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Investigation of bistable perception with the “silhouette spinner”: Sit still, spin the dancer with your will

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ABSTRACT

Many studies have used static and non-biologically related stimuli to investigate bistable perception and found that the percept is usually dominated by their intrinsic nature with some influence of voluntary control from the viewer. Here we used a dynamic stimulus of a rotating human body, the silhouette spinner illusion, to investigate how the viewers’ intentions may affect their percepts. In two experiments, we manipulated observer intention (active or passive), fixation position (body or feet), and spinning velocity (fast, medium, or slow). Our results showed that the normalized alternating rate between two bistable percepts was greater when (1) participants actively attempted to switch percepts, (2) when participants fixated at the spinner’s feet rather than the body, inducing as many as 25 switches of the bistable percepts within 1 min, and (3) when they watched the spinner at high velocity. These results suggest that a dynamic biologically-bistable percept can be quickly alternated by the viewers’ intention. Furthermore, the higher alternating rate in the feet condition compared to the body condition suggests a role for biological meaningfulness in determining bistable percepts, where ‘biologically plausible’ interpretations are favored by the visual system.

1. Introduction

Despite physically constant stimulus presentation, observers can have bistable perceptions when viewing different types of ambiguous display (Leopold & Logothetis, 1999). Previous electrophysiological and fMRI studies using ambiguous figures, bistable apparent motion, and structure-from-motion stimuli have explored the neural mechanisms underlying perceptual reversibility (Britz, Landis, & Michel, 2008; Brouwer & van Ee, 2007; Kornmeier & Bach, 2004; Williams et al., 2003) and voluntary control (e.g. Meredith & Meredith, 1962; Pitts, Gavin, & Nerger, 2008, for a review see Long & Toppino, 2004). These studies have also highlighted the ability of human mental effort (i.e. voluntary, top-down control) and its interaction with stimulus characteristics (i.e. bottom-up factors) (Brouwer & van Ee, 2006; Kohler et al., 2008; Kornmeier, Hein, & Bach, 2009; Long & Moran, 2007; Meng & Tong, 2004; Suzuki & Peterson, 2000; Taddei-Ferretti et al., 2008; , 2003; van Ee, van Dam, & Brouwer, 2005).

A study from Brouwer and van Ee (2006) suggested that angular velocities can influence the effect of intention on the temporal dynamics of perception of an ambiguous structure-from-motion sphere: The difference in mean durations between passive and intentional viewings decreased as velocity increased. They further examined the ratio of durations between conditions (i.e. intention/passive) and found that the effect of intention was directly dependent on stimulus characteristics. That is, when human intention met higher velocity, the power of intention was weakened to a certain extent.

In this study, we used an ambiguously rotating human body to investigate how human intention interacts with eye fixations on different body parts (i.e. the body or the feet in the “silhouette spinner” animation). In addition, we examined whether spinning velocity of the spinner would cause any influence on intention, and if so, how it interacts with voluntary control.

2. Material and methods

2.1. Participants

Right-handed students at National Central University in Jhongli City, Taiwan, with normal or corrected-to-normal vision participated in the experiment. Each participant gave informed consent

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prior to the experiment, and received monetary payment upon its completion. For Experiment 1, data were obtained from 24 students (8 female, 16 male). Experiment 2 consisted of a different group of 20 students (10 female, 10 male). The experiments were approved by the local ethical committee and were in accordance with the Declaration of Helsinki (World Medical Association, 2000).

2.2. Stimuli

The "silhouette spinner" animation (Fig. 1) was obtained from the website of its original designer in Japan, Nobuyuki Kayahara (http://www.procreo.jp/labo/labo13), who named the phenomenon the "silhouette illusion." Despite its physical constancy, it can be perceived as rotating either in a clockwise (CW) or counter-clockwise (CCW) direction. The whole cycle of rotation was divided into 34 frames, and we modified the horizontal position of each frame to keep the stimulus vertically stable and no longer jumping upward and downward (see original movie on the website). The shadow of the spinner was also removed. A fixation point (1° × 1°) was added to either the upper (i.e. at 1/4 length from the top of the spinner) or lower body (i.e. at 1/4 length from the bottom of the spinner), depending on the fixation condition. Thus, the body and feet fixation points were both at the center of the display and on the same vertical axis with the same spinning speed.

