Suprathreshold Motion Perception in Anisometropic Amblyopia: Interocular Speed Matching and the Pulfrich Effect

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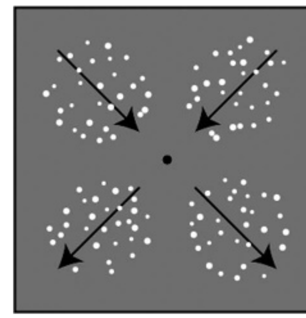
SIGNIFICANCE: Our results indicate that the difference in perceived luminance between the amblyopic and fellow eyes that is present under dichoptic viewing conditions does not affect the perceived speed of suprathreshold motion stimuli. This finding provides a new insight into suprathreshold perception in amblyopia.

PURPOSE: Interocular matching experiments indicate that dichoptically presented stimuli have a lower perceived luminance in amblyopic eyes relative to fellow eyes. This may be a consequence of interocular suppression. We investigated whether this effect extends to suprathreshold motion perception.

METHODS: Participants with amblyopia and control observers matched the perceived speed of dichoptically presented random-dot kinematograms and the perceived luminance of gray patches. Control participants also performed the speed matching task with a neutral density filter over one eye to simulate a perceived luminance reduction.

RESULTS: The amblyopia group exhibited lower perceived luminance in the amblyopic than in the fellow eye, as has previously been reported. However, interocular speed matching was veridical. For control observers, perceived speed was reduced in the eye with a neutral density filter relative to the nonfiltered eye. To assess whether the perceived luminance reduction in the amblyopic eye affected binocular function, we also measured the Pulfrich effect in the amblyopia group with equal luminance presented to each eye. No patients reported a spontaneous Pulfrich effect.

CONCLUSIONS: The results suggest that suprathreshold speed perception is intact in the amblyopic eye when both eyes are open.



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Amblyopia is a developmental visual deficit caused by strabismus, anisometropia, or deprivation. Patients with unilateral amblyopia typically show reduced contrast sensitivity and spatial resolution in the amblyopic eye,[1–3] along with deficits in stereopsis,[4] spatial perception,[5,6] temporal resolution,[7] and luminance perception.[8] Although the exact cause of amblyopia is still unclear, interocular suppression from the fellow eye to the amblyopic eye may play an important role.[9,10]

Studies of motion perception in amblyopia have suggested that detection and discrimination of first-order local motion are relatively intact in both the amblyopic and fellow eyes, particularly when spatial vision deficits are accounted for,[11–16] although see Wood and Kulikowski.[17] However, deficits in second-order motion perception,[18,19] spatial summation of motion,[16] and global motion processing[20–24] occur in amblyopia, with some deficits affecting both eyes.[25] Neurophysiological and functional magnetic resonance imaging studies of amblyopia have revealed abnormal responses in motion-sensitive area (the middle temporal visual area or V5) that may underlie some of these motion processing anomalies.[26–28]

Although most psychophysical amblyopia studies have involved threshold measurements for detection or discrimination, a small number have investigated perception of suprathreshold stimuli. For example, perception of suprathreshold luminance contrast was found to be near normal for amblyopic eyes, despite the presence of contrast sensitivity impairments at threshold.[29] This result was supported and extended by a more recent dichoptic matching study.[8] Participants with amblyopia had no difference between their eyes for suprathreshold contrast perception but did exhibit a reduction in perceived luminance for the amblyopic relative to the fellow eye. With regard to motion perception, Tredici and von Noorden[30] examined the Pulfrich effect in amblyopia. The Pulfrich effect is a visual illusion in which a horizontally moving stimulus seems to follow an elliptical path in depth when luminance is reduced in one eye.[31] In their experiment, three patients with anisometropic amblyopia reported that they perceived the Pulfrich effect spontaneously without a luminance decrease in one eye. This effect is consistent with reduced perceived luminance in the amblyopic eye[8] and was attributed to an increased transmission time for amblyopic eye inputs to visual processing.

