Investigating local and global effects of surface colours and contours in amodal completion
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ABSTRACT
We studied interpretations of partly occluded shapes. Models that account for amodal completion mostly deal with local and global contour characteristics. In the current study, we were interested in the effects of colour on local and global contour completions. In our stimuli, local contour completions comprised simple linear extensions of the partly occluded contours, whereas global contour completions accounted for global shape regularities. Our stimuli were designed such that the visible surface colour could also be completed in a local or global fashion, being consistent or inconsistent with contour completions. We tested the preferred interpretations of the partly occluded shapes by using a sequential matching task. Participants had to judge whether a test shape could be a previously shown partly occluded shape. We found that interpretations of partly occluded shapes depend on both colour and contour characteristics. Additional time bin analyses revealed that for fast responses colour and contour completions already depend on the visible context of the partly occluded shapes, while for slow responses the congruency between colour and contour completions play a role as well.

ARTICLE HISTORY
Received 6 July 2017
Accepted 12 September 2018

KEYWORDS
Amodal completion; local completion; global completion; contour; surface colour

When looking around we often only see parts of objects as they may occlude parts of themselves and parts of each other. Yet, we do not perceive them as incomplete. In general, partly occluded shapes tend to be perceived as complete, a phenomenon referred to as “amodal completion” (Michotte, Thinès, & Crabbé, 1964). Amodal completion can be considered as a consequence of so-called border ownership analyses (e.g., Kanizsa, 1979; Kogo, Strecha, Van Gool, & Wagemans, 2010; Rubin, 1915/1958; Rubin, 2001). Following such analyses, borders in the visual pattern are assigned to particular surfaces, thus revealing figure-background segregation, with the background surfaces being amodally completed (Rubin, 2001). To explicitly account for the shape of the amodally completed background surfaces, additional approaches have been developed. Here, a major distinction can be made between completion models that focus on local contour properties versus completion models that take into account global shape characteristics (see van Lier & Gerbino, 2015, for an overview). So far, research mostly focused on how contour characteristics determine the perception of complete shapes when they are partly occluded. In contrast to such contour characteristics, relatively few studies exist on how local and global surface properties influence amodal completion. The aim of the present study is to explore the interference of colour on both local and global contour completions.

The importance of local contour completion has been advocated by various researchers in the past decades (e.g., Kanizsa, 1985; Kellman & Shipley, 1991). Kellman and Shipley (1991) proposed a well-defined criterion, the relatability criterion, for the occurrence of a locally driven completion. This criterion provides conditions under which contours at both sides of an occluder are connected with each other. Other researchers also stressed the importance of some form of “good continuation” (see for example, Boselie, 1994; Fantoni & Gerbino, 2003; Fulvio, Singh, & Maloney, 2008; Kogo et al., 2010; Rubin, 2001; Wouterlood & Boselie, 1992). The influence of global contour properties, such as symmetry, has been investigated in quite a few studies as well (Buffart, Leeuwenberg, & Restle, 1981; Chen, Müller, & Conci, 2016; de Wit, Bauer, Oostenveld, Fries, & van Lier, 2006; Hazenberg, Jongsma, Koning, & van...
Lier, 2014; Plomp & van Leeuwen, 2006; Sekuler, 1994; Sekuler, Palmer, & Flynn, 1994; van Lier, van der Helm, & Leeuwenberg, 1994). In these studies local completions still play a role but now compete with alternative completions which are determined by global contour properties. Sekuler (1994), for example, considered two independent processes that triggered both local and global completions, weighting the strength of completions depending on the occurrence of certain properties. In van Lier et al. (1994, 1995), a distinction was made between occlusion patterns for which global and local completion strategies resulted in the same amodally completed shape, versus occlusion patterns for which global and local completions resulted in different amodally completed shapes. Examples of these two patterns are shown in Figure 1. For occlusion pattern A, both local and global completion strategies reveal the same interpretation A1, as the rectangle can be the result of a linear continuation of the contours (local completion), and of a global strategy (global completion) towards the most regular (symmetrical) shape. The interpretation A2 is completed with an indentation, which is possible, yet unexpected. For occlusion pattern B, following a local completion strategy, the partly occluded contours are extended in a linear fashion (see Figure 1-B1). In contrast, according to a global completion strategy, an indentation is added behind the occluder to maximise the overall symmetry in the pattern (see Figure 1-B2).

