The Müller-Lyer illusion: Investigation of a center of gravity effect on the amplitudes of saccades

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Previous research has compared the effects of visual illusions on perception with their effects on action to investigate if the action system and the perceptual system use different or common codes. Appropriate conclusions based on this comparison rely on effects that reflect the internal parameter estimates of the action and of the perceptual system. We investigated an additional factor that can possibly change the amplitudes of saccades along the Müller-Lyer illusion, the center of gravity effect. It refers to the finding that the endpoints of saccades can be diverted from the target point in the direction of the center of gravity of a stimulus configuration. We measured the perceptual (adjustment method) and the action effects (amplitudes of saccades) of the illusion. In addition, we let subjects carry out saccades along Müller-Lyer figures and a neutral figure that appeared to have the same size (but differed in actual sizes). The amplitudes of saccades differed for these figures. This was interpreted as evidence for a center of gravity effect. Its quantification allowed a correction of the action effect, which was then remarkably similar to the perceptual effect. Our results are in agreement with the notion of a common internal representation for perception and action.

Keywords: Müller-Lyer, illusion, perception, action, separate coding, common coding, dorsal stream, ventral stream, center of gravity


Introduction

Center of gravity effect (COGE)

The internal codes of the perceptual system and the action system are of considerable interest for current research in psychology and neuroscience. The separate coding approach (Milner & Goodale, 1995) is based on the assumption that visually guided movements and visual perception rely on different processes that can be tied to the so-called dorsal and ventral stream. The common coding approach (Franz, Fahle, Bültmann, & Gegenfurtner, 2001) assumes that a common internal representation for perception and visuomotor control exists. The effect of visual illusions on perception has been compared with their effect on action. Differences between these effects have been interpreted as evidence in favor of the separate coding approach (Aglioti, DeSouza, & Goodale, 1995; Dewar & Carey, 2006; Ganel, Tanzer, & Goodale, 2008; Haffenden & Goodale, 1998; Westwood, Heath, & Roy, 2000) whereas similar effects support the common coding model (de Grave, Biegastraaten, Smeets, & Brenner, 2005; Franz, Gegenfurtner, Bültmann, & Fahle, 2000; Franz et al., 2001; Pavan, Boscaglione, Benvenuti, Rabuffetti, & Farne, 1999).

Obviously, appropriate conclusions are only valid if the effects of visual illusions on perception and action reflect the internal parameter estimates (of e.g. size, form, weight etc.) used by the perceptual and the motor systems. If other factors increase or decrease the perception and/or action effect, fair comparisons cannot be made, unless these factors are controlled or corrected for. Gilster, Kuhtz-Buschbeck, Wiesner, and Ferstl (2006) investigated the maximum grip aperture (MGA) when the central disc of an Ebbinghaus illusion was grasped. By measuring the MGAs for the illusory conditions (small and large flankers surrounded the central disc that was grasped) and for a neutral condition as well (no surrounding flankers), it was shown that the MGA was largest for the neutral condition, although the perceived size lay in between the illusory conditions. It seems that the action system treated the flankers as obstacles despite the fact that they were two-dimensional. This unspecific reduction effect decreases the difference in the MGA between the illusory conditions, i.e. the action effect was reduced. Hence, it is questionable if a fair comparison between perception and action can be accomplished for the Ebbinghaus illusion.

Another unspecific effect, namely the center of gravity effect (COGE), could affect eye movements that occur during the inspection of visual illusions. According to Findlay (1982), the COGE can be “loosely described by saying [that] the saccade is directed to the center of gravity.
Figure 1. a) The Müller-Lyer illusion and a neutral figure. In the standard version of the Müller-Lyer illusion, the shaft (horizontal line) of the wings-out figure (top) appears to be larger than the shaft of the wings-in figure (middle), although their actual sizes are the same. The perceived size of a so-called neutral figure (bottom) lies somewhere between the illusory figures. The green dots mark the starting points of saccades. The target point of the saccade is the right vertex. According to the assumptions about the COGE, the endpoints of the saccades may be pulled towards the COG of the respective figure (red dots). The COG is assumed to lie in the center of the arrowhead. b) The Brentano version of the Müller-Lyer illusion. The COG (red dot) is shown for the region of the middle vertex. The green dots mark the starting points of saccades towards the middle vertex (blue dot) in the study of de Grave, Smeets, and Brenner (2006).

