Research Article

MULTIPLICATIVE EFFECTS OF INTENTION ON THE PERCEPTION OF BISTABLE APPARENT MOTION

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Abstract—*When viewing ambiguous displays, observers can, via intentional efforts, affect which perceptual interpretation they perceive. Specifically, observers can increase the probability of seeing the desired percept. Little is known, however, about how intentional efforts interact with sensory inputs in exerting their effects on perception. In two experiments, the current study explored the possibility that intentional efforts might operate by multiplicatively enhancing the stimulus-based activation of the desired perceptual representation. Such a possibility is suggested by recent neurophysiological research on attention. In support of this idea, when we presented bistable apparent motion displays under stimulus conditions differentially favoring one motion percept over the other, observers' intentional efforts to see a particular motion were generally more effective under conditions in which stimulus factors favored the intended motion percept.*

It is well known that people can attend to spatial locations other than where the eyes are looking (e.g., Helmholtz, 1896; Posner, Snyder, & Davidson, 1980). They can also selectively attend to individual objects and image features (e.g., color, shape, and motion); as a consequence, they process attended objects or features faster and more accurately than unattended objects or features (for reviews, see Cave & Bichot, 1999; Egeth & Yantis, 1997). People's ability to influence visual perception by means of mental effort is not limited to selectively attending to locations, objects, or features, however. When viewing ambiguous (bistable) displays, observers can exert intentional control over which interpretation they perceive.

Bistable displays are displays that afford at least two potential interpretations even though the physical displays remain unchanged. Examples include the Necker cube, Rubin's face-vase, binocular rivalry displays,[1] and bistable apparent motion (e.g., Fig. 1). At any given moment, only one interpretation of a bistable display is seen; over time, the two perceptual interpretations spontaneously and stochastically alternate (e.g., Taylor & Aldridge, 1974). When observers are instructed to try to see one alternative interpretation of a bistable display, they report seeing the intended interpretation more often (or for longer durations) than the other alternative. In this article, we use the term *intention effects* strictly to refer to the perceptual effects of mentally trying to see a particular perceptual interpretation of a bistable display.[2]

Intention effects may be mediated in some cases by strategic focusing of attention or eye fixation, that is, by attending to (e.g., Tsal, 1994) or looking at (e.g., Ellis & Stark, 1978) the spatial locations or image features that differentially favor one perceptual alternative in bistable pictures. Similarly, for bistable apparent motion displays, intention effects can be mediated by moving attention in the direction of the intended motion (i.e., "attentive tracking," Cavanagh, 1992). Furthermore, intentional control is possible even when eye fixation and location of spatial attention are controlled (e.g., Peterson, 1986; Peterson & Gibson, 1991; Peterson, Harvey, & Weidenbacher, 1991), suggesting that intention might operate via more central representations.

Recent behavioral and neurophysiological studies suggest that, regardless of the specific bistable display being used, conscious perception of bistability may arise as a result of competing high-level perceptual representations being activated in response to a given visual stimulus (e.g., Leopold & Logothetis, 1999; Logothetis, Leopold, & Sheinberg, 1996; Tong, Nakayama, Vaughan, & Kanwisher, 1998); consequently, the more strongly activated representation is seen at any given moment. Although the neural coding of these competing representations has yet to be uncovered, activity of many different cortical neurons has been found to vary in phase with the time course of bistability during binocular rivalry. These competing perceptual representations are thought to be high-level representations because large proportions of cells in higher visual cortical areas (V4; the middle temporal area, MT; the medial superior temporal sulcus, MST; the inferotemporal cortex; and the superior temporal sulcus) vary their activity in synchrony with the perceptual flipping of the competing percepts, whereas only small proportions of cells in lower cortical areas (V1 and V2) follow the perceptual flipping (Leopold & Logothetis, 1999).

Regardless of the exact neural substrate of bistability, one may speculate that intentional control might operate by enhancing the relative activation of the desired representation. This can be accomplished either by enhancing the desired representation, suppressing the alternative representation, or both. Although it is difficult to distinguish between these possibilities behaviorally, the net effect of intentional efforts may exhibit either of the following simple characteristics: (a) additive enhancement, in which intention effects increment the relative activation of the desired representation by some amount, or (b) multiplicative enhancement, in which intention effects multiply the relative activation of the desired representation.

Current neurophysiological findings on attention effects might favor the latter possibility. When monkeys focus their attention on a single stimulus (manipulated by task demand, difficulty, or reward contingency), the activity of V4 neurons that respond to the attended stimulus is multiplied if there is no other competing stimulus within their receptive fields[3] (e.g., Haenny & Schiller, 1989; McAdams &

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1. A different picture is presented to each eye simultaneously, but only one picture is perceived at any given moment.

2. Whether "intention" and "attention" effects share common neural mechanisms in visual-motor phenomena (e.g., Colby, 1996; Snyder, Batista, & Andersen, 1997), visual-perceptual phenomena (e.g., Leopold & Logothetis, 1999), or both is currently being debated.