The stimulus was displayed at the center of a 19 in. ViewSonic CRT monitor (1024 × 768 pixels, 100 Hz, distance 57 cm) via Experimental builder (SR Research Ltd.). The height of the stimulus was constant at 11.4°. The width of the spinner extended 2.3° (body) to 3.5° (body to protruding foot) wide. Since the spinner's foot spun across the entire frame, its motion covered a total width of 9.3° (3.5° on both sides and the width of the body). In Experiment 1, each 1-min trial contained approx. 54.26 cycles (325.5°/s) of spin. In Experiment 2, two other velocities were added: one was approx. 36.17 cycles/min (217°/s) and the other was 72.35 cycles/min (434°/s).

2.3. Design and procedure

Participants were seated in front of the display with their head position maintained by a chin rest. In Experiment 1, participants were instructed to indicate the spinner direction (CW/CCW) at first glance by pressing corresponding keys and continuously monitor any change of direction at any moment within each 1-min trial (passive condition). Participants first completed a 2-trial practice session, and then performed a block of 10 trials where they fixated at the upper body of the spinner, and another block at the lower body of the spinner (total of 20 trials). The order of fixation positions for the two block and two sessions was counterbalanced. Participants were given a break of over 30 s between each trial and over 1 min between blocks, and they could decide whether to continue to the next trial or block by pressing space key during the task. In order to avoid participants' potential inability to maintain a passive strategy toward this task, the passive condition was always run in the first session. This leaves open the possibility for a learning effect across the two sessions, as studies on static bistable figures such as the Necker cube have documented (e.g., Long, Toppino, & Kostenbauder, 1983). However, due to the importance of a passive attitude in the present study, and to avoid the large individual differences in bistable percept (between-subject), we proceeded with a within-subject design and conducted the passive condition in the first session. Thus, all participants were unaware of the bistable nature of the spinner at the time of the experiment. This was confirmed verbally by the experimenter at the start of the second session.

Eye movements were monitored with an Eyelink II system within a region (5° × 5°) around the fixation. If participants' eyes went beyond the boundary, data from that particular trial was not used for analysis, and a replacement trial was performed.

In the second session (1–2 days after the first session), participants were informed about the bistable nature of the spinner at the beginning, and were instructed to voluntarily switch the two percepts as quickly as possible (intentional condition). The remaining procedure was identical to the first session.

In Experiment 2, trials with three spinning velocities (see Section 2.2) were randomly repeated four times in one block for each fixation position (3 types × 2 fixation positions × 4 repeats, total of 24 trials). Practice trials had the intermediate spinning speed as in Experiment 1. The procedure was identical to Experiment 1.

2.4. Analysis

Alternating rate was collected from mean key presses per minute (except for the first press, which indicated initial identification

Fig. 1. The silhouette spinner. As for most bistable stimuli, this spinner can be perceived as spinning either in clockwise or counter-clockwise direction.

Table 1
Mean alternating rates (switches/min) across conditions in both Experiments 1 and 2 (mean ± SD).

Exp. 1 (fixation positions)	Body	Feet
Passive	5.18 ± 5.5	7.94 ± 6.8
Intentional	9.53 ± 9.6	17 ± 14.6

Exp. 2 (velocities)	Slow	Medium	Fast	Slow	Medium	Fast
Passive	2.11 ± 1.4	3.58 ± 2.3	7.48 ± 7.1	4.7 ± 4.5	6.86 ± 4.8	8.7 ± 5.5
Intentional	5.04 ± 4.5	8.3 ± 6.5	14.13 ± 10.1	11.84 ± 11.7	16.35 ± 13.7	25.84 ± 26.2

Table 2
Mean durations (s) across conditions in both Experiments 1 and 2 (mean ± SD).

