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3-D processing in the Poggendorff illusion

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Abstract

In the Poggendorff illusion two collinear oblique lines, separated by two vertical lines, appear to be misaligned. 3-D processing of the oblique but not the vertical lines is considered to cause this apparent misalignment. We investigated whether more explicitly triggering 2-D versus 3-D interpretations of the different parts of Poggendorff-like displays would influence the apparent misalignment. In Experiment 1, we found that compared to 2-D controls, 3-D interpretations of the vertical parts did not influence apparent misalignment, while for the oblique parts 3-D processing resulted in more apparent misalignment than 2-D controls. In Experiment 2, the amount of contour convergence of the oblique parts was manipulated resulting in the 3-D blocks, but not the 2-D line patterns, to be perceived as receding in depth. Now, apparent misalignment increased the more the 3-D blocks were perceived as receding in depth. We conclude that apparent misalignment in Poggendorff-like displays can be influenced by different interpretations of its separate parts, while keeping the local junctions between the different elements the same.

PsycINFO classification: 2323

Keywords: Poggendorff illusion; 3-D shape; Object perception

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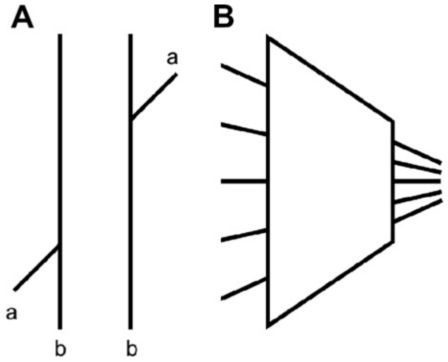

Fig. 1. (A) The Poggendorff illusion. The collinear oblique lines (indicated ‘a’), separated by two vertical lines (indicated ‘b’), are erroneously perceived as misaligned. (B) Alternative version of the Poggendorff illusion (after Gillam, 1971). All oblique lines converge into a single vanishing point, causing the perception of apparent misalignment to be reduced.

The Poggendorff illusion (see Fig. 1A) is a geometrical illusion in which two collinear oblique lines, separated by two vertical lines, appear to be misaligned. Apparently, the oblique line on the right in Fig. 1A is positioned too high for the two lines to be aligned. This powerful illusion, elicited by just a few simple lines, has intrigued many researchers. Because of the simplicity of the display, the interpretation appears rather ambiguous; is it a flat (2-D) figure or does it reveal orientations in depth as well? In the past decades, depth processing has been related to the occurrence of the Poggendorff illusion. For example, Gillam (1971) suggested that the oblique lines (i.e., the lines indicated with the letters ‘a’ in Fig. 1A, to be referred to as the lateral elements) are interpreted as receding in depth, whereas with respect to the vertical lines (i.e., the lines indicated with the letters ‘b’ in Fig. 1A, to be referred to as the central element), there would be no 3-D processing.

The interpretations of the lateral and central elements then would determine the perceptual outcome as follows. The intersections of the lateral elements with the central element are interpreted as lying in the same depth plane (i.e., the intersections are equidistant points with respect to the observer), because there is no 3-D processing of the central element. Consequently, the height difference between these two intersections in the image cannot be interpreted as a difference in depth (Gillam, 1971). Now, the 2-D height difference of the lateral elements affects their 3-D interpretation such that the lateral elements in Fig. 1A are perceived as non-collinear. That is, the lateral elements, which are likely to be interpreted as receding in depth, are not interpreted as a single object, but rather as two objects that are parallel, but not collinear, in 3-D space.

Both Gillam (1971), and Daniels and Gordon (1993) have suggested that the more perspective cues there are in a Poggendorff display, the smaller the apparent misalignment will be. Gillam, for example, provided an alternative display of the Poggendorff illusion (see Fig. 1B). In Fig. 1B, the oblique lines of both the central and the lateral elements converge into a single vanishing point. Gillam argued that in such a display apparent misalignment is reduced as there are no conflicting depth cues between the central and lateral elements. That is, in Fig. 1B, due to the pictorial arrangement, all the elements are readily perceived as receding along the same depth plane. This is in line with Schiffman (2001) who argued that apparent misalignment in a Poggendorff-like display such as the one in Fig. 1B should be minimal on the basis of perspective constancy. Nevertheless, in Fig. 1B, 3-D processing is likely to occur for both the central element and the lateral elements.

