Does task relevance shape the ‘shift to global’ in ambiguous motion perception?

Charlotte Boeykens

Laboratory of Experimental Psychology,
Department of Brain and Cognition, KU Leuven, Belgium

Johan Wagemans

Laboratory of Experimental Psychology,
Department of Brain and Cognition, KU Leuven, Belgium

Pieter Moors

Laboratory of Experimental Psychology,
Department of Brain and Cognition, KU Leuven, Belgium

Perception can differ even when the stimulus information is the same. Previous studies have demonstrated the importance of experience and relevance on visual perception. We examined the influence of perceptual relevance in an auxiliary task on subsequent perception of an ambiguous stimulus. Observers were presented with an ambiguous motion stimulus that could either be perceived as rotating dot pairs (“local”) or pulsating geometrical figures (“global”). Prolonged perception of this stimulus is characterized by a “shift to global”, but it remained unclear whether this process is due to relevance of the global percept or mere exposure to the stimulus. During a relevance learning phase over 5 successive days, participants were divided into conditions determining the relevant percept in an auxiliary task: local, global, or none (active exposure). In a pre- and posttest, individual points of subjective equality between local and global percepts were measured. Results indicate that there is indeed a shift to global. Interestingly, auxiliary task relevance does not seem to modify this process.

Introduction

Visual perception is not merely the result of stimuli being represented in passive observers. Our perceptual system disambiguates and interprets the information it receives through our eyes. The perception of ambiguous stimuli provides a clear demonstration of the dissociation between stimulus and percept: Identical stimuli are perceived in substantially different ways between different observers (interindividual differences) or from one moment to the next within single observers (intraindividual differences; Blake & Logothetis, 2002; Brascamp, Sterzer, Blake, & Knapen, 2018; Kornmeier

& Bach, 2012; Leopold & Logothetis, 1999; Necker, 1832; Nikolaev, Gepshtein, & van Leeuwen, 2016). For instance, a Necker cube can be perceived both facing the upper right corner and facing the lower left corner, even though the physical image remains the same. Perceptual organization describes how basic visual features are organized into more coherent units, which are employed in further processing (Wagemans, 2018). Understanding under which circumstances a stimulus is perceived one way or the other may guide our understanding of how sensory information is transformed into a perceptual representation.

Decades of research have been devoted to investigating what determines a perceptual outcome in the case of ambiguous stimuli. Differences in perception of ambiguous stimuli appear not to be merely coincidental; rather, they are systematically influenced by various factors. Brascamp et al. (2018) reviewed the literature on ambiguous perception, demonstrating the role of multiple information sources resolving perceptual ambiguities. One particularly important and complex source of information to resolve perceptual ambiguities is prior experience. Prior experience may influence perception in various ways, ranging from perceptual organization in the preceding seconds to implicitly and explicitly learned expectations (Denison, Piazza, & Silver, 2011; Di Luca, Ernst, & Backus, 2010; Piazza, Denison, & Silver, 2018; Schmack, Weinhhammer, Heinze, Stephan, & Sterzer, 2016). Even in traditional Gestalt psychology, Wertheimer (1912) described prior experience as an influencing factor in perceptual organization, in addition to isolated stimulus factors (see also Wagemans, 2018).

Prior experience may affect perception because it provides information about the relevance of sensory input to the observer. This way, our perceptual system

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Figure 1. Ambiguous motion stimulus as employed by Anstis and Kim (2011). Small arrows indicate rotation of the dot pairs and movement of the local percept. Large arrows indicate movement of the global percept. A similar animated version can be found under “stimuli” at <https://osf.io/jryb9/>.

is informed about which perceptual organization will allow successful interaction with the environment. Related to this, the interface theory of perception (Hoffman, Singh, & Prakash, 2015; Koenderink, 2011) describes perception as an adaptive interface that serves to guide useful actions, not to resemble truth. Accordingly, the formation of a percept from our basic visual experience should be shaped by what is relevant. What is found to be relevant by our visual system, however, may be variable and influenced by multiple information sources. We may distinguish three levels of prior experience constituting perceptual relevance. *Higher level* processes (e.g., previously experienced cognitive goals to perceive the Necker cube facing the upper right corner) may determine what is relevant to perceive. Alternatively, engagement with the same *mid-level percept* (e.g., previously perceiving the Necker cube facing the upper right corner) could determine its relevance. Or, *low-level exposure* to the same visual input (e.g., previously being presented with the Necker cube, irrespective of the percept) may be sufficient to determine its relevant percept.

