Differential changes in human perception of speed due to motion adaptation

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Visual systems adapt to the prevailing image conditions. This improves the ability to discriminate between two similar stimuli but has the side effect that veridical perception is degraded. For example, prolonged driving at 100 km/h may reduce the perceived speed to 80 km/h but improve the sensitivity to changes in the prevailing speed. Here we use radially expanding flow fields with a wide combination of adapt and test speeds to study human speed perception. Adaptation at speeds higher than the test always attenuates perceived speed, whereas adaptation at low and testing at high speeds increases perceived speed. We show that adaptation is stronger (i.e., post-adaptation speeds are perceived as slower) when the dots in the expanding flow field accelerate towards the periphery rather than traveling at constant speeds. We also show that speed discriminability is reduced following adaptation to low speeds when tested at high speeds and increased when the test speed is at or below prior adaptation speeds. We conclude that the relative speeds of the adaptation and test patterns are important parameters governing speed-related adaptation effects in the human brain.

Keywords: speed, velocity, motion, sensitivity, adaptation, discriminability, perception


Introduction

Neurons in the visual system adapt to many types of stimulus such as luminance (Barlow, 1969), contrast (Ohzawa, Sclar, & Freeman, 1982, 1985; Sclar, Lennie, & Deprist, 1989), and motion (for a review, see Clifford & Ibbotson, 2002). Neural adaptation to moving stimuli appears as a gradual reduction in firing rate during stimulation with a constant stimulus (Barlow & Hill, 1963). It can also be observed as a change in the sensitivity to stimuli presented after a period of constant stimulation (e.g., Greenlee & Heitger, 1988; Hietanen, Crowder, & Ibbotson, 2007). Maddess and Laughlin (1985) showed that the reduction in firing rate of motion sensitive neurons during adaptation to a moving pattern was accompanied by an increase in the sensitivity to changes in speed about the adapting value (also see Clifford, Ibbotson, & Langley, 1997; Clifford & Langley, 1996). These adaptation-related effects are thought to have a functional benefit for the visual speed coding system. Speed adaptation has also been demonstrated through psychophysical tests as a reduction of the perceived speed of an image moving at a constant speed (Goldstein, 1957; Thompson, 1981). This reduction has been shown to decline in an exponential fashion as a function of stimulus duration (Bex, Bedingham, & Hammett, 1999; Clifford & Langley, 1996; Goldstein, 1957; Hammett, Thompson, & Bedingham, 2000) and occurs concurrently with an increase in sensitivity to changes in the relative speed of the stimulus (Bex, Bedingham, et al., 1999; Clifford & Langley, 1996; Clifford & Wenderoth, 1999; Krekelberg, van Wezel, & Albright, 2006a). Thus, as occurs in some motion sensitive neurons (Clifford & Langley, 1996; Maddess & Laughlin, 1985), absolute speed sensitivity is reduced to improve relative speed sensitivity.

In an experiment examining the effect of drift-rate adaptation, Smith and Edgar (1994) found that the perceived drift-rate of a translating grating pattern is dependent on the previously presented drift-rates. That is, when adapting drift-rates were medium-to-high and test drift-rates were medium-to-low, perceived drift-rate was reduced relative to veridical perception. Conversely when adaptation drift-rates were low and test drift-rates were high, perceived drift-rate was increased. They presented a model based on the outputs of low-pass and band-pass temporal filters. Using the ratio of the outputs of the two filters and modifying the filter sensitivities with subtractive adaptation they accurately predicted perceived speeds. Hammett, Champion, Morland, and Thompson (2005) extended this model to examine the time course of adaptation to drifting gratings. However, both of these...
studies relied on filter profiles specific to a single spatial frequency (SF) and it is known that temporal filters derived psychophysically vary with spatial frequency (Anderson, 1985) and that perceived speed is dependent on spatial frequency (Campbell & Maffei, 1981; Smith & Edgar, 1991).

Krekelberg et al. (2006a) recorded from the middle temporal (MT) area of alert monkeys that were performing psychophysical speed judgments. MT contains speed tuned motion sensitive neurons that are directly involved in speed perception (Groh, Born, & Newsome, 1997; Liu & Newsome, 2003; Newsome & Paré, 1988; Nichols & Newsome, 2002). Krekelberg et al. used an ideal observer model to predict changes in perceived speed following a psychophysical speed adaptation protocol. This model predicts that adaptation to low speeds should provide an increase in the perceived speed of high-speed stimuli (although this was not examined experimentally) in addition to the more commonly reported reductions in perceived speed following speed adaptation.

