Frank H. Durgin

The Tinkerbell Effect

Motion Perception and Illusion

A new motion illusion is discussed in relation to the idea of vision as a Grand Illusion. An experiment shows that this 'Tinkerbell effect' is a good example of a visual illusion supported by low-level stimulus information, but resulting from integration principles probably necessary for normal perception.

Is visual consciousness a Grand Illusion? In one sense, the answer must be 'Of course.' On the other hand, it sure doesn't seem that way (which is why the illusion deserves to be called 'grand'). What visual consciousness seems to be, naively and subjectively, is a direct rendering of visually available information. Taking this naive view too seriously, however, would lead to some unfortunate conclusions. What I propose to argue in this paper is that perceptual awareness pretends to have access to more information than is actually available to visual cognition. The content of visual awareness when it goes 'beyond the information given' is often as accurate as the information-processing goals of 'seeing' require, but its apparent 'directness' can only be understood as an illusion, grand or otherwise.

One way of capturing the nature of visual consciousness was put forth by von Helmholtz in his classic general rule that '. . . such objects are always imagined as being present in the field of vision as would have to be there in order to produce the same impressions on the nervous mechanisms, the eyes being used under ordinary conditions.' (1910/1925, p. 2). What von Helmholtz is saying is not merely that perception involves unconscious inference, but that it is an act of imagination. Perception is an act of imagination based upon the available information.

To illustrate the power of this idea, consider Figure 1, which shows two sub-sampled images of a face. From close up, the distortion produced by sub-sampling is quite evident. But if you stand back a few meters, the pictures will appear to be clear and undistorted. At that distance the blockiness is not visible, but the resulting percept seems to assert more than it can possibly know (but in a way consistent with von Helmholtz's general rule). I call this sort of illusion

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Figure 1. Subsampled images. Viewed from a meter or two away, these images appear to be clear pictures. Squinting works too.

the filling-in of visual detail (Durgin, 1998). I don't think the detail itself is filled in anywhere in the brain. Rather, I think the apparent content of visual consciousness often goes beyond what is actually available to visual cognition. It is enough that the relevant face-encoding units in the brain all fire in their characteristic manner as if they were witnessing the clear image of the face. Such firing is indistinguishable from actually witnessing the clear image of the face.

Why do I doubt that the filling in actually occurs anywhere? I doubt this because there are many cases of perceptions where it is clear that the content of visual cognition is a kind of summary of the visual information given, and not a duplication of it. Visual textures are a good example of stimuli that have characteristic appearances but are too complex for full, lossless representation in visual cognition. Despite being based on summary information (cf. Durgin, 1995), visual consciousness seems to assert direct experience in the perception of visual texture. I was personally shaken out of the naive view of perception as direct access to visual information when I discovered, with Dennis Proffitt, the texture density after-effect: After adapting different regions of the visual system to different densities of texture, the perceptual registration of apparent texture density (and element numerosity) can be distorted by a factor of two (Durgin, 1995; Durgin and Proffitt, 1996). If 400 dots can be made to look like 200 dots, one wonders where the missing dots have got to — or whether it makes sense to believe that one is really seeing the actual dots at all — before or after adaptation.

To take a more extreme example, imagine viewing a detuned television set and observing the dynamic visual noise on the screen. Millions of dots change brightness 30 times per second and it feels like we are seeing it all. But for the brain to store those millions of bits of information (or even encode them all past the retina) would be simply ridiculous. Our visual experience presents itself to us as direct, unmediated, and complete. This is an illusion.

It is difficult not to view this as a happy illusion — happy because for normal purposes the visual system can get away with it without harm. I have argued elsewhere that the very goal of the visual system is to support this illusion by doing its best to make itself and its workings invisible (Durgin and Proffitt, 1996).

What cognition wants is information about the world, not about the visual system. Vision's methods work well for the most part.

The present paper concerns a new phenomenon that illustrates the problem of indirectness in motion perception very nicely. The phenomenon generally supports a Helmholtzian framework of perception as imagination. It concerns the illusory perception of coherent motion in dynamic noise. I call it the Tinkerbell effect.