Anstis and Kim (2011) studied perception of an ambiguous motion stimulus (Figure 1) that enabled a “local” and a “global” percept. The stimulus consists of multiple dot pairs placed around a common center. When the dot pairs change in phase position between two successive frames, one of two percepts can emerge. The local percept consists of multiple rotating dot pairs, whereas the global percept consists of two pulsating geometric forms. Such an ambiguous motion stimulus is particularly interesting since it allows us to control and manipulate its basic physical properties precisely, while still enabling us to study more complex perceptual interpretations (e.g., motion direction).

Prolonged perception of the ambiguous motion stimulus was found to be characterized by a “shift to global.” This implies that the longer an individual watches the stimulus, the more they report to perceive it globally. However, it remains unclear whether the shift to global occurs automatically over time, or is due to a

higher level attribution to the global percept. For instance, more relevance might be attributed to the global percept because it is initially more difficult to perceive and participants might try to achieve this in order to report both local and global percepts (as instructed). Accordingly, the global percept would become a higher level cognitive goal. Anstis and Kim (2011) interpreted the shift to global as a result of learning and adaptation in perceptual organization towards a global configuration. They concluded that higher level attention and perceptual interpretation underlie the perceptual strength of global versus local percepts, in analogy to the high-level processes involved in perception of ambiguous motion transparency stimuli (McOwan & Johnston, 1996). However, since the manipulation of Anstis and Kim (2011) merely involved a stimulus induced change, it is difficult to determine exactly what is implied with the term “higher level” and to exclude alternative explanations that do not rely on high-level perceptual processes.

Chopin and Mamassian (2010, 2011) examined the role of high-level processes in more detail and found that biases in perceptual organization can be updated on a short time scale based on relevance. They used an ambiguous motion transparency stimulus and had observers report the direction of motion that was perceived to be in front. In an auxiliary task, observers had to perform a visual search for a slowly moving dot in a similar stimulus. The preferred motion direction of the motion transparency task was altered by the direction of the slow dot in the visual search task. The authors concluded that the attribution of usefulness to one of the directions in the auxiliary task had an influence on spontaneous perception in the motion transparency task, even though this direction did not help them in that task. Harrison and Backus (2010) manipulated perceptual bias in rotating Necker cubes and showed that contextual information can bias subsequent perception of an ambiguous stimulus. Similarly, Feigin, Baror, Bar, and Zaidel (2017) found that previous behavioral relevance has a key role in biasing future perception. These findings suggest that higher level processes, such as auxiliary task relevance, can affect mid-level perception. If this is the case, the shift to global in the ambiguous motion stimulus employed by Anstis and Kim (2011) could be due to higher level relevance of the global percept.

In this study, we similarly examined if and how relevance shapes perceptual organization. In particular, we asked whether the previously observed “shift to global” in the stimulus used by Anstis and Kim (2011) is due to relevance (i.e., akin to the findings of Chopin and Mamassian, 2010, 2011) or can be explained by mere exposure to the ambiguous stimulus. Observers were presented with an altered version of the ambiguous motion stimulus (Figure 2) employed by Anstis

Figure 2. Ambiguous motion stimulus employed in the present study. Arrows indicate the movement of the dot pairs. Dot pairs were phase-shifted in comparison to Figure 1 in order to create a global percept with different characteristics (i.e., pulsating instead of shuffling). An animated version can be found under “stimuli” at <https://osf.io/jryb9/>.

and Kim (2011) and were asked to report their spontaneous percept. In a first session, their point of subjective equality (PSE) between the local percept (pairs rotating) and the global percept (geometric figures pulsating) was measured. In a relevance learning phase, which took place across 5 successive days, observers were then divided into three conditions determining their relevant percept. This time scale was chosen because it was assumed to provide a more robust manipulation of perceptual relevance. In the local condition, participants performed a task that could only be solved by adopting a local percept. In the global condition, participants performed a task that could only be solved by adopting a global percept. Lastly, in the exposure condition, participants performed a task that could be solved without having to consistently adopt either percept. Accordingly, the higher level relevance of either percept in the ambiguous motion stimulus was manipulated by means of a task. After the learning phase, participants’ PSE was measured again. A shift to global is reflected by an increase in the PSE.

If a higher order relevance of the global percept or engagement with the global percept is necessary to elicit a shift to global, we should find a differential effect for task relevance of the global percept compared with the local percept. That is, the global condition should elicit more global percepts, whereas the local condition should elicit more local percepts. If a higher order relevance of either percept or engagement with either percept is necessary to elicit a shift to global, we should find a differential effect for task relevance of either

percept compared with the exposure task. That is, relative to the exposure condition, we expect more global percepts for either condition. If exposure to the same visual input, irrespective of the constructed percept, is sufficient to elicit a shift to global, we should not find any differential effect for task relevance.