In the present work, we re-examined the speed dependence of motion adaptation in the human visual system, but due to differences in our approach we uncovered a series of novel findings. First, our stimuli were moving dot patterns that had broadband SF characteristics, thus allowing us to judge the effect of speed adaptation across many SFs. Second, given that Bex, Metha, and Makous (1999) found that motion aftereffects for radial stimuli were stronger than for translating stimuli, our stimuli were radially expanding flow fields whereas previous studies have used translating gratings. Third, we presented stimuli with different speed-gradient profiles (including acceleration and constant velocity). We found that the relative speeds of the adaptation and test patterns and the type of speed gradient presented are important parameters governing speed-related adaptation effects.

Methods

Subjects and equipment

Four subjects (ages 21 to 40) participated in the study. The subjects had normal or corrected to normal vision, with the exception that one subject, MH, had poor vision in one eye and wore an eye patch to reduce potential rivalry conflicts. Two subjects (NC and MJH) were naive observers while the other subjects (MH and MI) were experienced observers. All subjects were able to resolve the individual dots within the stimulus. All subjects participated voluntarily and provided informed consent (Australian National University human ethics committee protocol: 2004/256). All stimuli were generated on a VSG2/5 graphics card (Cambridge Research Systems Ltd.). Stimuli were presented at 100 Hz on a calibrated 20-in. monitor (Eizo T662-T, 800 × 600 pixels). The monitor was positioned 57 cm from the subject’s eyes and subjects (except MH) viewed the stimulus binocularly. Subject’s position relative to the screen was stabilized using a chin support.

Procedure

The stimulus consisted of two circular apertures (4° diameter), each with their center’s located 2.5° lateral to a central fixation point.

Each aperture contained 200 dots in randomly generated virtual 3-dimensional positions. For the left aperture (referred to as the invariable-speed aperture), the temporal order of presentation consisted of an initial adapting stimulus lasting 30 s, followed by a series of 40 tests (0.5 s).

A top up adaptation stimulus (4 s) was shown between each of the tests. For the right aperture (the variable-speed aperture), stimuli were present only during the test phases and acted as comparisons with the test phases presented in the left aperture. Thus, only visual neurons viewing the invariable-speed aperture were adapted. This adaptation protocol was run with all combinations of up to ten adapt and ten test speeds, both ranging from 1 to 24°/s.

Subjects reported which stimulus they perceived as “moving faster” during the test phase (i.e., left or right aperture) in a two-alternative forced-choice manner. The average speed of the elements in the right (variable-speed) aperture was manipulated between trials using two randomly interleaved QUEST staircases (Watson & Pelli, 1983) such that the average speed of the stimulus approached the perceived speed of the left (invariable-speed) aperture during the test phase. This procedure provided two concurrent estimates of the perceived speed and prevented any potential response bias by the two experienced observers. In control conditions, a blank screen of mean luminance (except for the fixation spot, which remained as normal) was presented during top-up adaptation phases. In these conditions the initial adaptation was omitted.

The speed profile of the dots in the stimuli was manipulated across 3 conditions. In the first condition the dots accelerated from 0°/s in a linear fashion such that a dot’s speed in a more peripheral position was faster than when in a central position. This condition was termed the acceleration condition. In the second, termed the constant-speed condition, the dots moved at a constant speed from the center to the periphery. In the final condition the dots accelerated from 2°/s. In the cases where dots accelerated, the mean speed of the dots across space is presented. A schematic outline of the stimulus sequence for the acceleration condition is...
presented in Figure 1. The speed and direction of motion of the dots in Figure 1 are represented by the lengths of the arrows leading from each dot.

Results

Perceived speed

The stimuli consisted of flow fields generated by dots expanding radially from a central point. Two such flow fields were briefly and simultaneously presented to subjects, one each side of a fixation point. Subjects were required to identify which flow field was moving faster using a two-alternative forced-choice procedure. The point of subjective equality (PSE) for each adapt and test combination was measured and used as a gauge of the perceived speed of the stimulus. A shift-in-PSE (sPSE) was then calculated, equating to a shift in perceived speed, using the formula

$$\text{Shift-in-PSE (sPSE)} = \frac{\text{PSE}_{ij} - \text{PSE}_{0j}}{\text{PSE}_{ij} + \text{PSE}_{0j}},$$

where $\text{PSE}_{ij}$ is the PSE following adaptation at a speed $i$ and with a comparison speed $j$, and $\text{PSE}_{0j}$ is the PSE speed in the non-adapted condition. This formula returned a positive value when the perceived speed of the test stimulus increased after adaptation and a negative value for a reduction in perceived speed, providing a normalized value to allow comparison between various adapt/test speed permutations.

