French, R. M., Lukowski-Duplessy, H., Rieth, C., and Cottrell, G. W. (2015). Turn, turn, turn: Perceiving global and local, clockwise and counterclockwise rotations. In R. Dale et al. (Eds.) Proceedings of the Thirty-seventh Annual Meeting of the Cognitive Science Society, Austin, TX: Cognitive Science Society, 740-745.

Turn, Turn, Turn: Perceiving Global and Local, Clockwise and Counterclockwise Rotations

Robert M. French[1], Helle Lukowski-Duplessy[2], Cory Rieth[3], Garrison W. Cottrell[4],

[1]robert.french@u-bourgogne.fr, [2]helle.duplessy@free.fr
LEAD-CNRS UMR 5022, Université de Bourgogne
21000 Dijon, France

[3]cory.rieth@gmail.com, [4]gary@ucsd.edu,
Computer Science and Engineering, UCSD
La Jolla, CA 92093-0404, USA

Abstract

The processing of Navon figures (Navon, 1977), i.e., hierarchical letter stimuli, has been studied in experimental settings for many years. In particular, they have been studied in the context of visual hemifield studies and yielded an interaction between hemifield and whether a target is at the local or global level, with a right hemisphere advantage for the global level, and a left hemisphere advantage for the targets at the local level (Sergent, 1982). This is a ventral stream process, however, and we were interested in whether there might be a similar interaction for hierarchical motion stimuli, presumably a dorsal stream process. Hence we developed a series of *dynamic* geometric Navon figures in order to study global/local rotation processing. These figures consist of a global figure (a triangle or a square) made up of local figures (also triangles or squares). Both global and local figures can rotate in either clockwise or counterclockwise directions independently. We found that there is no right or left visual field perceptual advantage for either the global or local levels of these figures. However, curiously enough, we found that there is a significant processing advantage for *clockwise* motion compared to counterclockwise motion. We also found a highly significant interaction between the detection of a particular rotational motion and the presence or absence of that motion in the figure being examined. Finally, our data strongly support the Global Precedence Hypothesis which says that people generally tend to focus on the global properties of an object before local properties and that processing proceeds in a global-to-local direction.

Introduction

Navon figures (Navon, 1977, Figure 1) are figures in which a global pattern is made up of smaller copies of some local pattern. For example, an alphabetical letter (e.g., the letter "H") could made up of smaller copies of another letter (e.g., "E"). These figures have been used in many different types of experiments studying attentional biases and deficits, in an attempt to learn more about how people process hierarchically structured information.

In particular, the Global Precedence Hypothesis (Navon, 1977) has been the focus of a considerable body of research. This hypothesis says that people generally tend to focus on the global properties of an object before turning their attention to its local properties, implying that processing generally proceeds in a global-to-local direction. This idea has received much support from the time of the original experiments by Navon (1977) to the present. Exceptions, however, have been found to this general rule, such as a study by Davidoff, Fonteneau and Fagot (2008) in which they observed local precedence in a non-Western (Himba) population of nomads. Visual hemifield studies have shown that it depends on which hemisphere is processing the stimulus, with a crossover interaction showing that the right hemisphere (RH) exhibits global precedence, but the left hemisphere (LH) exhibits local precedence (Sergent, 1982).

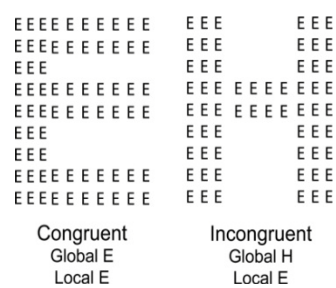

Figure 1. Congruent and incongruent Navon figures (from Watson, 2013).

Navon figures have also been used in developmental studies (e.g., Scherf, Behrmann, Kimchi, and Luna, 2009), autism (Gross, 2005), Williams Syndrome (Pani, Mervis, and Robinson,1999; Fayasse and Thibaut, 2002; Abreu, French, Cowell, and de Schonen, 2006), dyslexia (von Karolyi, Winner, Gray, and Sherman, 2003) and other disorders.