Methods

Participants

Thirty university students (five male, aged 18–24) participated in the study in return for course credit. The number of participants was based on previous studies employing an equivalent paradigm (Chopin & Massin, 2011; Harrison & Backus, 2010). All participants had normal or corrected-to-normal vision, provided informed consent, and were naive with respect to the goals of the study. The study was approved by the Social and Societal Ethics Committee of KU Leuven (SMEC, approval code G 2017 05 834) and adhered to the tenets of the Declaration of Helsinki.

Apparatus

All stimuli were displayed on a CRT monitor (Sony GDM F520) with a refresh rate of 60 Hz, a diagonal length of 50 cm and a resolution of 1024×768 pixels. Participants were positioned in a dark room at a viewing distance of 57 cm from the monitor by means of a chin rest. Stimulus presentation and response registration was controlled by software programmed in Python using the PsychoPy library (Peirce, 2007).

Stimuli

The ambiguous motion stimulus (Figure 2) consisted of six pairs of dots displayed on a uniform gray background (luminance 17.9 cd/m^2) around a white fixation point. One dot of each pair was white (luminance 76.8 cd/m^2), whereas the other dot was black (luminance 0.2 cd/m^2). The random allocation of these colors to the dots was determined at the start of each trial. The rationale for this color scheme is related to the relevance manipulation (see Procedure). The dots had a radius of 0.2° and were placed in pairs with an edge-to-edge distance of 0.39° . This distance may also be regarded as a phase shift of π rad around the pair center. The six dot pairs are placed around a central fixation point with a distance G from the center. Since the dot pairs are placed in a hexagon, distance G is also equal to the distance between the dot pairs. The

starting position of the dots varied according to the phase of their pair centers relative to the common center. Accordingly, the position of a dot was not only related to the other dot in its pair by a phase shift around the pair center, but also to other dots by the phase relation to the common center. Dots rotated around their pair center at a speed of 2π rad/s for 30 frames, or 500 ms, per trial. This rotation was either clockwise or counterclockwise, determined randomly at the start of each trial. At the end of each trial, the position of each dot pair differed from the starting position with a rotation of π rad around the pair center.

Design and procedure

A 2×3 design with within-subjects factor time (pre- and postlearning phase) and between-subjects factor relevance (local, global and exposure) was implemented. The experiment consisted of five separate sessions spread across 5 successive days. The first and last session lasted approximately 40 min; all other sessions lasted approximately 15 min. During the first session, a continuous version of the ambiguous motion stimulus was displayed shortly in order to assure that the participant could experience the difference between the local and the global percept. During the first and last session, the PSE was measured according to the procedure described below. During the relevance learning phase taking place in all five sessions, participants performed the relevance task, also described below. Participants were randomly assigned to a relevance condition for the learning phase, resulting in 10 participants per condition. The dependent measure of interest was the difference between the PSE pre- and postlearning, dependent upon the relevance condition. At the end of the experiment, participants were questioned about their knowledge of the experimental manipulation. We wanted to assure that participants did not figure out the purpose of the experiment, which could bias their responses. If participants had a vague idea about the purpose of the experiment, we questioned whether they altered their responses according to their expectations instead of their actual percepts.

Point of subjective equality

In a pre- and postlearning test, the PSE was measured for each participant. The PSE, or transition point, is the point (i.e., a particular stimulus configuration) at which both percepts of the ambiguous motion stimulus are equally likely. On each trial, participants were presented with the ambiguous motion stimulus for 500 ms, after which they had to indicate their percept by means of a button press (left arrow for

local, right arrow for global, or vice versa). Responses were not permitted before the end of the trial and the stimulus remained in the ending position until a response was given. Between two successive trials, the fixation point was displayed for 1,000 ms. The distance between the elements of the local percept, or between the dots of one dot pair, was kept constant at 0.39° . The distance G was manipulated on each trial according to an adaptive staircase procedure—Psi (Kontsevich & Tyler, 1999). We will refer to distance G at the PSE as G^* . When G is larger than G^* , an individual will perceive the ambiguous stimulus as local; when G is smaller than G^* , an individual will perceive the ambiguous stimulus as global. The longer distance G^* is, the longer the physical distance between the dot pairs can be for an individual to be able to see the global percept. A shift to global may thus be quantified by an increase in distance G^* . Three different Psi staircases, each consisting of 100 trials, were presented in an interleaved manner, resulting in 300 trials in total. Distance G^* was computed by taking the mean of the estimates for G^* of the three Psi staircases. Participants performed the relevance task in all five sessions of the learning phase with a stimulus that has the distance G^* measured in the beginning of their first session. This way, participants initially perform the relevance task with an equal probability of seeing the local and the global percept, irrespective of which percept is relevant for the task. After the learning phase, at the end of the last session, the PSE was remeasured.

