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Technical Note

Another Means for Measuring the Motion Aftereffect

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A new procedure for measuring the motion aftereffect (MAE) is described. The procedure involves adaptation to an animation sequence depicting dots moving in a given direction followed by presentation of a test sequence depicting dots moving in all possible directions. Under adaptation, the test sequence appears to have a directional bias opposite the direction experienced during adaptation. This MAE can be nullified by viewing an animation sequence in which a percentage of dots is constrained to move in a direction opposite the aftereffect. Using a method of constant stimuli, this percentage can be varied to find the value yielding incoherent motion. This dynamic MAE exhibits the same characteristics as the conventional MAE.

Motion aftereffect Adaptation Interocular transfer Cinematogram Apparent motion

INTRODUCTION

"What appears to move backward while actually standing still?" Those familiar with visual motion perception will quickly solve this riddle: "an object previously seen to move forward for a period of time". This phenomenon, of course, represents the familiar motion aftereffect (MAE). The MAE is easily induced simply by staring at a given direction of motion for a minute or so. Immediately following this period of motion adaptation, a stationary stimulus appears to drift in the opposite direction, with this illusory motion steadily slowing and finally dissipating within a relatively short period of time. The actual duration of the MAE depends, among other things, on the duration of adaptation to real motion.

The MAE has received considerable attention since the landmark paper by Wohlgemuth (1911) delineating the conditions eliciting illusory motion in a stationary display. In recent years, interest in the MAE has accelerated, in part because the phenomenon is thought to provide a psychophysical tool for studying the response properties of motion mechanisms in human vision (e.g. Anstis, 1980). Indeed, contemporary models of motion perception (van Santen & Sperling, 1984; Adelson & Bergen, 1985; Watson & Ahumada, 1985) routinely attempt to incorporate the MAE, and neurophysiologists have sought to uncover its neural concomitants (Marlin, Hasan & Cynader, 1988; Hammond, Mouat & Smith, 1985; Petersen, Baker & Allman, 1985; Vautin & Berkley, 1977). One limitation to these efforts, however, concerns the psychophysical index conventionally used to quantify the MAE. With some exceptions noted below, studies typically express the magnitude of the MAE in terms of its duration, defined as the time elapsing between presentation of the stationary test stimulus and the complete disappearance of illusory motion of that stimulus. This strength index, while easy to measure, has several shortcomings. First, duration merely specifies how long the MAE lasts, not how strong it appears at a given moment (e.g. immediately following adaptation). Second, observers can find it difficult to judge exactly when the MAE has dissipated completely, and they sometimes report that illusory motion spontaneously reappears after a few seconds. And third, duration provides a rather cumbersome metric for motion strength when developing and testing models or performing physiological experiments aimed at uncovering possible neural concomitants of the MAE.

There are several potential ways to circumvent these limitations. One could obtain numeric estimates of perceived (illusory) motion at some prescribed time (e.g. immediately following adaptation). Direct scaling, however, has never enjoyed widespread acceptance among visual scientists (see e.g. Brindley, 1970), particularly those concerned with modeling. After all, how do we relate numeric estimates of subjective strength to underlying neural processes? As an alternative, observers can be instructed to adjust the speed and direction of a comparison target undergoing real motion until it matches that of the illusory motion of a stationary object. While simple in principle, this task turns out to be challenging: observers can never exactly match the MAE using real motion, for the object undergoing illusory motion never goes anywhere. In fact, we have found that observers never confuse real motion with the illusory motion associated with the MAE (Hiris & Blake, 1992). So in a matching procedure, the match is at best an approximation. Now, one might try to nullify the

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illusory motion of the MAE using real motion in the opposite direction (Wright, 1986; Wright & Johnston, 1985). In our experience, however, this kind of nulling judgment can be challenging, again because of the paradoxical nature of the MAE: the test stimulus appears to move without ever going anywhere. And because the MAE typically dissipates steadily with time (in the absence of readaptation), an observer is always trying to null an aftereffect that is changing during the process.