Comparing Fig. 1A with Fig. 1B, it may be clear that the influence of different interpretations (i.e., more 2-D versus more 3-D) on the strength of the Poggendorff illusion is considerable. In addition, the influence of different interpretations (i.e., 2-D versus 3-D) on perceptual tasks has also been found in other studies (see e.g., Koning & Van Lier, 2003, 2005). Thus, to more closely examine the relative influence on the strength of the apparent misalignment in the Poggendorff illusion of the lateral and central elements separately, displays could be devised that trigger more 2-D or more 3-D processing of either the central element or the lateral elements. For example, when 3-D processing is triggered only for the central element, the two vertical lines of the central element may be perceived as lying in different depth planes. Now, because the intersections with the lateral elements do not necessarily have to be perceived as equidistant points, this may cause the apparent misalignment to be decreased. Should 3-D processing be triggered only for the lateral elements, perceiving these elements as receding in depth may become more evident, which could lead to more apparent misalignment. Therefore, in this study, we will examine the relative influence on the strength of the apparent misalignment in the Poggendorff illusion of both the lateral and the central elements separately, using pictorial cues to trigger more 2-D interpretations as well as more 3-D interpretations of the elements in Poggendorff-like displays.

Studies of apparent misalignment effects in the Poggendorff illusion, in combination with 3-D cues, have included stimuli using real life objects (Day & Parker-Halford, 1994; Liu & Kennedy, 1995), as well as pictures of real life objects (Fisher & Lucas, 1969; Lucas & Fisher, 1969). However, to control for the presence of 3-D (perspective) cues, we use line drawings. This way, a more direct investigation of different factors (i.e., 2-D versus 3-D processing) contributing to the strength of the Poggendorff illusion is possible as opposed to using real life objects. As a result, in the present paper, we will use pictorial cues to alter the global interpretations of both the central and lateral elements. For example, consider the displays shown in Fig. 2. First, in Fig. 2A, the central element is interpreted as a 3-D box, and the lateral elements as 3-D oblique bars. In Fig. 2B, the Y-junctions (that typically trigger a 3-D interpretation) of the central element have been replaced by T-junctions thereby giving the central element a more 2-D character. Further, in Fig. 2C a slightly modified version of the original central element of the Poggendorff display is shown. In this modified version of the central element, there is a small vertical offset between the two lines, which is identical to that of the 3-D and 2-D central elements. Thus, these relatively small modifications result in different global interpretations of the central element. Second, comparing the lateral elements in Fig. 2A and D one can see that similar modifications (i.e., replacing Y-junctions with T-junctions) also result in different interpretations for these elements. Overall, small modifications at the outer ends of both the central element and the lateral elements were made to trigger either 2-D interpretations or 3-D interpretations of these elements separately. In addition, it is important to note that for all combinations of the 3-D and 2-D elements in Fig. 2, the intersections of the central element with the lateral elements have exactly the same local junctions, with the local contours having the same orientations (i.e., the local contours at the intersections, not all local contours).

Using the above-mentioned displays, the 3-D and the 2-D central elements could result in different degrees of misalignment when participants are instructed to align the lateral elements. That is, the outer verticals of the 3-D central element are more likely to be perceived as lying in different depth planes than the outer verticals of the 2-D central element.

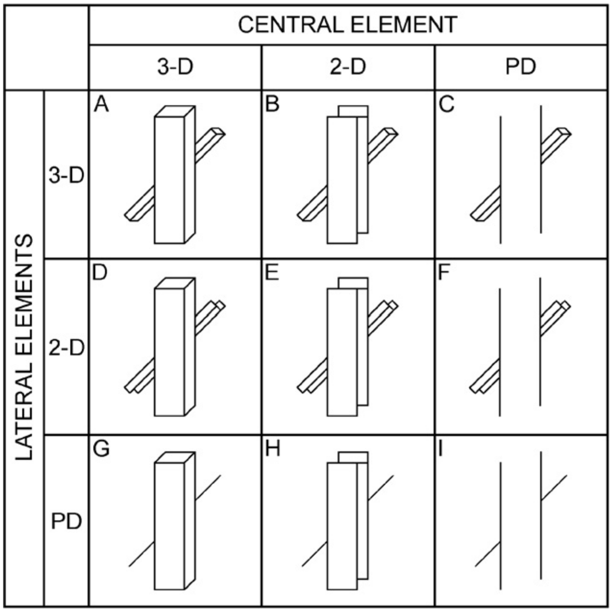

Fig. 2. Examples of the stimuli used in Experiment 1. Three different central elements were created: 3-D, 2-D, and PD (i.e., Poggendorff) as well as three different lateral elements: 3-D, 2-D, and PD. To control for the direction of perspective cues, the elements were also left-right reversed. All elements were combined to create an orthogonal design.

