investigated by manipulating the expectation of the upcoming target using priming and by manipulating the visual feature fixated first using cueing. Manipulation of the expectation affected categorization, but not gaze behaviour. Moreover, manipulating the fixation location appeared to affect both gaze behaviour and categorization. The relation between categorization and gaze behaviour seems to be mostly determined by the feature of the visual object first fixated. We have demonstrated that the strong relation between categorization and gaze behaviour is maintained when the location of the first fixation was manipulated. Where we look indeed determines what we see.

8

General Discussion

Mijke O. Hartendorp

The research topic of this thesis concerns object categorization: When does an object belong to a category and when does it not? In other words, when is the category boundary crossed? Categorical perception (CP; Harnad, 1987) of morphed objects is a phenomenon that suggests a strong category boundary halfway along the morph continuum. Typically, a tendency is shown to categorize a morphed figure as its dominant object (Newell & Bülthoff, 2002). However, does this preference also mean that the nondominant object is not processed at all? First, we have investigated *if* the nondominant object in a morphed figure is processed (*Chapter 2, 3 and 4*). Next, the question was addressed *when* the nondominant object is processed during the process of categorization (*Chapter 5*). Subsequently, we have examined at *what* level the nondominant object is processed (*Chapter 6*). Finally, it was investigated whether the processing of the nondominant object was also reflected in the gaze behaviour obtained for morphed figures (*Chapter 7*). A summary of the main findings is provided first, after which these findings will be discussed in light of theories on object categorization.

Summary

Categorical perception is usually examined by a discrimination and forced-choice identification task. The latter typically consists of a forced-choice paradigm in which observers are asked to identify a morphed figure as either one extreme or the other extreme. As was already suggested by Newell and Bülthoff (2002), this method might bias the observation of CP since identifying a morphed figure as an alternative different from one of its extremes is not allowed. In *Chapter 2* therefore, a free-naming experiment was conducted in which any interpretation of the morphed figure could be given. Interestingly, CP was still observed, albeit for only half of the tested morph series (series showing CP are referred to as cp-series and morph series showing no CP are referred to as non-cp-series). To examine the effects of the experimental method used to investigate CP, we also conducted a forced-choice experiment using the same stimulus set, which resulted in an increase of number of series showing CP compared to the findings of the free-naming experiment, though these were different morph series than showing CP in the free-naming experiment. In order to understand what makes the difference between a cp-series and a non-cp-series, a subsequent experiment was performed in which the similarity between the extreme objects of a morph series was compared on different aspects of similarity. This experiment revealed that higher perceptual similarity between the extremes of the morph series was strongly related to the finding of CP in the free-naming experiment, though not to the findings of CP in the forced-choice experiment. Similarity in intrinsic part structure was previously shown to play an important role in CP of morphed figures (Newell & Bülthoff, 2002) and in CP of nonmorphed figures (Rosielle & Cooper, 2001). We have shown that CP is not necessarily a consequence of the forced-choice method used, though forced choice can bias categorization of morphed figures.

In *Chapter 3*, we examined the absoluteness of categorical perception: Does CP mean that we only consider the dominant object as an interpretation, or do we also consider other alternatives, such as the nondominant object? In a double-naming experiment, participants were asked to give two interpretations of a morphed figure. When a second interpretation was given, a distinction was made between responses corresponding to the nondominant object and those corresponding to a completely different alternative. Analysing the first responses on showing a pattern of categorical perception divided the stimulus set into cp-series and non-cp-series. This distinction showed great overlap to the distinction of morph series found by the free-naming experiment described in Chapter 2. Second responses were particularly absent for figures in which the dominant figure was strongly represented (i.e. 80%20% and 70%30% figures). When the dominant figure was less strongly represented, an increase of nondominant interpretations was observed for cp-series, whereas an increase of alternative interpretations was observed for non-cp-series. Therefore, we argue that CP is not absolute: Though observers strongly stick to the dominant interpretation of a morphed figure over increasing morphing levels, they are able to switch to the nondominant alternative when forced to.

The findings of Chapter 3 show that we do process the nondominant object, albeit more strongly for figures of cp-series than for non-cp-series. The difference in categorization between cp-series and non-cp-series might have been caused by a difference in perceptual uncertainty. As was shown previously (De Houwer, Hermans, & Spruyt, 2001), perception of degraded stimuli was more influenced by priming than undegraded stimuli. The perceptual uncertainty of morphed figures therefore, might have its impact on the influence of context on the categorization of these figures. Hence in *Chapter 4*, we conducted a priming experiment in which a morphed figure was preceded by either a prime word corresponding to its dominant object, its nondominant object or an unrelated object. Overall, the dominant prime facilitated the categorization of morphed figures and the nondominant prime interfered with the categorization process. These findings are a replication of previous studies on priming of morphed figures (Daelli, van Rijsbergen, & Treves, 2010; Huart, Corneille, & Becquart, 2005). In addition, faster reaction times and more dominant responses were observed for cp-series than for non-cp-series, replicating the findings of Chapter 2. The effects of priming, however, were not different for cp-series and non-cp-series, again suggesting that the dominant and nondominant object are still processed to some extent in figures from both types of morph series. The difference in overall reaction time and response preference between cp-series and non-cp-series though, indicates that the dominant and nondominant object are probably stronger response options when categorizing figures of cp-series than figures of non-cp-series. This conclusion is also in accordance with the findings of Chapter 2 and 3.