The study that served as the springboard for the current work is the Sergent (1982) study described above. Sergent showed that the RH shows global precedence, while the LH shows local precedence. We were interested if the same was true of motion processing.

There have been numerous similar studies involving hemispheric asymmetries and global/local processing of spatial frequencies (e.g., Martin, 1979b). Computational models of these hemispheric asymmetries in global/local processing have recently been developed by Cipollini, Hsiao, and Cottrell (2012) and Hsiao, Cipollini, and Cottrell (2013).

While there have been many studies of the brain dynamics of processing static Navon figures, to our knowledge, there have been only a relatively small number of studies of the processing of *dynamic* Navon figures (e.g., Pomerantz, 1983; Anstis and Kim, 2011). The move to dynamic Navon figures is a natural one. The brain, after all, is designed to process dynamic information in the environment. There are many situations in everyday life where the component parts of an object do not necessarily move in the same direction as the object itself. The wings of an in-flight bird, for example, are moving up and down, whereas the bird is moving horizontally. When backing up your car, you turn the (local) steering wheel to the left in order to make the (global) car turn in the opposite direction.

We have developed a set of dynamic geometric Navon stimuli, some of which are shown in Figure 2 below. These stimuli were specifically designed to study hierarchical rotational movement. We wanted to investigate the central question raised by Sergent (1982) in the context of our hierarchical rotational stimuli. We were tentatively able to answer the following questions:

- Is there, as in Sergent (1982), a left-visual-field or right-visual-field preference for global/local clockwise or counterclockwise rotation?
  Answer: no.
- Is there a preference for the detection of clockwise or counterclockwise rotation, independent of the visual field?
  Answer: yes.
- Does the Global Precedence Hypothesis (Navon, 1977) hold for globally and locally rotating, geometric Navon figures?
  Answer: yes.

In what follows, we will first describe the dynamic, geometric Navon figures that we have developed and used in our experiments. We will then describe the methodology of the experiment reported here. And finally, we will show how the analysis of our results allows us to tentatively answer the above questions.

The Global-Local Rotation Stimuli

We wished to examine various aspects of the perception of global and local rotational movement and, therefore, we developed a set of "geometric" Navon figures (Navon, 1977), whose global figure (either a square or an equilateral triangles) was made up of either of equilateral triangles or squares. These figures are based on those used in Abreu et al. (2006). All global figures consist entirely of either squares or triangles. We felt that it was of particular importance that the stimuli be very simple geometrical forms because we wanted them to be easily recognized in any orientation. An upside-down or sideways U, for example, bears little, if any, resemblance to a U, whereas an equilateral triangle or a square, in any rotated position, is still instantly recognized as a triangle or a square. (It is true, however, that a square rotated 45° is a rhombus and, so, perhaps future studies should only use triangles.) We did not want participants focusing on how a figure transformed as it rotated, as would have been the case had we used traditional letter Navon figures and rotated them.

There are two types of rotation, clockwise (C) and counterclockwise (X). The global figures rotate either in a clockwise or counterclockwise manner about their center. Each of the local figures also rotates either clockwise or counterclockwise about its center. Each local figure rotates in the same direction and at the same speed around its axis of rotation as the other local figures. So, for example, participants will see (Figure 2, panel 1) a global square rotating clockwise whose component squares are each rotating in a counterclockwise direction. The convention we have adopted throughout this paper is to indicate the different classes of items by two letters, the first in upper case ("C" or "X") to designate the global movement, the latter in lower case ("c" or "x") to designate the local movement. There are, therefore, four classes of items: Cc (global and local clockwise), Cx (global clockwise, local counterclockwise), Xc (global counterclockwise, local clockwise), and Xx (global and local counterclockwise).

