The activation of alternative response candidates: When do doubts kick in?

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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.

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1. 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 and 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

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causing uncertainty that leads to activation of more response candidates. With increase of exposure time, the number of response candidates will decrease (Graboi & Lisan, 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 is the influence of alternative response candidates on the categorization process 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 et al., 2010; Newell & Bulthoff, 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 for publication) 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 Hoffding, 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 Fig. 1 for different switch sizes).

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

Fig. 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).

literature on CP that the similarity pattern does not show a continuous linear decrease, but an abrupt switch halfway 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 the morphed figure and its nondominant object). See also 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 (Hojtink, Klugkist, & Boelen, 2008; Klugkist, Laudy, & Hojtink, 2005; Mulder, Hojtink, & 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.

2. Method

2.1. 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 min in the short timing conditions to 45 min in the long timing conditions. The participants received 6 Euros or one course credit for their contribution.

2.2. Apparatus and stimuli

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 Sqrirlz-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 $4.29^\circ \times 3.34^\circ$, 7 cm $\times$ 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 Fig. 2 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.

2.3. Design and 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 $\times$ 7 morphed figures $\times$ 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 was 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 ms 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

Fig. 2. All fifteen morph series consisting of seven morphed figures (80%20% to 20%80%) and two extreme figures (100%0% and 0%100%) used as stimulus material in the current study. The first row represents the different morphing levels. The first column includes the names of the morph series. The first word refers to the most left extreme figure (100%0%) and the second word to the most right extreme figure (0%100%).

condition to which the participant was assigned. Subsequently, an extreme figure appeared that was presented until a response was entered by the participant making use of the keyboard. 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 ms after which the following trial started. When 105 trials were completed, a self-timed break was included.

3. Data analysis

3.1. Bayesian model selection approach

To evaluate which hypothesis gained the most support, a Bayesian model selection approach was used (Hojtink 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 et al., 2009, 2010).

3.2. 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 Fig. 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 Fig. 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.

3.3. 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, 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 Fig. 3.

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

4. 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 times: 50 ms, 300 ms and 3000 ms, respectively) and *Interval*

Fig. 3. 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).

Duration (short and long intervals: 300 ms and 3000 ms, respectively) were included in the design. This resulted in 84 different conditions (2 relations $\times$ 7 morphing distances $\times$ 3 presentation times $\times$ 2 interval durations). For each condition, the mean similarity ratings per participant

Fig. 4. 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.

Fig. 5. 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 interval condition and the dashed lines represent the long interval condition.

were measured. The mean similarity ratings are presented graphically in Figs. 4 and 5, with Fig. 4 representing the three presentation times of the morphed figures for the related and unrelated condition and with Fig. 5 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.

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 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.

5. 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 (Hojtink 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 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 activation of the nondominant response candidate increases 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. 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 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 extract 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, and 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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Appendix

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								
	$(15-27) - ((3-15) + (27-39))/2 > ((18-30) - ((6-18) + (30-42))/2$								

In the first table, the different conditions used in the experiment are presented. 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 in the following table.