Previous research has shown, by means of various paradigms, that both local and global contour completions may indeed be generated (Chen et al., 2016; de Wit et al., 2006; Hazenberg et al., 2014; Plomp & van Leeuwen, 2006; Sekuler, 1994; van Lier, Leeuwenberg, & van der Helm, 1995). These studies focus on contour and shape properties. Other studies have focused on volume completion (Ekroll, Sayim, & Wagemans, 2013; Ekroll, Sayim, Van Der Hallen, & Wagemans, 2016; Tse, 1999a; Tse, 1999b, 2017; van Lier, 1999; van Lier & Wagemans, 1999; Vrins, de Wit, & van Lier, 2009; Vrins, Hunnius, & van Lier, 2011). Rather few studies looked at the influences of inner surface properties in amodal completion (e.g., Dadam, Albertazzi, Canal, & Micciolo, 2012; Su, He, & Ooi, 2010). For example, Dadam et al. (2012) reported that contrast characteristics influenced the relative position of an amodally completed border; in specific displays, partly occluded bars tended to extend more behind an occluder when they were relatively dark (as compared to lighter bars). Su et al. (2010) found that the visible parts of a partly occluded shape containing the same, rather than opposite luminance contrast polarity resulted in surface completion. Both mentioned studies focused on particular luminance characteristics of the visible surface fragments. Using displays with illusory colours, Pinna (2008) showed that amodal completion colours could also be modulated by perceived colours and that they could even prevent completion to occur (which happened when the perceived colours suggested a hole instead of an occluder). More recently, Kim, Jeng, and Anderson (2014) studied the influence of lightness similarity, showing modulating effects of perceived surface similarities, e.g., after accounting for the effect of shadows on the visible contour fragments. A study that explicitly focused on the perceived surface characteristics behind the occluder was performed by Yin, Kellman, and Shipley (1997) who constructed stimuli to isolate surface colour completion from boundary completion. The surface features in their study comprised homogeneous colours, textures and also gradients. The authors reported that such surface characteristics were perceived to extend behind an occluder.

In the present study, we aim to connect the influence of surface properties with the distinction between local and global contour completions. For example, just like local and global contour completions, surface colours can also be completed either in a local or in a global fashion. As an example, consider Figure 2. Here, the partly occluded yellow rectangle can be completed behind the occluder with the same colour as the visible part (Figure 2-A1). This

![Figure 1. Examples of occlusion patterns adopted from de Wit et al. (2006). Both local and global completion strategies are used in (A) and (B). A1) A completion of occlusion pattern A that follows both local and global contour characteristics. A2) A rather unexpected completion of occlusion pattern A. B1) A local completion of occlusion pattern B. B2) A global completion of occlusion pattern B.](Image)
colour continuation can be thought of as being triggered by both local and global properties; the local colour completion is induced by the colours adjacent to the occluder, whereas the global colour completion is induced by the overall colour appearance of the visible parts of the rectangle. The completion in Figure 2-A2 clearly represents an anomalous completion. In Figure 2B, the situation is different as the rectangular surface has a regularly coloured pattern of alternating colours. The completion in Figure 2-B1 shows an example of a local colour completion; the yellow colour at both sides of the occluder is continued behind the occluder, irrespective of the alternation of the yellow and blue stripes in the visible parts of the rectangular shape. In contrast, the completion in Figure 2-B2 takes account of that property, and therefore can be considered as a global colour completion.

In the following experiment, we investigate the influence of such surface characteristics on local and global contour completions. Based on the previous findings regarding the relevance of global context in amodal contour completion (e.g., de Wit et al., 2006; Sekuler et al., 1994; van Lier et al., 1994), we expect that besides contour regularities, colour regularities play a role as well. That is, amodal completion is expected to be influenced not only by global contour regularity, but also by global surface colour regularities. More in particular, we expect that global colour completions are facilitated more than local colour completions.