3. When two competing stimuli are in a V4 cell's receptive field, attending to either stimulus makes the cell respond as if attention had selected that stimulus for the cell (e.g., Reynolds, Chelazzi, & Desimone, 1999).

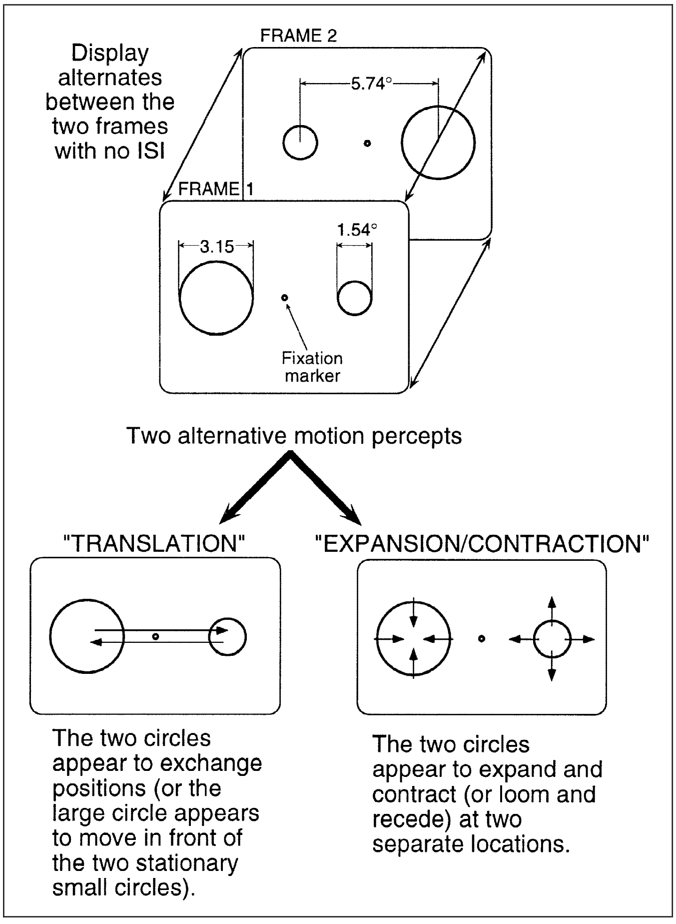

Fig. 1. Bistable apparent motion display used in Experiments 1 and 2. The circular stimuli were dark against a brighter background (as shown) in Experiment 2, but were bright against a dark background in Experiment 1. ISI = interstimulus interval.

Maunsell, 1999; Spitzer, Desimone, & Moran, 1988). In short, attentional enhancements of neural activity are larger when the stimulus-driven activation of those neurons is higher and smaller when the stimulus-driven activation is lower. One might speculate that intending to see a particular perceptual interpretation might influence perception via a mechanism similar to that involved in attending to a certain stimulus. Thus, these attention-related neurophysiological results suggest the intriguing possibility that intentional efforts might manifest themselves as multiplicative effects in influencing perceptual bistability.

The main distinction between the multiplicative mechanism and the additive mechanism is that the former predicts a specific interaction between intention effects and stimulus-based bias whereas the latter does not. Therefore, we evaluated these alternative possibilities by testing the effectiveness of intentional efforts while the bistable stimulus shown in Figure 1 was adjusted from moderately favoring the intended percept to moderately favoring the other percept.[4]

With appropriate choices of spatiotemporal parameters, the displays shown in Figure 1 afforded the perception of two types of compelling motion: translation or expansion-contraction (Oyama, Naito, & Naito, 1994). Pilot research using passive viewing instructions indicated that the baseline probabilities of seeing these alternative interpretations could be manipulated by varying the retinal eccentricity and the orientation of the display. Specifically, when observers viewed peripherally or vertically presented displays, they were more likely to report perceiving translation rather than expansion-contraction, whereas when they viewed centrally or horizontally presented displays, they were more likely to report perceiving expansion-contraction rather than translation[5] (see Fig. 2).

Intention effects were measured as the increase in the probability of seeing the desired motion when observers tried to see that motion relative to the baseline probability of seeing the same motion under passive viewing. If intention effects operate via additive enhancement, the likelihood of seeing the intended motion should increase by approximately the same amount, regardless of whether the baseline probability of seeing that motion is high or low (provided floor and ceiling are avoided). Alternatively, if intention effects operate via multiplicative enhancement, the likelihood of seeing the intended motion should increase by a relatively larger amount when the baseline probability of seeing that motion is higher rather than lower. It is possible that intention effects are neither additive nor multiplicative; in that case, intention effects might depend idiosyncratically on the stimulus manipulation. The baseline probabilities were varied by manipulating eccentricity (Experiments 1 and 2) and orientation (Experiment 2).

We also manipulated the stimulus onset asynchrony (SOA) between successive frames because, using different apparent motion displays, other researchers have shown that viewers' intentions are more effective when SOAs are long rather than short (e.g., Ramachandran & Anstis, 1983).