Relevance task

Participants performed the relevance task during each session on 5 successive days. Each task session consisted of 300 trials divided into six blocks interspersed with short breaks. Crucially, the presented stimulus was identical in all tasks, except for participant-specific G^* and a change in the color of the fixation point in the exposure task. Moreover, in all tasks, participants received the instruction to maintain their fixation on the fixation point, but to spread their visual attention across the entire stimulus. Therefore, the only difference between conditions should be the manipulation of relevance of the percept by means of the task.

In the local task, a local percept was necessary to perform the task. Participants had to indicate whether they saw a clockwise or counterclockwise rotation of the dot pairs (Figure 3, top row). Crucially, the global percept was irrelevant to perform the local task, and vice versa. As indicated in Figure 3, the same stimulus (rows) provides both a local and a global percept. However, as the Figure shows, a correct response in the global task corresponds to different correct responses in the Local task and vice versa.

Figure 3. Local and global tasks employing ambiguous motion stimuli and examples with correct answers. In this example, white dots should be used for the global task. Dot color does not have any meaning in the local task. The same stimulus (columns) can elicit both a local and a global percept (percepts are indicated in blue). A change in correct answer for the global task does not necessarily imply a change in correct answer for the local task, and vice versa.

In the global task, a global percept was necessary to perform the task. Participants had to indicate whether they saw a growing–shrinking or shrinking–growing pulsating movement of the global geometric form (Figure 3, bottom row). During one trial, both options can be valid. However, because of the color scheme, only one option is correct. More specifically, participants were instructed to report the pulsating movement direction for either the black, or the white dots. The color to be reported was counterbalanced across participants.

In the exposure task, neither a global nor local percept was necessary to perform the task. Participants had to report a color change (white to black) in the central fixation point, which occurred on 50% of the trials. Consequently, both percepts were irrelevant. Nevertheless, participants were engaged in a task that was intended to be equally attention demanding as the other conditions.

Data analysis

All data analysis was performed in R 3.4.1 (R Core Team, 2018). Statistical tests relied on model selection based on Bayes factors using the BayesFactor package 0.9.12.2 (Morey & Rouder, 2015). In the Bayesian statistical framework, Bayes factors quantify the consistency of the data with the predictions of a

particular statistical model over another. Bayes factors from 3 onwards were proposed as substantial evidence for one model over another by Jeffreys (1961). Fitted models included random intercepts for participants and used variables time (pre- and postlearning) and relevance (local, global, and exposure) as predictors. Default priors as implemented in the package were used. This amounts to a “medium” scale ($r = 0.5$) for fixed effects and a “nuisance” scale for random effects ($r = 1$). These scales apply to the so-called g-priors, which are placed on the effects in the analysis of variance model (for a detailed description, see Rouder, Morey, Speckman, & Province, 2012). The data and analysis code are available under “data” and “analysis” on the Open Science Framework (<https://osf.io/jryb9/>).

Results

The results of the Bayes factor analysis indicated that there was strongest support for a model with only a main effect of time. Table 1 shows Bayes factors of the model with the main effect of time compared with other models. The main effect of time indicates an overall change in perceptual organization after prolonged engagement with the ambiguous motion stimulus. G^* , the distance between the dot pairs of the ambiguous stimulus at the PSE, was larger after the

Model	Bayes factor
Time + participant	1.000
Time + relevance + participant	1.526
Participant	4.865
Time + relevance + time:relevance + participant	6.010
Relevance + participant	7.939

Table 1. Fitted models and Bayes factors. *Note.* Reported Bayes factors correspond to the best-fitting model (top row) with only main effects of time and participant, compared with each model.

learning phase ($M = 6.28^\circ$, $SD = 3.04^\circ$) than before the learning phase ($M = 5.36^\circ$, $SD = 2.85^\circ$). There are substantial individual differences in this effect, but the overall trend is in the direction of a shift to global, indicating that the global percept was more dominant in most individuals postlearning. Figure 4 shows G^* in the first and last session for all observers. Values of G^* above the diagonal imply a shift to global over time. Secondly, there is support for an additional main effect of relevance (a mere $BF = 1.526$ for a model without a main effect of relevance compared with a model with both main effects) indicating that there was a difference

in G^* depending on the assigned conditions of participants, irrespective of the learning phase. Participants assigned to the global condition ($M = 6.80^\circ$, $SD = 3.51^\circ$) had a larger G^* than participants assigned to the exposure condition ($M = 5.53^\circ$, $SD = 2.61^\circ$) and the local condition ($M = 5.14^\circ$, $SD = 2.53^\circ$). Even though participants were assigned to relevance conditions randomly, the distribution of perceptual dominance was uneven over conditions by chance. Although the absence of a main effect of relevance would have been desirable, we do not consider it to be problematic here, as the critical effect was the interaction between time and relevance.