Exp. 1 (fixation positions)	Body	Feet
Passive	16.38 ± 7.9	12.2 ± 8.7
Intentional	12.73 ± 8.5	8.06 ± 8

Exp. 2 (velocities)	Slow	Medium	Fast	Slow	Medium	Fast
Passive	22.35 ± 6.1	18 ± 7.6	14.17 ± 8.3	17.57 ± 8.8	13.41 ± 8.7	11.72 ± 9.3
Intentional	17.14 ± 8.0	12.33 ± 7.8	10.08 ± 8.7	10.78 ± 7.4	7.92 ± 6.4	6.42 ± 6.6

of spinning direction) across all trials. The normalized alternating rate for each participant was calculated by dividing the alternating rate in each condition (two intention and two fixation conditions) by the mean alternating rate of all conditions (Meng & Tong, 2004).

Mean durations of the two percepts (CW/CCW) were calculated by averaging the inter-press interval across all trials. We then carried out normalization for each condition to maximize potential effects and minimize variability between subjects. Normalization was derived from dividing the mean duration of each percept by the mean duration for all conditions under that percept. Thus the mean durations of CW and CCW percept were normalized separately.

We performed a repeated-measures analysis of variance (ANOVA) to test for possible effects and interactions among intention conditions and fixation positions (and velocities, in Experiment 2) on normalized alternating rates and mean durations. Since there was a bias in the stimulus, using alternating rates to address questions in this study would be more reasonable because the alternating rates could reflects both the ability to alternate "from CW to CCW" and the ability to alternate "from CCW to CW" (for data of alternating rates and mean durations, see Tables 1 and 2).

2.5. Mixed effect model in Experiment 1

The correlation between the initial percept and the duration distribution of that percept were tested by multilevel modeling (Goldstein, 2003). In Experiment 1, data were all binomial (e.g. initially-identified direction: CW vs. CCW; intention: passive vs. intentional; fixation position: body vs. feet), therefore the model used a multilevel logistic regression. Dependent variable was the duration difference between CW and CCW percepts in each trial. Significance was determined by log-likelihood ratio tests comparing a nested model to model that did not contain variable of interest (i.e. initially-identified direction).

3. Results

3.1. Experiment 1: effects of intention when viewing different body parts of the silhouette spinner

In Experiment 1, we analyzed the alternating rate and mean duration of two alternative percepts (for details please see Section 2.4) with a 2×2 factorial design: two intention conditions (passive vs. intentional) and two fixation positions (upper body vs. lower feet of the spinner). The results revealed that the normalized alternating rate was greater when attention was directed to the feet than to the body ($F_{1,23} = 40.439$, $p < .001$). In addition, observers who intentionally tried to increase their alternating rate experienced almost twice as much perceptual alternation than when passively viewing ($F_{1,23} = 38.652$, $p < .001$).

Moreover, we found a significant interaction between intention and fixation positions ($F_{1,23} = 4.437$, $p = .046$). The effect of intention on the increment of alternating rate compared to the passive condition was even greater when intention was directed to the feet (see Fig. 2).