Figure 2 shows contour plots for four subjects in which the shift-in-PSE is presented as a color code. Significant changes in perceived speed were determined using a minimum significant difference criterion based on the error associated with each estimate. White indicates non-significant changes in perceived speed (e.g., $p > 0.05$), and red and blue indicate an increase or decrease in perceived speed after adaptation, respectively. The solid diagonal line shows where adaptation and test speeds were equal. It is evident that for all subjects adaptation at high speeds and testing at low speeds (top left corner of the contour plots) produces a reduction in perceived speed. However, adapting at low-to-moderate speeds and testing at high speeds produces an increase in perceived speed (bottom right).

There is variation between subjects with MI showing increases in perceived speed only for limited adapt/test combinations and MH showing strong increases for a wide range of adapt/test combinations. However, the general trend is similar for all subjects.

Given this possible relationship between adaptation and test speed, we used a 2-way repeated-measures analysis of variance (ANOVA) to examine the contributions of the adaptation and test speeds on the sPSE (Table 1).

Table 1 shows that there was a main effect of the adaptation speed ($F = 31.13, p < 0.001$) indicating that the perceived speed of the test stimulus was dependent on the adaptation speed. There was also a main effect of the
test speed ($F = 22.54, p < 0.001$), showing that the change in perceived speed of the test stimulus following adaptation also depended on the value of the test speed. Finally, there was a significant interaction between the adaptation and test speed variables ($F = 4.96, p < 0.001$) indicating that the effect of the test speed on sPSE was different depending on which adaptation speed had been used. An examination of the size of the effects was conducted by calculating the eta-squared for each effect. This analysis showed that between-subjects effects accounted for 7.6% of the variability in sPSE. Adaptation speed could account for 17.0%, test speed 54.8%, and the interaction between adaptation and test speed accounted for 7.6% of the variability. This meant that the total variation in sPSE that can be accounted for by the combination of the adaptation and test speeds was 79.4%. Given the significant interaction between adaptation and test speeds on the sPSE, we determined in what form the relationship between adaptation and test speeds occurred.

To this end, we conducted three 2D a priori trend analyses to examine (1) whether sPSE decreased log-

Figure 2. Per-subject surface plots demonstrating shifts in perceived speed for each adapt-test permutation for the acceleration conditions. The average adaptation speed is shown on the ordinate and the average test speed on the abscissa. The solid diagonal line shows the conditions in which adaptation and test speeds were matched. The color bar indicates the shift in the point of subjective equality (sPSE) following adaptation. In general the trend demonstrated is of perceived speed reducing as the adaptation speed increases and the test speed decreases. The strength of the shift in perceived speed shows some variability between subjects.

Table 1. Results of a 2-way repeated measures ANOVA with shift-in-PSE as the dependent variable and adaptation speed (Adapt) and test speed (Test) as the independent variables. Tests for all main effects and interactions are presented. Significant results are indicated with an asterisk (*) in the right column.

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Table 2. Table of trend analysis weights used for the three potential patterns of results that were determined a priori. (1) The trend analysis examining the case where the sPSE is determined solely by the adaptation speed in a log-linear relationship; (2) the trend analysis examining the case where the sPSE is determined solely by the test speed in a log-linear relationship; and (3) the trend analysis examining the case where the sPSE is determined by an equal combination of the log-linear effects of adaptation and test speeds.

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(1) The trend analysis examining the case where the sPSE is determined solely by the adaptation speed in a log-linear relationship; (2) the trend analysis examining the case where the sPSE is determined solely by the test speed in a log-linear relationship; and (3) the trend analysis examining the case where the sPSE is determined by an equal combination of the log-linear effects of adaptation and test speeds.
linearly with increasing adaptation speed regardless of the subsequent test speed; (2) whether sPSE increased log-linearly with increasing test speed regardless of the preceding adaptation speed; and (3) whether sPSE was increased based on a contingent log-linear decrease in adaptation speed with a log-linear increase in test speed.