The Tinkerbell Effect

In 1981, while I was still a high-school student, a friend informed me that he had seen a demonstration on television of the ability of psychic powers to influence quantum processes. The theoretical significance of such a demonstration will not be lost on those interested in consciousness, nor did it fail to appeal to my imagination twenty years ago. What had impressed my friend was that, by a collective act of will, the audience members had apparently been able to influence the pattern of quantum activity when displayed as blips of light on a screen. That is, the quantum process that the demonstrator had set up could be perceived as random points of light that flashed around a ring. By inviting the audience to try to make the procession of blips move clockwise, the demonstrator was able to convince his audience that the action of their will influenced the movement of the dots. Whether the demonstrator was a charlatan or simply naive, I do not know. The reason I share this story is to emphasize that perceptual experience really does pretend to be an accurate record of visually available information, and that anyone convinced by such a demonstration would profit from understanding that perceptual experience is mediated, not direct, and that effects of conscious will on conscious perceptual experience should not be mistaken for effects of conscious will on the world itself.

As for myself, it was not until many years later that I realized that the demonstration had very different implications than those originally intended. First of all, this particular visual phenomenon does not even require a quantum-process generator. As I will discuss below, the phenomenon can be experienced with dots projected into pseudo-random positions by what is, in fact, a completely deterministic 'random number' generator on a computer. Thus, the sexy part of the demonstration, purporting to demonstrate the conscious control of *quantum* events, is simply invalid. Second, and more important, it is fairly trivial to show that if one group of observers is asked to try to make the dots move in one direction, while a second group is asked to make the dots go in the opposite direction, both groups will feel that they have succeeded simultaneously. Thus, contrary to the strong native assumption that visual experience is an unmediated conduit of reality, the wilful control of visual motion seems to concern the wilful control of perception, not of the displays themselves.

Because of its resemblance to the audience participation in Peter Pan, I refer to this phenomenon as the Tinkerbell effect. In the stage version of Peter Pan, a fairy named Tinkerbell intentionally drinks poison so as to prevent Peter Pan from drinking it. Sadly, Tinkerbell is left dying, but the audience (normally children) is then asked to demonstrate that they believe in fairies by clapping. Sure enough, they are thereby successful at restoring Tinkerbell to life. In the quantum control demonstration described above, a similar request is made with a similar illusory result. Of course, in the play, the illusory efficacy of the audience is supported by an external event performed by an actor, whereas the illusory perception of coherent directed motion (in actually random motion) is nearly entirely in the head of the beholder (in the Cartesian theatre?). Nonetheless, in both cases an illusion of control may be obtained. The question is, how does the head see coherent motion where there isn't any?

Classic Problems of Motion Interpretation and Integration

To begin to answer this question requires consideration of some of the information-processing demands involved in the visual perception of motion, because in order to understand how illusory motion might be perceived, it would be a good idea to understand how real motion is perceived. The two most relevant conceptions in this regard are known as the aperture problem and the correspondence problem.

The aperture problem concerns one way in which motion information is inherently ambiguous. It can be illustrated by the well-known barber pole illusion, in which the stripes of the barber pole appear to move vertically, though the pole itself is rotating horizontally about a vertical axis. A more general case may be observed by moving a piece of paper with diagonal stripes behind a circular aperture. Although the paper may be moved vertically or horizontally, the motion of the stripes will appear perpendicular to their orientation. This corresponds to the local motion signals — and is a good reflection of what motion detectors in the brain might tend to represent. What is therefore actually surprising is that when the aperture is removed, the motion is seen correctly — the local motion signals are somehow combined into a coherent image.

Although an incoherent random dot pattern does not have oriented elements, the visual system is still working with local motion information (i.e., from motion detectors with small receptive fields), which is subject to aperture-problem errors. Thus, it is a requirement of the accurate visual registration of motion that local motion signals must sometimes be reinterpreted by global constraints. That is, as each motion-detection unit in the early stages of processing provides information to a higher level, it is with the understanding that the provided information is ambiguous and subject to error.