Material and methods

Participants

Twenty students (aged 19 to 29 years; 7 male) of the Radboud University (RU) were paid to participate in the experiment. One participant was excluded from the data analysis because of a very low frequency of correct responses (17%). All participants could distinguish the colours we used in our experiment. They all gave written informed consent and had no current or past neurological or psychiatric illness. This study was approved by the local ethic committee of the RU, in accordance with the declaration of Helsinki.

Stimuli

We constructed four stimulus sets with four different types of occlusion patterns that allow both global and local contour completions, see Figure 3 for examples (more stimuli can be seen in Appendix 1). The surface colour of these patterns comprised either a single colour (Figure 3A and B), or two alternating colours (Figure 3C and D). As will be clear further on, the occlusion patterns with a single colour (Figure 3A, 3B) are to be regarded as control stimuli, whereas the occlusion patterns with alternating colours can be regarded as the actual test stimuli. In addition, we used a short occluder (Figure 3A and C) or a long occluder (Figure 3B and D). For patterns with a short occluder, the additional information, i.e., the visible indentation and colour patch result into different interpretations from those with a long occluder. For each occlusion pattern, there were four possible completions.

Each completion was constructed by applying different completion strategies regarding both contour properties and surface colour. Local contour completions extended the contours at points of occlusion in a linear fashion (see Figure 3-A1, -A2, -B1, -B2, -C1, -C2, -D1, -D2). In contrast, global contour completions extended the global contour regularity by adding contour indentations that fit with the global contour regularity (see Figure 3-A3, -A4, -B3, -B4, -C3, -C4, -D3, -D4). So, for each of the four occlusion patterns there was always either a local contour completion or a global contour completion. The same concepts were applied to colour completions. As the occlusion patterns with a single colour (Figure 3A, 3B) are to be regarded as control patterns, we first
describe the occlusion patterns with alternating colours, i.e., the test occlusion patterns (Figure 3C, 3D).

For the occlusion patterns with alternating colours (Figure 3C and D), local colour completions comprise the extension of the colours immediately juxtaposed to the occluder. With regard to occlusion pattern D, the situation is most clear. Here, extending the surface colours immediately at the left and right side of the long occluder reveals a local surface colour completion (Figure 3-D1, -D3). For occlusion pattern C, there are two possible local surface colour completions. One local surface colour completion is based on extending the colours left and right of the occluder (Figure 3-C1, -C3). Another local surface colour completion is based on the extension of the surface colours just above the occluder, which in fact results in the extension of the coloured bar (Figure 3-C2, -C4). The global surface colour completions were constructed by continuing the visible alternating colour pattern (Figure 3-C2, -C4 and -D2, -D4). As a result, completions C2 and C4 are based on both local and global surface colour completions, whereas completions D2 and D4 are based only on global surface completion.

We now turn to the control stimulus sets, i.e., the occlusion patterns with a single colour (Figure 3A and B). For the occlusion patterns in these sets, the local and global colour completions converge to a single completion that comprises the extension of the visible colour (see Figure 3-A1, -A3 and -B1, -B3). Completing these shapes with a different colour obviously results in rather unexpected, anomalous completions (see Figure 3-A2, -A4 and -B2, -B4). Note that both contours and colours in the completions of pattern A and B exactly match the contours and colours in the completions of pattern C and D, respectively; which is why they can be considered as control stimuli to further examine the effect of the colour context.

To increase the variability between stimuli and to create more stimuli, we had a few additional manipulations (see Appendix 1). Firstly, both “rectangular” and “wavy” contours were used. Secondly, the surface colours were also reversed (switching between purple/green and green/purple). Thirdly, we

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**Figure 3.** Examples of four occlusion patterns (A, B, C and D), and four possible completions (1–4) for each occlusion pattern. The displayed stimuli comprise examples from each of four stimulus sets; two control stimulus sets (*left column*: stimulus set A and B) and two test stimulus sets (*right column*: stimulus set C and D). For more stimuli from each set, please see Appendix 1.
constructed mirror images for each occlusion pattern (not shown in Appendix 1).