GENERAL METHOD

Observers

Forty undergraduate students (20 per experiment) at the University of Arizona participated to receive credit toward a course requirement. All observers had normal or corrected-to-normal vision, and were tested individually in a dimly lit room (just enough light to see the response keys).

Apparatus

Stimuli were presented on a 15-in. color monitor (67 Hz). The experiments were controlled using a Macintosh IIcx computer with the experimental software Vision Shell (Micro ML Inc., Quebec, Canada).

4. When bistable images are modified to strongly favor one of the alternative percepts, mental efforts cannot override the bias (e.g., Hochberg & Peterson, 1987; Peterson & Hochberg, 1983).

5. The effects of orientation and eccentricity were not unexpected. For similar orientation effects, see, for example, Chaudhuri and Glaser (1991); for a possible mechanism underlying the eccentricity effect, see Toet and Levi (1992).

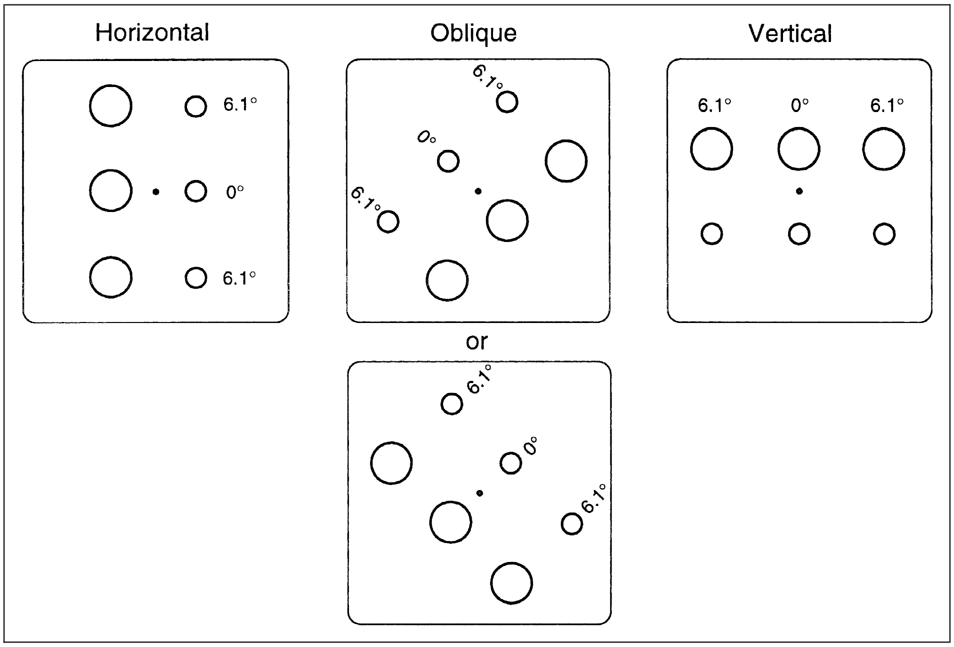

Fig. 2. The eccentricity and orientation manipulations. In the central-field (0°) condition, an imaginary line connecting the centers of the two circles would pass through the fixation marker. In the peripheral conditions, this imaginary line would be located at 6.1° eccentricity on opposite sides of the fixation marker with equal probability; eccentricity was varied in the direction orthogonal to the stimulus-array orientation. In Experiment 1, only the horizontal orientation was used, and the circular stimuli were bright against a dark background. In Experiment 2, all three orientations (horizontal, oblique, and vertical) were used, and the circular stimuli were darker than the background (as shown). The two oblique (45°) orientations occurred with equal probability.

EXPERIMENT 1

Method

Stimuli

Stimuli were drawn with 1-pixel-thick (2.3′) bright curves (11 cd/m^2) against a dark background (0.02 cd/m^2). The motion display consisted of two frames alternating in time with no interstimulus interval (ISI; see Fig. 1).

Prior to the experimental trials, the observers were shown unambiguous displays demonstrating the two types of motion. Unambiguous translation displays were created by making the size difference between the two circles sufficiently large (diameter ratio = .19) and inserting a blank frame between each successive pair of motion frames (ISI = 20 ms; SOA = 580 ms). Unambiguous expansion-contraction displays were created by making the size difference between the two circles sufficiently small (diameter ratio = .83) and using no ISI. In these demonstrations, the circles were displayed level with the fixation marker (Fig. 1).

For experimental trials, the two circles were placed either centrally—level with the fixation marker—or peripherally—displaced 6.1° vertically above or below the fixation marker (Fig. 2; horizontal orientation only). Four frame durations were used: 150, 225, 300, and 600 ms. These parameters were varied randomly within each block of 96 trials: 3 locations (upper, central, lower) × 4 frame durations × 8 repetitions.