As can be derived from Table 1, the model with only a main effect of time was supported substantially more by our analysis than a model with the interaction effect of interest ($BF = 6.010$ for a model without the interaction effect compared with a model including the interaction effect). This finding indicates that the manipulated relevance of either percept during the learning phase had no effect on the shift to global of G^* .

Responses to the questionnaire provided at the end of the last session indicated that almost none of the participants were aware of a link between the

Figure 4. Individual measures of G^* —the distance between the dot pairs of the ambiguous stimulus at the PSE—before and after the learning phase are plotted in a different color for each relevance condition. The mean of G^* for each condition is indicated by a larger icon. Error bars are means ± 1.96 times the standard error. The dotted diagonal line indicates no change in G^* over time. Values above the diagonal indicate a shift to global. The black symbol represents the mean shift to global over all individuals and conditions.

measurement of the PSE and the relevance manipulation during the learning phase. Importantly, none of the participants indicated that they had responded according to any reasoning other than their experienced percept.

Discussion

Absence of a differential effect of auxiliary task relevance

In the current study, we examined the role of previous experience and relevance on perceptual organization. Relevance may manifest itself on various levels, ranging from a high-level cognitive goal to low-level repeated exposure. Based on previous findings of Chopin and Mamassian (2010, 2011), we predicted that mid-level perceptual organization in an ambiguous motion stimulus could be shaped by higher level relevance triggered by an auxiliary task. Our results suggest that manipulating the relevance of a percept in an ambiguous motion stimulus by means of an auxiliary task does not affect its subsequent perception. This is in contrast to previous findings (Chopin & Mamassian, 2011; Feigin et al., 2017; Harrison & Backus, 2010).

An explanation for these contradictory findings could be that the time scale of the manipulation of Chopin and Mamassian (2011) and Harrison and Backus (2010) was shorter than the time scale of the current experiment. In the current experiment, the influence of the relevance manipulation was examined over the course of a whole week, whereas Chopin and Mamassian obtained their results based on one experimental session. However, it is important to note that the last session in the current experiment consisted of the relevance task followed immediately by the measurement of the PSE. This implies that, in principle, the relevance manipulation needed only to last for one experimental session, not for an entire week. Another important difference between both studies is the alternation of perceptual report and the auxiliary task. Observers in the experiment of Chopin and Mamassian alternated between the perceptual report and the auxiliary task, whereas observers in our experiment performed both tasks separately. Therefore, the findings of Chopin and Mamassian may also have been due to a short-term attentional bias. Indeed, a study by Meng and Tong (2004) showed that attention can selectively bias perceptual organization in ambiguous stimuli such as the Necker cube, but not so strongly in binocular rivalry, where the ambiguity has been argued to be solved at a lower level (Tong, 2001). However, in a previous study, Chopin and Mamassian showed that

the effect of task relevance is also present in binocular rivalry stimuli and argued against an account of attention for explaining their results. Since the effect of task relevance was still present in the last block of their experiment where it was not relevant to the auxiliary task anymore, the effect is not merely due to a short-term bias. Moreover, in the experiment of Harrison and Backus (2010), the perceptual report and auxiliary task were performed separately, as was the case in our experiment. Their reported effect was present on the next day and resisted reverse learning, eliminating the possibility of a short-term attentional bias. The absence of a differential effect of higher level relevance on the perception of the ambiguous motion stimulus may also be due to the specific stimulus employed in this paradigm. Indeed, previous research has shown that the size of the effect of learned expectations on the perception of ambiguous stimuli varies widely across different stimuli (Meng & Tong, 2004; Schmack et al., 2016; Weinhhammer, Stuke, Sterzer, & Schmack, 2018). If our visual system adapts our perception to what is useful, the extent of the effect of higher level relevance will naturally depend on which range of factors influences usefulness in a particular stimulus.

A last consideration regarding the absence of an effect pertains to the sample size used in the current study, which was based on the range reported by previous studies. More specifically, 10 participants per condition may appear to lack sufficient statistical power to find an effect of auxiliary task relevance. Here, it is important to note that the dependent variable in experimental designs (in our case, the PSE) is usually a summary measure based on repeated measurements. Aggregating over these repeated measurements decreases measurement error, a factor not regularly taken into account in conducting power analyses. Consequently, in many psychophysical experiments with small sample sizes, statistical power is frequently much higher compared with studies where the dependent variable consists of a single measurement for each participant (Brysbaert & Stevens, 2018; Rouder & Haaf, 2018). Furthermore, our Bayes factor analysis indicates that the data are informative in the sense that they are more consistent with the absence rather than the presence of an effect.