A closely related problem is known as the correspondence problem, which assumes that creating the global motion percept depends on matching local image features between successive 'frames' of motion. In a stable pattern that translates between two frames, this matching can be done using high-dimensional feature analysis, but it can become quite problematic when there is added visual noise, or when the elements are highly uniform. Not surprisingly, the correspondence problem becomes more difficult as the displacements between corresponding points in coherent motion become larger (i.e., the points to be matched up are farther apart than other, spurious candidate matches).

Braddick (1974) defined $d_{\max}$ as the maximum displacement of a random-dot pattern at which the direction of coherent motion could still be detected. Eagle and Rogers (1996) showed that $d_{\max}$ was dependent on the density of elements. In essence, for lower-density displays, larger displacements are acceptable because fewer nearby elements could produce spurious matches. The correspondence problem in motion is probably solved using visual codes that are more abstract than mere texture elements (Glennerster, 1998). For present purposes, it is only important to note that global motion signals can be ambiguous when reliable matches between local elements become difficult to make.

The Tinkerbell effect may arise, in part, because the visual system is designed to organize motion signals that are intrinsically noisy. In order to document the effect and study its properties, Feng He and I conducted an experiment in which we often embedded directional motion signals within an otherwise incoherent sequence of dot patterns. We were particularly interested in addressing the possibility that the perceived speed of motion depended on dot density, because dot density could affect both the distance over which the correspondence problem can be solved and the magnitude (average distance) of the random motion signals that might be generated by the displays.

Measuring the Tinkerbell Effect

Measuring hallucinated motion is somewhat complicated. Our primary goal was to demonstrate that we could get observers to perceive coherent motion of a certain direction in dynamic incoherent dots patterns, but we also wanted to have a fairly precise measure of perceived speed. In order to try to measure perceived speed, we had to make a number of design decisions that will require explanation. For instance, we were particularly interested in using a speed-matching task to assess perceived speed. However, the visual system is notoriously susceptible to motion after-effects (for example, Wöhlgemuth, 1911). Thus, if we required an observer to compare the hallucinated motion to real motion, we ought to be concerned that the real motion would produce strong after-effects that might alter the perceived speed in the target display. To avoid directionally biasing after-effects, we ensured that all motion signals presented were balanced by equal and opposite motion signals. Thus, the speed-matching task employed dynamic dot fields in which half of the signal dots moved clockwise about the annular display and the other half moved counter-clockwise. Visually, this appeared as two overlapping sets of dots moving in opposite directions.

Moreover, because speed perception is affected by the size and contrast of the particular stimulus used, we wanted the target and comparison displays to be as similar as possible. Finally, we were concerned that the task itself appear meaningful to the observers, and therefore chose to embed real motion signals in many of the trials. This allowed us to test whether our observers were sensitive to these embedded motion signals.

Pilot investigations indicated that observers could indeed respond differentially to different speeds if we embedded a weak bi-directional motion stimulus in our otherwise random dynamic dots fields. On the other hand, we were also predicting that denser displays might appear to move more slowly than sparse displays. Our pilot studies had also suggested that effects of density could be found alongside effects of embedded speed provided that the embedded speed signal was not so strong as to overwhelm the possible effects of dots spacing. With this in mind we conducted an experiment to investigate the role of dot density in the Tinkerbell effect.

Methods

Observers: Sixteen college students participated in the experiment in exchange for money or course credit. Of these, one had to be eliminated for failing to follow instructions.

Apparatus: The experiment was conducted using a Cambridge Visual Stimulus Generator driving a Sony GDM-F500T9 display set to a resolution of 800 × 600 pixels refreshed at 100 Hz.

Procedure: Each observer was instructed to judge the speed of coherent motion embedded within an otherwise incoherent dynamic dot stimulus. Note that the observer was not informed that on 40% of the trials, there would be no actual embedded coherent motion. Neither were observers informed about the amount of embedded motion. All stimuli were presented as an annulus of dynamic grey dots on a black background, and each trial was preceded by instructions as to the direction of motion (clockwise or anticlockwise) to be judged. The target stimulus then appeared and stayed on until the observer pressed a button to view the adjustable matcher stimulus (which began at a random speed). If no further button were pressed, the matcher would appear for 800 ms and then the target stimulus would reappear. The subject used two buttons to adjust the speed of the matcher up or down (each button initiated display of the newly adjusted matcher). A third button was used to toggle between the target and matcher stimulus, and a fourth button was used to indicate that the match was now satisfactory. Each observer made matches for 60 target stimuli in about 25 minutes.