In addition, based on work by Martin (1979a), that showed for static Navon figures, sparse figures can lead to local dominance, we varied the sparsity (number of components) making up the global figures. We used an equal number of sparse and dense items. A dense global square has 8 local figures; a sparse global square has 4 local figures, one at each of its vertices. A dense global triangle has 6 local figures; a sparse local triangle has 3 local figures, one at each of its vertices. We counterbalanced the number of dense and sparse figures in the design of the experiment. We did not consider the density of the items in the present analysis, as preliminary analysis showed there was no effect of sparsity on our results.

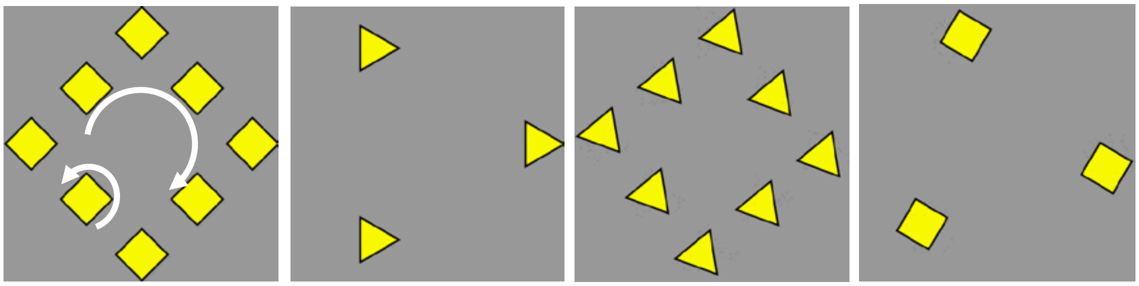

Figure 2. Four examples of the geometric Navon figures. The global and local figures can rotate in either clockwise or counterclockwise direction, as shown in the first panel. The 2nd and 4th figures are sparse – the others dense.

Experiment

Overview

We wished to establish whether there was a right/left visual field preference for global/local rotational movement similar to the one shown in Sergent (1982) for static letter-based Navon figures. The design of the present experiment, if not the stimuli, was largely based on Sergent (1982). To our surprise we discovered an overall preference for clockwise or counterclockwise motion. And finally, we wanted to ascertain whether or not the Global Precedence Hypothesis (Navon, 1977) applied to the globally and locally rotating stimuli that we developed.

Participants

The participants in this experiment were 81 undergraduate students, 69 women and 12 men (average age: 19.7 years, age range: 17-37 years) studying at the University of Burgundy, Dijon, France. Three participants were removed because their responses indicated that they had not understood the instructions. All participants had normal or corrected-to-normal vision. Of the remaining 78 participants 69 were right-handed and 43 had a right-eye ocular dominance (Chaurasia and Mathur, 1976). All participants received course credit for their participation in the experiment. Explicit informed consent was obtained from all participants. All participants were informed that they could terminate the experiment at any time and for any reason without incurring loss of course credit.

Stimuli

The stimuli were as described above in the section "Global/Local Rotation Stimuli".

Methodology

Participants were seated approximately 60 cm from the computer screen on which the stimuli appeared. Each global figure fit in a 10 cm x 10 cm square and the local figures fit in a 1.8 cm x 1.8 cm square. There was a fixation cross in the center of the screen. Half of the figures were presented so that the center of the global figure was either 2° left or 2° right of the fixation point; the other half were presented 4° to the left or 4° to the right of the fixation point. Each item was left on the screen for exactly 250ms.

A block design was used with a Clockwise block and a Counterclockwise block. Half of participants saw the Clockwise block first; half saw the Counterclockwise block first. In the Clockwise block, participants were asked whether or not they saw Clockwise (C) motion in either the global figure or the local figures of the item that appeared on the screen. In the Counterclockwise block, they were asked if they saw Counterclockwise (X) motion in either the global figure or its component local figures. Half of the participants began the experiment with the Clockwise block, the other half began with the Counterclockwise block. In the Clockwise block, participants saw 8 Cc, 8 Cx, 8 Xc, and 24 Xx items. The reason that there were more Xx items was to ensure that the yes/no answers to whether or not there was the designated motion were balanced. In an identical fashion, the Counterclockwise block consisted of 8 Xx, 8 Xc, 8 Cx, and 24 Cc items and participants had to say whether they saw counterclockwise motion in the displayed item. Items were displayed on the screen in a serial manner.