Shift to global

Even though task relevance did not affect perceptual organization in our experiment, this does not necessarily suggest that relevance does not have an influence in any other way. As our results show, prior experience with the ambiguous motion stimulus affects its perception over time. The current experiment replicated earlier findings of a shift to global (Anstis & Kim, 2011); the

more observers see the ambiguous motion stimulus, the more they perceive it globally. Returning to the three levels of prior experience constituting perceptual relevance, the most probable candidate determining the shift to global in our study would be low-level exposure to the same visual input. Since there was no differential effect for task relevance of either percept compared with the exposure task, higher level processes (i.e., previously experienced cognitive goal to solve the global task) or any specific mid-level percept (i.e., previously experienced local or global percept) were not necessary to elicit a shift to global. Moreover, since the shift to global was present within one experimental session in the study of Anstis and Kim (2011), it is unlikely that it took as long as the time scale of our experiment (i.e., five short sessions spread across 5 successive days) to occur.

As was established previously, the absence of a differential effect of the relevance task on the shift to global is most probably not due to the absence of a short-term attentional bias compared with previous studies (Chopin & Mamassian, 2011). However, attention may play a role in the shift to global in general. In the exposure condition, no particular percept was necessary to perform the task. Nevertheless, a certain amount of attention to the stimulus was present in all conditions. Accordingly, the necessity of attention to the stimulus for a shift to global remains an open question. Previous research has shown that attention influences perception of ambiguous stimuli (Meng & Tong, 2004). However, it is unclear why attention would bias the perception of ambiguous stimuli towards one particular perceptual interpretation (i.e., global) in the current study, irrespective of which perceptual interpretation the observer has previously paid attention to. Future research should clarify whether the shift to global still occurs when attention is averted from the stimulus.

Another important question is whether the shift to global occurs passively and purely stimulus-driven, versus actively and observer-driven. In the former case, the change in perception of the stimulus would occur in any observer, regardless of how the particular observer's visual system may interpret it. In the latter case, the change in perception of the stimulus is due to an observer-driven reinterpretation. As stated by Maloney, Martello, Sahm, and Spillmann (2005): "We conclude that the visual system does not passively remember perceptual state: It analyzes recent perceptual history and attempts to predict what will come next. These predictions can alter what is seen" (p. 364). We may argue that the fact alone that a stimulus shows up in our environment more often might make it more relevant. More specifically, our visual system may notice the reoccurrence of the stimulus and alter its perception to allow more efficient processing in the

future. Accordingly, individuals may differ in the change of their perceptual dominance, depending on whether and how their visual system interprets the reoccurring stimulus. Indeed, there is individual variability in change in perception of the ambiguous motion stimulus (Figure 4).

Lastly, an essential issue is the role of globality in the perceptual organization of the ambiguous motion stimulus. The term globality here refers to the level of comprehensiveness and simplicity of the perceptual representation. For example, the percept of one diamond versus four different bars in the bistable diamond (see example in de-Wit, Kubilius, Wagemans, & Op de Beeck, 2012). In the study of Chopin and Mamassian (2011), both percepts of the ambiguous motion transparency stimulus were equal in globality. That is, the stimulus information was perceptually organized in an equal number of groups in both percepts. This was not the case for the ambiguous motion stimulus. As stated by Anstis and Kim (2011): "[The global percept] groups the maximum amount of evidence into the minimum number of perceptual hypotheses" (p. 11). Previous research has shown that effects of globality in a stimulus interact with effects of relevance of the stimulus (Poirel, Pineau, & Mellet, 2008). Therefore, it is possible that an effect of task relevance in the current experiment may have been overshadowed by an effect of globality. Our perceptual system might favor a global perceptual organization of a reoccurring stimulus because a configuration of multiple dots in two pulsating convex hexagons is a better Gestalt than six dot pairs moving coherently. Accordingly, it allows more efficient processing (Garner, 1974) and is stored more easily in memory (Attneave, 1955; Woodman, Vecera, & Luck, 2003). This rationale is in accordance with the notion that the purpose of perception is to be useful, not to resemble truth (Hoffman et al., 2015; Koenderink, 2011). The global perceptual organization might take some more time and effort when the stimulus is still unfamiliar compared with when it is more familiar and already represented, leading to an increase in global perceptual organization over time.

Conclusions

The results of our study imply that perception of the ambiguous motion stimulus used here (Figure 2) is not influenced by auxiliary task relevance, in contrast to previous studies where different ambiguous stimuli were used (Chopin & Mamassian, 2011; Harrison & Backus, 2010). An effect of time showed that prolonged engagement with the ambiguous motion stimulus does result in a perceptual change—a shift to global—

irrespective of which percept was relevant in the auxiliary task during the relevance learning phase (local, global, or neither). Although low-level exposure to the stimulus suffices to elicit the shift to global, we consider this to be an active process driven by the observer's visual system as well as by the stimulus. The necessity of attention to the ambiguous motion stimulus, as well as the role of globality of the percepts, remain open questions to be addressed in future research.