Design: The two manipulated variables in the design were the density of the dots (0.08, 0.16, or 0.24 dots per square degree — each square degree was the area of 100 dots, so these numbers can be interpreted directly as percentage filled), and the speed of the embedded motion (180, 360, or 720 degrees per sec, or undefined — for the completely incoherent displays). There were twice as many undefined-speed trials as for each other speed. That is, there were eight undefined speed trials at each level of density, and only four of each of the other three speeds. Half the trials required clockwise judgements and half anticlockwise.

Initial matcher speed was randomly selected among 26 possible values within the range of 4–200 degrees per second. These values were approximately evenly distributed in logarithmic space (each about 15% higher than the next). The order of trials was completely random.

Stimuli: The target motion displays were presented within annuli having an inner radius of 5 degrees and an outer radius of 12 degrees of visual angle (total area was 384 square degrees). In order to blur the edges of the annulus, dot luminance was modulated across the width of the annulus, falling off parabolically toward the edges. On every video frame, the stipulated density of dots was presented (i.e., 30, 60, or 90 dots). All but seven percent of these dots (i.e., all but 2, 4, or 6 dots per frame) were scattered randomly on each frame. The remaining seven percent were correlated with the previous frame (on embedded motion trials) by being offset by 1.8, 3.6, or 7.2 degrees in rotation from dots in the previous frame (half moved clockwise, and half anticlockwise). A new seven percent were correlated on each frame. Note that, because dot speeds were stipulated in terms of angular rotation within the annulus, the middle speed, of 360 degrees per sec, for example, could be represented by a linear displacement of 0.31 to 0.78 degrees of visual angle per frame (31 to 78 degrees of visual angle per second), depending on eccentricity.

The matcher displays were constructed similarly, with density matched to that of the target display. However, in the matcher displays, 50% of the dots on each frame were correlated with dots in the previous frame (25% moving in each direction — this is the maximum correlation possible given that each dot's position is re-randomized after it moves one frame). In addition, the observer controlled the speed of movement. (This speed could be set to zero, or range from 40 to 2000 degrees per second by steps of about 15%.) These matcher displays clearly depicted two transparent scintillating textures moving in opposite directions, and were readily used for making speed-matching judgments for either direction of motion.

Results and Discussion

How readily was the Tinkerbell effect experienced? Of the fifteen observers, twelve were able to perform the task consistently for all displays. Two of the other observers seemed only to see coherent motion (give non-zero matches) in the lowest density conditions, and the third was unable to reliably perceive coherent motion (give non-zero matches) in any condition. The main statistical conclusions from the data are essentially the same whether all fifteen subjects are analyzed together or only the twelve who reliably saw motion in all the displays. So as not to artificially deflate perceived speed of motion for these twelve, graphs and statistical analyses will be reported for them only. Mean perceived rotational speeds as a function of density and of embedded speed are shown in Figure 2.

A 3 (density) x 4 (embedded speed) repeated measures ANOVA was conducted using mean matches from each observer, collapsing across direction of motion. Although our primary concern is with the effect of manipulating dot density, we will first consider the effects of embedding various speeds of coherent dots.