Two previous studies used the Brentano version of the Müller-Lyer illusion (Figure 1b) to investigate possible influences of a COGE. McCleary, Kramer, and DiGirolamo (2003) analyzed the amplitudes of saccades according to a median split for movement latency, since COGEs are known to be larger for short-latency saccades in comparison to long-latency saccades (Coëffé & O’Regan, 1987; Ottes, van Gisbergen, & Eggermont, 1985). However, an effect of the movement latency could not be found. Interestingly, they found larger amplitudes for wings-out figures in comparison to wings-in figures despite the fact that the perceived sizes were equal (i.e. their actual sizes were different). The authors suggested that this difference might be due to an imperfect adjustment of shaft lengths because it had been carried out in a pre-test by two subjects only. Yet, it seems also plausible that the difference might be due to a COGE, since it is in accordance with the expectations for such an effect.

de Grave, Smeets et al. (2006) used vertically oriented Brentano figures (Figure 1b) and let subjects carry out saccades towards the middle vertex of the shaft. The eye movements started from the top or bottom vertex of the Brentano illusion (i.e. vertical saccades, along the shaft) and from outside the figure (i.e. horizontal saccades, perpendicular to the shaft). The deviation of saccade endpoints from the middle vertex was measured for both the vertical and horizontal saccades. For the vertical saccades, the authors found effects that were similar to the perceptual judgements, whereas the horizontal saccades did not deviate in a vertical direction. This absence of a vertical error of the horizontal saccades was interpreted as evidence against a COGE. However, this interpretation is only valid if it is assumed that the influence of the COG on the amplitudes (i.e. increase or decrease of the amplitude) of saccades is directly comparable to the influence on the direction of saccades (i.e. deviation of the saccade from the principal direction that connects the starting point and the target point). Clearly, their results ruled out the possibility that the COG affects the direction of saccades in the Brentano illusion. Yet, a small or nonexistent influence on direction does not necessarily rule out the possibility that the amplitudes of saccades are influenced by the COG. After all, the amplitude and the direction of the saccade differ with respect to the contributions of the involved eye muscles. A change in amplitude indicates a change of contractions of the same eye muscles, whereas a deviation in direction indicates a change of the muscular activation pattern.

In our view, it remains an open question if the absence of a COGE on direction rules out a possible influence on the amplitudes of saccades. To this end, we conducted perceptual and action measures using the Müller-Lyer illusion. In Experiment 1 (Perceptual adjustments) we measured the perceptual effect and obtained sizes for perceptually adjusted figures (i.e. the actual sizes of the Müller-Lyer figures and the neutral figure were adjusted,
so that the perceived sizes became equal). In Experiment 2 (Saccades) we let subjects carry out saccades along the Müller-Lyer figures and along the neutral figure. By using the same actual sizes for these figures, we calculated the action effect and compared it with the perceptual effect. In addition, we also investigated saccades along the perceptually adjusted figures, which had been obtained in Experiment 1. If the amplitudes of saccades do not differ between perceptually adjusted illusory and neutral figures, then this would speak against the COGE. If however, the amplitudes of saccades for perceptually adjusted illusory figures deviate from the neutral figure, then this would be evidence for the COGE. The quantification of such an effect can ensure that comparisons between perceptual and action effects are conducted under fair circumstances.

**Experiment 1: Perceptual adjustments**

The aim of Experiment 1 was to determine the size of the perceptual effect and to obtain sizes for perceptually adjusted figures (different actual sizes that appear to be of the same size) that are used in Experiment 2 in order to investigate the COGE.

We used the adjustment task (Franz, 2003; Franz et al., 2000) for the perceptual measures. The subject actively varies figure sizes in order to make the figures equivalent in perceived size (by changing figure sizes on a computer screen). Subjects were presented with two figures and were asked to perceptually adjust the size of one of the figures (the match figure = MF) to the size of the second figure (the target figure = TF). The configurations used for both the MF and the TF were the wings-out, the wings-in, and the neutral figure. Essentially, this resulted in nine different adjustments for each size of the target figure (4 cm and 6 cm, Figure 2).

From these adjustments, the perceptual effect can be obtained in two ways (Franz et al., 2000) depending of the type of comparison (indicated on the right in Figure 2). In the direct comparison, subjects adjust one illusory configuration (e.g. the wings-in figure) to the other nonidentical illusory configuration (e.g. the wings-out figure). In the indirect comparison, the neutral figure is adjusted to each of the illusory figures. Both comparisons can also be carried out in the reversed direction (reversed direct and indirect comparisons in Figure 2). The perceptual effects were computed only for the direct and indirect comparisons (marked with asterisks in Figure 2). For methodical details on how the effects are computed, see Figure 3 and the description in the Results section. Former research indicates that the perceptual effects obtained by direct and indirect comparisons may differ. Franz et al. (2000) used the Ebbinghaus illusion and measured larger perceptual effects for the direct comparison in contrast to the indirect comparisons. They argued that motor tasks are much more comparable to the indirect comparisons because only one illusory figure is attended to during these tasks.

Note that we also investigated adjustments where the MF and the TF had the same configuration (same configuration adjustment = SCA). We did this for two reasons: First, comparisons between perceptual and action effects are only appropriate if the slopes of the functions that relate the actual size of the object with the size of the perceptual and the motor measures are the same (Franz, 2003; Franz et al., 2000). If the slopes differ, one can divide the perceptual and action effects by the slope that characterizes the respective method of measurement and thereby correct for these differences. Depending on the comparison under consideration, the SCA can be used to determine the slope in order to correct the perceptual effect (see Figure 3 in the Results section). Second, the SCA is needed to correct for possible “offsets” of the adjustments. This is important for the direct comparisons because offsets inherent in a comparison are not accounted for (Figure 3a). In contrast, possible offsets in the indirect comparisons are counterbalanced and thus corrected indirectly (Figure 3b).