In Chapter 3 and 4, it was shown that despite the strong preference for categorizing a morphed figure as its dominant object, the nondominant object is processed as well. In *Chapter 5*, we investigated when the nondominant object is processed during the categorization process. Two activation accounts were proposed. According to an early activation account, we are uncertain about how to interpret the visual information early in the categorization process. This uncertainty will vanish over time and therefore, the number of possible response options decreases over time. According to a late activation account, the visual information is categorized quickly, but after extensive viewing alternative interpretations become more strongly activated. Therefore, the number of possible response options increases over time. To examine which of these two accounts is most applicable to the categorization of morphed figures, the similarity in intrinsic part structure (Chapter 2; see also Newell & Bülthoff, 2002; Rosielle & Cooper, 2001; Wilder, Feldman, & Singh, 2011) between a morphed figure and its dominant and nondominant object was established. In particular, the similarity rating between morphed figures and their nondominant object was taken as an indicator for the activation of the nondominant response option: High similarity indicates that the nondominant object is relatively strongly activated as an alternative response. Presentation times were varied in order to distinguish between the early and late activation account. If the similarity between morphed figure and its nondominant object is judged higher with a brief presentation time of the morphed figure (50 ms) than with an extended presentation time (3000 ms), support was found for the early activation account. A reversed pattern in similarity rating supported the late activation account. Using a Bayesian model selection approach (Hoijtink, Klugkist, & Boelen, 2008), support was found for the late activation account, but not for the early activation account. It thus seems that in a late stage of the categorization process the influence of the nondominant response option is strongest.

In *Chapter 6*, it was investigated what kind of information of the nondominant object is activated during the categorization process. By means of a picture-word interference task, the influence on the categorization process of different types of distractor words was examined. These distractor words were identical, semantically related or unrelated to either the dominant or the nondominant object of a morphed figure. For instance, if one of the extremes of a morph series was 'banana', the identical distractor word was *banana,* the semantically related word *mango* and the unrelated word could be *sweater*. It is known from studies using the picture-word interference paradigm that an identical word facilitates naming and a semantically related word interferes with naming (Bloem, van den Boogaard, & La Heij, 2004; Glaser & Düngelhoff, 1984; Mädebach, Oppermann, Hantsch, Curda, & Jescheniak, 2011; Sailor, Brooks, Bruening, Seiger-Gardner, & Guterman, 2009). However, the pictures used in those studies were primarily unambiguous ones. Using morphed figures, we showed that the words related to the dominant object revealed a similar pattern as was reported by the picture-word interference studies mentioned above: Facilitation of the naming process induced by an identical word and interference induced by a semantically related word. However, this response latency pattern was only observed for distractor words related to the dominant object. In contrast, identical words related to the nondominant object interfered with the naming process. Moreover, the distractor words semantically related to the nondominant object appeared to have a weak interference effect on the categorization process: A word semantically related to the nondominant object affected the categorization process only when it was a member of the response set. It is, therefore, more likely that the perceptual information of the nondominant object is more strongly activated during the categorization process of a morphed figure than the semantic information. Since the semantic information mainly affected the response candidate eventually selected, we argue that semantic information is not activated until one response candidate is selected. In other words, only the perceptual information and not semantic information of the nondominant object is activated during the categorization process.

In the foregoing chapters, strong support was gathered for the notion that the nondominant object is processed to some extent when categorizing a morphed figure. In *Chapter 7*, we investigated whether the processing of the nondominant object in a morphed figure is also reflected in the eye movement pattern. In previous studies on eye movements a strong relation was observed between how a visual object was interpreted and which features of the object were fixated (Chelnokova & Laeng, 2011; Ellis & Stark, 1978; Sæther, Van Belle, Laeng, Brennen, & Øvervoll, 2009). For instance, when presented with an animal, we prefer to look at the head (Drewes, Trommershäuser, & Gegenfurtner, 2011; Kovic, Plunkett, & Westermann, 2009). Three experiments were conducted to investigate the relation between categorization and gaze behaviour obtained for morphed figures. In all three experiments, free-naming responses and eye movements were recorded simultaneously. The first experiment showed that there is a strong relation between the interpretation and the fixated part of a morphed figure. The next question concerned whether gaze patterns drive categorization or vice versa. In the second experiment, morphed figures were preceded by a prime word. A priming effect on categorization was found, but not on gaze behaviour. In the third experiment, a cue directed the observer's gaze to a particular location on the morphed figure. Interestingly, the cueing experiment showed a cueing effect not only on gaze behaviour but also on categorization. We argue, therefore, that where we look affects how we interpret a morphed figure. Moreover, an increase of uncertainty in categorization observed for figures more to the middle of the morph continuum (i.e. 50%50% figures) caused a decrease in the strength of correspondence between categorization and gaze behaviour. The relation between categorization and gaze behaviour is still present for these figures but not as strong as was observed for the less uncertain figures (e.g. 80%20% figures). This suggests that the categorization pattern observed for morphed figures is reflected in the eye movement pattern.

Discussion

From the findings described throughout this thesis, we can conclude that human beings are very well able to deal with perceptual uncertainty, suggesting that visual perception is robust to small changes in the external world. This makes it possible to deal with the uncountable number of objects by assigning similarly shaped objects to the same category. This similarity in shape and in particular the intrinsic part structure of the visual object appeared to play an important role in the categorization of morphed figures (see also Newell & Bülthoff, 2002; Wilder et al., 2011). The information extracted from the shape contour can in turn be used to activate multiple interpretations that show similarity to the intrinsic part structure of the visual input but also to the other considered response options. Two models on object categorization will be discussed here that provide a possible explanation for our findings on the categorization of morphed figures. First, the results will be discussed in terms of the skeleton model by Feldman and Singh (2006). Next, the object recognition model by Bar (2003) incorporating response competition will be considered.

Skeletal Representation

The MAP-skeleton model by Feldman and Singh (2006) explains object categorization by the skeletal representation of an object, which is extracted from its shape contour. Several skeleton models have been proposed to understand the algorithms underlying object categorization (Blum, 1973; Blum & Nagel, 1978). The skeleton model of Feldman and Singh, however, can handle small violations to the shape contour. Specifically the latter property of the model is of great interest for our findings, since the morphed figures used as stimulus materials throughout this thesis were created by changing the shape contour of one object into the shape contour of another object. Despite the changes to the shape contour, morphed figures of many morph series (i.e. cp-series) could still be categorized as their dominant object. When adopting the MAP-skeleton model to our findings, we propose that the changes to the shape contour due to the morphing procedure did not violate the skeletal representation of the original dominant object. This makes it possible to categorize the morphed figures still as their dominant object. Halfway along the morph continuum however, the skeletal representation adopts more characteristics of the other extreme object, causing a change in interpretation. This pattern of categorical perception was not observed for all morph series (i.e. non-cp-series). The response pattern observed for figures of these series was much more variable than for figures of cp-series. Again, the absence of a pattern of categorical perception can be explained in terms of violations to the skeleton of these figures. We propose that when morphing the shape contour of the extreme objects of non-cp-series, the shape contour is violated to such an extent that the skeletal representation is changed as well and will no longer resemble the dominant object.