Keywords: *ambiguous stimulus, task relevance, perceptual relevance, multistable perception, bistable perception, motion perception, local global*

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Corresponding author: Charlotte Boeykens.

Email: charlotte.boeykens@kuleuven.be.

Address: Brain and Cognition, KU Leuven, Leuven, Belgium.

References

- Anstis, S., & Kim, J. (2011). Local versus global perception of ambiguous motion displays. *Journal of Vision*, 11(3):13, 1–12, <https://doi.org/10.1167/11.3.13>. [PubMed] [Article]
- Attneave, F. (1955). Symmetry, information, and memory for patterns. *The American Journal of Psychology*, 68(2), 209–222.
- Blake, R., & Logothetis, N. K. (2002). Visual competition. *Nature Reviews Neuroscience*, 3(1), 13–21, <https://doi.org/10.1038/nrn701>.
- Brascamp, J., Sterzer, P., Blake, R., & Knapen, T. (2018). Multistable perception and the role of the frontoparietal cortex in perceptual inference. *Annual Review of Psychology*, 69(1), 77–103, <https://doi.org/10.1146/annurev-psych-010417-085944>.
- Brysbaert, M., & Stevens, M. (2018). Power analysis and effect size in mixed effects models: a tutorial. *Journal of Cognition*, 1(1), <https://doi.org/10.31234/osf.io/fahxc>.
- Chopin, A., & Mamassian, P. (2010). Task usefulness affects perception of rivalrous images. *Psychological Science*, 21(12), 1886–1893, <https://doi.org/10.1177/0956797610389190>.
- Chopin, A., & Mamassian, P. (2011). Usefulness influences visual appearance in motion transparency depth rivalry. *Journal of Vision*, 11(7):18, 1–8, <https://doi.org/10.1167/11.7.18>. [PubMed] [Article]
- de-Wit, L. H., Kubilius, J., Wagemans, J., & Op de Beeck, H. P. (2012). Bistable Gestalts reduce activity in the whole of V1, not just the retinotopically predicted parts. *Journal of Vision*, 12(11):12, 1–14, <https://doi.org/10.1167/12.11.12>. [PubMed] [Article]
- Denison, R. N., Piazza, E. A., & Silver, M. A. (2011). Predictive context influences perceptual selection during binocular rivalry. *Frontiers in Human Neuroscience*, 5, <https://doi.org/10.3389/fnhum.2011.00166>.
- Di Luca, M., Ernst, M. O., & Backus, B. T. (2010). Learning to use an invisible visual signal for perception. *Current Biology*, 20(20), 1860–1863, <https://doi.org/10.1016/j.cub.2010.09.047>.
- Feigin, H., Baror, S., Bar, M., & Zaidel, A. (2017). Behaviorally relevant prior experience biases subsequent perception. *Journal of Vision*, 17(10):493, <https://doi.org/10.1167/17.10.493>. [Abstract]
- Garner, W. R. (1974). *The processing of information and structure*. Oxford, U.K.: Erlbaum.
- Harrison, S. J., & Backus, B. T. (2010). Uninformative visual experience establishes long term perceptual bias. *Vision Research*, 50(18), 1905–1911, <https://doi.org/10.1016/j.visres.2010.06.013>.
- Hoffman, D. D., Singh, M., & Prakash, C. (2015). The interface theory of perception. *Psychonomic Bulletin & Review*, 22(6), 1480–1506, <https://doi.org/10.3758/s13423-015-0890-8>.
- Jeffreys, H. (1961). *Theory of probability*. Oxford: Oxford University Press.
- Koenderink, J. (2011). Vision as a user interface. *Human Vision and Electronic Imaging XVI (Vol. 7865)*, pp. 786504–786513, <https://doi.org/10.1117/12.881671>.
- Kontsevich, L. L., & Tyler, C. W. (1999). Bayesian adaptive estimation of psychometric slope and threshold. *Vision Research*, 39(16), 2729–2737, [https://doi.org/10.1016/S0042-6989\(98\)00285-5](https://doi.org/10.1016/S0042-6989(98)00285-5).
- Kornmeier, J., & Bach, M. (2012). Ambiguous figures—What happens in the brain when perception changes but not the stimulus. *Frontiers in Human Neuroscience*, 6, <https://doi.org/10.3389/fnhum.2012.00051>.
- Leopold, D. A., & Logothetis, N. K. (1999). Multi-