With respect to the lateral elements, as can be seen in Fig. 2, it could be argued that the perceived recession in depth of the 2-D and the 3-D lateral elements is rather ambiguous. Thus, even though the changes made at the outer ends of these elements result in different interpretations, it is possible that the 3-D and 2-D lateral elements result in an equal degree of apparent misalignment. To test these expectations, two experiments are performed. In the first experiment, three kinds of central elements and three kinds of lateral elements are used. In the second experiment, perceived depth recession of 3-D bars is further investigated.

1. Experiment 1

1.1. Methods

1.1.1. Participants

Nine participants were given course credit or were paid for their time. All participants had normal or corrected-to-normal vision.

1.1.2. Stimuli

Three different central elements were created. The 3-D central element consisted of a box (see Fig. 2A, D, and G). The oblique lines of the box were drawn at an angle of 45° with respect to the horizontal plane. The 2-D central element was created by modifying the outer ends of the 3-D central elements (see Fig. 2B, E, and H). These modifications consisted of altering the Y- and arrow-junctions that typically result in 3-D interpretations. For the third central element, the Poggendorff central element (to be referred to as the PD central element), all lines between the two outer verticals of the 2-D central element were removed (see Fig. 2C, F, and I). The width of all central elements was 4 cm. To control for the direction of perspective cues, the central elements were left-right reversed.

Three different types of lateral elements were created. All lateral elements were drawn at an angle of 45° with respect to the horizontal. The 3-D lateral elements represented a 3-D oblique bar (see Fig. 2A–C). Analogous to the 2-D central elements, the 2-D lateral elements were created by making small modifications at the outer ends of the 3-D lateral elements (see Fig. 2D–F). In addition, the lengths of the oblique lines (i.e., the lines that intersect with the central element) were kept constant. The Poggendorff lateral elements (to be referred to as the PD lateral elements) consisted of a single line (see Fig. 2G–I). To control for the direction of perspective cues, the lateral elements were also left-right reversed.

1.1.3. Procedure

The experiment was conducted at the University of Nijmegen. The lighting was dimly lit and was kept constant across all participants. Trials were presented on a 19-in. monitor (at a resolution of 1024×768 pixels), controlled by a Pentium III computer. The participants were seated at one meter from the screen with their heads stabilized by a chin rest. The images covered an area of 13 cm by 10 cm (i.e., a visual angle of less than 8° by less than 6°). To prevent the participants from using the edges of the monitor in their judgments, a circular aperture was placed in front of the monitor. Each trial was preceded by a blank screen (750 ms). As soon as a stimulus was presented, the participant could press either the up-arrow or the down-arrow on the keyboard to move one of the lateral elements. It was the participant's task to align the lateral elements in such a way that the lateral elements were collinear, by moving one of them. The movable part could be either the lateral element on the left side or the lateral element on the right side. The participants were instructed to take as much time as they needed for each trial.

To make sure that alignment of the parts was possible (i.e., the lateral elements had to be aligned behind the occluding central element), random starting positions of the parts were determined by the computer. That is, the parts that were not movable were randomly placed (in each trial) in an area between the horizontal midline of the central element and 2 cm above or below the midline of the central element. Alternatively, the movable parts were randomly placed (in each trial) along the vertical lines of the central element. A total of 144 trials were used: three types of central elements, two directions of perspective for the central elements (left–right reversal), three types of lateral elements, two directions of perspective for the lateral elements (left–right reversal), two locations of the movable parts (left or right), and two random starting positions of the movable parts. The experiment took about 50 min to complete. The degree of misalignment of the lateral elements was measured in millimeters (mm) by subtracting the position of the movable part as it was judged by the participant, from the correct position of the movable part (i.e., the position of the movable part when the lateral elements were physically aligned) in each trial.