The reason for the difference between morph series in categorical perception may be sought in a difference in the similarity in intrinsic part structure of the extreme objects of a morph series (see also Newell & Bülthoff, 2002). Extreme objects of cp-series turned out to be perceptually more similar than extreme objects of non-cp-series, particularly in intrinsic part structure. Returning to the skeleton model of Feldman and Singh (2006), the violations to the shape contour, and therefore indirectly to the skeletal representation, will be limited in case of morphing two similar objects, whereas these changes will be drastic in case of morphing two dissimilar objects. Since the original skeleton of the dominant extreme object is more maintained for cp-series because of the limitations in violations to the shape contour, it is easier for morphed figures of cp-series to be categorized as their dominant object and harder to do so for figures of non-cp-series. In addition, the foregoing also explains why the nondominant object is still considered as a response option, particularly in case of cp-series. The small changes to the shape contour due to morphing two similar objects do not only result in a skeletal representation resembling the dominant object but also the nondominant object to some extent. Morphing two dissimilar objects does not completely diminish a resemblance between the skeletal representation of the morphed figures to the dominant and nondominant object, but alternative objects also match the skeletal representation as is reflected in the variability of responses observed for non-cp-series.

Response Competition

The idea that a skeletal representation of a morphed figure shows resemblance in a greater or lesser extent to a number of objects stored in memory (e.g. the dominant and nondominant object) is in line with theories explaining object categorization in terms of the similarity in shape between the visual input and stored concepts (Lamberts, 1995; Medin & Schaffer, 1978; Nosofsky, 1984). Particularly, models on object categorization including response competition are of great relevance here (Graboi & Lisman, 2003; Panis, Vangeneugden, & Wagemans, 2008). For instance, the neurological model by Bar (2003) suggests that an object is first represented as a blurred, coarse image extracted from the low-spatial information of the visual input. Based on this blurred image a number of response candidates are selected that match the blurred image more or less. In a later stage, the fine, detailed information will be matched to this selection of response candidates leading to one candidate gaining most support based on this detailed information. Two perceptually similar objects are more likely to be coactivated as response candidates than two perceptually dissimilar objects. This may also explain the difference between cp-series and non-cp-series. The dominant and nondominant object are strong response candidates when categorizing morphed figures of a cp-series in which the extreme objects show strong perceptual similarity to one another and therefore also to their morphed figures, whereas the dominant and nondominant object might not be strong response candidates when categorizing a morphed figure of a non-cp-series in which the extreme objects show less perceptual similarity and therefore also less perceptual similarity to their morphed figures.

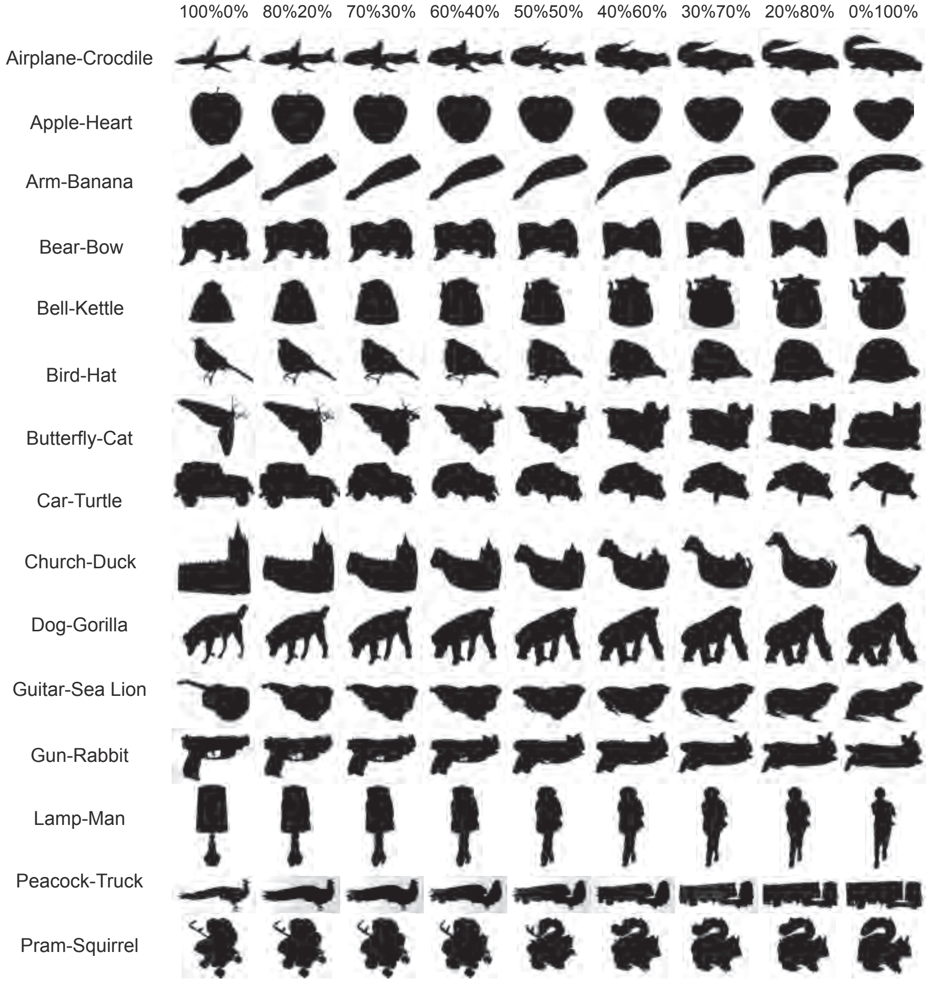
According to the model proposed by Bar (2003), the number of response candidates selected depends on the difficulty of the interpretability of the visual object. Evidence for this idea came from an fMRI-study (Bar, Tootell, Schacter, Greve, Fischl, Mendola, Rosen, & Dale, 2001) in which the neural activity in the prefrontal cortex, where the response selection is suggested to take place, increased with decrease of presentation duration of the stimuli. This might explain the increased time to interpret a morphed figure and the increased variability in responses when a morphed figure more to the middle of the morph continuum (i.e. more perceptual uncertainty) had to be categorized. In addition, Bar also proposes that repetition priming can influence the number of response candidates selected. The findings of repetition suppression observed in the prefrontal cortex (Rainer & Miller, 2000) indicate a similar explanation; repetition priming reduces the number of selected response candidates and thus less activity will be observed. Although we cannot specify whether priming reduced or enlarged the number of response candidates or whether priming weakened or enhanced response competition, we can say that priming affected the activation of the dominant and nondominant response candidates. A dominant prime reduced the time necessary to categorize a morphed figure and increased the number of dominant responses, while a nondominant prime increased the categorization time accompanied by an increase of number of nondominant responses. Furthermore, Bar also proposes that semantic knowledge is activated at a post-recognition stage. Our results also suggest that semantic information only interferes with the categorization process when concerning the dominant object, or in other words, the finally selected response candidate. We propose that the nondominant prime interferes with the categorization process at the stage of response competition, despite the fact that the outcome was not directly biased towards the nondominant object. This suggests that both the dominant and nondominant object are activated response candidates during the categorization process of morphed figures based on their similarity to the visual input.