In this Technical Note, we describe a new procedure for inducing and measuring the MAE, one that sidesteps the problems mentioned above. A key to our procedure is the use of a test display that is dynamic, not static; for this reason we refer to the resulting aftereffect as the dynamic MAE (DMAE). To introduce this procedure, we start with some definitions.

INDUCING AND MEASURING THE DYNAMIC MOTION AFTEREFFECT

Imagine an animation sequence consisting of several hundred small black dots whose spatial positions within a circular area* are changing from frame to frame (see Fig. 1). When all dots are repositioned a fixed distance but in random directions from frame to frame, motion appears totally incoherent, with no hint of motion in a given direction. We shall term this incoherent stimulus random dynamic visual noise (DVN). Now suppose a specified percentage of the dots in such an animation sequence are constrained to move in a single direction, say upward. We shall call this subset "signal" dots and the remainder, which are free to move in any direction, "noise" dots. We term this stimulus "biased" DVN, since a given percentage of dots are biased to move in a given direction. Varying the percentage of signal dots influences the perceived coherence of the global display. In the extreme, all dots can be specified as "signal", yielding pure translational motion in a single direction.

With these definitions in mind, suppose an observer adapts to an animation sequence in which all dots move in a given direction, say upward, for an extended period of time. Immediately following this period of adaptation to unitary motion, the observer views DVN. Rather than appearing random, the test stimulus will appear to have a general flow of motion in the direction opposite that seen during adaptation, i.e. downward for the condition mentioned above. This illusory perception of coherent motion constitutes the DMAE. Moreover, its strength can be simply gauged by determining the percentage of signal dots needed to null the illusory coherent motion, so that the motion again looks entirely random. The larger the percentage of signal dots needed to null the DMAE, the stronger the aftereffect.

In our implementation of this procedure, an observer is initially adapted for a minute to motion in a single direction. Then, 1-sec exposures of a test stimulus are interleaved with 10-sec periods of readaptation. During each brief test period the observer views biased DVN, and the percentage of signal dots in this stimulus is varied randomly from trial to trial. Following each test exposure the observer simply indicates the general direction of motion experienced—up vs down. The observer cannot predict from trial to trial what should constitute a "correct" answer, for signal values are selected to range from ones reliably seen as upward to those reliably seen as downward. From the resulting psychometric function (see Fig. 2), we estimate the signal value for which up and down responses are equally probable. This value invariably turns out to be some relatively large percentage of dots moving in the same direction as that experienced during adaptation; DVN (0% signal) invariably elicits responses opposite of that experienced during adaptation.

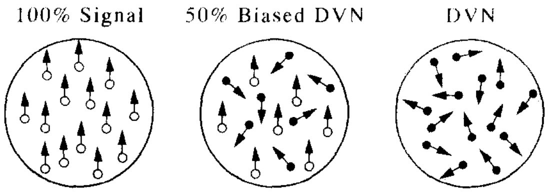

FIGURE 1. Schematic of random-dot cinematograms (Williams & Sekuler, 1984) used to induce and measure the DMAE. Each dot is displaced 5 pixels (0.089°) from frame to frame (16.67 frames/sec, 1.5°/sec); the arrows in these drawings denote the direction of displacement. In the actual experiments, the animation sequences consisted of 100 black dots seen against a white background. In this schematic, the left panel—100% signal—represents a typical adaptation display. All dots move in a single direction from frame to frame (upward, in this case). This type animation sequence constitutes the adaptation display used to induce the DMAE. The middle panel depicts biased DVN. Here, a specified percentage of the dots (shown as open circles) move in a given direction from frame to frame, with the remaining dots moving in directions equally distributed around 360°. Animation sequences of this type are used to nullify the DMAE. The right panel depicts pure DVN, in which dots move in directions equally distributed around 360°. This animation sequence temporarily appears to have a directional bias following adaptation. For our displays, the direction a dot moved from frame to frame was determined randomly from the distribution of possible directions (random-path motion). The results described in the text can be obtained with fixed-path or limited lifetime dots, too.