Procedure

A trial began with the fixation marker and the sound of a warning beep. The observers were instructed to fixate the fixation marker throughout the trial. The apparent motion display began 2,200 ms later and lasted eight frames. The initial position of the large circle (left or right) was randomly determined in each trial. At the end of the motion display, the observers used a computer keyboard to indicate whether they saw translation ("/") or expansion-contraction ("z"). Observers were instructed to indicate the dominant motion if the perceived motion alternated between translation and expansion-contraction during the eight-frame display. Observers were given an option of pressing the space bar if it was impossible to determine which type of motion was seen (e.g., if frame alternations were too fast for any coherent motion to be seen or if neither type of motion was dominant). Viewing distance was 55 cm.

Each observer was tested in three conditions in a blocked design. The passive condition, in which the observers were simply told to view the display and indicate the type of motion they saw, was always tested first. This enabled us to obtain baseline measures before informing observers that they might be able to mentally control which type of motion they saw. After the passive condition, the observers were told that they might sometimes be able to see the intended type of motion through mental effort if they tried. They were instructed to "try to see translation" in one block of trials and to "try to see expansion-contraction" in another block of trials. The order of the two intention conditions was counterbalanced. It was strongly emphasized to the observers that the main purpose of the study was to determine the degree to which mental effort might influence perception. Therefore, although they were expected to try hard to induce the desired type of motion, it was of paramount importance that they indicate the perceived motion honestly. Observers were given up to 10 practice trials before the passive condition.

Results and Discussion

Space-bar responses were relatively infrequent (4.6%), and were obtained mainly for short frame durations and peripheral presentations. Because these responses were rare, and are tangential to the purposes of this article, we do not discuss them further. Instead, we focus our analysis on the trials in which the observers reported seeing one or the other type of motion.

Passive viewing condition

As expected from our pilot work, main effects of eccentricity were obtained. Translation was seen significantly more frequently at 6.1° eccentricity than at 0° eccentricity, $F(1, 19) = 27.605$, $p < .0001$ (Fig. 3a). Not surprisingly (because the space-bar responses were relatively rare), the trend was reversed for expansion-contraction, which was seen more frequently at 0° eccentricity than at 6.1° eccentricity, $F(1, 19) = 44.058$, $p < .0001$ (Fig. 3b).

We also found small effects of visual hemifield (upper vs. lower at 6.1°). Translation was seen more often in the lower visual field than in the upper visual field (69.7% vs. 60.6%), $F(1, 19) = 7.686$, $p < .02$, and expansion-contraction was seen more often in the upper visual field than in the lower visual field (31.7% vs. 23.3%), $F(1, 19) = 8.706$, $p < .01$. These hemifield effects did not replicate in Experiment 2; hence, we do not consider them further.

The rate of seeing translation increased as the frame duration increased, $F(1, 19) = 13.213$, $p < .0001$ (Fig. 4a), whereas the rate of seeing expansion-contraction decreased as the frame duration increased, $F(1, 19) = 8.228$, $p < .0001$ (Fig. 4b). Like the hemifield effects, these frame-duration effects did not replicate in Experiment 2.

We next examine how these trends were modulated by the observers' intentional effort.

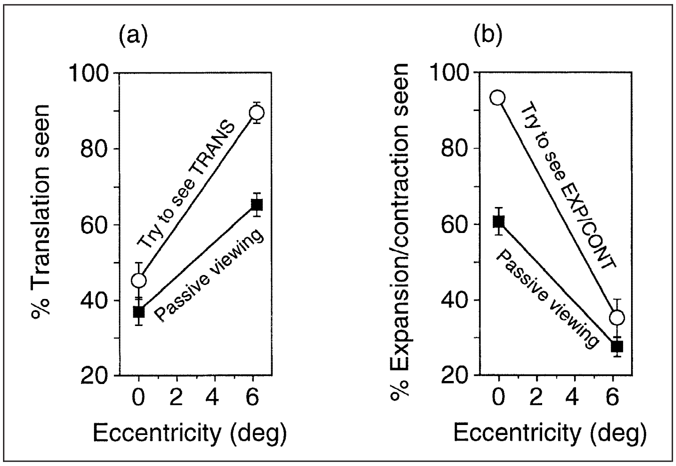

Fig. 3. Mean rates of seeing translation (a) and expansion-contraction (b) at 0° and 6.1° eccentricities in Experiment 1. Filled squares indicate the passive condition, and open circles indicate the try-to-see-translation (TRANS) condition (a) and the try-to-see-expansion-contraction (EXP/CONT) condition (b). The effectiveness of intentional effort is reflected in the increased rates of seeing the intended motion in the intention conditions relative to the passive conditions. Error bars represent ±1 *SE*. Note that the rates of translation and expansion-contraction responses do not necessarily sum to 100% for the passive condition because sometimes observers responded that they could not determine which type of motion they saw (space-bar responses).