The purpose of this study was to investigate whether amblyopia affects suprathreshold motion perception. Perceived speed can be affected by luminance and contrast.[32–35] Therefore, the difference in perceived luminance between the amblyopic and fellow eyes[8] might cause an interocular mismatch in perceived speed. To test this possibility, we asked observers to match the speed of dichoptic random-dot kinematograms presented simultaneously to the two eyes. Dichoptic presentation allowed us to assess suprathreshold speed perception in the presence of active interocular suppression.[8,36,37] To link our results to the previous literature, we also tested whether our patients with amblyopia had an interocular mismatch in perceived luminance[8] and whether they experienced a spontaneous Pulfrich effect.[30]

METHODS

Apparatus

Stimuli were generated using a Windows PC (Endeavor Pro5500; Epson, Suwa, Japan) with MATLAB (Mathworks, Natick, MA) and Psychtoolbox[38] and were presented on a video monitor (VG278HE; ASUS, Taipei, Taiwan) with a resolution of 1920 × 1080 pixels and a refresh rate of 120 Hz. Dichoptic presentation was achieved using liquid-crystal shutter goggles (3D Vision 2; NVIDIA, Santa Clara, CA). The highest screen luminance measured through the shutter goggles was 40 cd/m^2 for each eye. The viewing distance was 57 cm.

Speed Matching

Stimuli consisted of four fully coherent random-dot kinematograms constructed from 30 moving dots with a luminance of 40 cd/m^2 against a 20-cd/m^2 background (Fig. 1). Dots had a limited lifetime, whereby there was a 5% chance that a dot would be redrawn at a random position on each frame. The size of each dot was randomly chosen to be 0.15, 0.19, 0.22, or 0.25° of visual angle. Each random-dot kinematogram was presented in a circular aperture (radius, 2.2° of visual angle), which was located in each quadrant of a square stimulus display area. The aperture centers had an eccentricity of 4.2°. A square frame subtending 12° of visual angle was presented to both eyes to support binocular fusion. A fixation point subtending 0.34° was presented at the center of the stimulus display area. The frame and fixation point were presented throughout a session and had a luminance of 0 cd/m^2.

One eye viewed the random-dot kinematograms in the top-left and bottom-right quadrants, and the other eye viewed the random-dot kinematograms in the top-right and bottom-left quadrants. Dots in the first pair of quadrants moved right downward (or left upward), whereas dots in the other pair moved left downward (or right upward). The participants' task was to adjust the speed of random-dot kinematograms seen by one eye (the comparison stimulus) to match the perceived speed of the random-dot kinematograms seen by the other eye (the standard stimulus) using button presses. Each button press changed the speed of the comparison stimulus exponentially. Both the comparison and standard stimuli were presented continuously during the adjustment process. The comparison stimuli were presented either to the amblyopic eye or to the fellow eye (nondominant eye or dominant eye for control observers with normal vision). Standard stimuli had speeds of 2, 3, or 4.5°/s for control observers, whereas the speed was fixed to be 3°/s for patients with amblyopia. Control observers completed the task with and without a 2.0-log-unit strength neutral density filter, which reduced luminance by a factor of 100, in front of the nondominant eye.

Control observers with normal vision completed eight trials for each condition. Comparison stimuli had an initial speed that was faster than the standard stimuli in four of eight trials. Because there were 2 (eye) × 3 (speed) × 2 (filter) = 12 conditions, the total trial number was 96. Patients with amblyopia completed 4 to 16 trials each for the amblyopic and fellow eyes at the standard speed of 3°/s. Comparison stimuli were always faster than standard stimuli at the beginning of a trial because the matching task was easier when decreasing the speed of comparison stimuli than when increasing it. We used matching values averaged over trials for each condition as individual measurements.

In addition, we tested normal observers using the weaker neutral density filter with 0.3-log-unit strength, which reduced luminance by a factor of 2, because, as described hereinafter, the reduction in perceived luminance in the amblyopic eye was much smaller than the physical luminance reduction induced by a 2.0-log-unit strength neutral density filter. The standard speed was 2°/s for this additional experiment.