Finally, there were also four non-match shapes for each occlusion pattern (see Appendix 2). The non-match shapes always have either a completely different contour (e.g., “wavy” versus “rectangular”), or different colour patterns. The non-match shapes were chosen from one of the other possible completion shapes, so that each completion shape was presented an equal number of times.

**Procedure**

The experiment was run using Presentation (Version 17.2, Neurobehavioral Systems, Inc.). Participants were seated in front of the monitor (75-Hz refresh rate). A sequential matching task was employed (see e.g., Hazenberg et al., 2014). A fixation cross appeared for 1000 ms, after which an occlusion pattern appeared for 1000 ms. After that, a Gaussian noise picture was shown to mask the occlusion pattern for 300 ms. Next, a test shape (match or non-match) appeared and remained on the screen for 5000 ms, or until participants responded. Participants had to indicate if the test shape matched with the partly occluded shape (Yes/No) by pressing a button as quickly as possible. That is, the participants had to press the “Yes-button” whenever a particular completion was possible, disregarding whether the completion was considered to be likely or unlikely. The response keys were counterbalanced between participants. Response times (RTs) to test shapes were recorded.

Before the experiment, participants completed a practice block of 15 trials to get familiar with the procedure. Five participants completed the practice block two times, as they found the task to be rather difficult and they needed more practice trials to get familiar with it. The experiment consisted of three blocks, and every block consisted of 256 trials (128 trials with match shapes and 128 trials with non-match shapes, all randomized together). There was a rest after completing each block. The experiment lasted for approximately 45 minutes.

**Analyses**

Our analyses were performed on RTs of correct judgements to match shapes, which complies with earlier research (e.g., de Wit et al., 2006; Gerbino & Salmaso, 1987; Hazenberg et al., 2014).

**Single stimulus set analyses**

Regarding different combinations of colour completion and contour completion factors, we performed a two-way repeated measures analysis of variance (ANOVA) having two levels of colour completion and two levels of contour completion separately for each stimulus set as follows: stimulus set A and B: Colour (anomalous, local-and-global) × Contour (local, global); stimulus set C: Colour (local, local-and-global) × Contour (local, global); stimulus set D: Colour (local, global) × Contour (local, global).

**Colour context analyses**

As previously introduced, the stimuli were designed such that the completed parts of the completions for the single-coloured occlusion patterns in Figure 3A and 3B are exactly the same as for the multi-coloured occlusion patterns in Figure 3C and 3D, respectively. For example, the completed parts in Figure 3-A1 and -C1 comprise exactly the same contour extensions and the same colour patches. The only difference is the colour context. Thus, we reason that any differential effect between comparing the two completions must be due to the apparent fit between the completions and the colour context in the occlusion patterns. Therefore, to determine the colour context effects, stimulus set A served as a baseline for stimulus set C, and stimulus set B served as a baseline for stimulus set D. We calculated difference RTs (ΔRTs) by subtracting RTs to each particular completion in stimulus set A from the respective completion in stimulus set C, and that in stimulus set B from stimulus set D. Next, ΔRTs were subjected to a two-way repeated measures ANOVA having two levels of colour completion and two levels of contour completion separately for both comparison sets: short-occluder comparison set: Colour (local, local-and-global) × Contour (local, global); long-occluder comparison set: Colour (local, global) × Contour (local, global).

**Time bin analyses**

To see whether results are consistent over time, we also performed exploratory post hoc analyses on the fastest response times and the slowest response times. The selection was made such that for each participant, for each condition, the one-third fastest and the one-third slowest response times were pooled into a “fast bin” and a “slow bin”, respectively. For each time bin, we used the same analyses that we
applied in the single stimulus set analysis and in the colour context analysis. The time bin analyses opens a window to see whether – and if so, how – effects of colour and contour change over time. For example, the “slow bin” may show different results just because participants take more time and cognitive influences may play a larger role. That is, effects may be triggered by rapid perception-like processes, but it may also be influenced by more cognitive processes.