Intention effects

Observers' mental efforts significantly influenced perception in both intention conditions. When observers tried to see translation, translation reports increased compared with baseline (passive condition), $F(1, 19) = 39.813$, $p < .0001$. Similarly, when observers tried to see expansion-contraction, expansion-contraction reports increased compared with baseline, $F(1, 19) = 40.261$, $p < .0001$. More important, intentions were more effective at the eccentricity where the baseline probability of seeing the intended motion was higher under the passive viewing condition. That is, intentions to see translation were more effective at 6.1° eccentricity than at 0° eccentricity, $F(1, 19) = 5.659$, $p < .03$ (Fig. 3a), whereas intentions to see expansion-contraction were more effective at 0° eccentricity than at 6.1° eccentricity, $F(1, 19) = 21.557$, $p < .0005$ (Fig. 3b). In other words, the observers' mental efforts boosted the bias due to the eccentricity manipulation in a multiplicative manner.

How did frame duration affect the intention effects? Intentions to see translation were approximately equally effective across the range of frame durations used (150–600 ms); the interaction between frame duration and the intention condition (try to see translation vs. passive viewing) was not significant, $F(3, 57) = 0.432$, $p < 1$ (Fig. 4a). For expansion-contraction, however, intentions to see expansion-contraction were more effective as frame duration increased, $F(3, 57) = 3.258$, $p < .03$ (Fig. 4b). The results obtained with expansion-contraction are consistent with the idea that top-down cognitive influences on perceived apparent motion increase as frame duration increases (e.g., Braddick, 1980; Pantle & Picciano, 1976; Ramachan-

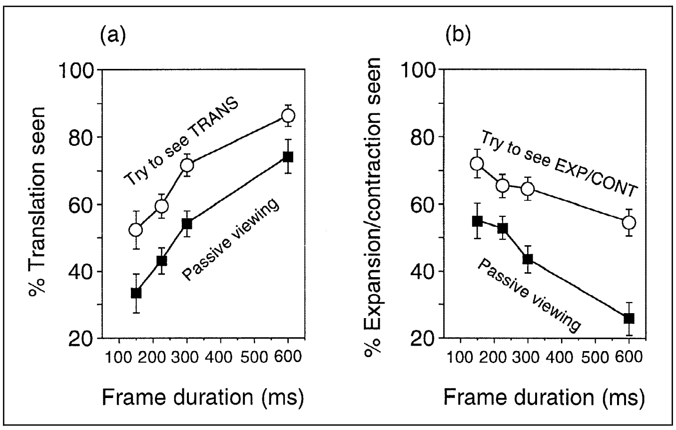

Fig. 4. Mean rates of seeing translation (a) and expansion-contraction (b) as a function of frame duration in Experiment 1. Filled squares indicate the passive condition, and open circles indicate the try-to-see-translation (TRANS) condition (a) and the try-to-see-expansion-contraction (EXP/CONT) condition (b). Error bars represent ±1 *SE*.

dran & Anstis, 1983; Shiffrar & Freyd, 1993). The absence of the frame-duration effect for translation does not necessarily constitute contradictory evidence because ceiling effects may have been operating at the longer exposure durations.

To summarize, the observers' mental efforts significantly increased the probability of seeing the desired type of motion. Furthermore, the effectiveness of mental efforts interacted with the eccentricity-based bias in a multiplicative manner: Larger intention effects were obtained when the display was presented at the eccentricity where the baseline probability of seeing the intended motion was higher. In Experiment 2, we examined whether multiplicative intention effects would be evident when the baseline probabilities of seeing translation or expansion-contraction were altered by changing orientation as well as eccentricity.

EXPERIMENT 2

Method

Stimuli

The stimuli used were the same as those used in Experiment 1 except that orientation and eccentricity were both varied (Fig. 2). In a within-observer design, adding a parameter (e.g., orientation) increases the number of experimental trials. To reduce any discomfort induced by staring at flickering displays on a larger number of trials, we reversed the contrast polarity of the display and reduced the stimulus contrast (dark figures, 11 cd/m^2, in a gray background, 54 cd/m^2). Other changes made to shorten the length of the experiment included reducing the number of motion frames per trial from eight to four, and reducing the number of frame durations tested from four to three (150, 300, and 600 ms).

As in Experiment 1, observers initially viewed unambiguous demonstrations of the two types of motion for each of the three orientations, but always at 0° eccentricity (centered at fixation marker). The characteristics of the demonstration displays were the same as in Experiment 1. For the experimental trials, orientation, eccentricity, and frame duration were varied randomly within each block of 144 trials: 2 eccentricities (0° and 6.1°) × 3 orientations (horizontal, oblique, and vertical) × 3 frame durations × 8 repetitions. The left and right oblique orientations (see Fig. 2) occurred at an equal probability, and the data from these two oblique orientations were combined for the analyses.

Procedure

The procedure was the same as in Experiment 1.

Results and Discussion

As in Experiment 1, space-bar responses were rare (0.9%), and occurred mostly for the shortest frame duration. Once again, we focus our analysis on the trials in which the observers indicated that they saw one or the other type of motion.