Integration of Skeleton and Response Competition Model

An integration of the skeleton model by Feldman and Singh (2006) and the response competition model by Bar (2003) explains the findings as described in this thesis best. The blurred, coarse image proposed by Bar leaves all details out, but still makes it possible to recognize the global shape contour of the object. Next, the skeletal representation can be derived from this global information of the visual input. The blurred image makes that small changes to the shape contour are not detectable during this stage of the categorization process. Moreover, this also explains the robustness of human categorization behaviour to small changes within the shape contour. Subsequently, the skeletal representation is used to select a number of response candidates. To end, we argue that categorization of morphed figures follows the same rules as categorization of any visual object. First, the skeletal representation will be extracted using the shape contour of the object. A number of response candidates will be activated that show similarity to this skeletal representation, which will compete for crossing the categorization threshold first. The response *selection* is influenced by the perceptual certainty of the visual input, whereas response *competition* can be influenced by context which enhances the activation of the corresponding response candidate. Together this suggests an accumulation of evidence for an ultimate response candidate amidst a continuum of on-going competition before the categorization threshold is reached. Crossing the category boundary means full awareness of only one interpretation. If anything this is of crucial benefit in a complex, dynamic visual world.

Appendix

Appendix A. The morph series used as stimulus materials in Chapter 2 to 7.



Appendix B. The morph series used as stimulus materials in Experiment 1 of Chapter 7.

Morph Series	***Delta Gap1***	***X50_1***	***Delta Gap2***	***X50_2***
Airplane-Crocodile	0.29	0.51	0.16	0.62
Apple-Heart	0.20	0.57	0.16	0.58
Arm-Banana	0.43	0.61	0.54	0.45
Bear-Bow	0.25	0.69	0.32	0.53
Bell-Kettle	0.29	0.53	0.60	0.27
Bird-Hat	0.49	0.47	0.35	0.66
Butterfly-Cat	0.26	0.45	0.19	0.74
Car-Turtle	0.03	0.58	0.03	0.59
Church-Duck	0.07	0.55	0.02	0.59
Dog-Gorilla	0.21	0.63	0.19	0.62
Guitar-Sea Lion	0.05	0.57	0.09	0.54
Gun-Rabbit	0.03	0.59	0.47	0.31
Lamp-Man	0.37	0.47	0.12	0.56
Peacock-Truck	0.06	0.54	0.03	0.58
Pram-Squirrel	0.41	0.47	0.03	0.59

Appendix C. Separate presentation of Delta Gap and X50 values for both interpretations of all morph series obtained for the double-naming experiment in Chapter 3. Delta Gap1 and X50_1 refer to the first series name (e.g. Delta Gap1 for *Arm-Banana* refers to *Arm*) and Delta Gap2 and X50_2 refer to the second name of a series (e.g. Delta Gap2 for *Arm-Banana* refers to *Banana*). The series are presented in alphabetic order. For fitting the CP restrictions, the Delta Gap should be smaller than 0.24 and the X50 should be or should be in-between 0.40 and 0.60. Furthermore, both interpretations should match these restrictions before a morph series can be labelled as a cp-series. Otherwise, if one or none of the interpretations do not match the CP restrictions, the series will be labelled as a non-cp-series.

Conditions			morphing distance						
relation	**interval**	**morph**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**
related	short	short	1	7	13	19	25	31	37
		medium	2	8	14	20	26	32	38
		long	3	9	15	21	27	33	39
	long	short	4	10	16	22	28	34	40
		medium	5	11	17	23	29	35	41
		long	6	12	18	24	30	36	42
unrelated	short	short	43	49	55	61	67	73	79
		medium	44	50	56	62	68	74	80
		long	45	51	57	63	69	75	81
	long	short	46	52	58	64	70	76	82
		medium	47	53	59	65	71	77	83
		long	48	54	60	66	72	78	84