As just described, the procedure is implemented as a method of constant stimuli. But in principle, one could employ an adaptive staircase procedure to locate the nulling signal strength, with the signal value on any given trial conditioned on the response from the previous trial. For that matter, the observer could manually control the percentage of signal dots, with the instruction to adjust the display until its motion appears entirely random with no net directional flow. With this last procedure, however, the observer would have to make the adjustment rather rapidly, to minimize effects of decay of the aftereffect. Moreover, the staircase procedure and the method of adjustment sacrifice the more objective nature of the method of constant stimuli, wherein observers cannot anticipate the "correct" response.

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*For purposes of description, we shall assume this area is circular and the dots are black seen against a white background; neither of these details is crucial.

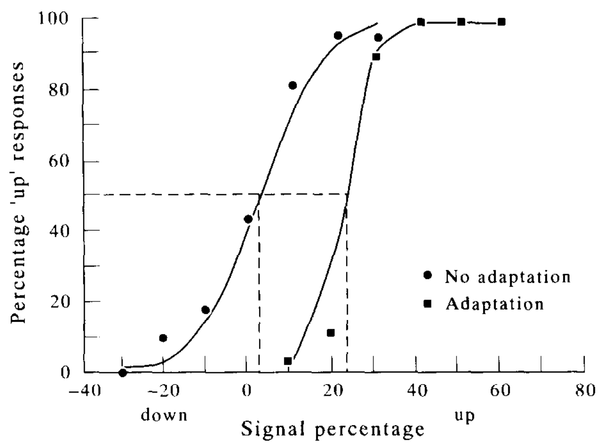

FIGURE 2. Psychometric functions for one observer with and without adaptation to pure translational motion upward. The solid curves are best-fit by probit analysis. The ordinate gives the percentage of trials the observer responded "up" to the stimulus given on the abscissa. The numbers on the abscissa refer to the percentage of dots in the stimulus that are signal; negative numbers refer to downward signal motion, positive numbers to upward signal motion; and 0 refers to no signal motion (DVN). Each data point is based on 50 observations. There is no consistent tendency for the slopes of these functions to change under adaptation. In the absence of adaptation, pure DVN (i.e. 0 signal) yields approximately equal numbers of "up" and "down" responses. Following adaptation to upward motion, pure DVN always appears to move downward, and approx. 25% upward signal must be added to generate equi-probable responses. In the absence of adaptation, 25% upward signal is almost always reported as "upward".

CHARACTERISTICS OF THE DYNAMIC MOTION AFTEREFFECT

We have successfully used this nulling technique to document several characteristics of the DMAE, and those findings can be summarized as follows.

Reliability

Following 1 min of adaptation, different observers require anywhere from 30 to 50% signal to nullify the DMAE. While there are individual differences in the mean value, this nullifying value is quite reliable for a given observer. For two observers, we obtained seven estimates of the nulling value, with each estimate derived in a separate daily testing session. The standard error of these seven estimates averaged 1.5% over observers.

Duration of adaptation

The strength of the DMAE (i.e. the percentage of signal dots needed to nullify the DMAE) increases with the duration of adaptation, up to about 30 sec of adaptation. (For these measurements, the duration of readaptation was always one-sixth that of the duration of initial adaptation.)

Interocular transfer

The DMAE can be induced in one eye and observed in the unadapted eye. This interocularly transferred aftereffect is weaker, however, than the direct aftereffect (i.e. that measured in the adapted eye). In one observer tested extensively, the direct DMAE averaged 33% signal to null while the transferred DMAE averaged 26% signal to null, a statistically significant difference given the reliability mentioned above.