Luminance Matching

The luminance matching experiment used the same methodology as our previous study.[8] Stimuli consisted of four square patches subtending 3° of visual angle. They were presented within the four quadrants of a black square subtending 12° at an eccentricity of 4.2°. A fixation point was presented at the center of the square. The background luminance was 20 cd/m^2.

One eye viewed the patches in the top-left and bottom-right quadrants, and the other eye viewed the patches in the top-right and bottom-left quadrants. The participants were instructed to adjust the brightness of patches seen by one eye (comparison stimulus) so that they had the same brightness as the patches seen by the other eye (standard stimulus). The luminance of the comparison stimulus was adjusted using button presses that changed luminance exponentially. Both the comparison and standard stimuli were presented continuously during the adjustment process. The comparison stimuli were presented either to the amblyopic eye or to the fellow eye (nondominant eye or dominant eye for control observers with normal vision). Standard stimuli had a luminance of 20 cd/m^2.

Patients with amblyopia completed 16 to 32 trials, with the comparison stimulus presented to the amblyopic eye for half of the trials. Comparison stimuli were presented with a higher starting luminance than standard stimuli for half of the trials and a lower starting luminance for the remainder. We used median matching values for each eye as individual measurements because even the highest possible luminance (40 cd/m^2) did not match the standard luminance (20 cd/m^2) for some trials in patients 2, 3, 4, 8, 9, and 10.

The Pulfrich Effect

A white dot, which subtended 3° of visual angle, oscillated horizontally through 15° of visual angle with a sinusoidal velocity profile. Each motion cycle took 1 second. A fixation point subtending 0.4° of visual angle was presented at the trajectory center. The stimulus was viewed without stereo shutter goggles. The luminance values of the dot, fixation point, and background were 69.5, 34.8, and 0 cd/m^2, respectively. We asked participants to fixate and report if they perceived the moving dot to change in depth and, if yes, to describe the path and the direction of the