	(in)equality constraints
H1:	1>43, 2>44, 3>45, 4>46, 5>47, 6>48, 7>49, …, 41>83, 42>84
H2A:	(13-25) - ((1-13)+(25-37))/2 and (16-28) - ((4-16)+(28-40))/2
H2B:	(14-26) - ((2-14)+(26-38))/2 and (17-29) - ((5-17)+(29-41))/2
H2C:	(15-27) - ((3-15)+(27-39))/2 and (18-30) - ((6-18)+(30-42))/2
H3A:	(13-25) - ((1-13)+(25-37))/2 < (14-26) - ((2-14)+(26-38))/2 < (15-27) - ((3-15)+(27-39))/2 and (16-28) - ((4-16)+(28-40))/2 < (17-29) - ((5-17)+(29-41))/2 < (18-30) - ((6-18)+(30-42))/2
H3B:	(13-25) - ((1-13)+(25-37))/2 > (14-26) - ((2-14)+(26-38))/2 > (15-27) - ((3-15)+(27-39))/2 and (16-28) - ((4-16)+(28-40))/2 > (17-29) - ((5-17)+(29-41))/2 > (18-30) - ((6-18)+(30-42))/2
H4A:	((13-25) - ((1-13)+(25-37))/2 < ((16-28) - ((4-16)+(28-40))/2 and ((14-26) - ((2-14)+(26-38))/2 < ((17-29) - ((5-17)+(29-41))/2 and (15-27) - ((3-15)+(27-39))/2 < ((18-30) - ((6-18)+(30-42))/2
H4B:	((13-25) - ((1-13)+(25-37))/2 > ((16-28) - ((4-16)+(28-40))/2 and ((14-26) - ((2-14)+(26-38))/2 > ((17-29) - ((5-17)+(29-41))/2 and (15-27) - ((3-15)+(27-39))/2 > ((18-30) - ((6-18)+(30-42))/2

Appendix D. In the table, the different conditions are presented used in the similarity experiment in Chapter 5. The variable *morphing distance* contains seven levels (20% to 80%, with steps of 10%), *relation* consists of two levels (related and unrelated), *interval* (duration) consists of two levels (short and long interval: 300 and 3000 ms, respectively) and (presentation time of) *morph* consists of three levels (short, medium and long: 50, 300 and 3000 ms, respectively), ending up with 84 conditions. Each condition received its own number that was used to translate the five informative hypotheses into (in)equality constraints that are presented below the table.

Experiment 1		Dutch Distractor Words			Translation Distractor Words		
Morph Series	Object	Identical	Semantic	Unrelated	Identical	Semantic	Unrelated
Airplane-Crocodile	Airplane	vliegtuig	Bus	ring	airplane	bus	Ring
	Crocodile	krokodil	Slang	magneet	crocodile	snake	Magnet
Arm-Banana	Arm	arm	Voet	krant	arm	foot	Newspaper
	Banana	banaan	Mango	tafel	banana	mango	Table
Bear-Bow	Bear	beer	Tijger	deur	bear	tiger	Door
	Bow	strik	Stropdas	speen	bow	tie	Teat
Car-Turtle	Car	auto	Trein	koffer	car	train	Suitcase
	Turtle	schildpad	Kicker	hamer	turtle	frog	Hammer
Church-Duck	Church	kerk	Paleis	potlood	church	palace	Pencil
	Duck	eend	Bij	trui	duck	bee	sweater
Guitar-Sea Lion	Guitar	gitaar	Trompet	bal	guitar	trumpet	ball
	Sea Lion	zeeleeuw	Penguin	telefoon	sea lion	penguin	telephone
Gun-Rabbit	Gun	pistool	Zwaard	sleutel	gun	sword	key
	Rabbit	konijn	Hond	zwembad	rabbit	dog	swimming pool
Peacock-Truck	Peacock	pauw	Hert	bed	peacock	deer	bed
	Truck	vrachtwagen	Zeilboot	lepel	truck	sailboat	spoon
Pram-Squirrel	Pram	kinderwagen	Draagzak	bloem	pram	carrier	flower
	Squirrel	eekhoorn	Wolf	ei	squirrel	wolf	egg

Appendix E. The distractor words used in Experiment 1 of Chapter 6. The first column represents the names of the morph series. The second column represents one of two objects of the morphed figures in that particular morph series. The third column represents the identical words for the object in that particular row, the fourth column represents the semantically related words for the object in that particular row and the fifth column represents the unrelated words. The eighteen unrelated words were combined on every trial with another morphed figure of another morph series. Column six to eight contain the English translation of the Dutch distractor words.

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Nederlandse Samenvatting

Introductie

In ons dagelijkse leven zijn we omringd door objecten, zoals de stoel waar je op zit terwijl je dit proefschrift leest, het kopje koffie dat voor je staat en je goudvis die je aanstaart vanuit zijn glazen kom. Het is noodzakelijk dat je deze objecten identificeert om te weten hoe je hiermee om kunt gaan. Gelukkig heeft het menselijke brein een mechanisme ontwikkeld, genaamd *categorisatie*, om objecten te groeperen in zogeheten *categorieën* en om informatie verzameld over deze categorie toe te passen. Categorisatie lijkt in eerste instantie een simpel mechanisme, aangezien het ons weinig tijd kost een object te categoriseren en we weinig fouten maken tijdens dit proces. Ondanks deze ogenschijnlijke eenvoud is het nog niet gelukt het mechanisme achter categorisatie bloot te leggen. De vraag die de gemoederen bezig houdt: Wanneer behoort een object tot de ene en wanneer tot de andere categorie? Met andere woorden, wanneer wordt de categoriegrens overschreden?

Een belangrijk aspect van categorisatie is dat we de wereld niet indelen in continue, maar in discrete categorieën. Zoals Harnad (2003) schreef: "Iets is een vogel of iets is niet een vogel: Een pinguïn is een 100% vogel, een vogelbekdier is een 100% niet-vogel". Deze discrete classificatie van eenheden in onze omgeving is ook zichtbaar wanneer twee stimuli in elkaar overvloeien, een procedure die *morfing* wordt genoemd. In 1957 rapporteerden Liberman, Harris, Hoffman en Griffith dat de geleidelijke verandering van het foneem *ba* in het foneem *da* niet werd waargenomen als een geleidelijke verandering, maar als een abrupte verandering van de ene categorie naar de andere categorie halverwege het continuüm, een fenomeen dat *categorische perceptie* wordt genoemd (afgekort als *CP*). CP is gevonden voor een breed scala aan stimulusmaterialen. Zo is CP ondermeer gevonden voor kleuren (e.g. van blauw naar groen; Bornstein, 1987; Bornstein & Korda, 1984; Okazawa, Koida, & Komatsu, 2011), voor fonemen (e.g. van *ba* naar *pa*; Liberman et al., 1957), voor basisemoties (e.g. van een vrolijk gezicht naar een boos gezicht; Calder, Young, Perrett, Etcoff, & Rowland, 1996; Etcoff & Magee, 1992; McCullough & Emmorey, 2009), en voor concrete objecten (van een fles naar een lamp; Newell & Bülthoff, 2002). CP is zelfs geobserveerd bij dieren, zoals krekels (Wyttenbach, May, & Hoy, 1996) en cavia's (McGee, Kraus, King, Nicol, & Carrell, 1996).