The trend analyses were examined using the formula:

$$L_{pi} = \frac{\sum_{a,t} n_{a,t} \lambda_{Pa,t} X_{i,a,t}}{\lambda_{Pa,t}}$$

where $L_{pi}$ is the degree to which person $i$ reflected the expected pattern of results, $X_{i,a,t}$ is person $i$'s sPSE at a given adaptation speed ($a$) and test speed ($t$). Finally, $\lambda_{Pa,t}$ is the trend analysis weight for the adaptation speed and test speed being examined. The trend analysis weights ($\lambda_{Pa,t}$) used for the three trend analyses we conducted are shown in Table 2.

The degree to which the participants conformed to the patterns outlined in Table 2 was examined using $t$-tests:

$$t = \frac{\bar{L}_P}{\sqrt{\frac{S^2_{LP}}{n_i}}}$$

where, $L_P$ and $S^2_{LP}$ are the mean and variance of the $L_{pi}$'s for each subject, respectively, and $n_i$ is the number of subjects. We found that (1) sPSE decreased as the adaptation speed increased and test speed was ignored ($t = 5.721, p < 0.05$); (2) sPSE decreased as test speed decreased and adaptation speed was ignored ($t = 6.361, p < 0.05$); and (3) sPSE decreased as adaptation speed was increased and test speed was decreased ($t = 10.410, p < 0.01$). Similar results were obtained for the constant velocity and “acceleration plus constant velocity” conditions. That is, the trend analysis (Table 2) that relied on both the adaptation and test speeds produced the most significant results ($t = 4.612, p < 0.05$, and $t = 7.9345, p < 0.05$, respectively). Given that sPSE is related to log-linear changes in both adaptation speed and test speed we transformed the data by calculating an adapt/test speed ratio.

In Figure 3 we present a scatterplot of the sPSE as a function of the adapt/test ratio. In this figure values on the abscissa of less than unity show that the test speed was faster than the preceding adaptation speed while values greater than unity indicate that the test speed was slower than the adaptation speed. Negative values on the ordinate (negative sPSEs) indicate that the perceived speed was slower than the test speed and positive sPSEs indicate that the perceived speed was faster than the test speed. In the figure black dots show tests that had an sPSE significantly

![Figure 3](http://jov.arvojournals.org/pdfaccess.ashx?url=/data/journals/jov/932851/ on 04/26/2017)
different from zero (t-tests, alpha = 0.01), while red dots show non-significant sPSEs.

It is evident that the sPSE is highly correlated with the adapt/test speed ratio, such that when test speeds are at, or slower than, the preceding adaptation speed (right of the vertical dotted line) the perceived speed is significantly reduced ($p < 0.001$). However, when test speeds are much faster than the adaptation speed (left side of vertical line) there are significant increases in perceived speed for some tests. This relationship can be described with a log-linear fit (Figures 3A–3C, bold lines, adjusted $R^2$s = 0.33, 0.67, 0.67, respectively). The lines of best fit in Figure 3 become steeper left-to-right while concurrently the sPSE at unity also become more negative. These results indicate that image acceleration produces stronger adaptation than the constant velocity stimulus and that when acceleration is added to a constant-speed the reduction in perceived speed is even greater.

Figure 4. Scatter-plots graphing the shift in error (SIE; see Results) as a function of the adaptation/test speed ratio (A–C) and as a function of test speed (D–F). For comparison with Figure 3, black dots represent tests in which the sPSE was significantly different from 0 while red dots indicate non-significant sPSEs. (A–C) SIE plotted against the adapt/test speed ratio. The lines are log-linear lines of best fit through the data ($R^2$s = 0.03, 0.34, and 0.33). (D–F) SIE plotted against the test speed. Once again the lines are log-linear fits ($R^2$s = 0.15, 0.36, 0.28). When the speed profile of the stimulus has an acceleration component and the adaptation speed is at or above the test speed there is a reduction in error. In the constant velocity condition the reduction in error was not related to the adapt/test speed ratio (A) or test speed (D). SIE was not related to the adaptation speed (not plotted) in any condition ($R^2$s < 0.06).
Discriminability

To address whether speed discriminability improved following adaptation, we examined the relative amplitudes of the errors associated with each estimate of the perceived speed using the formula:

\[
\text{Shift-in-error (SIE)} = \frac{\text{EPS}_{ij} - \text{EPS}_{0j}}{\text{EPS}_{ij} + \text{EPS}_{0j}},
\]

where \(\text{EPS}_{ij}\) is the standard error associated with the perceived speed following adaptation (as provided by the QUEST procedure) at a speed \(i\) and with a comparison speed \(j\), and \(\text{EPS}_{0j}\) is the error associated with the perceived speed in the non-adapted condition. If the SIE is negative, the error decreased after adaptation (indicating improved discriminability), and if it is positive it increased after adaptation (indicating reduced discriminability).