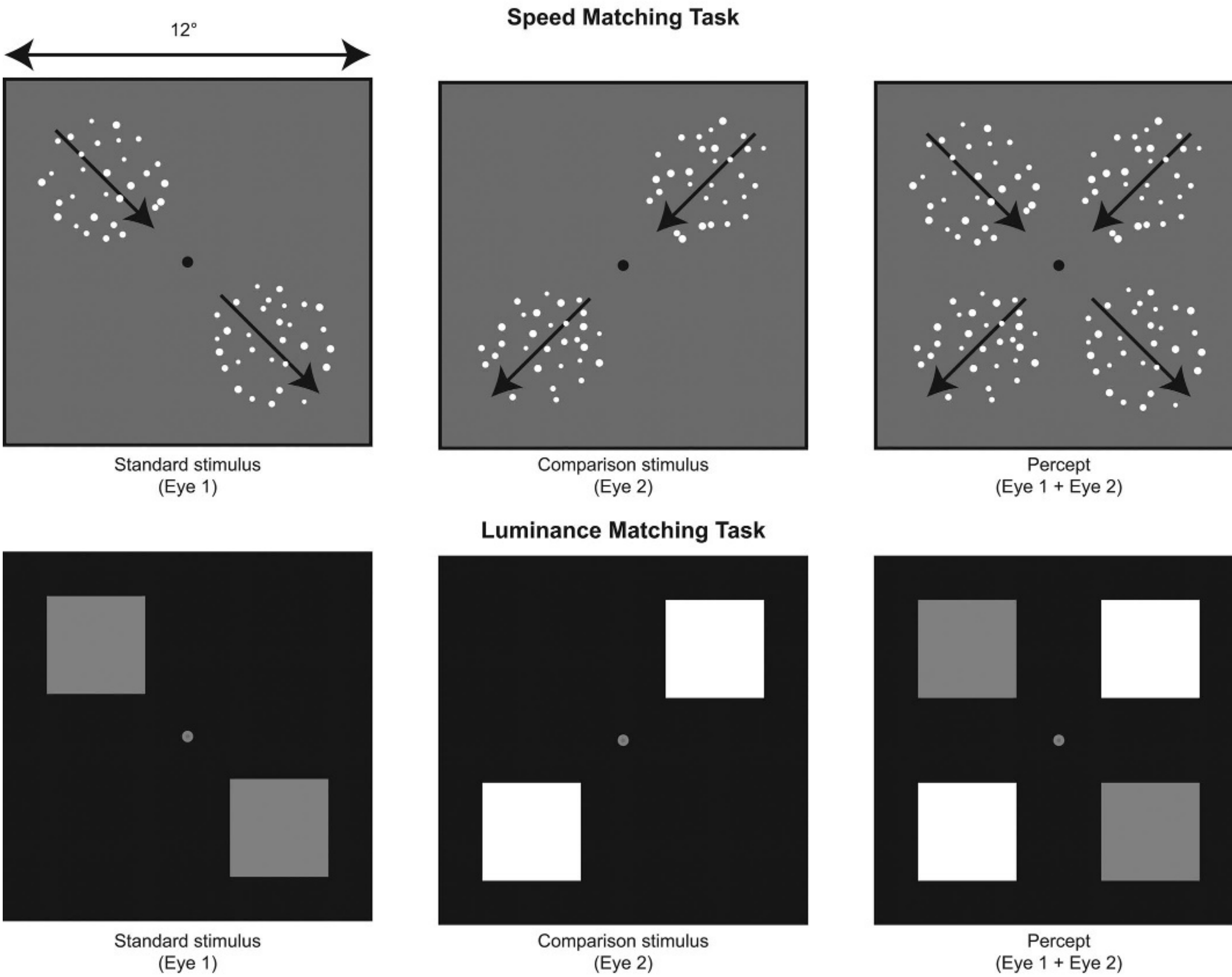

FIGURE 1. Stimuli presented in the speed matching and luminance matching experiments. There were 30 moving dots in each quadrant of the stimulus for speed matching. One eye viewed the standard stimulus, whereas the other eye viewed the comparison stimulus. Participants matched the speed or luminance of the comparison stimulus to that of the standard stimulus.

moving dot. Observers viewed the stimuli first without a neutral density filter. A neutral density filter was then placed over one eye, and the test was repeated. The neutral density filter was then switched to the other eye. Following this procedure, the strength of the neutral density filter was gradually increased. The filter strengths were 0.3, 0.6, 1.0, 1.3, 1.5, 2.0, and 2.5 log units. Viewing time was not limited.

Participants

Ten observers with normal vision, including one of the authors (GM), participated in the main speed matching experiment (nine 22-year-olds and one 40-year-old). Another set of 10 normal observers, including 2 of the authors (GM and TY), participated in the additional speed matching experiment with the 0.3-strength neutral density filter (mean [standard deviation] age, 25.2 [8.4] years). Eleven patients with amblyopia were recruited. Their clinical details are provided in Table 1. Patients 2 and 11 had mixed amblyopia caused by anisometropia and strabismus. All other patients had anisometropic amblyopia. Their ages ranged from 8 to 17 years, except for patient 5 (58 years old). No patient had had strabismus surgery. Visual acuity was measured in decimal units using the Landolt ring chart and converted to logMAR units. Unilateral amblyopia was defined as best-corrected visual acuity worse than 0.1 logMAR (<0.8 in decimal units) in the amblyopic eye because of anisometropia and/or strabismus, and best-corrected visual acuity of 0 logMAR (1.0 in decimal unit) or better in the fellow eye at the first clinical visit. Anisometropia was defined as an interocular difference in spherical equivalent refractive error of more than 2.0 diopters. All patients participated in the speed matching experiment, whereas 10 patients (patients 1 to 10) took part in the luminance matching experiment. Seven of 11 patients (patients 1, 4, and 7 to 11) and 10 observers with normal vision (mean [standard deviation] age, 25.2 [8.4] years),