Een morfcontinuüm bestaat uit een aantal gemorfte figuren. Ieder gemorft figuur bevat informatie van zowel het ene extreme object als het andere extreme object, waarbij de verhouding van deze informatie per gemorft figuur verschilt. Uit onderzoek is gebleken dat een gemorft figuur voornamelijk wordt waargenomen als het extreme object het meest aanwezig in het gemorfte figuur, oftewel het *dominante object*.

Ondanks dat ieder gemorft figuur informatie bevat van beide extreme figuren, geeft men er blijkbaar de voorkeur aan om het gemorfte figuur als het dominante object waar te nemen. Betekent dit echter ook dat men de informatie van het andere extreme object, het *niet-dominante object*, niet verwerkt tijdens het categorisatieproces?

Met het onderzoek beschreven in dit proefschrift heb ik bovengenoemde vraag onderzocht. Allereerst is onderzocht *of* het niet-dominante object in een gemorft figuur verwerkt wordt (*Hoofdstuk 2, 3 en 4*), vervolgens *wanneer* het niet-dominante object tijdens het categorisatieproces verwerkt wordt (*Hoofdstuk 5*) en daarna op *welk niveau* het niet-dominante object verwerkt wordt (*Hoofdstuk 6*). Als laatste is onderzocht in hoeverre de verwerking van het niet-dominante object weerspiegeld is in het oogbewegingspatroon (*Hoofdstuk 7*). Deze vragen zijn onderzocht met behulp van psychologische experimenten waarbij het gedrag van de mens gemeten wordt door te kijken naar welke interpretatie men aan een object geeft, hoe snel men dit object herkent en naar welk deel van het object men kijkt. Daarnaast heb ik gekeken of de interpretatie en de interpretatiesnelheid te beïnvloeden zijn door onder andere de objecten in verschillende contexten aan te bieden, bijvoorbeeld door de proefpersoon aan een bepaald concept te laten denken en vervolgens een gemorft figuur te laten categoriseren. De gemorfte figuren die in dit onderzoek als stimulus materiaal gebruikt zijn, zijn terug te vinden in de Appendix (Appendix A en B).

Experimenten

In het onderzoek naar CP van gemorfte figuren wordt normaliter gebruik gemaakt van *forced-choice*, waarbij men de keuze krijgt een individueel gepresenteerd gemorft figuur te identificeren als het ene extreme object van het morfcontinuüm of als het andere extreme object. De uiteindelijke keuze van het dominante object als interpretatie kan bepaald zijn doordat men geen andere keuze heeft behalve deze twee opties. Om uit te sluiten dat CP geen gevolg is van de forced-choice methode, is in *Hoofdstuk 2* gebruik gemaakt van zogeheten *free naming*. In dit experiment werd de proefpersoon vrijgelaten welk object men in het gemorfte figuur herkende. De resultaten laten zien dat ondanks het gebruik van free naming toch CP werd gevonden voor gemorfte figuren. Echter, niet alle morfcontinua lieten CP zien. Dit werd met name veroorzaakt doordat voor een aantal gemorfte figuren andere alternatieve interpretaties gegeven werden in plaats van het dominante object. Zo werd een gemorft figuur van het morfcontinuüm *Arm-Banaan* niet als *arm* of *banaan* gecategoriseerd, maar ook vaak als iets anders, zoals *tak* of *sok*. Dit leidde ertoe dat de stimulus set werd opgesplitst in morfcontinua die CP lieten zien (i.e. *cp-series*) en morfcontinua die geen CP lieten zien (i.e. *non-cp-series*). In een vervolg experiment is proefpersonen gevraagd in hoeverre de twee extreme objecten van een morfcontinuüm gelijkenis vertonen in *intrinsic part structure* (intrinsieke onderdelen structuur). Om deze laatste term te verduidelijken kunnen we een trui met een boekenkast vergelijken. Een trui heeft een meer horizontale opbouw kijkend naar de mouwen, terwijl een boekenkast een verticale structuur laat zien door de boekenplanken. De mate van gelijkenis in intrinsic part structure blijkt hoger te zijn voor extreme objecten van cp-series dan van non-cp-series. Ook uit latere studies is gebleken dat de intrinsic part structure een belangrijk aspect is voor het vinden van CP voor een morfcontinuüm.

In *Hoofdstuk 3* is de absoluutheid van CP onderzocht: Houdt CP in dat we alleen maar het dominante object als interpretatie overwegen, of worden andere interpretaties ook overwogen, zoals het niet-dominante object? Deze vraag is onderzocht door simpelweg proefpersonen te vragen om twee interpretaties van een individueel gepresenteerd gemorft figuur te geven. Uit de resultaten kwam naar voren dat voor de figuren waarin het dominante object sterk vertegenwoordigd is (80%20% en 70%30% figuren) men het moeilijk vond om een tweede interpretatie te geven. Voor de gemorfte figuren waarin het dominante object minder sterk vertegenwoordigd is (60%40% en 50%50% figuren) was men wel in staat om een tweede interpretatie te geven, welke vaak de niet-dominante bleek te zijn voor figuren van cp-series en een andere interpretatie voor figuren van non-cp-series. Dit bevestigt dat het fenomeen van CP niet absoluut is: Men is in staat een ander object naast het dominante object te herkennen in een gemorft figuur, en bij voorkeur het niet-dominante object.