Thus, the SIE is a measure of the relative difference between the discriminability of speeds presented at the adaptation site. Figures 4A–4C plot this factor as a function of the adaptation/test ratio while Figures 4D–4F plot SIE against test speed. The data points can be described using a log-linear relationship (Figures 4A–4C, line adjusted \(R^2s = 0.04, 0.33, 0.34\)). The relationship shows that for increasing values of adaptation/test ratio, the error is reduced. Figures 4D–4F show that the SIE is correlated with test speed in a log-linear manner (\(R^2s, 0.15, 0.37, 0.28\)) while not correlating with the adaptation speed (data not presented: \(R^2s < 0.06\)). As such, while differences in the sPSE are better predicted with a ratio of adaptation and test speed, the SIE is solely related to the speed of the test stimulus. Thus, while adaptation at high speeds and testing at low speeds generates the smallest error and therefore the most accurate discrimination between the two test speeds, this effect is due to reductions in error at low speeds regardless of the prior adaptation speed.

The colors of the dots in Figure 4 indicate whether the sPSE associated with each specific point was significantly different from 0.

It is evident that the vast majority of the trials with positive SIE (Figures 4A–4C, left of unity) also had sPSEs that were not significantly different from 0. As such, the trials in which the discriminability may have been reduced following adaptation were also the trials in which the perception of the test speed following adaptation was closest to veridical.

Discussion

Most previous studies of speed adaptation have shown that perceived speed is reduced after motion adaptation (Goldstein, 1957; Krekelberg et al., 2006a, Krekelberg, van Wezel, & Albright, 2006b; Thompson, 1981). Our data show that this is true if test speeds are at or below the adaptation speed. However, when adapting with low speeds and testing with high speeds, perceived speed is increased. This result is less pervasive in the literature with conflicting results from different laboratories. Thompson (1981) required subjects to match the speed of a sine-wave grating with another grating after 2 minutes of adaptation and found no reliable increase in perceived speed after adaptation at any speed. Smith and Edgar (1994) used a matching protocol employing a dynamic two-alternative forced-choice design and translating sine-wave gratings to compare perceived speed before and after adaptation. When the adaptation speed was low and test speeds were high, there was an increase in perceived speed (also see Hammett et al. 2005). We found that for radially expanding motion with three different speed profiles that there is both enhancement and reduction in perceived speed, dependent on which combination of adaptation and test speeds were used.

A neural code for speed

Krekelberg et al. (2006b) showed that a labeled-line model in which a cell votes for its peak speed with a weight proportional to its firing rate is unlikely to be used to drive speed perception from MT. Instead, based on Liu and Newcombe’s (2005) finding that choice probability is better than chance level when the preferred speed of a cell is above the speed of a presented stimulus and at chance level when it is not, they postulate that speed may be encoded by the total firing rate of all MT cells. While this simple hypothesis could predict reductions in perceived speed, it cannot easily predict increases. To code increases in speed following adaptation, the total firing of the MT cells contributing to the judgment must increase after adaptation. Adaptation-related increases in firing rate are not typically found in the visual system. The opposite finding that adaptation to motion attenuates firing rates is more common (e.g., Carandini & Ferster, 1997; Hietanen, Crowder, Price, & Ibbotson, 2007; Ibbotson, Clifford, & Mark, 1998; Kohn & Movshon, 2003; Krekelberg et al., 2006a).

As first suggested by Krekelberg et al. (2006a) in their discussion of the separation of cells that use the rising and falling edges of their tuning functions, it is possible that the increases in perceived speed are produced by the cells that code increases in speed as decreases in firing rate. However, this coding scheme requires a decision about which cells should code an incoming speed. At first glance this may seem to be circular in that the brain needs a representation of the input speed to determine how it will code the input speed. However, this can be resolved if the inputs to the cells are from at least two differently tuned speed channels. A comparison between low-speed and high-speed channels would provide enough information...
about the incoming speed to decide whether to use the leading or falling edge of a cell’s tuning curve. For example, if A is a low-speed channel and B is a high-speed channel: If the A input is stronger than the B input, use the leading edge (increases in firing indicate increases in speed) and vice versa. It is also important to note that the distinction between “low” and “high” speed channels is relative for a given cell.