- stable phenomena: changing views in perception. *Trends in Cognitive Sciences*, 3(7), 254–264, [https://doi.org/10.1016/S1364-6613\(99\)01332-7](https://doi.org/10.1016/S1364-6613(99)01332-7).
- Maloney, L. T., Martello, M. F. D., Sahm, C., & Spillmann, L. (2005). Past trials influence perception of ambiguous motion quartets through pattern completion. *Proceedings of the National Academy of Sciences, USA*, 102(8), 3164–3169, <https://doi.org/10.1073/pnas.0407157102>.
- McOwan, P. W., & Johnston, A. (1996). Motion transparency arises from perceptual grouping: Evidence from luminance and contrast modulation motion displays. *Current Biology*, 6(10), 1343–1346, [https://doi.org/10.1016/S0960-9822\(02\)70722-7](https://doi.org/10.1016/S0960-9822(02)70722-7).
- Meng, M., & Tong, F. (2004). Can attention selectively bias bistable perception? Differences between binocular rivalry and ambiguous figures. *Journal of Vision*, 4(7):2, 539–551, <https://doi.org/10.1167/4.7.2>. [PubMed] [Article]
- Morey, R. D., & Rouder, J. N. (2015). *BayesFactor: Computation of Bayes factors for common designs*. R package version 0.9.12-2. Retrieved from <https://CRAN.R-project.org/package=BayesFactor>.
- Necker, L. A. (1832). LXI. Observations on some remarkable optical phænomena seen in Switzerland; and on an optical phænomenon which occurs on viewing a figure of a crystal or geometrical solid. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 1(5), 329–337, <https://doi.org/10.1080/14786443208647909>.
- Nikolaev, A. R., Gepshtein, S., & van Leeuwen, C. (2016). Intermittent regime of brain activity at the early, bias-guided stage of perceptual learning. *Journal of Vision*, 16(14):11, 1–22, <https://doi.org/10.1167/16.14.11>. [PubMed] [Article]
- Peirce, J. W. (2007). PsychoPy—Psychophysics software in Python. *Journal of Neuroscience Methods*, 162(1–2), 8–13, <https://doi.org/10.1016/j.jneumeth.2006.11.017>.
- Piazza, E. A., Denison, R. N., & Silver, M. A. (2018). Recent cross-modal statistical learning influences visual perceptual selection. *Journal of Vision*, 18(3):1, 1–12, <https://doi.org/10.1167/18.3.1>. [PubMed] [Article]
- Poirel, N., Pineau, A., & Mellet, E. (2008). What does the nature of the stimuli tell us about the Global Precedence Effect? *Acta Psychologica*, 127(1), 1–11, <https://doi.org/10.1016/j.actpsy.2006.12.001>.
- R Core Team. (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>
- Rouder, J. N., Morey, R. D., Speckman, P. L., & Province, J. M. (2012). Default Bayes factors for ANOVA designs. *Journal of Mathematical Psychology*, 56(5), 356–374, <https://doi.org/10.1016/j.jmp.2012.08.001>.
- Rouder, J. N., & Haaf, J. M. (2018). Power, dominance, and constraint: A note on the appeal of different design traditions. *Advances in Methods and Practices in Psychological Science*, 1(1), 19–26, <https://doi.org/10.1177/2515245917745058>.
- Schmack, K., Weilhhammer, V., Heinze, J., Stephan, K. E., & Sterzer, P. (2016). Learning what to see in a changing world. *Frontiers in Human Neuroscience*, 10, <https://doi.org/10.3389/fnhum.2016.00263>.
- Tong, F. (2001). Competing theories of binocular rivalry: A possible resolution. *Brain and Mind*, 2(1), 55–83, <https://doi.org/10.1023/A:1017942718744>.
- Wagemans, J. (2018). Perceptual organization. In J. T. Wixted (Series Ed.) & J. Serences (Vol. Ed.), *The Stevens' handbook of experimental psychology and cognitive neuroscience: Vol. 2. Sensation, perception & attention* (Chapter 18, pp. 803–872). Hoboken, NJ: Wiley.
- Weilhhammer, V. A., Stuke, H., Sterzer, P., & Schmack, K. (2018). The neural correlates of hierarchical predictions for perceptual decisions. *The Journal of Neuroscience*, 38(21), 5008–5021, <https://doi.org/10.1523/JNEUROSCI.2901-17.2018>.
- Wertheimer, M. (2012). Untersuchungen zur Lehre von der Gestalt, II. [Investigations on Gestalt principles]. In L. Spillmann (Ed.), *Max Wertheimer: On perceived motion and figural organization* (pp. 127–182). Cambridge, MA: MIT Press.
- Woodman, G. F., Vecera, S. P., & Luck, S. J. (2003). Perceptual organization influences visual working memory. *Psychonomic Bulletin & Review*, 10(1), 80–87, <https://doi.org/10.3758/BF03196470>.