Het verschil tussen cp-series en non-cp-series wordt wellicht veroorzaakt door een verschil in perceptuele onzekerheid, waarbij figuren van cp-series minder perceptuele onzekerheid veroorzaken dan figuren van non-cp-series. Een studie van De Houwer, Hermans en Spruyt (2001) heeft aangetoond dat moeilijker leesbare stimuli meer werden beïnvloed door de context waarin ze werden gepresenteerd dan stimuli die duidelijk leesbaar waren. Deze vorm van context heet *priming*, waarbij een stimulus wordt voorafgegaan door een andere stimulus, een zogeheten *prime*. Dit zou betekenen dat non-cp-series vanwege hun grotere perceptuele onzekerheid meer beïnvloed zouden worden door de prime dan cp-series. Het kostte de proefpersonen meer tijd om een gemorft figuur van een non-cp-serie te categoriseren en werd een dergelijk figuur vaker als het niet-dominante object gecategoriseerd dan een gemorft figuur van een cp-serie. Echter, geen verschil in effect van context is gevonden tussen de cp-series en non-cp-series. Dit suggereert dat in beide type morfcontinua zowel het dominante als het niet-dominante object verwerkt wordt, waarbij het dominante en niet-dominante object waarschijnlijk sterker vertegenwoordigd zijn in een gemorft figuur van een cp-serie dan in een gemorft figuur van een non-cp-serie.

In *Hoofdstuk 5* is onderzocht wanneer het niet-dominante object tijdens het categorisatieproces verwerkt wordt. In een experiment waarbij men eerst een gemorft figuur kreeg te zien waarvan de presentatieduur werd gevarieerd van zeer kort tot zeer lang, werd men gevraagd dit gemorfte figuur te vergelijken met een extreem object (het dominante of het niet-dominante object) op hun gelijkenis in intrinsic part structure. De mate van gelijkenis werd aangegeven op een zevenpuntschaal (1 = geen gelijkenis, 7 = sterke gelijkenis). Uit de resultaten bleek dat men de gelijkenis tussen het gemorfte figuur en het extreme, niet-dominante object hoger beoordeelde wanneer de presentatieduur van het gemorfte figuur zeer lang was ten opzichte van de zeer korte presentatieduur. Hieruit kan opgemaakt worden dat men meer tijd nodig heeft om het niet-dominante object in een gemorft figuur te verwerken. Daarom kan geconcludeerd worden dat in een later stadium van het categorisatieproces de activatie van het niet-dominante object het sterkst is.

In *Hoofdstuk 6* is onderzocht tot welk niveau het niet-dominante object verwerkt wordt. Dit is gedaan door een gemorft figuur te laten zien en tegelijkertijd een woord over het figuur heen aan te bieden dat genegeerd dient te worden. De woorden waren identiek, semantisch gerelateerd of ongerelateerd aan het dominante en niet-dominante object van een gemorft figuur. Bijvoorbeeld, een gemorft figuur van de *Auto-Schildpad* serie werd aangeboden met de identieke woorden *auto* en *schildpad*, de semantisch gerelateerde woorden *trein* en *kikker* (woorden zijn van dezelfde categorie, respectievelijk *voertuig* en *dier*), en met de ongerelateerde woorden *hamer* en *koffer*. Uiteindelijk is gevonden dat vooral een woord gerelateerd aan het niet-dominante object invloed heeft op het categorisatieproces wanneer deze identiek is aan het niet-dominante object, maar niet wanneer deze semantisch gerelateerd is aan het niet-dominante object. Dit duidt erop dat het niet-dominante object wel op perceptueel niveau verwerkt wordt, maar niet op semantisch niveau.

In *Hoofdstuk 7* is onderzocht of de verwerking van het niet-dominante object ook weerspiegeld wordt in het oogbewegingspatroon. In eerdere studies is een sterke relatie gevonden tussen de interpretatie van een object en naar welk deel van het object gekeken wordt (Chelnokova & Laeng, 2011; Ellis & Stark, 1978; Sæther, Van Belle, Laeng, Brennen, & Øvervoll, 2009). Zo kijkt men bijvoorbeeld direct naar de kop van een dier en naar het centrale gedeelte van een menselijk gezicht. In het geval van gemorfte figuren hebben wij in een oogbewegingsstudie inderdaad een dergelijke relatie gevonden: wanneer men een auto herkende in een gemorft figuur van de *Auto-Schildpad* serie werd de eerste oogbeweging gemaakt naar de plek waar het raam van de bestuurder hoort te zitten en wanneer men een schildpad in hetzelfde figuur herkende werd de eerste oogbeweging gemaakt naar de plek waar de kop van de schildpad hoort te zitten. Vervolgens is onderzocht of de oogbewegingen door de interpretatie worden gedreven of vice versa. Het eerste is onderzocht door het gemorfte figuur vooraf te laten gaan door een woord, bijvoorbeeld *schildpad*, dat een bepaalde verwachting van de interpretatie schept. Hierdoor is men wellicht geneigd om direct op zoek te gaan naar de kop van de schildpad. Het tweede is onderzocht door de ogen naar een bepaald deel van het object te laten gaan, bijvoorbeeld de plek waar de kop van de schildpad hoort te zitten, zodat dit de eerste visuele informatie is die men binnenkrijgt van het object. Uit de resultaten bleek dat de interpretatie wel wordt gedreven door de oogbewegingen, maar niet andersom. Waar je als eerste naar kijkt heeft dus invloed op hoe je het object interpreteert.