Results

The averaged percentage of correct responses to match shapes across participants is 93%, with a range of 89 ~ 95%.

Single stimulus set analyses

In stimulus set A (Figure 4), results showed a main effect of Colour, revealing shorter RTs to local-and-global colour completions than RTs to anomalous colour completions \( F(1, 18) = 6.91, p = .017, \eta^2_p = .227 \). In contrast, no main effect of Contour was found \( F(1, 18) = .19, p = .669, \eta^2_p = .010 \). There was a significant interaction between Colour and Contour \( F(1, 18) = 10.05, p = .005, \eta^2_p = .358 \). Paired t-tests showed that for global contour completions, RTs to local-and-global colour completions (A3) were significantly shorter than RTs to anomalous colour completions (A4), \( t(18) = -3.727, p = .002 \). No such significant results were found at neither level of Colour.

Figure 4. In each stimulus set (A, B, C and D), the RTs to each of four possible completions are averaged and plotted separately. Error bars represent the standard error of the mean.
The results of stimulus set B were comparable to those of stimulus set A. That is, results showed a main effect of Colour, with shorter RTs to local-and-global colour completions than RTs to anomalous colour completions \([F(1, 18) = 14.55, p = .001, \eta_p^2 = .447]\). Neither a main effect of Contour \([F(1, 18) = .30, p = .591, \eta_p^2 = .016]\), nor an interaction between Colour and Contour was found \([F(1, 18) = 3.42, p = .081, \eta_p^2 = .160]\).

In stimulus set C, results showed a main effect of Colour, with shorter RTs to local-and-global colour completions than RTs to local colour completions \([F(1, 18) = 12.08, p = .003, \eta_p^2 = .402]\). Neither a main effect of Contour \([F(1, 18) = .06, p = .818, \eta_p^2 = .003]\), nor an interaction between Colour and Contour was found \([F(1, 18) = .06, p = .813, \eta_p^2 = .003]\).

In stimulus set D, results revealed a main effect of Contour \([F(1, 18) = 5.03, p = .019, \eta_p^2 = .271]\), with shorter RTs to global contour completions than RTs to local contour completions. Neither a main effect of Colour \([F(1, 18) = .33, p = .574, \eta_p^2 = .018]\), nor an interaction between Colour and Contour was found \([F(1, 18) = 2.97, p = .102, \eta_p^2 = .142]\).

### Colour context analyses

As previously mentioned, to account for shape differences and to have a closer look at the effect of colour context, we proposed the colour context analyses. Accordingly, RTs to completions of set A and B served as a baseline for RTs to completions of set C and D, respectively (see also Figure 5, and for a summary of the results see Table 1, first row “Overall analyses”). For the short-occluder comparison set, results showed a main effect of Colour, revealing shorter ΔRTs to local-and-global colour completions than ΔRTs to local colour completions \([F(1,18) = 20.07, p < .001, \eta_p^2 = .527]\). Neither a main effect of Contour \([F(1,18) = .05, p = .828, \eta_p^2 = .003]\), nor an interaction between Colour and Contour was found \([F(1, 18) = 3.54, p = .076, \eta_p^2 = .164]\).

For the long-occluder comparison set, results showed a main effect of Colour, revealing shorter ΔRTs to global colour completions compared with local colour completions \([F(1, 18) = 8.82, p = .008, \eta_p^2 = .329]\). No main effect of Contour was found \([F(1, 18) = 3.43, p = .081, \eta_p^2 = .160]\). There was a significant interaction between Colour and Contour \([F(1, 18)

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**Figure 5.** Susceptibility to colour context (accounting for contour differences, see Colour context analyses in both Analyses and Results section for details). Difference RTs in short-occluder comparison set (panel 1) and long-occluder comparison set (panel 2). Error bars represent the standard error of the mean.
Table 1. F-values and Significance of the Colour and Contour Effects in the Short-occluder Comparison Set and the Long-occluder Comparison Set for three colour context analyses: the initial overall analyses, the fast bin analyses (one-third fastest response times per participant, per condition), and the slow bin analyses (one-third slowest response times, per participant, per condition).