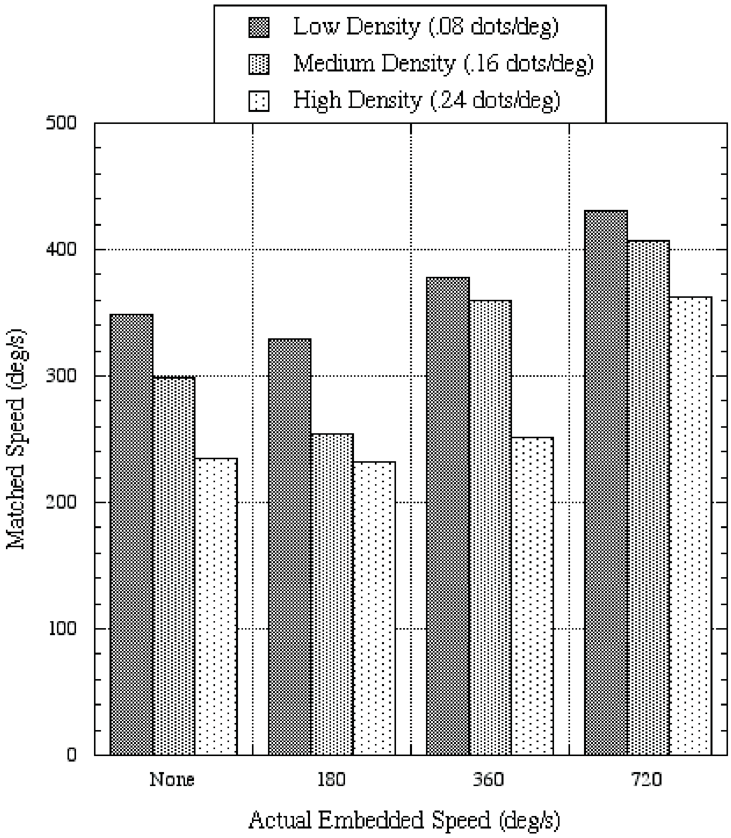

Figure 2. Results of experiment measuring speed of perceived rotation as a function of embedded speed and dot density. Data are average of twelve observers.

Relative speed comparisons

As expected, speed judgments differed as a function of embedded speed, F(3, 33) = 6.01, $p < .01$. Planned comparisons showed that the judgments of the highest embedded speed (M = 400 deg/s) were reliably higher than those of the lowest embedded speed (M = 272 deg/s), t(11) = 12.8, $p < .01$. They were also higher than judgments when no coherent motion was embedded (M = 294 deg/s), t(11) = 10.6, $p < .01$. No other differences among embedded speed conditions were statistically reliable.

Absolute speed comparisons

We originally chose our embedded speeds based on what we expected the illusory speed would be. Our lower two embedded speeds did in fact bracket the mean illusory speed. In the absence of any embedded speed, the mean perceived speed (294 deg/s), was reliably less than 360 deg/s, t(11) = 2.87, $p < .05$, but greater than 180 deg/s, t(11) = 4.98, $p < .01$. When speeds were embedded, the average judgments of the middle speed (M = 369 deg/s) did not differ reliably from the actual embedded speed (360 deg/s), t(11) = 0.18, n.s. However, the judgments of the lowest speed (M = 272 deg/s) were higher than the actual embedded speed (180 deg/s), t(11) = 3.50, $p < .01$, and the judgments of the highest embedded speeds (M = 400 deg/s) were much lower than the actual embedded speed (720 deg/s), t(11) = 7.97, $p < .01$. Indeed, judgments of the lowest embedded speed were reliably lower than 360 deg/s, t(11) = 3.34, $p < .01$, but judgments of the highest embedded speed did not differ reliably from 360 deg/s, t(11) = 1.00, n.s. In summary, although there is clear evidence of some sensitivity to embedded speeds (which is impressive given that only 7% of the dots were correlated from frame to frame!), that sensitivity is fairly weak.

Perceived speed as a function of density. In addition to the effect of embedded speed, there was a highly reliable main effect of dot density on perceived speed, F(2,22) = 6.80, $p < .01$. We had hypothesized that higher speeds would be perceived for lower densities. Although the mean matched speed for the lowest density (352 deg/s) was not reliably different from that for the middle density (330 deg/s), t(11) = 0.67, $p > .10$, each of these was higher than the mean speed for the highest density (271 deg/s), t(11) = 3.54, $p < .01$ (30 vs. 90 dots), t(11) = 2.76, $p < .05$ (60 vs. 90 dots).

If differences in speed judgments were related directly to differences in density by virtue of the concomitant changes in inter-dot distances, we would expect the three speeds to fall in a ratio of 1: 1.22: 1.73, corresponding to the square roots of the 1:2:3 changes in density. In fact, they fall in ratio of 1.0: 1.22: 1.30. In other words, the speed–density relationship is quantitatively predicted for the higher two densities, but perceived speed falls off from what might be expected for the lowest density / fastest speed.