TABLE 1. Clinical details of patients with amblyopia

	Age (y)	Type	Amblyopic eye	Refraction (RE)	Refraction (LE)	LogMAR VA (RE)	LogMAR VA (LE)	Stereopsis (arc sec)	Age detected (y)	Patching	Surgery
1	8	Anisometropic	L	S +2.00	S +6.50	−0.18	0.22	240	6	8 mo; age, 6 y	None
2	8	Mixed	L	S +0.50 C −0.50 A 170	S +5.75 C −1.75 A 180	−0.18	0.30	240	3	None	None
3	17	Anisometropic	L	S +3.00	S +5.50	−0.18	0.30	400*	15	None	None
4	15	Anisometropic	L	S −3.25	S +0.25 C −0.50 A 180	−0.18	0.10	NA	3	1 y; age, 8 y	None
5	58	Anisometropic	L	S −0.50 C −1.50 A 80	S −1.50 C −0.50 A 90	−0.18	0.40	120	6	None	None
6	12	Anisometropic	L	0	S +7.00 C −0.50 A 10	−0.18	0.30	240	7	2 y; age, 7 y	None
7	10	Anisometropic	R	S +4.75 C −0.75 A 180	S +2.75	0.10	−0.18	NA	7	2 y; age, 7 y	None
9	11	Anisometropic	L	S +0.75	S +7.25 C −1.50 A 5	−0.18	0.40	240	10	1 y; age, 10 y	None
10	12	Anisometropic	L	S −0.75	S +4.25 C −1.50 A 180	0.00	0.40	480	11	1 y; age, 11 y	None
11	11	Anisometropic	R	S +6.75 C −1.00 A 110	S +1.50 C −0.50 A 180	0.22	−0.18	120	7	Unknown; age, 11 y	None
12	17	Mixed	L	S −0.50	S +2.00 C −0.75 A 180	−0.18	0.40	NA	3	Unknown; age, 3 y	None

*Stereoacuity was measured with the Titmus stereotest. The TNO (Netherlands Organization for Applied Scientific Research) stereotest was used for the other patients. A = cylindrical axis; C = cylinder; LE = left eye; RE = right eye; S = sphere; VA = visual acuity.

including 2 of the authors (GM and TY), completed the Pulfrich effect measure. The study followed protocols approved by the institutional ethics committee that were in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

RESULTS

Speed Matching

Fig. 2 shows the mean matching speed for control observers with normal vision. We subjected the data to a three-way analysis of variance with factors of filter (no filter or filtered), eye (dominant or nondominant), and standard speed (2, 3, or 4.5° of visual angle). The measurements were transformed to logarithmic values (dB re 1) before analysis. The mean matching speed was faster for the nondominant eye (3.45°/s; 95% confidence interval, 3.11 to 3.82°/s) than for the dominant eye (2.65°/s; 95% confidence interval, 2.42 to 2.90°/s) when a 2.0-log-unit strength neutral density filter lowered the luminance in the nondominant eye. On the other hand, without a neutral density filter, the mean matching speed was comparable between the nondominant eye (3.16°/s; 95% confidence interval, 2.94 to 3.39°/s) and the dominant eye (3.01°/s; 95% confidence interval, 2.88 to 3.14°/s). These effects were reflected in the significant interaction between the factors of the filter and eye ($F_{1,9}$ = 22.9; P = .001) and the significant main effect of the eye ($F_{1,9}$ = 6.47; P = .03). We can see from Fig. 2 that, for the filtered condition, the interocular mismatch was largest at the standard speed of 2°/s, and there was little mismatch at the standard speed of 4.5°/s. This produced a significant interaction between the eye and the standard speed ($F_{2,18}$ = 11.7;