Interestingly, we observed significantly longer mean duration of CW percepts than CCW in all conditions (paired-sample *t*-test; passive-body: $t_{23} = 2.686$, $p = .013$; intentional-feet: $t_{23} = 3.206$, $p = .004$; intentional-body: $t_{23} = 3.462$, $p = .002$) except for the passive-feet condition (paired-sample *t*-test, $t_{23} = 1.643$, $p = .114$), as illustrated in Fig. 3. However, since not all participants reported seeing CW direction at first glance of stimulus onset (some identified the direction as CCW), we attempted to correlate the initially-identified spinning direction to the distribution of duration of CW/CCW in each trial. By using the mixed effect model (see Section 2.4), we found that when compared to the model without initially-identified direction, factors such as intention, fixation, and block order, had no significant influences on the duration difference between CW and CCW. However, when we added the initially-identified direction into the model, it resulted in a highly significant improvement in model fitting compared to the baseline model (i.e. a model that does not include the variable of initially-identified direction) ($\chi^2(1) = 59.3$, $p < .001$). In other words, when participants recognized the spinner as rotating "CCW", the total CCW duration would be longer than CW in that trial, and vice versa. Most importantly, the model showed that intention did not affect this imbalanced distribution.

Given the interesting predictive power of the initial percept, we checked whether the initial percept was affected by the last percept of previous ($n - 1$) trial. We conducted a chi square analysis on the relationship between "initial percept of *n* trial" and "last percept of $n - 1$ trial". We found that only the two intentional conditions (body and feet) have significantly higher "congruent trials", where initial percept matches the very last percept of previous trial (passive-body: $\chi^2(1) = 3.376$, $p = .066$; passive-feet: $\chi^2(1) = .469$,

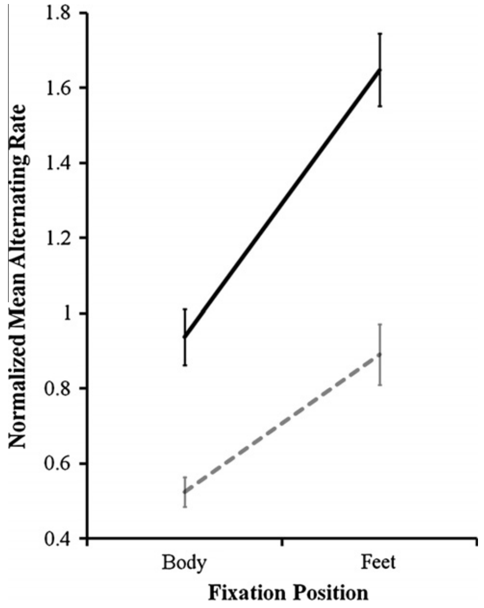

Fig. 2. Normalized mean alternating rate for intention with fixation on different body parts (i.e. body or feet) of the silhouette spinner in Experiment 1 ($N = 24$). Participants were instructed to passively monitor the alternation of spinning directions while fixating at either the body or the feet of the spinner (gray dashed line). In the second session, they were told to intentionally increase the alternating rate as much as possible (black solid line). Error bars represent ±1 SEM. Note that both intention and fixation effects reached significance, and a significant interaction was also observed.

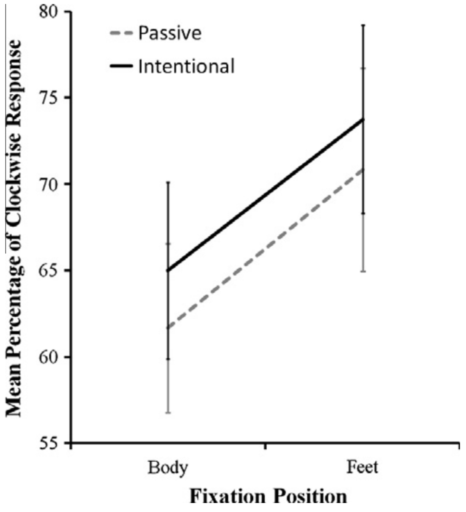

Fig. 3. Mean percentage of clockwise percepts.

$p = .493$; intentional-body: $\chi^2(1) = 12.474$, $p < .001$; intentional-feet: $\chi^2(1) = 4.244$, $p = .039$). Thus, the intentional effort from the participants to switch percepts actually *carried over* their perception to the next trial, which is consistent with previous research (Lalonde & Chaudhuri, 2002; Magnussen & Greenlee, 1992).