Discriminability

It has been shown psychophysically that the sensitivity/discriminability of the speed of a stimulus increases as a result of adaptation to speed (Bex, Bedingham, et al., 1999; Clifford & Langley, 1996; Clifford & Wenderoth, 1999; Krekelberg et al., 2006a). An examination of the error associated with each perceived speed estimate in the present study showed that as the adapt/test ratio increased the error in the estimate decreased. This meant that following adaptation at speeds equal to or higher than the test speed there was a decrease in the error of the perceived speed (Figure 2). While this experiment did not look at discriminability per se, it is likely that the decreased error would lead to increased discriminability. Previous studies have directly examined improvements in discriminability at or around the adaptation speed (e.g., Bex, Bedingham, et al., 1999; Clifford & Langley, 1996; Clifford & Wenderoth, 1999; Krekelberg et al., 2006a). While we also show reduced error when adaptation and test speeds are matched, we present the novel finding that the greatest reductions in error (and presumably increases in sensitivity) occur when the adaptation speed was far higher than the test speed. Interestingly the trials in which sensitivity to speed decreased also tended to be the trials in which the perception of speed was closest to veridical. These findings suggest that the visual system operates in two modes. (1) When test speeds are higher than the prevailing speed the system maintains an accurate absolute representation of speed. (2) When test speeds are lower than the prevailing value the system has increased sensitivity about the current perceived speed at the expense of an accurate representation of absolute speed. Future tests of speed discriminability should perhaps use high adaptation speeds but look for increased discriminability at a range of low test speeds.

Flow field types

In the natural world expanding flow fields, like those used here are most often encountered when the observer moves forward in the world. The speed profiles of expanding flow fields depend on the relative depths of objects in the visual environment (Gibson, 1979; Edwards & Ibbotson, 2007). A positive speed gradient will occur when objects are at the same depth or when the central objects are further away. A constant speed gradient will occur in a cluttered environment where there are many objects at a range of distances. Our results show a clear effect of speed gradients. Adaptation to expanding flow fields with positive speed gradients (acceleration from the stimulus center) generates larger reductions in perceived speed than for constant-speed expansion.

Recordings from neurons in monkey MT have revealed that cells are speed tuned but not acceleration tuned (Lisberger & Movshon, 1999; Price, Ono, Mustari, & Ibbotson, 2005). Therefore, it is unlikely that the acceleration specificity of the adaptation we observed arises directly from processing in MT. However, a population model was able to extract an acceleration signal from the population of MT cells, suggesting that an acceleration signal might be available in the higher-cortex (Price et al., 2005). Moreover, for Price et al.’s (2005) model to work effectively, it was essential to account for speed adaptation (Price, Crowder, Hietanen, & Ibbotson, 2006). If an acceleration signal is available in the higher cortex, it could account for the increased levels of adaptation observed for accelerating dots as compared to constant-speed dots in the present work.

Schlack, Krekelberg, and Albright (2007) claimed that acceleration coding in MT neurons derives from differential adaptation at the numerous speeds that make up an acceleration trajectory. This suggests that the increased adaptation present following adaptation using an accelerating stimulus may be due to the larger adaptation of the higher speeds present at the peripheral edges of the stimulus. Increasing the average speed, either by adding a constant speed to an accelerating stimulus or by introducing acceleration when comparing to the constant velocity stimulus, exposes a greater area of the stimulus to relatively higher speeds. If the strength of adaptation is not linearly proportional to speed, this would not average out and could lead to the differences in the changes in perceived speed between the different speed gradient profiles found in our experiments.

It is well established that neurons in specific regions of the primate cortex, such as the medial superior temporal area (MST), have cells selectively tuned to detect radially expanding flow fields (Duffy & Wurtz, 1991, 1997; Tanaka, Fukada, & Saito, 1989; Tanaka & Saito, 1989). Britten and van Wezel (1998) showed that area MST has a direct role in the perception of the heading of expanding flow fields. While cells with specific radial expansion coding are found in targeted brain areas, neurons selectively tuned to code translating motion are found throughout the visual cortex (e.g., Henry, Bishop, & Dreher, 1974). It is possible that the stronger adaptation associated with accelerating expansion may relate to separate adaptation mechanisms in different brain regions. We conclude that speed, acceleration, and the type of optic flow are important parameters governing speed-related adaptation effects in the primate brain.
Acknowledgments

This work was supported by grants to MI from the National Health and Medical Research Council (224263) and the Australian Research Council Centre for Excellence in Vision Science (CE0561903) and to NC from the National Science and Engineering Research Council of Canada.

Commercial relationships: none.

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