1.2. Results

Preliminary analyses revealed no main or interaction effects for the variables Location of Movable Part, Left–Right reversal of Central Element, and Left–Right reversal of

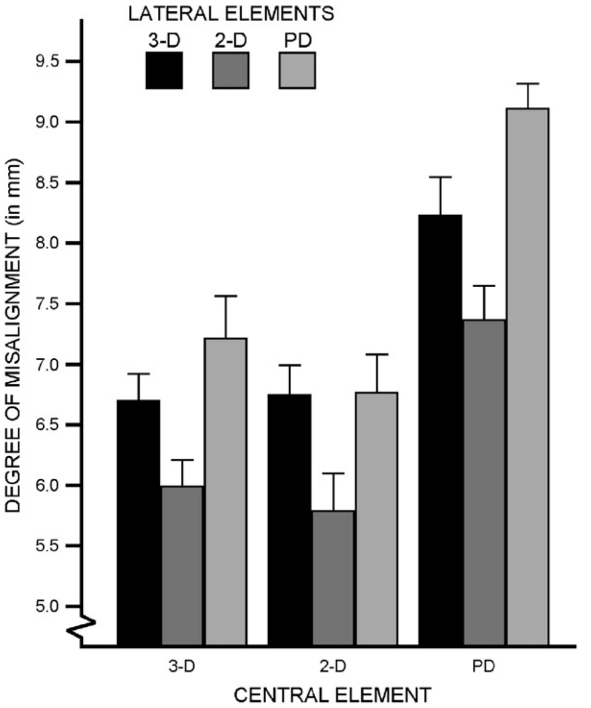

Fig. 3. Results of Experiment 1. Graph of the mean misalignments measured in millimeters (mm) as a function of Central Element and Lateral Elements. PD stands for Poggendorff. Error bars represent one standard error of the mean.

Lateral Elements. Therefore, the data were pooled over these variables. A two factorial repeated measures analysis of variance (ANOVA) was performed with the following independent variables: Central Element (3) × Lateral Elements (3). The dependent variable was the Degree of Misalignment (measured in mm). A main effect was found for the variable Central Element [$F(2,7) = 10.79$, $p < .01$]. Contrast comparisons revealed that, compared with the PD central element, both the 3-D central element [$F(1,8) = 17.25$, $p < .005$] and the 2-D central element [$F(1,8) = 24.30$, $p < .005$] yielded significant better alignments. The results on the 3-D and 2-D central elements did not differ significantly ($p > .3$). A second main effect was found for the variable Lateral Elements [$F(2,7) = 9.50$, $p < .05$]. Contrast comparisons revealed that the 2-D lateral elements showed significantly better alignments compared with both the PD lateral elements [$F(1,8) = 8.14$, $p < .05$] and the 3-D lateral elements [$F(1,8) = 18.75$, $p < .01$]. The results on the PD and 3-D lateral elements did not differ significantly ($p > .2$). The interaction effect was not significant. Fig. 3 shows the graphs of the degree of misalignment as a function of the independent variables Central Element and Lateral Elements separately.

1.3. Discussion

First of all, the results on the PD elements showed that the participants were sensitive to the illusion. In fact the PD elements induced the strongest illusory effect. That is, disambiguating the depth interpretation of the elements (both central and lateral) in a Poggendorff-like display decreases the apparent misalignment. Notice, however, that the results of the PD elements cannot be directly compared to those of the 3-D and 2-D elements as the number of lines between the elements differ. In fact, the smaller misalignments that were found for the 3-D and 2-D central elements in comparison with the PD central element are in line with the results by Masini, Sciaky, and Pascarella (1992), who showed that adding textures between the outer verticals of the central element decreases apparent misalignment.

A crucial finding here is that relatively small modifications at the outer ends of the elements in Poggendorff-like displays, leading to different 2-D/3-D interpretations, resulted in different degrees of apparent misalignment. This is in line with the claim by Spehar and Gillam (2002) that spatial layout cues in Poggendorff displays are important for apparent misalignment to occur, but in contrast with the suggestion by Morgan (1999) (see also Spehar & Gillam, 2002) that apparent misalignment is largely due to judging the orientation of the virtual line segment that connects the lateral elements.