Passive viewing condition

Results for the passive condition were consistent with the results in Experiment 1: The rate of seeing translation was higher at 6.1° than at 0° eccentricity, $F(1, 19) = 32.297$, $p < .0001$ (Fig. 5a), whereas the rate of seeing expansion-contraction was higher at 0° than at 6.1° eccentricity, $F(1, 19) = 33.240$, $p < .0001$ (Fig. 5b). Confirming our pilot tests regarding orientation, the rate of seeing translation increased, $F(2, 38) = 13.166$, $p < .0001$, while the rate of seeing expansion-contraction decreased, $F(2, 38) = 14.587$, $p < .0001$, as the stimulus array was rotated from horizontal to oblique (45°) to vertical (Figs. 6a and 6b). Neither of these effects interacted with the visual fields (upper vs. lower or left vs. right) in which the displays were presented.

Neither the rate of seeing translation, $F(2, 38) < 0.062$, $p < 1$, nor the rate of seeing expansion-contraction, $F(2, 38) = 0.192$, $p < 1$, depended on frame duration (Figs. 7a and 7b). The disappearance of

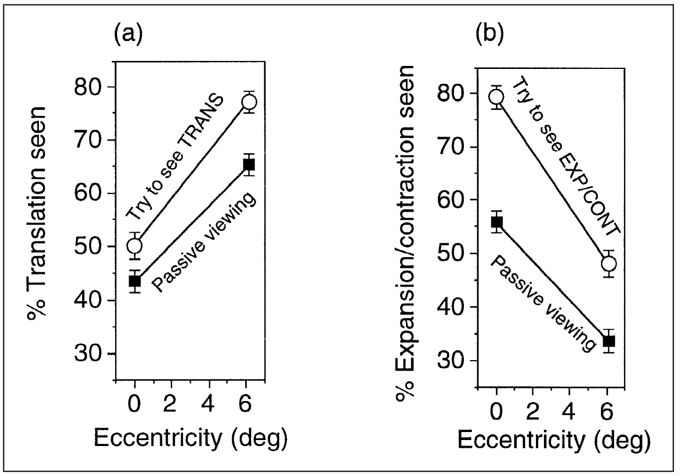

Fig. 5. Mean rates of seeing translation (a) and expansion-contraction (b) at 0° and 6.1° eccentricities in Experiment 2. Filled squares indicate the passive condition, and open circles indicate the try-to-see-translation (TRANS) condition (a) and the try-to-see-expansion-contraction (EXP/CONT) condition (b). Error bars represent ±1 *SE*.

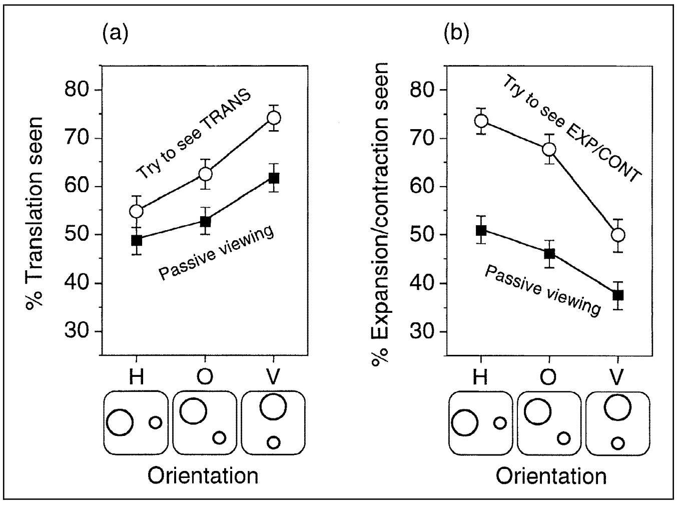

Fig. 6. Mean rates of seeing translation (a) and expansion-contraction (b) for the horizontal, oblique (±45°), and vertical orientations in Experiment 2. Filled squares indicate the passive condition, and open circles indicate the try-to-see-translation (TRANS) condition (a) and the try-to-see-expansion-contraction (EXP/CONT) condition (b). Error bars represent ±1 *SE*. H = horizontal; O = oblique; V = vertical.

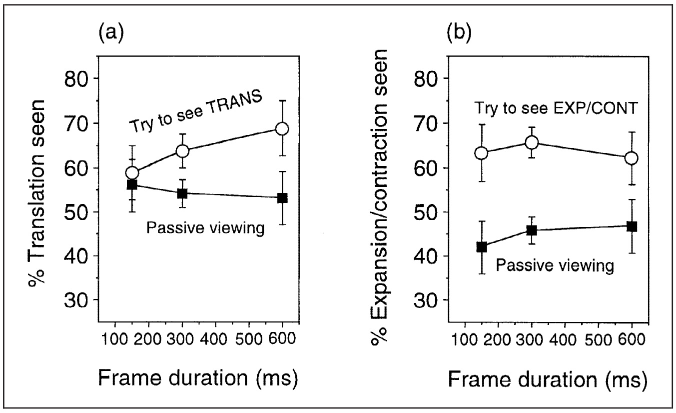

Fig. 7. Mean rates of seeing translation (a) and expansion-contraction (b) as a function of frame duration in Experiment 2. Filled squares indicate the passive condition, and open circles indicate the try-to-see-translation (TRANS) condition (a) and the try-to-see-expansion-contraction (EXP/CONT) condition (b). Error bars represent ±1 *SE*.

the frame-duration effects obtained in Experiment 1 could be due to the changes in the contrast polarity and luminance contrast, to the inclusion of different orientations, or to the use of a different group of observers.