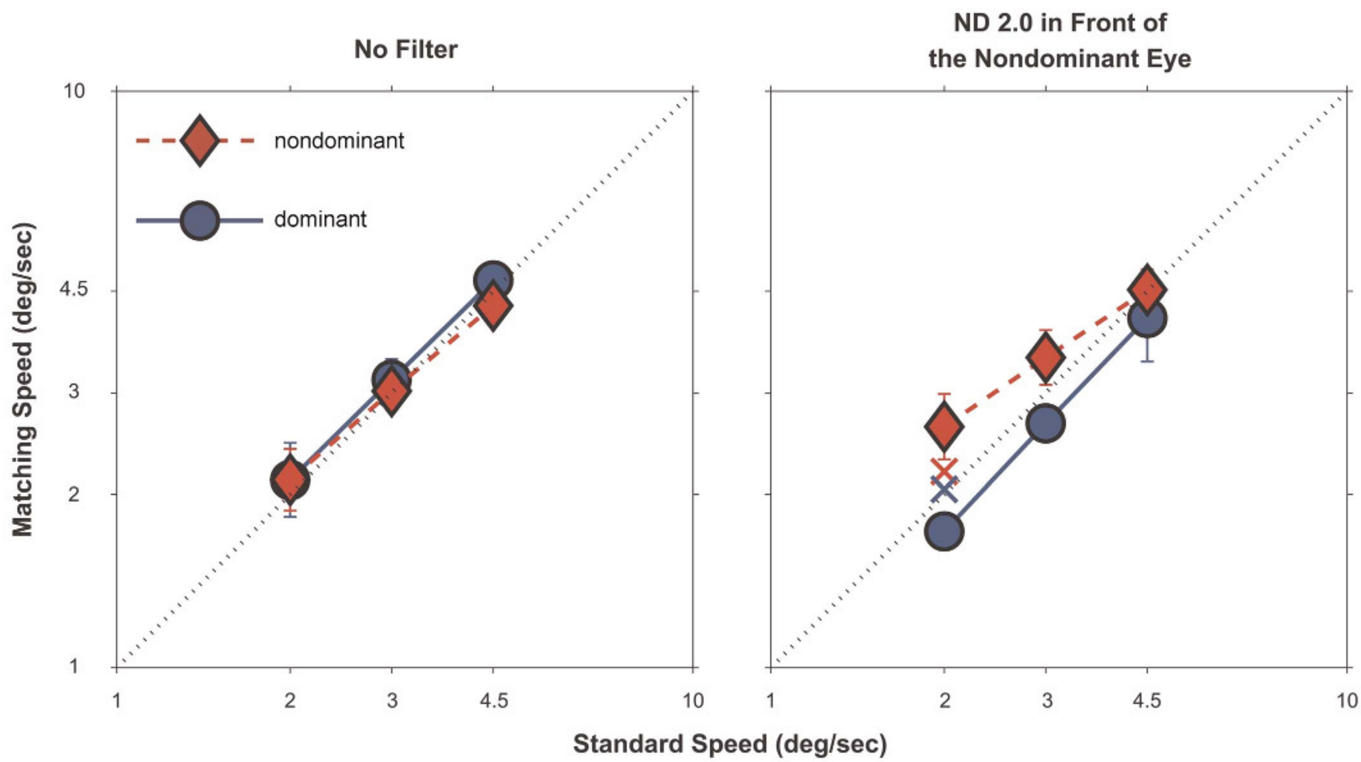

FIGURE 2. The mean matching speed in control observers with normal vision. There was little mismatch when there was no neutral density (ND) filter (left panel). On the other hand, the matching speed was faster for the nondominant eye (red diamond) than for the dominant eye (blue circle) when the nondominant eye viewed the stimuli through a 2.0-log-unit strength ND filter (right panel). Error bars show 95% confidence interval. The matching speed was comparable between the nondominant and dominant eyes (red and blue cross, respectively; no error bar is shown for clarity) when a 0.3-log-unit ND filter was placed over the nondominant eye.

P = .001), but the three-way interaction between the filter, eye, and standard speed was not significant (P > .05). As expected, the matching speed increased as the standard speed increased ($F_{2,18}$ = 428; P < .001). No other main effects or interactions were significant (P > .05). In the additional experiment using the weaker neutral density filter with 0.3-log-unit strength, the mean matching speed was 2.04 and 2.19°/s for the dominant and nondominant eyes (blue and red crosses in Fig. 2), respectively, at the standard speed of 2°/s, producing no significant difference (P > .05). That is, the matching speed was comparable between two eyes when the luminance reduction was only 50%.