The results with respect to the central elements partly support the suggestion by Gillam (1971) and Daniels and Gordon (1993) that more perspective cues diminish the apparent misalignment. That is to say, for both the 3-D and 2-D central elements the degree of apparent misalignment was smaller than the PD central element. Thus, adding pictorial cues that lead to different global interpretations (i.e., 3-D versus 2-D) diminishes the degree of apparent misalignment. However, it is important to note that the 2-D central element could be perceived as two overlapping surfaces due to the presence of T-junctions, thereby triggering a depth interpretation. Although such a depth interpretation is less likely to occur as compared with the 3-D central elements, this might have resulted in the equal degree of apparent misalignment for the 3-D and 2-D central elements. Therefore, a control experiment was performed. The 3-D central element from the first experiment was used, as well as a modified version of the 2-D central element (see Fig. 4). Note that in Fig. 4, the 2-D central element does not give rise to an occlusion interpretation, but is rather seen as a mosaic pattern. Only the PD lateral elements were used. The procedure was the same as that of the first experiment, and fourteen new participants were tested. The results on the 3-D and 2-D central elements did not differ significantly from each other

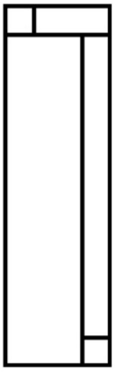

Fig. 4. The new 2-D central element used in the control experiment. This central element is more readily seen as a mosaic pattern, rather than as two or more overlapping surfaces.

($F < 1$). Thus, based on the results of both experiments, it can be said that with respect to the central element, adding pictorial cues to make the central element appear either 3-D or 2-D decreases the apparent misalignment in Poggendorff-like displays.

Regarding the lateral elements, we found that the 3-D lateral elements yielded larger misalignments than the 2-D lateral elements. Still, this finding does not contradict the depth processing theory (Gillam, 1971). That is, as mentioned, the recession in depth of both the 2-D and the 3-D lateral elements is rather ambiguous. This is most likely to be due to the orthographic nature of the stimuli. Thus, from the present experiment, it remains unclear as to how apparent misalignment relates to perceived depth recession of the lateral elements. In the second experiment, we will focus more closely on this.

To conclude, the results of the first experiment provide evidence that not only local junctions, such as the acuteness of the angle between the central element and the lateral elements (Hotopf & Hibberd, 1989; Wilson, 1983) or an estimation of the virtual line between the lateral elements (Morgan, 1999) influence the apparent misalignment in the Poggendorff illusion. Relatively small modifications at the outer ends, resulting in different interpretations of the elements, can influence the apparent misalignment as well.

2. Experiment 2

In Experiment 1, the perceived recession in depth of the 3-D lateral elements was rather ambiguous. Therefore, a second experiment was performed to more closely examine how a perception of depth recession of 3-D lateral elements relates to the strength of the Poggendorff illusion. As in the first experiment, a judgment task was used in which the participants had to align the lateral elements of a Poggendorff-like display. Now, an interpretation of the 3-D bars as objects receding in depth was made clearer. Different amounts of depth recessions were examined by rotating 3-D oblique bars in depth. Regarding the central element, the results of the first experiment showed that the largest misalignments were found in the case of the PD central element. As we are now interested in the differences between the lateral elements, only the PD central element was used, as this is the central element that is most closely related to the original display. Additionally, in contrast with for example Fig. 1B, the PD central element is not expected to greatly influence the perceived recession in depth of the lateral elements. As a result, it is expected that the more the 3-D lateral elements are interpreted as receding in depth, the stronger the apparent misalignment will be (Day & Parker-Halford, 1994).

2.1. Methods

2.1.1. Participants

Ten participants, who did not participate in Experiment 1, were given course credit or were paid for their time. All participants had normal or corrected-to-normal vision.