**Method**

**Subjects**

Subjects were nine adults from the University of Kiel. Because of technical problems in Experiment 2, one of the
subjects was excluded from the analysis. From the remaining eight subjects, six were naive to the purpose of the experiment and were recruited from the Department of Psychology. They participated in order to earn credit points as part of a study fulfillment. Two of the subjects were the authors. All subjects had normal or corrected to normal vision.

**Apparatus**

Stimuli were presented on a computer screen (17”, 1024 × 768 pixels, 85 Hz). The viewing distance of 55 cm was fixed. Adjustments of the match figure were made using the “+” and the “−” keys on a keyboard. One press on either key resulted in an increase or decrease of 1 mm. The adjustment was accepted by pressing the “*” key.

**Stimuli**

The stimuli consisted of two figures (match figure (MF) and target figure (TF)) presented side by side. The shafts were oriented horizontally with their midpoints placed six centimeters to the right (respectively to the left) emanating from the center of the screen. The size of the TF was either 4 cm or 6 cm. The size of the MF at the beginning of a trial was chosen randomly between 2 cm and 9 cm. The colors of the figures were red for the TF and green for the MF for four subjects and vice versa for the remaining subjects. The background color was gray. The wings for the illusory figure configurations were angled at 30° for the wings-in figure and 150° for the wings-out figure relative to the shaft. The angle for the neutral figure was 90°. The length of the wings was one third of the length of the shaft. The thickness of the shafts was 1 mm.

**Procedure**

Each subject performed two blocks of 72 adjustments (nine match figures × two target sizes × eight repetitions) in random order (Figure 2). For each condition, the TF was presented four times on the right side and four times on the left side. In total, the eight subjects carried out 1152 adjustments. In each trial, a TF and a MF were presented. Subjects were instructed to adjust the MF to the TF (indicated by the color of the figures) until the lengths of the two shafts appeared to be equal. The adjustment was carried out using the keyboard. By pressing the “+” key, the subject confirmed the adjustment. The next trial started immediately after. No time limit was given for the adjustments. Trials were excluded from further analysis if the adjustments exceeded ± three standard deviations of the respective condition. This resulted in a loss of 0.8% of all trials.

**Results**

Results of Experiment 1 are shown in Figure 3. The figure illustrates how the perceptual effects are determined for the direct and indirect comparison (see the Appendix A for a tabular account of results). In principle, the analysis is the same for the two comparisons. First, the size of the MF (which is perceptually adjusted to the TF) for the comparison under consideration is plotted against the size of the TF (e.g. the adjustment of the wings-in figure to the wings-out figure in the direct comparison, see Figure 3a). Second, the appropriate SCA (same configuration adjustment) for the figure that serves as a target is plotted in order to determine the slope (d/p) for correction purposes and to detect possible offsets of the adjustments. D (respectively d1 and d2 in the indirect comparison) is defined as the difference between the comparison under consideration and the SCA at the average size of the TF. Following Bruno and Franz (2009), the perceptual effect is then determined as:

\[
\% = \left( \frac{d}{\text{slope} \times \text{average size of TF}} \right) \times 100
= \left( \frac{p}{\text{average size of TF}} \right) \times 100. \tag{1}
\]

The slopes for the two SCAs are close to 1.0, meaning that there is almost no difference between d and p (respectively between d1 + d2 and p1 + p2 in the indirect comparison). However, we found a slight offset of 0.11 ± 0.02 cm (mean ± SEM) for the SCA of the wings-out figure [t(7) = 4.92, P = 0.002, two-tailed, Figure 3a]. The offset (0.07 ± 0.03 cm) of the SCA for the wings-in figure (Figure 3b bottom) was marginally significant [t(7) = 2.30, P = 0.055, two-tailed]. Note that without the SCA, the difference d in the direct comparison (Figure 3a) would be computed as the difference between the matched size of the wings-in figure and the dashed line, resulting in an overestimation of d and p and thus in turn to a larger perceptual effect. For the indirect comparison (Figure 3b), offsets are compensated for indirectly because over- and underestimations are counterbalanced. Also note that we used only the conditions marked with an asterisk in Figure 2 for the computation of the direct and indirect comparison. The conditions that were left out represent the “reversed direct and indirect comparisons”. Since the perceptual effects of these reversed comparisons were quite similar to the effects computed here, we decided to omit the presentation of these effects. Nevertheless, all adjustments shown in Figure 2 are used in Experiment 2.