Fig. 3 shows the mean matching speed and the individual results for patients with amblyopia. Although there was individual variability, the mean matching speed was comparable between the amblyopic eyes (3.23°/s; 95% confidence interval, 2.81 to 3.71°/s) and the fellow eyes (3.23°/s; 95% confidence interval, 2.86 to 3.65°/s). A one-way analysis of variance was nonsignificant (P > .05). This suggests that there was no mismatch in perceived speed between the two eyes.

Although there was little interocular mismatch in perceived speed for patients with amblyopia, their matching might have been less accurate than that of the normal observers. Therefore, we compared absolute values of the deviation from the standard speed (3°/s) between the patients and the control observers using a two-way analysis of variance with factors of eye and group. The measurements were not converted to log units for this analysis of variance because the measurements included values of 0 (minus infinity in log units). The mean absolute deviation was not significantly larger for the patients (0.55 and 0.51°/s for the amblyopic and fellow eyes, respectively; 95% confidence interval, 0.17 to 0.92°/s and 0.11 to 0.90°/s) than for the control observers (0.25 and 0.33°/s for the nondominant and dominant eyes, respectively; 95% confidence interval, 0.11 to 0.38°/s and 0.17 to 0.49°/s; P > .05), suggesting that accuracy was equal for patients and controls in the speed matching task. However, there was some individual variability, with patients 1 and 5, showing relatively large deviations.

Luminance Matching

Fig. 4 shows the mean matching luminance and the individual results (medians) for patients with amblyopia. The median matching luminance of patient 8 reached the highest luminance we could present (40 cd/m^2) for the amblyopic eye. This means that patient 8 could not match the luminance between the two eyes even at the highest possible comparison stimulus luminance on more than half of the trials. Therefore, the matching luminance (40 cd/m^2) is underestimated for patient 8.

The mean matching luminance was higher for the amblyopic eye (24.2 cd/m^2; 95% confidence interval, 19.7 to 29.7 cd/m^2) than for the fellow eye (18.1 cd/m^2; 95% confidence interval, 15.9 to 20.5 cd/m^2). That is, perceived luminance was reduced by approximately 15% for the amblyopic eye. Note that the matching difference between the eyes was halved here to avoid counting the perceptual difference twice. An analysis of variance using log-transformed data also indicated that this difference was significant ($F_{1,9}$ = 5.23; P = .05). However, there were individual