The limited range of perceived speeds. With respect both to density and to embedded speed predictions, there seemed to be a limited range of perceived speeds. Mean estimates of perceived rotation speed ranged from 232 deg/s in the highest density, lowest embedded speed condition to 430 deg/s in the lowest density, highest embedded speed condition, despite a fourfold change in embedded speed and a threefold change in density. It is not that higher speeds cannot be perceived, however. Pilot studies suggest that if the percentage of dots given embedded speed were increased, a broader (more accurate) range of speed matches would have resulted. However, with only these weak motion signals provided, the range of perceived speeds is apparently curtailed.

General Discussion

The Tinkerbell effect is presented here as a demonstration that conscious visual experience may be very loosely supported by ‘sense’ impressions, as in the case of dynamic visual noise. It represents a case where a top-down selection of information seems to create a perceptual experience that, while clearly illusory in one sense, masquerades as the true state of the world. The dots truly do seem to move in the direction the observer attempts to see. Our concern has been to measure the speed of that perceived motion and examine its relationship to stimulus factors that might well be expected to influence the motion detection systems. True to von Helmholtz's (1910/1925) dictum, the act of imagination evidenced here is responsive to stimulus factors relevant to normal motion processing.

Although we decided not to ask our subjects to 'control' the motion of the dots, we did require them to 'find' the motion in the direction specified at the outset of the trial. By focussing their attention on matching the rotation speed of the dots we required them to organize the dot motion. Their responses indicate sensitivity both to motion signals that were intentionally embedded, as well as to the effects of element density. While no specific motion integration model is being considered here, the general model is one in which low-level, noisy motion information is treated as the raw materials for an integrative process of imagination.

There are two other motion phenomena that are probably relevant to understanding the motion-processing aspects of the Tinkerbell effect. One of these was reported by MacKay in 1961, and labelled the *omega effect* in 1965. It concerns the spontaneous appearance of directional motion in visual noise confined to a narrow channel. The other was also reported by MacKay (1961), though it is better know as *motion capture*, the name given by its re-discoverers, Ramachandran and Anstis (1983). It concerns the spurious perception of coherent motion in dynamic visual noise when a strong motion signal overlays the noise.

MacKay's omega effect

MacKay (1957) reported that visual noise, when superimposed on near-parallel lines (such as gratings or concentric circles), would seem to stream at right angles to the local orientation of the lines. In addition to this orthogonal streaming, however, MacKay (1961) later noted that, with concentric patterns, there seemed to be slow rotations of the noise within the channels formed by the rings — or even within a single narrow circular channel (only a few minutes of arc in width). MacKay (1965) dubbed this narrow-channel noise drift the 'omega effect' and reported that the period of perceived rotation was fairly consistent across a wide range of annular diameters provided the width of the aperture was increased in proportion to the diameter. (No account of the method of speed estimation is given. The periods of rotation that MacKay reports range from about two to four rotations per second or 90–180 deg/s.) In these demonstrations, MacKay's noise stimuli consisted of visual snow, such as on a detuned television set. MacKay (1965) varied the frame rate of his displays (which had no effect on perceived speed), and reported no effect of varying element size.

It is particularly notable that, in a later study that examined whether various visual noise effects could be produced under conditions of retinal stabilization, MacKay *et al.* (1979, p. 715), reported that 'voluntarily reversible omega motion' was observed. In other words, though the omega effect is presented as unavoidable (unlike the Tinkerbell effect), its direction can be wilfully controlled. It seems reasonable to suppose that the Tinkerbell effect might be a low-signal version of the omega effect. That is, both effects may depend on the same kinds of underlying principles of motion perception systems, but the sparse density and wider channel employed in the present experiments may push the visual system to a more extreme case of signal 'recovery'.