T-tests were used in order to compare the perceptual effects (Figure 4). Remember that Franz et al. (2000) found that the perceptual effect for the direct comparison was larger than the effect for the indirect comparison. However, we found no evidence for an enhanced perceptual effect for the direct comparison [t(7) = −0.57, P = 0.59].
Discussion

In Experiment 1, we measured perceptual effects and obtained sizes for perceptually adjusted figures that are used in Experiment 2. The perceptual effects were obtained with the direct and the indirect comparisons. We found no evidence for differences between the sizes of the perceptual effects determined with these methods. This result is in contrast to the findings of Franz et al. (2000), who investigated the Ebbinghaus illusion. In their study, the direct method yielded a perceptual effect that was 50% larger than the indirect method. It was argued (see also Franz & Gegenfurtner, 2008) that this difference between the perceptual effects is caused by an interaction of the surrounding circles in the direct comparisons. Evidently, such an enhancing effect is not present in the Müller-Lyer illusion. Hence, the present result shows that direct comparisons do not always yield larger perceptual effects than indirect comparisons.

Experiment 2: Saccades

The aim of Experiment 2 was to investigate the center of gravity effect (COGE) with respect to amplitudes of saccades. Since the conclusions about the internal format of the action and perceptual system (separate coding vs. common coding) rely on fair comparisons of perceptual and action effects (i.e. the effects should be due to the internal size estimate in the action and perception system), possible factors that change these effects, like the COGE,
need to be controlled for (de Grave, Smeets et al., 2006). Therefore, we let subjects carry out saccades along the Müller-Lyer figures and a neutral figure, which were of the same actual sizes. We calculated the action effect (AE) and compared it with the perceptual effect (Experiment 1). In addition, saccades were carried out along perceptually adjusted figures. If the saccades are scaled according to the perceived equal sizes of the figures, they will always have about the same amplitude. If however, the amplitudes of saccades differ for perceptually adjusted figures in the direction of the center of gravity (e.g. larger amplitudes for wings-out figures in comparison to wings-in figures), then this would indeed indicate the existence of a COGE.

In Experiment 2 we will again use the terms target figure (TF) and match(ed) figure (MF). They refer to the conditions in Experiment 1. MFs are size adjusted figures, whose adjustments have been carried out to TFs with fixed sizes (i.e. length of shaft) of either 4 cm or 6 cm (Figure 2). The three MFs that are of the same configuration as the TFs (e.g. wings-out MF and wings-out TF) are called SCA figures. The shaft lengths of the SCA figures were always 4 cm or 6 cm.

The aims of Experiment 2 can be achieved by letting subjects carry out saccades to the MFs (nine MFs \( \times \) two TF sizes). By comparing the amplitudes of saccades for the SCA figures, the action effect can be computed. The COGE is investigated by comparing the amplitudes of saccades for each “triplet” of MFs that belongs to a TF.

Method

Subjects

The same eight subjects from Experiment 1 participated in Experiment 2.

Apparatus

Stimuli were presented on the same monitor as in Experiment 1. Eye movements were recorded with an eye tracker (iView X Hi-Speed, SMI Berlin) with a temporal resolution of 240 Hz and a spatial resolution of 0.25°. If an eye movement exceeded the velocity of 75°/s and if the single peak velocity was reached in the range of 20% to 80% of the distance between start point and endpoint, it was classified as a saccade. The distance from the eye to the midpoint of the screen was 55 cm (as in Experiment 1). A chin rest was used to control for the viewing distance.

Stimuli

The MFs were presented horizontally with their left end or their right end of the shaft placed on the center of the screen. The sizes of the MFs corresponded to the adjusted sizes in Experiment 1. In cases where the MF configuration (the SCA figure) was identical to the corresponding TF, the size of the SCA figure was either 4 cm or 6 cm. The color of the MF was either red or green (according to the color in Experiment 1 for the subject). The background color was gray. Stimuli were otherwise identical to Experiment 1.

Procedure

Each subject performed three blocks of 72 saccades (nine MFs \( \times \) two TF sizes \( \times \) twelve repetitions) in random order. For each condition, the MF was presented six times on the left (i.e. the right end of the shaft was positioned in the center of the screen) and six times on the right. In total, the eight subjects performed 1728 saccades. Each trial started with the presentation of a fixation cross in the center of the screen. After three seconds, the cross disappeared and a MF was presented for two seconds, resulting in the fixation of the right end or the left end of the horizontal shaft. Subjects were instructed to carry out a saccade to the other end of the horizontal shaft right after the appearance of the figure. A gray screen followed for three seconds. The next trial started immediately after.

Results

Data analysis

We were interested in the amplitudes of the primary saccades. Secondary (corrective) saccades were not analyzed. Several reasons could lead to the exclusion of a trial: The saccade was carried out too early (<50 ms after stimulus presentation), too late (>1000 ms), or not at all. Furthermore, trials were discarded if the subject blinked during the execution of the movement or if the amplitudes deviated ± 1 cm from the mean value of the condition under consideration. Overall, this resulted in 84.3% valid trials. In order to compare the perceptual...
measures with the action measures, we calculated the “covered distances on the screen” (in cm) as the amplitudes of saccades. The action effects were computed analogous to the perceptual effects in Experiment 1, i.e. we took into account the neutral figure as well. Hitherto, only a few studies did this (Bernardis, Knox, & Bruno, 2005; de Grave, Franz, & Gegenfurtner, 2006; Knox & Bruno, 2007). In these studies, effects were computed using the formula \[(\text{difference between illusory figures}) / \text{neutral} \] \times 100. In the study conducted by Bernardis et al. (2005), the comparison between the perceptual and the action effect based on this measure was justified by the fact that the authors found similar slopes for the verbal estimations (perceptual measure) and for the amplitudes of saccades (action effect). Hence, there was no need to correct for the slopes. In the other two studies, only action effects were obtained. If corrections have been carried out in other studies (due to different slopes for the perceptual and the action measures), the slope was calculated as the average of the slopes obtained from the illusory figures (Franz, 2003; Franz et al., 2000). This procedure implicitly assumes that the slope for the neutral figure is equal to the mean of slopes for the illusory figures. By actually measuring the slope for the neutral figure, one should be able to see if this assumption is justified.