2.1.2. Stimuli

Only the PD central element of Experiment 1 was used (see Fig. 5). The PD central element was also left-right reversed, as in Experiment 1. To create the lateral elements, three bars were generated using 3-D modeling software (3DStudio Max R2, Autodesk, Inc.). The bars were drawn in perspective and were about equal in length to each other at the image

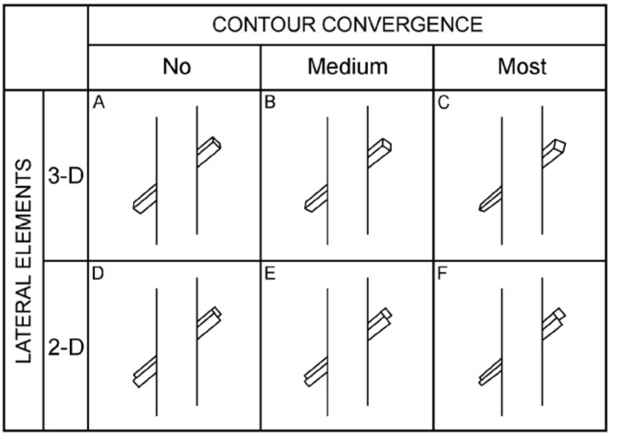

Fig. 5. Examples of the stimuli used in Experiment 2. Only the Poggendorff central element was used. Three different 3-D bars were created and were rotated in depth. Because the 2-D lateral elements cannot be described based on an orientation in depth, references to these lateral elements are made according to the amount of convergence of their outer contour (No, Medium, and Most). That is, the more the long sides of the lateral elements converge into a single vanishing point, the stronger the contour convergence is. The 3-D bar showing no contour convergence was positioned parallel to the frontal plane. The 3-D bar showing medium contour convergence was rotated 30 degrees in depth (with respect to the frontal plane). The 3-D bar showing the most contour convergence was rotated 60° in depth (A–C). The 2-D variations of the 3-D lateral elements were created by modifying only the outer ends of the corresponding 3-D lateral elements (D–F).

level. The first bar was positioned parallel to the frontal plane, but viewed slightly from above to avoid an accidental viewpoint of the 3-D bar. The second bar was rotated 30° in depth (with respect to the frontal plane), and the third bar was rotated 60° in depth (see Fig. 5A–C). The 3-D bars thus had different degrees of slant, but at the image level the angles of these lateral elements bars with the central element were the same. To control for the perspective cues, 2-D variations of the 3-D lateral elements were created by modifying the outer ends of the corresponding 3-D lateral elements (see Fig. 5D–F). These modifications were done in the same way as in Experiment 1. Due to the T-junctions in the 2-D lateral elements, these elements could be interpreted as two flat overlapping surfaces. However, it might be clear that a 3-D interpretation (i.e., a perception of the elements as receding in depth) is more pronounced for the 3-D lateral elements than for the 2-D lateral elements. In addition, note that the 2-D lateral elements cannot be easily described based on an orientation in depth. Therefore, all lateral elements will be referred to according to the amount of convergence of their outer contour (i.e., no, medium, and most contour convergence). For example, whereas in Fig. 5A (i.e., the 3-D lateral element showing no contour convergence) the longest oblique lines are parallel to each other, in Fig. 5C (i.e., the 3-D lateral element showing the most contour convergence) the longest oblique lines are strongly converging into a single vanishing point.

2.1.3. Procedure

The procedure was the same as that of Experiment 1 with the following exceptions. A total of 96 trials were used: two kinds of lateral elements (3-D and 2-D), three amounts of contour convergence (no, medium, and most), left–right reversal of the central element, left–right reversal of the lateral elements, two locations of the movable part (left or right), and two random starting positions of the movable part. The experiment took about 35 min to complete.

2.2. Results

Preliminary analyses revealed no main effects or interactions effects for the variables Left–Right reversal of Central Element, Left–Right reversal of Lateral Elements, and Location of Movable Part. The data were therefore pooled over these variables. A two-factorial, Lateral Elements (2) × Contour Convergence (3), repeated measures ANOVA was performed with Degree of Misalignment (measured in mm) as the dependent variable. Both main effects and the interaction effect were significant. First, the main effect for the variable Lateral elements [$F(1,9) = 19.54$, $p < .01$] revealed that the 2-D lateral elements yielded significantly better alignments than the 3-D lateral elements. Second, the main effect for the variable Contour Convergence [$F(2,8) = 6.77$, $p < .05$] was significant. The interaction effect between the two independent variables was also significant [$F(2,8) = 19.90$, $p < .01$]. Contrast comparisons showed that for the 2-D lateral elements, the different amounts of contour convergence (i.e., no, medium, and most contour convergence) did not differ from each other (all p's > .05). For the 3-D lateral elements the different amounts of contour convergence all differed significantly from each other. The 3-D bars showing no contour convergence differed from both the 3-D bars showing medium contour convergence [$F(1,9) = 12.51$, $p < .01$] and the 3-D bars showing the most contour convergence [$F(1,9) = 17.33$, $p < .01$]. The 3-D bars showing medium contour convergence also differed from the 3-D bars showing the most contour convergence [$F(1,9) = 13.98$, $p < .01$]. See Fig. 6 for the graph of the Degree of Misalignment as a function of the two independent variables.