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<th>short-occluder comparison set</th>
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<tr>
<td>Overall analyses</td>
<td>20.07***</td>
<td>0.05ns</td>
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<tr>
<td>Fast bin analyses</td>
<td>26.55**</td>
<td>1.42ns</td>
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<td>Slow bin analyses</td>
<td>5.93*</td>
<td>0.12ns</td>
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Note: *indicates significant effect at the .05 level; **indicates significant effect at the .001 level; ***indicates no significant effect.

Correlation coefficients for the same data are also shown (set A and B), RTs to local-and-global colour completions (D4 - B4), RTs to local colour completions (D2 - B2), t(18) = −2.490, p = .023. No other significant results were found.

Time bin analyses

Similar to the colour context analyses on all correct responses, the repeated two-way ANOVA was applied to the fast response times and the slow response times in each of two comparison sets (see Figure 6; for a summary of the results see also Table 1, second and third row, “Fast bin analyses” and “Slow bin analyses”).

Fast bin. For the fast response times, we first discuss the short-occluder comparison set. We found a main effect of Colour [F(1, 18) = 26.55, p < .001, $\eta_p^2 = .596$], revealing shorter ΔRTs to local-and-global colour completions than ΔRTs to local colour completions. Neither a main effect of Contour [F(1, 18) = 1.42, p = .249, $\eta_p^2 = .073$], nor an interaction between Colour and Contour was found [F(1, 18) = .58, p = .457, $\eta_p^2 = .031$].

Next, for the long-occluder comparison set, we found a main effect of Colour [F(1, 18) = 41.70, p < .001, $\eta_p^2 = .698$], revealing shorter ΔRTs to local colour completions than ΔRTs to local colour completions. There was also a main effect of Contour [F(1, 18) = 5.08, p = .037, $\eta_p^2 = .220$], revealing shorter ΔRTs to global contour completions than ΔRTs to local contour completions. No significant interaction between Colour and Contour was found [F(1, 18) = .05, p = .834, $\eta_p^2 = .003$].

Slow bin. For the slow response times, the analysis in the short-occluder comparison set showed a main effect of Colour [F(1, 18) = 5.93, p = .026, $\eta_p^2 = .248$], revealing shorter ΔRTs to global colour completions than ΔRTs to local colour completions. Neither a main effect of Contour [F(1, 18) = .124, p = .729, $\eta_p^2 = .007$], nor an interaction between Colour and Contour was found [F(1, 18) = 2.78, p = .113, $\eta_p^2 = .134$].

For the long-occluder comparison set, however, there was neither a main effect of Colour [F(1, 18) = .75, p = .399, $\eta_p^2 = .040$], nor a main effect of Contour [F(1, 18) = 2.25, p = .151, $\eta_p^2 = .111$]. Instead, an interaction between Colour and Contour was found [F(1, 18) = 6.05, p = .024, $\eta_p^2 = .252$]. Paired t-tests showed that for global contour completions, ΔRTs to global colour completions were significantly shorter than ΔRTs to local colour completions (D4 - B4 versus D3 - B3), t(18) = −2.608, p = .018. For global colour completions, ΔRTs to global contour completion (D4 - B4) were significantly shorter than ΔRTs to local contour completions (D2 - B2), t(18) = −2.612, p = .018. No other significant results were found.

In Appendix 3 and 4, we additionally plotted the graphs for each of the four stimulus sets for fast responses and slow responses respectively, along with the statistical results.

Discussion

We investigated the relative impact of contour completion and surface colour completion in amodal completion, and found that both colour and contour regularities determined amodal completion, which is consistent with our expectations.

We shortly discuss the basic results of stimulus sets A-D. For the occlusion patterns with a single colour (set A and B), RTs to local-and-global colour completions were, not surprisingly, faster relative to anomalous colour completions (see Figure 4-1 and 4-2). For
occlusion patterns with multiple colours, we found effects of colour (set C) and contour (set D). These basic findings already show that amodal completion can be influenced by the visible colours in the occlusion pattern. In addition, these results are consistent with previous findings that surface characteristics,
more specifically colour, play a role in amodal completion (Dadam et al., 2012; Kim et al., 2014; Pinna, 2008; Su et al., 2010; Yin et al., 1997).