### The action effect

The action effect can be determined by comparing the amplitudes of saccades for the three configurations that are of the same actual size (i.e. for the SCA figures; Figure 5a). For illustrative purposes, results for the saccades that were carried out from right to left were mirror-reversed and collapsed on the saccades that were carried out from left to right.

The mean amplitudes of the saccades for the SCA figures are plotted against their actual sizes (Figure 5b). Applying the formula of Bruno and Franz (2009), the action effect is then calculated as:

\[
\begin{align*}
\% &= \left( \frac{d_1 + d_2}{\text{slope} \times \text{average size of SCA figure}} \right) \times 100 \\
&= \left( \frac{m_1 + m_2}{\text{average size of SCA figure}} \right) \times 100.
\end{align*}
\]

The action effect amounts to 27.34 ± 3.77%. Note that the slope for the neutral figure is different from the arithmetic mean of the slopes that characterize saccades along the two illusory figures. While the slope for the wings-out figure was 1.16 ± 0.03, the slope for the wings-in figure amounted to 0.87 ± 0.03, which was almost identical to the slope of the neutral figure (0.90 ± 0.03). Thus, the implicit assumption (Franz, 2003; Franz et al., 2000) that the mean slope of the illusory figures (1.02 ± 0.02) equals the slope for the neutral figure is not justified \([t(7) = 2.38, P = 0.049, \text{two-tailed}]\). Hence, by correcting the action effect with the slope obtained from the neutral figure (which serves as a reference for the illusory figures), the effect slightly increases. It should also be mentioned that the (primary) saccades along the neutral figure undershot the actual figure size, as can be appreciated in Figures 5a and 5b. Such undershoots are well known (Becker & Fuchs, 1969; Troost, Weber, & Daroff, 1974) and cannot
be interpreted in terms of imprecise measures. In addition, secondary saccades (not shown here) that were carried out by the subjects in order to compensate for deviations from the endpoint of the shaft, confirmed this interpretation.

The center of gravity effect (COGE)

Figure 6 shows mean amplitudes of saccades in comparison with the mean actual sizes of these MFs (yellow background). For each TF (wings-out, wings-in, neutral) with the size of 4 cm or 6 cm, the saccades (saccade triplet, white background) and the actual sizes of the corresponding MFs (adjusted sizes triplet, yellow background) are shown (see Tables A1 and A2). The saccades were carried out along the MFs that had the actual sizes shown in the yellow vertical bars. Note that although the sizes of the MFs in each adjusted sizes triplet were different, they were perceived to be of equal size (see Experiment 1). While the actual sizes show the largest values for the wings-in, medium values for the neutral, and smallest values for the wings-out figure in each adjusted sizes triplet, this sequence is reversed for the saccade triplets. This reversed sequence is evidence of the center of gravity effect (COGE). Dashed figures indicate saccades along the SCA figures (i.e. the actual sizes of these figures were either 4 cm or 6 cm, see also Figure 5). Error bars depict ± SEM. MF = matched figure; TF = target figure.

Figure 6. Mean amplitudes of the saccades along the MFs (shown on white background) in comparison with the mean actual sizes of these MFs (yellow background). For each TF (wings-out, wings-in, neutral) with the size of 4 cm or 6 cm, the saccades (saccade triplet, white background) and the actual sizes of the three corresponding MFs (adjusted sizes triplet, yellow background) are shown (see Tables A1 and A2). The saccades were carried out along the MFs that had the actual sizes shown in the yellow vertical bars. Note that although the sizes of the MFs in each adjusted sizes triplet were different, they were perceived to be of equal size (see Experiment 1). While the actual sizes show the largest values for the wings-in, medium values for the neutral, and smallest values for the wings-out figure in each adjusted sizes triplet, this sequence is reversed for the saccade triplets. This reversed sequence is evidence of the center of gravity effect (COGE). Dashed figures indicate saccades along the SCA figures (i.e. the actual sizes of these figures were either 4 cm or 6 cm, see also Figure 5). Error bars depict ± SEM. MF = matched figure; TF = target figure.