3.2. Experiment 2: effect of spinning velocities of the silhouette spinner on alternating rate

In addition to the fixed velocity in Experiment 1, we added two other angular velocities to the spinner, one slower and the other faster (see Section 2.2), to test how velocity affects intentional conditions and fixation positions. Similar to Experiment 1, intention and fixation effects were highly significant (intention: $F_{1,19} = 54.31$, $p < .001$, fixation position: $F_{1,19} = 28.58$, $p < .001$), as well as their interactions ($F_{1,19} = 5.06$, $p = .036$). In addition, spinning velocity had a significant effect on alternating rate ($F_{1,19} = 35.90$, $p < .001$), and interacted with intentions ($F_{2,38} = 5.96$, $p = .006$). Post-hoc analysis indicated that the differences between passive and intentional conditions on the normalized alternating rate were higher when velocity increased in both fixation positions. We found a significant difference between the passive and intentional condition on the normalized alternating rate when comparing fast to medium velocity under the condition of feet fixation ($t_{19} = -2.18$, $p = .042$), as well as fast to slow velocity under the condition of body fixation ($t_{19} = -2.09$, $p = .050$) (Fig. 4).

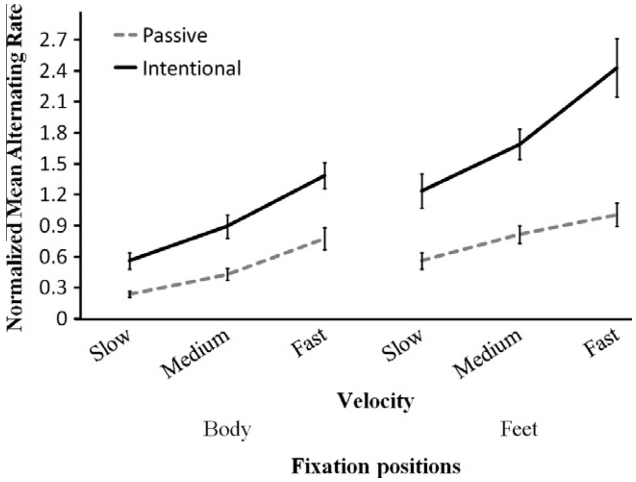

Fig. 4. Normalized mean alternating rate across conditions in Experiment 2 ($N = 20$). Gray dashed lines and black solid lines represent passive and intentional conditions, respectively. Error bars represent ±1 SEM. We observed significant effects of intention, fixation, and velocity, as well as interaction for both int. × fix. and int. × vel.

These differences, however, were eliminated when we adopted Brouwer and van Ee's (2006) method of analysis by dividing the intentional alternating rate by the passive rate. This measure was proposed by Brouwer and van Ee to truly test whether the effect of intention was 'directly' dependent on velocity. A similar interaction between intention and velocity could have been obtained if intention merely decreases the durations between percepts by a fixed ratio or gain during passive viewing. When velocity increases during passive viewing, durations could decrease even further during intentional viewing due to the multiplicative effect of applying a fixed ratio or gain. Therefore, the effect of intention here was independent of velocity because the significant interaction between the two variables was mainly driven by a fixed ratio or gain due to intention.

4. Discussion

We used a high-level motion stimulus, a silhouette human spinner, to investigate the interactions between intentional effort, fixated locations, and spinning velocity on bistable perception. First, the normalized alternating rate between the two bistable percepts was greater in the intentional viewing condition, where participants actively attempted to switch percepts, than in the passive viewing condition (intention effects). The alternating rate was also greater when observers fixated at the spinner's *feet* than at the body (fixation position effects). This pattern of results is consistent with the finding that the information carried by the local motion of the feet is critical for the identification of the direction of body movement in biological motion (Troje & Westhoff, 2006). Furthermore, we found a multiplicative effect of voluntary control on bistable perception, which is similar to the findings in a previous study (Suzuki & Peterson, 2000). The intentional effect was also significantly stronger when observers fixated at the spinner's *feet* than at the body. These findings indicate that the power of human intention was generally more effective under conditions in which stimulus characteristics favored its exertion.