Next, we proposed an analysis in which we had a closer look at the net effect of colour context, i.e., the colour context analyses. By applying these analyses, we had two comparison sets of stimuli: a comparison set with short occluders and a comparison set with long occluders (see Figure 5). Following these analyses (see Table 1), a main effect of colour would reflect an influence of the fit between the specific colour completion and the colour-shape context of the visible parts of the shape, whereas a main effect of contour would reflect an influence of the fit between the contour completion and the colour-shape context of the visible parts of the shape. An interaction effect of colour and contour then reflects the fit between the colour completion and the corresponding contour completion.

In the short-occluder comparison set (see Figure 5-1), both colour completions comply with an extension of colours bordering the occluder. In one of the completions, the background colour left and right of the occluder is extended, whereas in the other completion the coloured bar is extended behind the occluder. As indicated earlier, the latter completion also complies with a global completion. Therefore, for the short-occluder comparison set the differential effect of the local colour completion of just the background colour versus the local-and-global colour completion of the coloured bar is tested. Here, the results reveal a clear colour effect. This indicates that, regardless of contour completion, the local-and-global colour completion of the coloured bar fit better with the colour-shape context than the local colour completion.

In the long-occluder comparison set (see Figure 5-2), one colour completion was based on local completion in which the bordering background colour extended behind the occluder, whereas the other colour completion was based on a global completion of the coloured bars. In the latter case, the completion of the coloured bar is not based on a local colour extension, but purely driven by a global completion tendency, based on the overall surface colour regularity. Again, there was an effect of colour, now showing that global colour completions fit best with the colour-shape context. However, the interaction between colour completion and contour completion shows that this is only the case for global contour completions. It seems that completions are only facilitated if both colour and contour are compatible with the global context. In contrast, local contour completions appear less preferred even if they are completed with a global colour. Overall, these results reveal that surface filling-in can be driven by global surface context. These findings seem to parallel previously found sensitivities to global contours (e.g., de Wit et al., 2006; Sekuler et al., 1994; van Lier et al., 1994).

The successive time bin analyses showed that we should still be cautious in drawing strong conclusions on the overall pattern of results as these analyses clearly show an effect of the response speed (see Table 1). We applied the same analyses as discussed above to the one-third fastest and to the one-third slowest response times. For the short-occluder comparison set, the results were stable and similar to the overall analysis. That is, for both fast and slow response times, local-and-global colour completions were facilitated relative to local colour completions. For the long-occluder comparison set, in which local completions are directly compared with global colour completions, the results were remarkably different. For the fast response times, there was a main effect of both colour completion and contour completion, with smallest ΔRTs for both global colours and global contours. For the slow response times, however, there were no main effects. Instead, there was a clear interaction, revealing the smallest ΔRTs for completions that had a global contour completion and a global colour completion.

The above difference between the fast bin and slow bin for the long-occluder comparison set reveals an unexpected twist. As shown in Table 1, given the main effect of both contour and colour in the fast bin, it can be said that for fast responses the fit between the colour/contour of the completed part and the global colour-contour properties of the visible part plays a decisive role. For the slow bin, the situation is different, as now the fit between the colour and contour properties of the completed part appears crucial. We speculate that initially, contour and colour completions are processed rather independently, but that at a later moment contour and colour completions depend on each other.