The endpoint of saccades for the neutral figure serves as a reference point for the saccades carried out to the illusory conditions. Remember that this figure is neutral (in a literal sense) because the COG is located on the end of the shaft (see Figure 1a). The undershoot of saccades for the neutral figure is typical (Becker & Fuchs, 1969; Troost et al., 1974). Since the illusory figures and the neutral figure are perceived to be of equal size, one would expect no differences for the endpoints of saccades from the reference point (i.e. the green cross in Figure 7) if the COGE did not exist. However, the saccades along the wings-out figure were larger compared to the neutral figure \[ t(7) = 2.82, P = 0.013, \text{one-tailed} \] by about 5.0%. Also, the saccades for the wings-in figure were smaller than the neutral figure \[ t(7) = 1.98, P = 0.044, \text{one-tailed} \] by about 4.2%. Together, this indicates the existence of the COGE.
Comparison of perceptual and action effects

Since the action effects (AE and AEnoCOGE) are obtained using the neutral figure as a reference for correction purposes, an obvious choice for fair comparisons is the perceptual effect obtained from the indirect comparisons, which also relies on a neutral figure as a reference for correction purposes.

The perceptual effect was significantly smaller than the AE \( t(7) = 2.90, P = 0.023, \text{two-tailed} \). In contrast, the action effect that was corrected for the center of gravity effect (AEnoCOGE) did not differ from the perceptual effect \( t(7) = 0.224, P = 0.83, \text{two-tailed} \).

Discussion

In Experiment 2, we measured action effects for the amplitudes of saccades using the Müller-Lyer illusion. We showed that the action effect (AE) was considerably larger than the perceptual effect. This “dissociation” between perception and action is in contrast to the assumptions of the separate coding approach (Milner & Goodale, 1995) that postulates stronger perceptual effects and weaker action effects. However, the large AE was in part due to a COGE, i.e. the saccades were pulled towards the center of gravity (COG) of the respective illusory figure. Therefore, a fair comparison between perceptual and action effects (i.e. effects are only due to the internal size estimates in the perceptual and action system) can only be assured if the additional COGE is eliminated from the AE. By

The action effect corrected for the center of gravity effect

The existence of a COGE has implications for the comparison between perceptual and action effects. Clearly, the action effect that was determined earlier (Figure 5) includes the COGE. Consequently, for a fair comparison between perceptual and action effects, the part of the action effect that is caused by the COGE should be eliminated. Since the amplitudes of the saccades for the wings-out figures are enlarged by 5.0% due to the COGE, a reduction by this amount should yield the true action effect (i.e. the action effect that is caused only by the visual illusion). The same argument applies for the wings-in figure, resulting in an increase of 4.2%. Figure 8 shows how the action effect (without the COGE) is determined. The measured values for the mean amplitudes of the saccades are increased by 4.2% for the wings-in figure, decreased by 5.0% for the wings-out figure and unchanged for the neutral figure. Therefore, the action effect without the center of gravity effect (AEnoCOGE) decreases to 17.29 ± 1.78%. The AE (27.34%) and the AEnoCOGE (17.29%) differ significantly \( t(7) = 4.21, P = 0.02, \text{one-tailed}, \) see Figure 4.

![Figure 7. Illustration of the center of gravity effect (COGE). The amplitudes of the saccades and the actual sizes of the MFs (matched figures) are pooled over the configuration (wings-in, wings-out, neutral) and the size of the TF (target figure), resulting in an average adjusted sizes triplet (shaft lengths are indicated) and in an average saccade triplet (amplitudes of saccades are shown on the right; endpoints of saccades are indicated with colored crosses in the figure). For illustrative purposes, saccades carried out from right to left were mirror-reversed and collapsed on the saccades that were carried out from left to right. The deviation of the orange cross to the right (+5.0%) and the deviation of the blue cross to the left (−4.2%) from the reference point (green cross) add up to the center of gravity effect (COGE).](https://jov.arvojournals.org/)

![Figure 8. The action effect without the center of gravity effect (AEnoCOGE). The mean amplitudes of the saccades were increased by 4.2% for the wings-in figure and decreased by 5.0% for the wings-out figure to correct for the COGE. The values for the neutral figure were unchanged. The AEnoCOGE is then computed as: \(|d_1 + d_2 / (\text{slope} \times \text{average size of SCA figure})\) \times 100 = \([m_1 + m_2 / 5] \times 100 = 17.29 \pm 1.78\%\).](https://jov.arvojournals.org/)

![Figure 7. Illustration of the center of gravity effect (COGE). The amplitudes of the saccades and the actual sizes of the MFs (matched figures) are pooled over the configuration (wings-in, wings-out, neutral) and the size of the TF (target figure), resulting in an average adjusted sizes triplet (shaft lengths are indicated) and in an average saccade triplet (amplitudes of saccades are shown on the right; endpoints of saccades are indicated with colored crosses in the figure). For illustrative purposes, saccades carried out from right to left were mirror-reversed and collapsed on the saccades that were carried out from left to right. The deviation of the orange cross to the right (+5.0%) and the deviation of the blue cross to the left (−4.2%) from the reference point (green cross) add up to the center of gravity effect (COGE).](https://jov.arvojournals.org/)
quantifying the COGE, we were able to correct the action effect and determine an action effect without the center of gravity effect (AEnoCOGE). The AEnoCOGE was almost identical in size to the perceptual effect, i.e. although the action effect was corrected (and therefore decreased in size), the action effect was not smaller than the perceptual effect. This result is in accordance with the common coding approach (Franz et al., 2001).