2.3. Discussion

The relative influence of differences in contour convergence of both 3-D and 2-D lateral elements on the strength of the Poggendorff illusion was examined. Both main effects were significant, but since the interaction effect was also significant, the results will be discussed in terms of this interaction effect. That is, whereas for the 2-D lateral elements the amount of contour convergence did not influence apparent misalignment, for the 3-D lateral elements, stronger contour convergence resulted in a larger degree of apparent misalignment. More importantly, an increase in the amount of contour convergence resulted in an increased perception of recession in depth for the 3-D lateral elements, while this was not the case for the 2-D lateral elements. Consequently, the more the 3-D lateral elements could be perceived as receding in depth, the stronger the apparent misalignment was. This is in line with Day and Parker-Halford (1994). Merely adding 3-D cues, as suggested by Gillam (1971) and Daniels and Gordon (1993), might thus help in decreasing apparent misalignment, but this depends on whether the resulting lateral elements are perceived as receding in depth. This is also in line with the depth processing theory (Gillam, 1971).

To conclude, the 3-D and the 2-D lateral elements differed only with respect to small modifications at the outer ends, showing again that the interpretation of the lateral elements plays an important role. More importantly, when 3-D processing of the lateral elements is triggered and this leads to these elements being perceived as receding in depth, the more such elements are perceived as receding in depth, the stronger the apparent misalignment becomes.

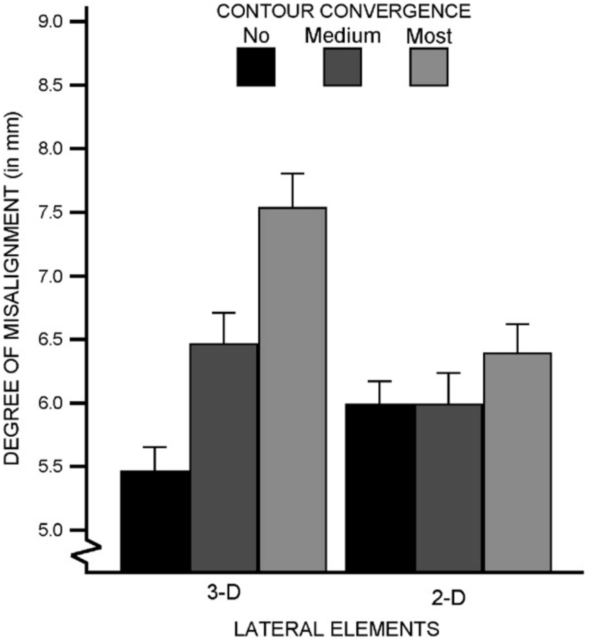

Fig. 6. Results of Experiment 2. Graph of the mean misalignments measured in millimeters (mm), as a function of Lateral Elements and Contour Convergence. Error bars represent one standard error of the mean.

3. General discussion

To summarize the results, in two experiments it was found that the apparent misalignment in the Poggendorff illusion is affected by 3-D versus 2-D interpretations of both the central element and the lateral elements. Considering the central elements, it was expected that differences would be found between the 3-D and 2-D versions. However, no such differences were found in the first experiment, and also not in the control experiment. Rather, we found that when the central element is likely to be interpreted as 3-D (e.g., a box) the apparent misalignment decreases and that the same occurs when the central element is likely to be interpreted as 2-D (e.g., a mosaic pattern). Although no firm conclusions can be made based on this result, it is in contrast with the original central element of the Poggendorff illusion, in which the perception of the outer verticals as lying in the same depth plane is ambiguous. Alternatively, it seems that the interpretation of the lateral elements is a more dominant factor for apparent misalignment to occur in Poggendorff-like displays. Regarding the 2-D and the 3-D lateral elements, in the first experiment no differences were expected to be found. However, the participants performed significantly better for the 2-D lateral elements than for the 3-D lateral elements. Apparently, relatively small modifications at the outer ends of the lateral elements are sufficient to result in different degrees of apparent misalignment. The better alignments that were found for the 2-D lateral elements compared to the 3-D lateral elements could have been due to the orthographic nature of the lateral elements, resulting in a rather ambiguous perception of depth recession of the 3-D lateral elements. When the recession in depth of the 3-D lateral elements was made clearer in the second experiment, the apparent misalignment increased for the 3-D lateral elements when the amount of contour convergence increased compared to 2-D controls with the same increases in amount of contour convergence. As a result, the larger the perceived recession in depth of 3-D lateral elements is, the larger the apparent misalignment will be in a Poggendorff-like display.