MacKay (1961; 1965) provides little explanation of the omega effect. With modern theories of motion detection, it is fairly easy to construct a rough explanation based on two principles. The first principle is that, within a narrow channel of visual noise, there will be a statistical bias to sense motion signals (temporal image correlations) along the longer axis — so that the possibility of relatively strong motion signals along the channel (as apposed to across them) is fairly well suggested by current theories of motion detection. This principle is illustrated in Figure 3, which shows how the distribution of possible match locations might be biased to lie along the channel. The second principle is that these low-level visual motion signals are organized according to higher-level hypotheses that seek to find a single common motion when possible. Thus, although the visual system is perfectly capable of perceiving overlapping transparent surfaces of dots moving in opposite directions (as in our matcher displays), it seems to organize random noise signals in a narrow channel into a single direction in the omega effect. Evidently, spurious noise 'evidence' of directional motion is not adequate to support two directions simultaneously in the omega effect.

The explanation of the omega-like motion in the Tinkerbell displays used here would have to depend less on the presence of sharp edges, because our annuli

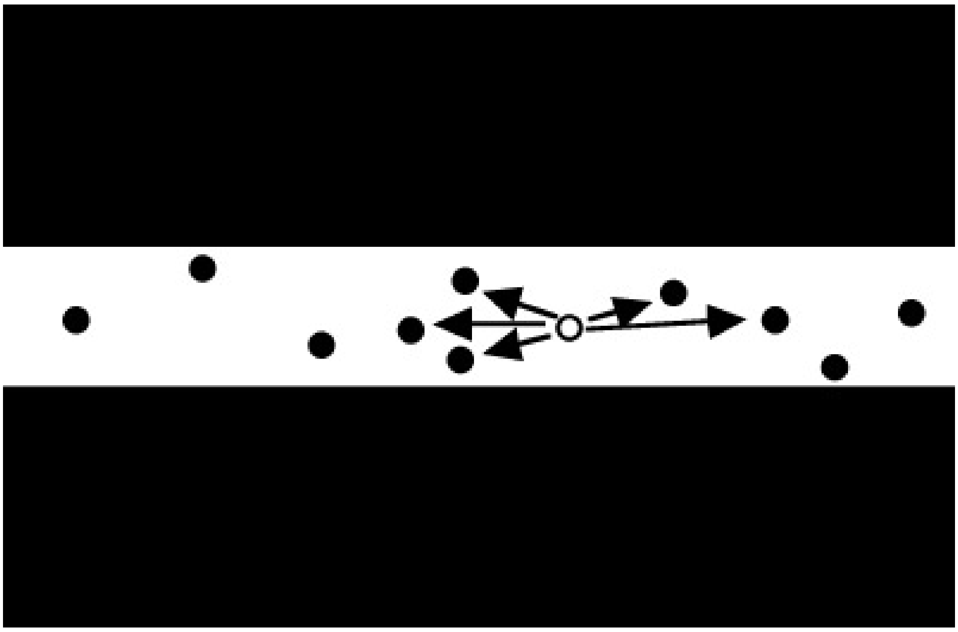

Figure 3. Schematic illustration of how random correspondences within a narrow channel might lead to a directional motion signal along the channel, leading to an omega effect.

were quite wide and the edges were blurred intentionally by ramping down luminance near the edges. Nonetheless, a statistical bias for registering motion signals along the annulus might still play a role in providing bottom-up support for the top-down rotational motion interpretation in the Tinkerbell effect. The important phenomenal difference between omega motion and Tinkerbell motion (that the former is involuntarily perceived whereas the latter is voluntarily perceived) may therefore result from differences of the strength of the bottom-up directional-motion signal. This was presumably much weaker in the displays used here than in those used by MacKay (1961; 1965). To the extent that the Tinkerbell effect is related to the omega effect, the present data showing effects of density variations is an important extension of MacKay's findings. Further exploration is warranted.

Motion capture

There is a second class of motion illusions in which coherence emerges from incoherent visual noise when a strong coherent motion signal is overlaid on the noise. MacKay (1961; 1965) reported that when a wire frame was dragged across dynamic visual noise, the noise seemed to be carried along by the frame. He called this the frame adhesion effect, and he reported it worked with a fingertip as well. Ramachandran and Anstis (1983) described a similar effect produced by superimposing a moving sinusoidal grating atop incoherent dynamic noise. They dubbed this phenomenon 'motion capture', and argued that it showed that the visual system did not bother to solve the correspondence problem in vision when it could substitute a solution from a more readily matched (lower spatial frequency) source.