**General discussion**

In this study, we investigated the center of gravity effect (COGE) on saccades in the Müller-Lyer illusion. To this end, we not only measured the perceptual effect and the action effect, but we let subjects also carry out saccades along perceptually adjusted Müller-Lyer figures (same perceived size; different actual sizes).

Regarding the perceptual measures, we followed Franz et al. (2001) and distinguished the direct (wings-in figure is adjusted to the wings-out figure) and the indirect comparison (the neutral figure is adjusted to the wings-in as well as to the wings-out figure). The perceptual effects obtained with these two methods did not differ significantly. By contrast, Franz et al. (2000) found a considerably larger perceptual effect for the direct method in comparison to an indirect method. Various reasons may explain this discrepancy. First, while Franz et al. (2000) used the Ebbinghaus illusion, we investigated the Müller-Lyer illusion. It was argued (Franz & Gegenfurtner, 2008) that the difference between the direct and indirect methods may be due to an enhancing effect, i.e. by an interaction of the surrounding circles of the Ebbinghaus illusion in the direct comparisons. This explanation might not be true for the Müller-Lyer illusion. Therefore, direct comparisons may not per se yield larger perceptual effects than indirect comparisons.

With respect to fair comparisons between perceptual and action effects, it needs to be established that the slopes of the functions that relate the actual size of the figure with the size of the perceptual measure (adjustments) and the motor measures (amplitudes of saccades) are the same; otherwise corrections are necessary (Bruno & Franz, 2009). Since the basic idea for the use of visual illusions is that an illusory size change has the same effect as a physical size change of a neutral figure, it seems mandatory to determine the slopes of the functions for the neutral figure. While the perceptual measures yielded slopes close to 1.0, the action measures resulted in a slope for the neutral figure of 0.9. This value was different from the average slope for the two illusory figures (~1.0). This is not overly surprising given the fact that the neutral figure is defined only as “not biased in perceived size due to wings”. Thus, the neutral figure is neither considered lying exactly in the middle of the illusory figures with respect to perceived size nor with respect to the slope of the function that relates the actual figure size with the size of the dependent measure. Hence, it is necessary to measure not only the motor responses for the illusory figures but for the neutral figure as well (Figure 5b).

The action effect (AE) was considerably larger than the perceptual effects. However, it could be shown that the amplitudes of saccades were influenced by a center of gravity effect (COGE). A fair comparison between perception and action (with the aim to test the assumptions of the separate and common coding approaches) should account for the influence of factors that constitute a bias for the respective effects. Certainly, the tendency of saccades to be pulled towards the center of gravity of a stimulus configuration (Findlay, 1982; He & Kowler, 1989) is such a factor. The quantification of the COGE allowed for the computation of a corrected action effect (AEnoCOGE). This action effect did not differ from the perceptual effect.

The COGE found in the present study appears to be at odds with previous research on the Brentano version of the Müller-Lyer illusion. de Grave, Smeets et al. (2006) did not report an indication of a COGE. While the amplitudes of the saccades along the shafts of the Brentano figure (oriented vertically) were similar to the perceptual effect, the horizontal saccades (perpendicular to the shaft) from outside the figure to the midpoints of the Brentano figure did not show deviations in the direction of the expected COGE. Three reasons may explain the difference between the study of de Grave, Smeets et al. (2006) and our study: First, de Grave and colleagues excluded that a COGE changed the direction of saccades that started from outside the Brentano illusion (see Figure 1b, green dot) and aimed at the middle vertex of the figure (Figure 1b, blue dot), while we investigated influences of a COGE on the amplitude of saccades that were carried out along the shaft of Müller-Lyer figures. It is possible that saccades along the shaft of a visual illusion are influenced more by a COGE than saccades that are carried out perpendicular to the shaft. Isodirectional influences enlarge or diminish the amplitude of saccades without changing their direction. Orthogonal influences alter the direction of saccades and therefore involve other neuro-physiological mechanisms (change of the muscular activation pattern, recruitment of other external eye muscles). Concerning the (vertical) saccades along the shaft of the Brentano illusion, de Grave and colleagues could not differentiate between effects of the perceived size and a possible additional COGE. By analyzing saccades along perceptually adjusted figures (perceived sizes were equal), our Experiment 2 aimed to disentangle this issue. Second, in the study of de Grave, Franz et al. (2006) the target point was indicated with a small dot in each trial (Figure 1b, blue dot). The presentation of the target point superimposed on the middle vertex of the Brentano illusion might have reduced or even eliminated a possible influence of the COG on the direction of the saccade. Third, de Grave and colleagues did not vary the size of the...
Brentano illusion. Therefore, they could not measure the slopes of the functions that relate the dependent variable with the actual sizes of the figures. Hence, it remains open if the perceptual and action effects would have differed if a correction by the slopes had been carried out.