Intention effects

As can be seen in Figure 5a, when observers tried to see translation, translation reports increased compared with the passive baseline condition, $F(1, 19) = 10.397$, $p < .005$. Moreover, intentions to see translation were more effective in the peripheral-presentation condition, in which the baseline probability of seeing translation was higher. This trend, however, was only marginally significant[6] for translation responses, $F(1, 19) = 3.172$, $p < .10$.

As can be seen in Figure 5b, when observers tried to see expansion-contraction, expansion-contraction reports increased compared with the passive baseline condition, $F(1, 19) = 34.316$, $p < .0001$. Moreover, intentions to see expansion-contraction were more effective in the central-presentation condition, in which the baseline probability of seeing expansion-contraction was higher. The trend was significant for expansion-contraction responses, $F(1, 19) = 5.090$, $p < .04$.

As in Experiment 1, intentions to see a particular type of motion were largely more effective at that stimulus eccentricity where the baseline probability of seeing that type of motion was higher. Next, we examine whether these multiplicative effects of intention were obtained when baseline responses were biased by orientation, rather than eccentricity.

As can be seen in Figure 6a, the effectiveness of intentions to see translation increased from 5.9% for the horizontal orientation, to 9.7% for the oblique orientation, to 12.3% for the vertical orientation; this linear trend was significant, $F(1, 19) = 4.633$, $p < .05$. Thus, the effectiveness of intentions to see translation increased as the baseline probability of seeing translation increased. Similarly, the effectiveness of intentions to see expansion-contraction increased from 12.3% for the vertical orientation, to 21.7% for the oblique orientation, to 22.6% for the horizontal orientation, $F(1, 19) = 8.566$, $p < .01$ (Fig. 6b). Thus, the effectiveness of intentions to see expansion-contraction also increased as the baseline probability of seeing expansion-contraction increased.

Thus, the idea that mental effort is more effective when the stimulus parameters are more conducive to perceiving the intended type of motion applies when the relevant stimulus parameter is orientation as well as eccentricity. To illustrate how the two stimulus parameters jointly affected the effectiveness of mental efforts, Figure 8 shows the effectiveness of intentions to see translation and intentions to see expansion-contraction with respect to the six combinations of eccentricities and orientations used (2 eccentricities × 3 orientations). The abscissa represents the corresponding baseline probabilities in the passive condition. The figure shows that both types of intentional effort became more effective as the baseline probability of seeing the intended type of motion was increased (from about 30% to 70%) by jointly manipulating stimulus eccentricity and orientation.

How did the intention effects vary with frame duration? As shown in Figure 7a, intentions to see translation increased in effectiveness when the frame duration increased, $F(2, 38) = 4.246$, $p < .03$. However, as shown in Figure 7b, intentions to see expansion-contraction did not increase with frame duration, $F(2, 38) = 0.589$, $p < 1$. Faced with these variable results within and across experiments, we can conclude only that for our displays, increasing frame duration (from 150 ms up to 600 ms) did not necessarily make intentional control of bistable apparent motion more effective.

To summarize, Experiment 2 extended the main finding of Ex-

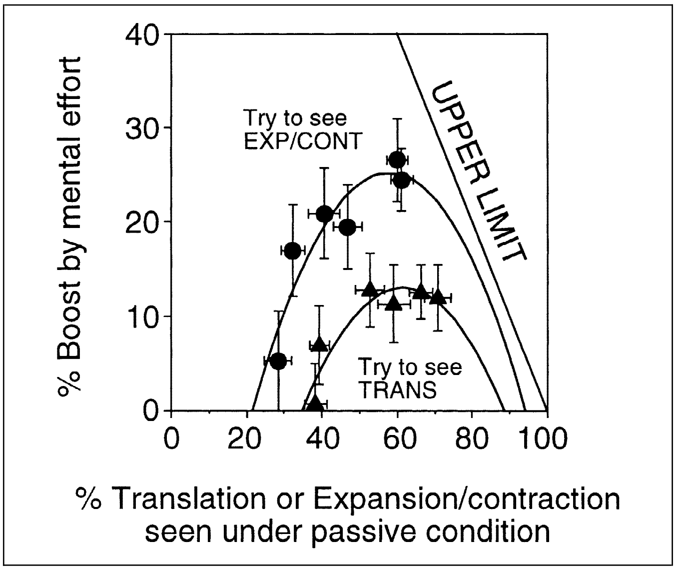

Fig. 8. Boost in the rate of seeing translation (TRANS; triangles) or expansion-contraction (EXP/CONT; circles) in the intention condition of Experiment 2 as a function of the baseline probability of seeing the corresponding type of motion in the passive condition. Each point corresponds to a particular combination of eccentricity and orientation. The slanted line ($x + y = 100\%$) indicates the upper limit for the boost that might be exerted. For example, for the baseline probability of 60%, the maximum possible boost would be 40% (the sum cannot exceed 100%). Because of this upper limit, the data points are fit (least squares fit) with curvilinear functions (second-order polynomials). Error bars represent ±1 *SE*.