Ramachandran's (1991) description of motion capture is rather forceful. He states that when the incoherent random dots were 'captured' by the gratings (for example, in the work of Ramachandran and Cavanagh, 1987), the percept is indistinguishable from coherently moving dots superimposed on a grating. He suggests that the visual system simply throws away (or inhibits) the motion information from the dots (in favour of that from the grating or frame). In our lab, however, we have reproduced the displays used by Ramachandran and Cavanagh (1987) and observed that even when capture is achieved, incoherent dot patterns are readily distinguishable from coherently moving dots because they tend to seem to move faster. (This is true up until the point when the displacement is so large that the coherent dot motion is no longer detectable as such.) In other words, our observation is more consistent with the Helmholtzian principle that requires that available data be accounted for rather than all of it being tossed out. Although the visual system need not solve the correspondence problem on a point-by-point basis, local motion-detector systems provide information, nonetheless, about the kinds of possible motion out there.

Culham and Cavanagh (1994) provided evidence that motion capture can be achieved with attentive tracking. Using an annular dynamic dot display, they superimposed a radial grating that moved in ambiguous apparent motion (each frame was 180 degrees out of phase with the next). Motion capture followed the direction of motion tracked by the observers. It is notable that this is very similar to the Tinkerbell effect except that there is no explicit support for tracking in the latter. It is possible that observers in our experiments tended to attentively track random features within the incoherent noise. The important point, again, is that stimulus characteristics of the dot patterns themselves were influential in setting the speed of the resultant perceived motion in our experiments. That is, the Tinkerbell effect clearly feeds off motion information in the display. We have demonstrated this by manipulating embedded coherent signals and dot density, which is a correlate of the average dot displacement.

Supporting the Grand Illusion

The Grand Illusion of perception is the illusion of direct and complete vision. In the change blindness literature, much emphasis is placed on the limited amount of information that can be encoded at one time. At the extreme of information overload comes dynamic visual noise. It is easy to summarize visual noise (for example, in terms of spatial and temporal statistics), but it is a gargantuan task to represent it accurately in detail. Although we seem to see the noise ‘in detail’, that seeing is certainly not based on representing all the information actually necessary for specifying every flashing pixel. Instead, motion perception summarizes and organizes information. The Tinkerbell effect brings out the Helmholtzian character of perception as an act of imagination fitted to the visually available information. Motion processing, in particular, entails integration processes that can apparently be fooled when enough noise is fed into the system. The resulting perceptions seem to accord well with von Helmholtz’s rule of vision discussed in the introduction.

There are a number of behind-the-scene visual and cognitive activities that support (i.e., enable) the Grand Illusion in practice. For example, although visual cognition actually has less information than our conscious experience might lead us to believe, it is also privy to implicit learning strategies that make it much more powerful than a high-resolution camera would be. Included in these are adaptation and calibration processes that keep visual processing efficient (cf., Durgin and Proffitt, 1996), as well as implicit learning of successful oculomotor habits (for example, Durgin, 1999). These kinds of processes provide necessary support for successful visual cognition, and thus help to maintain the illusion that visual cognition is simply direct.

Von Helmholtz’s doctrine of perception is best understood in terms of his first general rule of vision. That rule is essentially a version of the Grand Illusion doctrine. It states that perception is an act of imagination based on the available sensory information. The integration of motion information from motion detection systems is a complex problem. The visual system’s solution to that problem requires the use of summary information and the integration of inherently ambiguous signals. This leaves the visual system open to systematic errors, such as the hallucination of coherent rotational motion in the Tinkerbell effect. What is particularly notable about the Tinkerbell effect is both that it involves an act of will and that it shows up the difficulties of simply believing ones eyes. Illusions are often helpful in understanding the processes of normal perception. Although the visual system is designed to be a transparent medium for cognition and action to receive accurate information about the world, it is a mediating mechanism, which can only imperfectly capture that information. What is often more interesting than its failures, however, are the intricacies involved in its typical success.

Acknowledgments

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