Storage

For this experiment we first measured the duration of the DMAE following 1 min of adaptation to upward motion. Then, we inserted a blank period between the end of a 1 min adaptation period and the presentation of DVN, with the duration of the blank period equalling the average duration of the DMAE. For both observers tested, a "stored" DMAE was observed, meaning that illusory coherent motion upon viewing DVN was experienced following a period during which the DMAE would normally have decayed. This stored DMAE was always briefer in duration than that measured immediately following termination of adaptation.

Perceived smoothness of apparent motion

The observations described above were made using animation sequences in which the frame rate and step size were optimized to yield smooth apparent motion (e.g. see Williams & Sekuler, 1984). To what extent does the strength of the DMAE vary with the quality of adapting and/or test motion? To answer this question, we measured the DMAE produced by adapting to motion that was smooth (4 pixel steps; 14.4 frames/sec), motion that was jerky but unambiguous (8 pixel steps; 7.2 frames/sec) and motion that was very jerky and frequently ambiguous (12 pixel steps; 4.8 frames/sec); the nulling stimulus was always smooth and compelling. For the first condition DMAE strength was 26%, for the second it was 16% and for the last it was 8%. Thus, more compelling apparent motion yields a stronger DMAE. Degrading the quality of apparent motion in the test stimulus (by changing step size and/or frame rate) reduced the slope of the psychometric function.

CONCLUSION

In summary, the DMAE is analogous to the more conventional MAE observed using a static test display: both grow with adaptation duration, both exhibit interocular transfer and both show storage. The DMAE, however, has several advantages compared to its static counterpart. The task can be arranged to provide a more objective response, since observers cannot anticipate the "correct" answer from trial to trial (at least when implemented using a method of constant stimuli). The judgment itself is simple and observers find the instructions easy to follow. The effect is compelling and sufficiently robust* to permit the study of factors that influence the strength of the DMAE. It is quite simple to manipulate potentially interesting variables such as speed or dot density while still varying signal strength. It is also possible to alter the statistical distribution of directions of motion, creating animation sequences in

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*The authors will gladly mail an application illustrating the DMAE. The application runs on a Macintosh computer. Those interested in receiving the application should send a stamped, self-addressed floppy disk mailer to the first author.

which the range of possible directions is restricted to something <360 deg. This bandwidth manipulation, like signal strength, affects the perception of global motion flow. These "directional bandwidth" stimuli can be used either as adaptation or test stimuli in the study of the DMAE; indeed we have found that the DMAE varies in strength with the bandwidth of motion directions present during adaptation (Hiris & Blake, 1992).

Finally, this procedure involving the nullification of a DMAE with signal motion works equally effectively with rotational motion or with expansion/contraction. In other work in this lab (Steiner, Blake & Rose, unpublished observations) using random-dot cinematograms, we find that adaptation to dots rotating clockwise (or counterclockwise) causes DVN to appear temporarily to rotate counterclockwise (or clockwise). Moreover, this rotational MAE seen with DVN can be nulled by constraining a percentage of dots (signal) actually to move in a clockwise (counterclockwise) direction. Similarly, adaptation to dots depicting expansion (or contraction) causes DVN to appear to contract (to expand), and this contraction (expansion) too can be nulled by the addition of signal dots.

As a final note, we believe this new procedure for inducing and measuring a DMAE can be readily generalized to physiological experiments. Imagine recording from a directionally selective cell while stimulating its receptive field with moving dots. One could measure the minimum percentage of signal dots (i.e. dots moving in the cell's preferred direction) required to evoke a reliable response. This same measurement could then be repeated following adaptation of the cell to strong motion in any direction, including the preferred direction or the opposite direction. Changes in the threshold signal strength (i.e. the minimum signal percentage giving a reliable response) would provide a quantitative index of motion adaptation. The same procedure could easily be applied to cells preferring rotation or expansion/contraction (e.g. neurons in area MST).

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