References

- Bar, M. (2003). A cortical mechanism for triggering top-down facilitation in visual object recognition. *Journal of Cognitive Neuroscience*, 15(4), 600–609.
- Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, 94(2), 115–147.
- Daelli, V., van Rijsbergen, N. J., & Treves, A. (2010). How recent experience affects the perception of ambiguous objects. *Brain Research*, 1322, 81–91.
- De Winter, J., & Wagemans, J. (2004). Contour-based object identification and segmentation: Stimuli, norms and data, and software tools. *Behavior Research Methods, Instruments, & Computers*, 36(4), 604–624.
- De Winter, J., & Wagemans, J. (2006). Segmentation of object outlines into parts: A large-scale integrative study. *Cognition*, 99, 275–325.
- Downing, P. E., Bray, D., Rogers, J., & Childs, C. (2004). Bodies capture attention when nothing is expected. *Cognition*, 93, B27–B38.
- Edelman, S. (1998). Representation is representation of similarities. *The Behavioral and Brain Sciences*, 21, 449–498.
- Feldman, J., & Singh, M. (2006). Bayesian estimation of the shape skeleton. *Proceedings of the National Academy of Sciences*, 103(47), 18014–18019.
- Gerlach, C., Law, I., & Paulson, O. B. (2004). Structural similarity and category-specificity: A refined account. *Neuropsychologia*, 42, 1543–1553.
- Gomez, C., Argandona, E. D., Solier, R. G., Angulo, J. C., & Vazquez, M. (1995). Timing and competition in networks representing ambiguous figures. *Brain and Cognition*, 29, 103–114.
- Graboi, D., & Lisman, J. (2003). Recognition by top-down and bottom-up processing in cortex: The control of selective attention. *Journal of Neurophysiology*, 90, 798–810.
- Harnad, S. (1987). Introduction: Psychophysical and cognitive aspects of categorical perception: A critical overview. In S. Harnad (Ed.), *Categorical perception: The groundwork of cognition* (pp. 1–25). Cambridge: Cambridge University Press.
- Hartendorp, M. O., Van der Stigchel, S., Burnett, H. G., Jellema, T., Eilers, P. H. C., & Postma, A. (2010). Categorical perception of morphed objects using a free-naming experiment. *Visual Cognition*, 18(9), 1320–1347.
- Hartendorp, M. O., Van der Stigchel, S., Wagemans, J., & Postma, A. (submitted for publication). The absoluteness of categorical perception: One or two interpretations?.
- Hoffding, H. (1891). *Outlines of psychology*. London: Macmillan.
- Hoffman, D. D., & Singh, M. (1997). Saliency of visual parts. *Cognition*, 63, 29–78.
- Hojitink, H., Klugkist, I., & Boelen, P. A. (2008). *Bayesian evaluation of informative hypotheses*. New York: Springer.
- Kass, R. E., & Raftery, A. E. (1995). Bayes factors. *Journal of the American Statistical Association*, 90(430), 773–795.
- Klugkist, I., Laudy, O., & Hoijtink, H. (2005). Inequality constrained analysis of variance: A Bayesian approach. *Psychological Methods*, 10(4), 477–493.
- Lamberts, K. (1995). Categorization under time pressure. *Journal of Experimental Psychology: General*, 124(2), 161–180.
- Lamberts, K., & Freeman, R. P. J. (1999). Categorization of briefly presented objects. *Psychological Research*, 62, 107–117.
- Leopold, D. A., & Logothetis, N. K. (1996). Activity changes in early visual cortex reflect monkeys' percepts during binocular rivalry. *Nature*, 379, 549–553.
- Long, G. M., & Toppino, T. C. (2004). Enduring interest in perceptual ambiguity: Alternating views of reversible figures. *Psychological Bulletin*, 130(5), 748–768.
- Malt, B. C., Ross, B. H., & Murphy, G. L. (1995). Predicting features for members of natural categories when categorization is uncertain. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 21(3), 646–661.
- Medin, D. L., & Schaffer, M. M. (1978). Context theory of classification learning. *Psychological Review*, 85(3), 207–238.
- Mulder, J., Klugkist, I., Van der Schoot, R., Meeus, W. H. J., Selfhout, M., & Hoijtink, H. (2009). Informative hypotheses for repeated measurements: A Bayesian approach. *Journal of Mathematical Psychology*, 53, 530–546.
- Mulder, J., Hoijtink, H., & Klugkist, I. (2010). Equality and inequality constrained multivariate model selection: Objective model selection using constrained posterior priors. *Journal of Statistical Planning and Inference*, 140, 887–906.
- Murphy, G. L., & Ross, B. H. (2010). Uncertainty in category-based induction: When do people integrate across categories? *Journal of Experimental Psychology: Learning Memory & Cognition*, 36(2), 263–276.
- Newell, F. N., & Bulthoff, H. H. (2002). Categorical perception of familiar objects. *Cognition*, 85, 113–143.
- Nosofsky, R. M. (1984). Choice, similarity, and the context theory of classification. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 10(1), 104–114.
- Op de Beeck, H., Wagemans, J., & Vogels, R. (2003). Asymmetries in stimulus comparisons by monkey and man. *Current Biology*, 13, 1803–1808.
- Op de Beeck, H., Torfs, K., & Wagemans, J. (2008). Perceived shape similarity among unfamiliar objects and the organization of the human object vision pathway. *The Journal of Neuroscience*, 28(40), 10111–10123.
- Panis, S., Vangeneugden, J., & Wagemans, J. (2008). Similarity, typicality, and category-level matching of morphed outlines of everyday objects. *Perception*, 37(12), 1822–1849.
- Pöppel, E. (1997). Review: A hierarchical model of temporal perception. *Trends in Cognitive Sciences*, 1(2), 56–61.
- Rosch, E., Mervis, C. B., Gray, W. D., Johnson, D. M., & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology*, 8, 382–439.
- Roselle, L. J., & Cooper, E. E. (2001). Categorical perception of relative orientation in visual object recognition. *Memory & Cognition*, 29(1), 68–82.
- Schwarzer, G., Huber, S., & Dümmler, T. (2005). Gaze behavior in analytical and holistic face processing. *Memory & Cognition*, 33(2), 344–354.
- Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, 6(2), 174–215.
- Torfs, K., Panis, S., & Wagemans, J. (2010). Identification of fragmented object outlines: A dynamic interplay between different component processes. *Visual Cognition*, 18(8), 1133–1164.
- Verstijnen, I. M., & Wagemans, J. (2004). Ambiguous figures: Living versus nonliving objects. *Perception*, 33, 531–546.
- Ward, T. B., & Scott, J. G. (1987). Analytical and holistic models of learning family-resemblance concepts. *Memory & Cognition*, 15, 42–54.
- Wilder, J., Feldman, J., & Singh, M. (2011). Superordinate shape classification using natural shape statistics. *Cognition*, 119, 325–340.