Considering the overall pattern of results, the strength of the Poggendorff illusion was found to be stronger in the first experiment than in the second experiment. However, the results of the two experiments reported here cannot be easily compared to each other. First, the method of projection differs between the two experiments. Whereas in Experiment 1 the 3-D objects were drawn orthographically, in the second experiment the 3-D objects were drawn in perspective. Second, the temporal context differs between the two experiments. That is, in Experiment 1 both the central and the lateral elements could be 2-D, 3-D or more like the original Poggendorff elements. In Experiment 2, with new participants, only the lateral elements could be 2-D or 3-D, while the central element was similar to that of the original Poggendorff illusion. Finally, it must be noted that we did not investigate how participants actually perceived the elements in the experiments. As a result, although we cannot be sure whether the elements were in fact perceived the way we intended them to be, the emphasis here is on the pictorial cues we employed (at the outer ends of the elements) to induce the difference in the global interpretations of the elements (e.g., 2-D versus 3-D and gradual changes in perceived depth recession in Experiment 2). Nevertheless, based on the present experiments, it can be suggested that the apparent misalignment in the Poggendorff illusion strongly depends on perceiving the lateral elements as receding in depth.

More specifically, adding perspective cues to the lateral elements of the Poggendorff illusion can either strengthen or weaken the apparent misalignment. When 3-D processing of the lateral elements is triggered by the addition of perspective cues, but the recession in depth is rather ambiguous (e.g., Experiment 1, 3-D lateral elements), apparent misalignment is relatively high. In contrast, in displays where 3-D processing of the lateral elements is less likely (e.g., Experiment 1, 2-D lateral elements) apparent misalignment is relatively low. Furthermore, when 3-D processing of the lateral elements is triggered and a recession in depth of these lateral elements is made clear, the apparent misalignment depends on the amount of perceived depth recession. That is, larger amounts of perceived depth recession result in larger apparent misalignments (Experiment 2, 3-D bars showing medium and most contour convergence). In addition, if a perception of depth recession is virtually absent (Experiment 2, 3-D bar showing no contour convergence), apparent misalignment is relatively small.

The importance of perceived depth recession of the lateral elements in the Poggendorff illusion is in line with the depth processing theory by Gillam (1971). However, as suggested, merely adding perspective cues in a Poggendorff-like display does not necessarily lead to smaller apparent misalignments (Gillam, 1971; Daniels & Gordon, 1993), but depends on the perceived depth recession of the lateral elements. After all, the smallest misalignments were obtained when the 3-D lateral elements in Experiment 2 showed no contour convergence, and as a result were not perceived as receding in depth. This also shows the importance of the perceived depth recession of the lateral elements. Finally, regarding the central elements, not only the addition of 3-D cues diminishes the strength of the illusion, but also a 2-D (mosaic) interpretation.

In conclusion, the present experiments show that different interpretations (3-D versus 2-D) of the lateral elements strongly influence the apparent misalignment in the Poggendorff illusion. That is, any analysis that is based merely on local junctions between the central and lateral elements of Poggendorff-like displays would have difficulty to explain the current results. More specifically, the contour convergence of the lateral elements affects the misalignment when that element is perceived as a 3-D bar. For the present type of displays, the perception of equidistant points at intersections of the central and lateral elements appears less crucial, whereas the perceived depth recession of the lateral elements largely determines the degree of misalignment. Taken together, the powerful illusion of misalignment in Poggendorff-like displays is largely driven by global interpretations of simple line configurations in which 3-D processing plays an important role.

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