6. This interaction would have been significant, $F(1, 18) = 5.899$, $p < .03$, without 1 outlying observer who showed an atypically large trend (>2 *SD*) in the opposite direction.

periment 1 in showing that the effectiveness of mental effort to see one type of motion in a bistable display increased as the stimulus eccentricity and orientation were manipulated to increase the baseline probability of seeing the intended motion. We confirmed this conclusion while the baseline probability was varied from about 30% to 70% (Fig. 8). Obviously, if the baseline probability were too high, whatever boost might be given by mental effort would be limited by the upper boundary.

GENERAL DISCUSSION

Using a bistable apparent motion display with intention instructions, we found that observers' intentional efforts increased the probability of seeing the desired motion in a multiplicative manner. That is, the stronger (weaker) the perceptual bias established by the stimulus parameters was, the larger (smaller) were the effects of mental effort in boosting that bias. The fact that the intention effects were multiplicative rules out several possible criticisms of this study.

One possible criticism is that our observers merely increased their overall frequency of reporting the desired motion in order to demonstrate their compliance with the experimental instructions. However, this does not appear to have been the case because such a strategy would have increased the frequency of reporting the desired motion equally regardless of the stimulus-based bias. Another potential criticism arises from our use of the passive condition as the baseline against which intention effects were measured. Given that intention can affect perception, perhaps the passive condition was not truly passive, but was contaminated by uncontrolled intentions. For example, observers may have tried to see translation on some passive trials and expansion-contraction on the remaining passive trials. Were this the case, the probabilities of seeing each interpretation in the passive conditions should have been linear combinations (weighted averages) of the probabilities obtained in the two intention conditions. If so, the absolute slopes of the passive viewing curves shown in Figures 3, 5, and 6 would have been somewhere between the absolute slopes of the two intention-condition curves for each figure, but they were not (the passive slopes were shallower than either of the intention slopes, indicating multiplicative interactions).

It is conceivable that the intention effects measured were due to focused spatial attention or attentive tracking. When trying to see translation, observers might have spread their attention across the two circles or tracked the translational motion by moving their focus of attention, whereas when trying to see expansion-contraction, observers might have attended to the individual circles or tracked expansion-contraction by expanding and contracting their attentional focus. However, it is difficult to explain why the effectiveness of these attentional strategies would be systematically affected by the eccentricity and orientation manipulations to produce the obtained multiplicative interactions. For example, it is not clear why spreading attention across the two circles or attentively tracking the translational motion might have been more effective when the stimulus array was peripherally presented and vertically oriented. Instead, it seems simpler to speculate that intention effects enhanced the high-level representation of the desired type of motion in a multiplicative manner.

Future research must determine where these high-level representations are located in the brain. One possibility, based on existing knowledge, is that they are located in the cortical areas MT and MST. In MT, cells are tuned to translating motion, including apparent motion (e.g., Mikami, 1991; Mikami, Newsome, & Wurtz, 1986). Neural activity in MT has been closely linked to the conscious perception of motion (e.g., Newsome, Britten, & Movshon, 1989; Salzman, Britten, & Newsome, 1990). In MST, some cells are tuned to expansion-contraction (e.g., Graziano, Andersen, & Snowden, 1994). Furthermore, neural responses in both MT and MST are closely linked to perceptual bistability (e.g., Leopold & Logothetis, 1999; Logothetis & Schall, 1989), and the cells respond more strongly to their preferred motion stimulus when the stimulus is attended (e.g., Treue & Maunsell, 1996).

Methodologically, our results suggest that observers can indeed passively view a bistable apparent motion display without actively intending to see one or the other alternative motion. However, if the robust intention effects we obtained (up to about 25%) generalize to other stimuli, uncontrolled intentions could seriously confound experimental results. For example, if observers believed a particular relationship between the stimulus condition and the perceived motion existed, such an expectation could override a relatively weak stimulus effect or could create an effect that might falsely be attributed to the stimulus parameters tested. Thus, when stimulus manipulation is suspected to affect observers' expectations, it would be wise to control intentions. Our results suggest that if intentions are controlled, that is, if observers consistently try to see a particular motion under different stimulus conditions, their mental efforts do not alter the pattern of the underlying effects of stimulus parameters (provided ceiling effects are avoided); indeed, consistent intention might even enhance the stimulus-based effects relative to passive viewing.

In closing, we suggest that applying the current paradigm to a variety of bistable displays (both stationary and dynamic) will reveal whether or not a multiplicative boost is a general characteristic of intention effects on perception.

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