In the "clockwise detection" block, the participant would look for clockwise motion in the items. If clockwise motion was detected in the displayed item, he/she would press the "L" (= "yes") key on a computer keyboard attached to the display. If no clockwise motion was detected, the participant pressed the "S" key (= "no") on the keyboard. (The yes/no key correspondence was counterbalanced over subjects.) They were instructed to respond as quickly and accurately as possible. Because the item remained on the screen for only 250ms., participants often made errors. For example, in the "clockwise detection" block, they might have responded "no" to an Xc item, when in fact, the local figures were moving in a clockwise direction.

Items were chosen in such a way that there were as many Dense items as Sparse items, and that there were equal numbers of items displayed for each of the 4 visual angles (i.e., -2°, +2°, -4°, +4° with respect to the fixation point). We randomly chose the types of component figures (squares or triangles) used to build the global figures. So, a global square comprised of local triangles was considered to be equivalent for our purposes to a global triangle made up of local triangles. In short, we were concerned with the directions of global and local rotations, not the exact composition of the global-local figures. So, for example, for an Xc item, a global shape (e.g., a square) and a local shape (e.g. a triangle) were randomly selected and the Xc movement imposed on these shapes.

The experiment lasted between 20 minutes and half an hour.

Results

For certain participants this experiment proved difficult and tiring. We analyzed reaction time (RT) data only for correct responses. For each of the conditions, we removed RT outliers beyond 2 standard deviations from the mean. We then excluded any participant who, in either the Clockwise block or the Counterclockwise block, did not have correct and non-outlier responses for more than 50% of the items. In all, 63 participants met these criteria. The reported analyses are using the data from these participants. No data imputation was used to replace missing data.

We collected data on participants' right- or left-handedness and their ocular dominance. For the 63 participants whose data we analyzed, all but 6 were right-handed. This overwhelming imbalance of right-handed participants meant that we did not analyze right-handed and left-handed participants as two separate groups. On the other hand, 33 of the participants had a right-eye ocular dominance, and 30 had left-eye ocular dominance (Chaurasia and Mathur, 1976) and we therefore treated Ocular Dominance as a between-subjects variable in our analysis.

Further, and importantly, for the analyses concerning rotation-type detection, we considered only items with "pure" clockwise rotation or "pure" counterclockwise rotation, i.e., items in which both the Global figure and associated local figures rotated in the same direction (i.e., Cc or Xx items). We used only these items because we wanted to compare how quickly the presence or absence of a rotation type could be detected when it was either completely present or completely absent from the observed item. This choice was, in addition, particularly important because there were so many errors when the answer for a "mixed" item (i.e., Xc or Cx) was at the local level. For this reason no "mixed" rotation items were considered in this analysis.

An ANOVA on this data produced the following results.

There was no significant main effect of Ocular Dominance (right-eye, left-eye), p = 0.83. There was also no significant main effect of Visual Angle (2°, 4°) with respect to the central fixation point (p = 0.122) or of Visual Field (p = 0.55). Most importantly, with respect to the results reported in Sergent (1982), there was no significant interaction between Left Visual Field (LVF) and Right Visual Field (RVF) and Global/Location rotation (p = .605).

<u>Detecting Clockwise vs. Counterclockwise motion</u>

Of particular importance for the present paper is the main effect of Detect Rotation (Clockwise, Counterclockwise). We compared the time to determine whether clockwise (C) motion was present in a Cc item or absent in an Xx item with the time to determine whether counterclockwise (X) motion was present in an Xx item or absent in a Cc item. Clockwise motion detection turns out to be significantly faster than Counterclockwise motion detection. $F(1,53) = 13.1$, p = 0.0007, $\eta^2 = 0.20$. There is also a highly significant interaction between Detect Rotation (Clockwise, Counterclockwise) x Rotation type (Cc, Xx). $F(1,53)$ = 102.6, $p < 0.00001$, $\eta^2 = 0.66$. (Figure 3). This result is not particularly surprising, since it simply says that it is easier to find something when it is present, than discovering that it is not present. In the first case, the search stops as soon as an instance of the sought-after pattern (in this case a type of motion) is found. In the latter case, all patterns must be searched to be sure that the sought-after pattern is not present.