Interestingly, we observed significantly longer mean durations of CW perception than CCW perception among all conditions except for the passive-feet condition. This imbalanced distribution of CW/CCW duration across trials might have resulted from stimulus characteristics, as suggested by Michael Bach: they are not completely identical in likelihood, because on left rotation the 3D arrangement is perceived as if one is looking from below – at the sole of the foot. This may explain the statistical preference for rightward motion (more comments are available on his website, http://michaelbach.de/ot/sze_silhouette/), which was also reported to correlate with one's natural reading direction (Morikawa & McBeath, 1992). Indeed, a recent paper by Troje and McAdam (2010) uncovered the cause behind the imbalanced distribution between CW/CCW durations. They found a linear functional relationship between different camera elevations (±10°, ±3°, and 0°, with respect to horizontal perspective) and the proportion of CCW responses. Therefore, it is likely that this 'viewing-from-above' bias produced by camera elevation that causes this imbalance between the two percepts in Kayahara's silhouette illusion.

In addition to the difference between CW and CCW percepts from Experiment 1, in Experiment 2 we found that combined manipulations of angular velocities revealed a significant effect of velocity as well as its interaction with intention. That is, higher velocity actually facilitated the effect of observers' intention. This interaction is inconsistent with Brouwer and van Ee's recent study (2006) that reported a decreased effect of intention when velocity of a rotating sphere increased. We speculate that the difference between the two studies may be due to the different levels of stimulus representation between the rotating sphere and the human body. That is, a human body is composed of many cuing surfaces that cannot be found elsewhere (e.g., contours of the head, hair, leg, etc.), thus leaving room for the observer to exert top-down intentional control based on the provided cues. A sphere, on the other hand, does not contain many distinctive features that the observers can utilize to bias perception. This trend becomes more apparent when the rotating velocity of the sphere increases, presumably because the fast velocity 'locks in' a particular percept by eliminating the brief moments where intentional control are easily exerted, thus making it harder for the observers to intentionally break away from one particular percept.

The fact that fixating at different parts of the silhouette spinner can generate different alternating rates without favoring one particular percept provides little evidence for the focal-feature hypothesis, which states that attending to different focal areas would favor different interpretations of an ambiguous Necker cube (Toppino, 2003). The precise reason why the body and the feet would require different time for adaptation still remains unknown. It may be due to the different temporal dynamics of the peripheral body parts (i.e. the protruding hand near the upper body and the protruding foot near the lower body). It may also be the case that humans prefer the feet as the salient rotational axes over the body, hence the higher alternating rates when attention was directed towards the feet.

5. Conclusion

When viewing human silhouette bistable motion, participants had different alternating rates when attending different body parts. Similar to most bistable phenomena, the alternating process with the silhouette motion can also be controlled voluntarily, to a certain extent, by human intention. Further, the effect of intentional control is facilitated by higher velocity. Interestingly, we found that initially-identified spinning directions enjoyed longer durations of perception, as if it became the "default" spinning direction. Furthermore, when participants intentionally attempted to increase alternations, thus decreasing mean durations, the differences between the duration of CW and CCW percepts still existed. A recently published article by Troje and McAdam (2010) suggested it is the viewing-from-above bias generated by camera elevation that causes this imbalance between the two percepts in the silhouette illusion.

One major finding from the present study is that more perceptual alternations occurred when participants fixated at the spinner's feet than at the body. This effect was even stronger in the higher velocity condition. These results indicate that biological plausibility can constrain the effect of intentional control in bistable motion perception. In other words, the motion patterns of different body parts may have different saliencies that differentially affect perceptual stabilization.

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