Given the different response patterns for the two time bins for the long-occluder comparison set, it
seems apparent that time-dependent differential processing underlies the results. It is also good to realize that the current differential effects show up after the relatively long presentation times of the occlusion pattern (1000 ms and a mask of 300 ms). Still, the initial, fast response times might be more perceptually driven, whereas the slow response times are more likely to be influenced by cognitive evaluation. In our view, these differential effects may provide a stepping stone towards a fruitful future research avenue. Note however, that a clear border between perceptual and cognitive processes cannot be given here. In the past decades, there have been discussions about the processing levels of amodal completion (see for example, Chen et al., 2016; Ekroll et al., 2013; Hazenberg & van Lier, 2016; Kanizsa, 1985; Kellman, 2001; Lee & Vecera, 2005; van Lier & Gerbino, 2015). Interpretations of complex partly occluded shapes may deal with a mixture of completion strategies in which both lower level and higher level processes have an influence (see also Hazenberg & van Lier, 2016; Yun, Hazenberg, & van Lier, 2018).

In conclusion, we can say that both colour and contour properties play a role in amodal completion. Previously found susceptibilities to global contour regularities in amodal completion appear to hold for global colour properties as well. The time bin analyses suggest that initially colour and contour contribute independently to amodal completion, whereas at later moments the congruency between colour-defined boundary and contour-defined boundary plays a role.

Note

1. This analysis on the 1/3 slowest and 1/3 fastest response times was suggested by an anonymous reviewer.

Acknowledgments

We would like to thank the Chinese Scholarship Council, which financially supported X.Y.’s PhD life in the Netherlands. We also thank three anonymous reviewers for their truly helpful suggestions on a previous version of the manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

References


Ekroll, V., Sayim, B., Van Der Hallen, R., & Wagemans, J. (2016). Illusory visual completion of an object’s invisible backside can make your finger feel shorter. *Current Biology, 26*(8), 1029–1033. doi:10.1016/j.cub.2016.02.001


Tse, P. U. (2017). Dynamic volume completion and deformation. i-Perception, 8(6), 2041669517740368. doi:10.1177/2041669517740368


Appendices

Appendix 1: Occlusion Patterns with Match Shapes
Figure A1. The stimuli of four occlusion patterns with corresponding match shapes. Stimulus set A and B are control stimuli, while stimulus set C and D are test stimuli.

Note: The mirror images are not shown in this figure.
Figure A2. The stimuli of four occlusion patterns with corresponding non-match shapes.

Note: The mirror images are not shown in this figure.
Appendix 3: Averaged RTs for the One-third Fastest Responses in each Stimulus Set

In the single stimuli pattern analysis of the one-third fastest responses, a main effect of Colour was found in both stimulus set A \( F(1, 18) = 19.21, p < .001, \eta^2_p = .516 \), and stimulus set B \( F(1, 18) = 55.87, p < .001, \eta^2_p = .756 \). Results in stimulus set C revealed a main effect of both Colour \( F(1, 18) = 14.18, p = .001, \eta^2_p = .441 \), and Contour \( F(1, 18) = 4.91, p = .040, \eta^2_p = .214 \). Stimulus set D revealed a main effect of Contour \( F(1, 18) = 8.75, p = .008, \eta^2_p = .327 \). No other significant results were found.

Figure A3. In each stimulus set (A, B, C and D), the averaged RTs for the one-third fastest responses are plotted separately for four possible completions. Error bars represents the standard error of the mean.
Appendix 4: Averaged RTs for the One-third Slowest Responses in each Stimulus Set

In the single stimuli pattern analysis of the one-third slowest responses, stimulus set A revealed a significant interaction between Colour and Contour \( [F(1, 18) = 8.87, p = .008, \eta_p^2 = .330] \). Paired t-tests showed that at the level of global contour completions, RTs to local-and-global colour completions (A3) were significantly shorter than RTs to anomalous colour completions (A4), \( t(18) = -2.830, p = .011 \). Stimulus set B revealed a main effect of Colour \( [F(1, 18) = 4.73, p = .043, \eta_p^2 = .208] \), and a significant interaction between Colour and Contour \( [F(1, 18) = 4.92, p = .040, \eta_p^2 = .215] \). Paired t-tests again revealed the same effect at the level of global contour completions (B3 versus B4), \( t(18) = -2.807, p = .012 \). No other significant results were found.

Figure A4. In each stimulus set (A, B, C and D), the averaged RTs for the one-third slowest responses are plotted separately for four possible completions. Error bars represents the standard error of the mean.