In addition, a Tukey HSD post-hoc shows that it takes significantly less time (p = 0.026) to detect clockwise (C) motion in Clockwise items (Cc) than it is to detect counterclockwise motion (X) in Counterclockwise items (Xx). The same analysis shows that it does not take significantly longer to detect the absence of clockwise motion in Counterclockwise items than it does to detect the absence of counterclockwise motion in Clockwise items (p = 0.148).

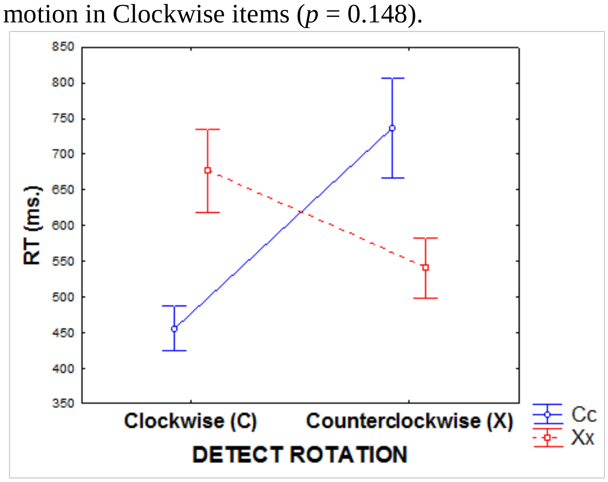

Figure 3. A strong interaction between the type of rotation that is to be detected (either C or X) and the type of item rotation (either Cc or Xx). (SEM error bars)

Global Precedence Hypothesis

Our results also demonstrate the validity of the Global Precedence Hypothesis (Navon, 1977) for dynamic, geometric Navon figures in which there is both global and local rotational movement. If we collapse across the density of the local figures (which had no significant main effect) in each of the items and their location on the screen with respect to the fixation point (which also had no main effect), there are four item types, corresponding to the types of rotation at the global and local levels. These item types are: Cc, Cx, Xc, and Xx. To reiterate, for each Detection Block the participant had to detect a certain type of motion in each block, either clockwise (C) or counterclockwise (X). This motion could either be at the global or local level of the figure.

Across all participants, we recorded the number of errors made for each category of items. The results are shown in Figure 4. Participants accuracy for all item types, except two, is anywhere between 77% and 95%. So, for example, when detecting the presence or absence of clockwise motion (C) in Cc, Cx, or Xx items, participants' accuracy is at 88%, 78%, and 95% respectively. Likewise, when detecting the presence or absence of counterclockwise motion (X) in Cc, Xc, and Xx, their performance is 90%, 77%, and 83% respectively. However, when detecting clockwise (C) motion in Xc items or counterclockwise (X) motion in Cx items, their performance plummets to an abysmal 35% and 36%, respectively. In other words, participants are performing considerably worse than they would have done had they simply been guessing!