McCarley et al. (2003) analyzed the amplitudes of saccades post-hoc according to the movement latency (median split), based on the assumption that COGEs are larger for short-latency saccades compared to long-latency saccades (Coéffé & O’Regan, 1987; Ottes et al., 1985). Since the authors found no effect for movement latency, a COGE was ruled out. However, given the fact that movement latency was not varied systematically, the differences between the conditions for each type of saccade (reflexive or voluntary) after the median split can be assumed to be rather small (the authors gave no information on differences between saccade latencies after the median split). Hence, it remains unclear if the differences in movement latency between the groups after the median split were large enough so that COGEs could be expected to show up. Nonetheless, in the very same study, the authors found that amplitudes of voluntary saccades along perceptually adjusted wings-in and wings-out figures differed in the expected direction of the COGE. This finding is in line with the results in our study.

With respect to the assumptions about the COGE as spelled out in this study, some further points need to be addressed. Here, we followed McCarley et al. (2003) as well as de Grave, Smeets et al. (2006), who treated the COGE as an effect on saccades only, i.e. only the action system but not the perceptual system is influenced. We treated the effect of the illusion on saccades and the effect of the COG as two separate additive effects. However, it is possible that these two effects cannot be disentangled that easily. A prominent interpretation of the Müller-Lyer illusion stems from Gregory (1966). He tried to explain the illusion with the (so called false) attempt of the visual system for size constancy. It was assumed that the wings-in figure is near to the observer, like the protruding corner of a building, while the wings-out figure is supposed to be further away. This idea is questionable, since the dumbbell illusion (which is supposedly a variation of the Müller-Lyer figure) cannot be explained in the same way. According to another interpretation of Ginsburg (1986), the illusion may be caused by spatial filtering mechanisms, leading to size distortions in the filtered images that are similar to the perceived sizes. This filtering theory resembles the assumptions for the COGE on saccades. Yet, so far no consensus has been found with respect to the causation of the illusion.

The study of Bernardis et al. (2005) may provide an interesting hint concerning the size of perceptual effects. The authors found no difference between the perceptual effect (obtained with verbal estimations) and the action effect (obtained with saccades) using a modified Müller-Lyer illusion (only wings, no shafts), i.e. the perceptual and the action effect were similar even without correcting for the COGE. The perceptual effect in the study of Bernardis et al. (2005) was larger (22.3 ± 2.2%) than the effect that we obtained in the present study (17.7 ± 1.8%). Interestingly, the verbal estimation task as employed by Bernardis et al. (2005) was carried out with short presentation times (200 ms) of the illusory figures, comparable to the presentation time in their eye movement task. This resulted in perceptual and action effects that did not differ statistically. It is conceivable that the perceptual effect can be enhanced when presentation times are short. An obvious possibility to test this would be to vary the presentation times of the stimuli for the perceptual measures as well as for the motor responses.

The usual range of perceptual effects has been reported by Bruno and Franz (2009). In their review on 15 studies that investigated grasping at the Müller-Lyer illusion, the mean perceptual effect was 10.7% (range from 5% to 18.8%). All studies were conducted with the “classical” Müller-Lyer illusion, i.e. the stimuli consisted of (separate) wings-in and wings-out figures that contained a shaft. Moreover, all reported effects were corrected for the slope. However, in another review (Bruno, Bernardis, & Gentilucci, 2008) on 11 studies that investigated pointing at the “Müller-Lyer family” (including the “classical” Müller-Lyer illusion, the “no shaft” Müller-Lyer illusion, the Brentano illusion, the Dumbbell illusion, the Judd illusion and the Kanisza’s compression illusion), the mean perceptual effect amounted to 22.4% (range from 4% to 36.7%). In addition to the fact that the stimuli were quite inhomogeneous, the effects were (in most cases) not corrected for the slopes. These striking differences of the perceptual effects may indicate that they are quite variable if the stimulus conditions change and/or if the effects are not corrected for the slopes. And yet, it should be kept in mind that the variability of perceptual effects does not per se pose a problem to the general idea to compare perceptual and action effects. While the separate coding approach always predicts a dissociation between perception and action (i.e. the action effects are smaller than the perceptual effects), the common coding approach predicts associations between perception and action (i.e. no differences between effects). These predictions are, so to speak, not dependent on the “strength” of the illusion but only on the internal size estimate (that may vary in accordance with the “strength” of the illusion) in the perceptual and in action system. However, if additional factors (that may arise due to different stimulus conditions) influence the size of an effect, like the COGE, the interpretation of comparisons between perceptual and actions effects is impeded.

In the present study, an attempt was made to measure such an additional factor on saccades, the so called center of gravity effect (COGE). The results indicate that the COGE should be taken into account when dealing with the “classical” Müller-Lyer illusion. This has been demonstrated for action effects that were obtained with the amplitudes of saccades. To conclude, our results are in accordance with the common coding approach (Franz et al., 2001).
Appendix A

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