Discussie

Op basis van de bevindingen in dit proefschrift kunnen we allereerst concluderen dat de mens erg goed in staat is om te gaan met perceptuele onzekerheid door gelijkvormige objecten toe te schrijven aan dezelfde categorie en in het bijzonder objecten met grote gelijkenis in hun intrinsic part structure. De bevindingen uit dit proefschrift zullen bediscussieerd worden aan de hand van het skelet model van Feldman en Singh (2006) en het respons competitie model van Bar (2003). De intrinsic part structure kun je vertalen in een skelet van het object (zie Figuur 1.1 in Hoofdstuk 1 voor een voorbeeld). Volgens het skelet model blijft het skelet van een object intact ondanks kleine veranderingen in de omlijning van een object (Feldman & Singh, 2006). Dit patroon zien we ook terug in het categoriseren van gemorfte figuren. De omlijning van een object wordt door het morfingproces met kleine stappen veranderd in een ander object. Ondanks deze kleine veranderingen in de omlijning is men toch in staat het extreme, dominante object in het gemorfte figuur te herkennen. Op zijn beurt blijft het skelet van het niet-dominante object ook redelijk intact wanneer twee objecten worden gemorft die grote gelijkenis vertonen in hun intrinsic part structure, waardoor men ook in staat is het niet-dominante object te herkennen.

Uit de experimenten komt verder naar voren dat niet slechts één interpretatie wordt overwogen, namelijk de dominante, maar ook andere interpretaties, waaronder de niet-dominante. Volgens het respons competitie model van Bar (2003) wordt de stimulus in het visuele mechanisme in het brein eerst gerepresenteerd als een vage weergave van de stimulus, een proces dat zeer snel gaat. Op basis van deze vage weergave kunnen een aantal respons opties geactiveerd worden die perceptuele gelijkenis vertonen met deze vage weergave. Vervolgens wordt de gedetailleerde informatie van de stimulus verder verwerkt, een trager proces. Op basis van de gedetailleerde informatie kan een van de geactiveerde respons opties geselecteerd worden als uiteindelijke interpretatie van de stimulus. De context waarin de stimulus wordt aangeboden speelt vooral een rol bij welke respons opties geactiveerd worden, waardoor het categorisatieproces versneld of juist vertraagd kan worden.

Door het skelet model en het respons competitie model te combineren kunnen de huidige bevindingen omtrent het categoriseren van gemorfte figuren verklaard worden. De skeletinformatie van een gemorft figuur is vooral van belang bij het activeren van de mogelijke respons opties. De vage weergave van de stimulus verdoezelt onregelmatigheden in de omlijning, waardoor de algehele skeletstructuur nog wel zichtbaar is, maar kleine veranderingen ontstaan door het morfingproces niet. Op basis van deze skeletstructuur zullen een anatal concepten geactiveerd worden, waaronder het dominante en niet-dominante object van het gemorfte figuur. Deze zullen de competitie met elkaar aangaan. De gedetailleerde informatie levert in de meeste gevallen meer bewijs voor het dominante object, hoewel een context gelijk aan het niet-dominante object het categorisatieproces kan vertragen en zelfs in zoverre kan beïnvloeden dat het gemorfte figuur als het niet-dominante object geïnterpreteerd wordt. Een dergelijk proces is niet alleen van toepassing op gemorfte figuren, maar op alle visuele objecten. Kortom, wanneer jij het rechthoekige blok dat naast je kopje koffie ligt wilt identificeren, kunnen op basis van de snelle, maar vage weergave van het object de concepten *cake, portemonnee en spons* mogelrijk worden geactiveerd vanwege hun overeenkomst in intrinsic part structure met het object. Het concept *cake* is wellicht sterker geactiveerd door de context van het kopje koffie. Op basis van de tragere, maar gedetailleerde informatieverwerking zal uiteindelijk een van deze geactiveerde respons opties geselecteerd worden als jouw identificatie van het object. Wellicht dat je na het lezen van dit proefschrift een andere kijk op de wereld hebt gekregen.

Publications

Publications

Hatendorp, M. O., Van der Stigchel, S., Wagemans, J., Klugkist, I., & Postma, A. (2012). The activation of alternative response candidates: When do doubts kick in? *Acta Psychologica, 139*, 38-45.

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Oral Presentations

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Curriculum Vitae

Mijke Olga Hartendorp was born on 9 September 1981 in Dongen, the Netherlands. In 1999 she graduated from St. Oelbert Gymnasium in Oosterhout, after which she studied Psychology at Leiden University. In 2007, she received her Master's degree in Cognitive Psychology. She performed her Master's research at the Max Planck Institute for Psycholinguistics in Nijmegen within the Language and Cognition Group under supervision of dr. Asifa Majid. She started her PhD at the Experimental Psychology department of Utrecht University in November 2007. Her PhD project was part of the European project *Unconscious boundaries of mind: Research into the extended mind hypothesis*, a collaboration of Utrecht University, University of Leuven and University of Hull. During her PhD, she visited the Laboratory of Experimental Psychology at University of Leuven to collaborate with Prof. dr. Johan Wagemans for two months in 2009. In the last year of her PhD, she was also teaching in Psychology at Utrecht University. Currently, she is working as a postdoctoral researcher at Incas^3 in Assen within the Cognitive Systems Research Group.

Mijke Olga Hartendorp werd geboren op 9 september 1981 te Dongen. In 1999 behaalde ze haar VWO-diploma aan het St. Oelbert Gymnasium te Oosterhout, waarna zij Psychologie aan Universiteit Leiden ging studeren. In 2007 studeerde zij af met Cognitieve Psychologie als specialisatie. Haar afstudeeronderzoek heeft zij uitgevoerd aan het Max Planck Instituut voor Psycholinguïstiek te Nijmegen binnen de Language and Cognition Group onder begeleiding van dr. Asifa Majid. In november 2007 is zij haar promotietraject ingegaan aan Universiteit Utrecht bij de afdeling Psychologische Functieleer. Haar promotieproject maakte deel uit van het Europese project *Unconscious boundaries of mind: Research into the extended mind hypothesis*, een samenwerking tussen Universiteit Utrecht, KU Leuven en University of Hull. In 2009 heeft zij binnen dit project twee maanden onderzoek gedaan aan KU Leuven in samenwerking met Prof. dr. Johan Wagemans. In haar laatste jaar van haar promotie was zij ook aangesteld als docent Psychologie aan Universiteit Utrecht. Momenteel is zij werkzaam als postdoctoraal onderzoeker bij Incas^3 te Assen binnen de Cognitive Systems Research Group.