However, these results can be explained very simply by invoking the Global Precedence Hypothesis. If one considers that participants are overwhelmingly

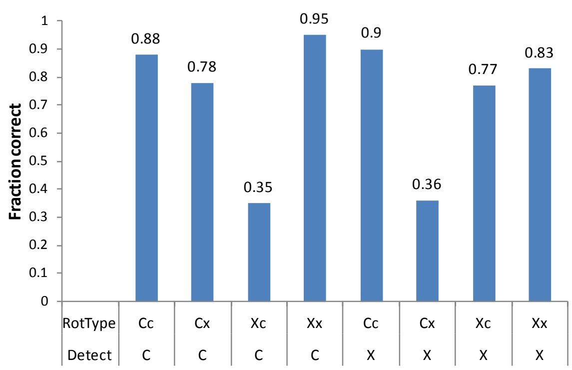

Figure 4. The fraction of correct responses for each item type and detection type.

influenced by the global rotation, then this is precisely the pattern of results that would be expected. In other words, ignoring, or largely ignoring local rotation would produce the results in Figure 5. If one is focusing on global rotation, the only items that will cause problems are, indeed, those in which the rotation type to be detected is the rotation type of the local figure. Now, obviously, if participants were relying exclusively on global rotation, then their rate of correct responses for C_Xc ("Detect C in Xc") and X_Cx ("Detect X in Cx") would be 0. Since this is not the case, it is reasonable to assume that there is still some influence of the local rotation on the answer. In any case, these results clearly support the Global Precedence Hypothesis in the case of dynamic (i.e., rotating) Navon figures. One possibility that is closely in line with this explanation is the motion-silencing illusion (Suchow and Alvarez, 2011), in which global rotation makes it hard to detect changes in local elements, which in this case would be their motion.

General Discussion

The general issue we were investigating was whether the interaction between visual field and local or global dominance that is presumably mediated by the ventral processing stream (form perception) extended to the dorsal (motion processing) stream. Hemispheric asymmetry in processing of motion has been found in deaf signers (Bosworth and Dobkins, 1999), with left hemisphere dominance, but not in hearing individuals. Our hypothesis was that, while there may be no main effect of visual field in hearing subjects, there still could be an interaction between visual field and local/global processing. However, we found no evidence of such an interaction.

On the other hand, we found, to our surprise, that clockwise motion is more easily detected than counterclockwise motion. We considered the fact that perhaps clockwise motion is more common in the environment than counterclockwise motion. But upon reflection this is not obviously so. We drive counterclockwise around traffic circles, observe counterclockwise track races, remove screws, open tops on jars, etc., all of which involve counterclockwise motions. Perhaps the fact that in the West readers scan written material from left to right could produce the "clockwise bias" we observed, which is something that could be empirically tested by seeing if this bias exists in cultures where reading proceeds from right to left. In any case, this puzzling finding has no obvious, simple explanation that we can suggest, but if it replicates, then it would be an interesting phenomenon to try to explain with a model. Further experiments should be done to verify this effect.

On the other hand, the finding that there is dominance of global motion is consistent with the global precedence hypothesis. However, global precedence has been found in static displays to be affected by visual field, sparsity, and culture, among other things (Sergent, 1982, Martin, 1979a, Davidoff, et al., 2008). We believe we can rule out that the global dominance is affected by visual field, based on our experiments. Sparsity in static displays can lead to local dominance (Martin, 1979a). Since we found no effect of sparsity either, and the levels of sparsity we used were as sparse as possible given the shapes we used, we don't believe that future sparsity manipulations will alter the result.

One issue with our results is that subjects actually were *worse* than chance at detecting the local motion when it was in the context of global motion in the opposite direction. Our experiments should be repeated with longer exposure time to see if this bias can be overcome.

The interaction we found between the target type and the rotation type seems less interesting, as it could simply be the result of finding the target taking a shorter time than not finding the target. This should be confirmed in future experiments.

In summary, our results suggest that there is no hemispheric asymmetry in motion processing at the local versus the global level. However, our data are consistent with the global precedence hypothesis for static images. Finally, the finding that clockwise motion is easier to detect than counterclockwise motion deserves further study, as it is a finding that is as puzzling as it is intriguing.

Acknowledgments

This work was financed in part by a grant (ORA-10-0056) from the French ANR to the first author, and NSF grant SMA 1041755 to the Temporal Dynamics of Learning Center, an NSF Science of Learning Center, to the last author. The authors would like to extend particular thanks to Stéphane Argon for the long hours he spent getting the stimuli right.

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