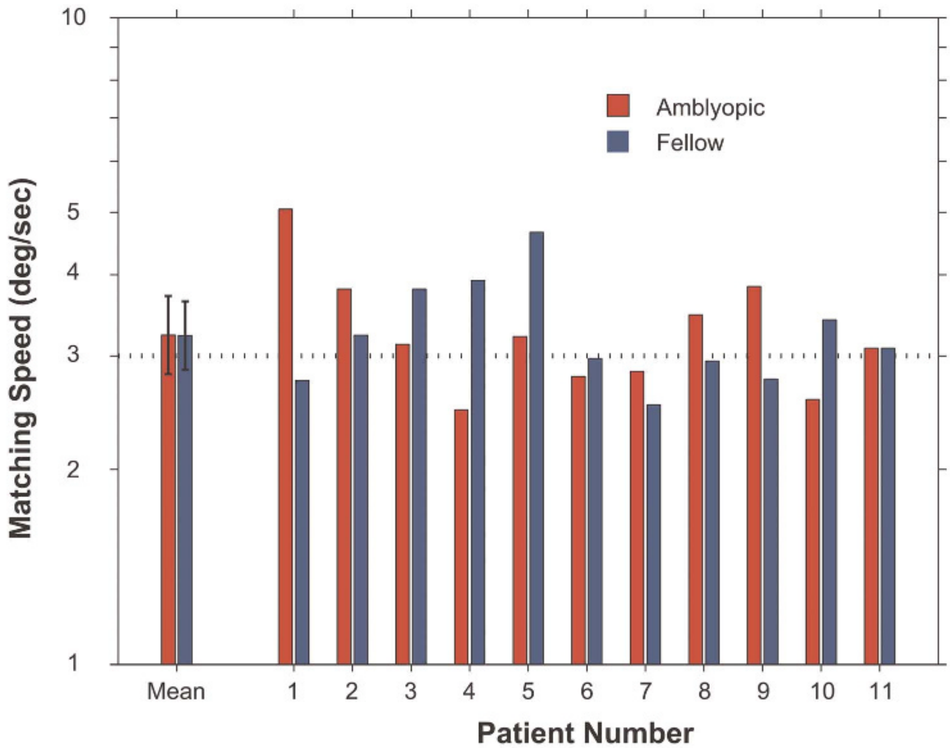

FIGURE 3. The mean matching speed and the individual results for patients with amblyopia. There was little interocular mismatch in the mean matching speed. The dashed line represents the standard speed. Error bars show 95% confidence interval.

differences. Specifically, 6 of 10 patients (patients 1 to 4, 8, and 9) showed substantially higher matching luminance in the amblyopic eye, whereas others showed relatively small mismatches (patients 5, 7, and 10) or the opposite trend (patient 6).

We also tested if interocular mismatches in matching speed and matching luminance were correlated. The correlation was weak ($r = 0.07$) and not significant ($P > .05$). The matching luminance also did not significantly correlate with the difference in visual acuity between the two eyes ($r = 0.167$; $P > .05$). There was no significant difference in matching luminance between patients with stereo vision and those without ($P > .05$).

The Pulfrich Effect

Although none of the seven patients with amblyopia tested reported a spontaneous Pulfrich effect, five of them perceived a rotation in depth when a neutral density filter was placed in front of one eye. Table 2 summarizes the results and the strength of the neutral density filter required to induce the perception of a rotation in depth. Patients 1 and 7 reported the appropriate rotation in depth (anticlockwise for a right eye filter, clockwise for a left eye filter). Patients 9, 10, and 11 perceived a rotation that was opposite to that predicted by the Pulfrich effect when a neutral density filter was applied to the amblyopic (patients 9 and 11) or the fellow (patient 10) eye. Patients 4 and 8 reported no rotation in depth at all, possibly because of suppression of the amblyopic eye. For observers with normal vision, a 0.3- to 1.5-log-unit strength neutral density filter was required to induce a perceived rotation in depth when the filter was placed over the nondominant eye. The median strength was the 1.0-log-unit, 90% luminance reduction. Patients 1, 7, 9, 10, and 11 reported a rotation in depth with 0.9- to 2.5-log-unit strength neutral density filters (Table 2). There were considerable individual differences both for normal observers and for patients in the strength of neutral density filter that induced the Pulfrich effect.

DISCUSSION

The present study investigated suprathreshold motion perception in patients with amblyopia. In particular, because luminance can affect speed perception[33–35] and perceived luminance is reduced in the amblyopic eye,[8] we expected that there might be a mismatch in perceived speed between the amblyopic and fellow eyes. However, we found no evidence for a consistent mismatch in perceived speed between amblyopic and fellow eyes, and speed matching accuracy was equivalent between patients and controls. This indicates normal suprathreshold speed perception in amblyopia. In addition, we replicated the previous finding of a perceived interocular luminance mismatch in amblyopia, whereby the amblyopic eye had a lower perceived luminance than did the fellow eye by approximately 15%. However, the interocular mismatch in perceived speed did not correlate with the interocular mismatch in perceived luminance. This is further evidence that the luminance mismatch does not affect motion perception.

In controls, placing a neutral density filter over the nondominant eye to simulate the amblyopic eye–perceived luminance reduction did reduce perceived speed relative to the nonfiltered dominant eye. This could indicate that the amblyopic eye–perceived luminance reduction does not have the same properties as a physical luminance reduction. In agreement with this idea, we found no

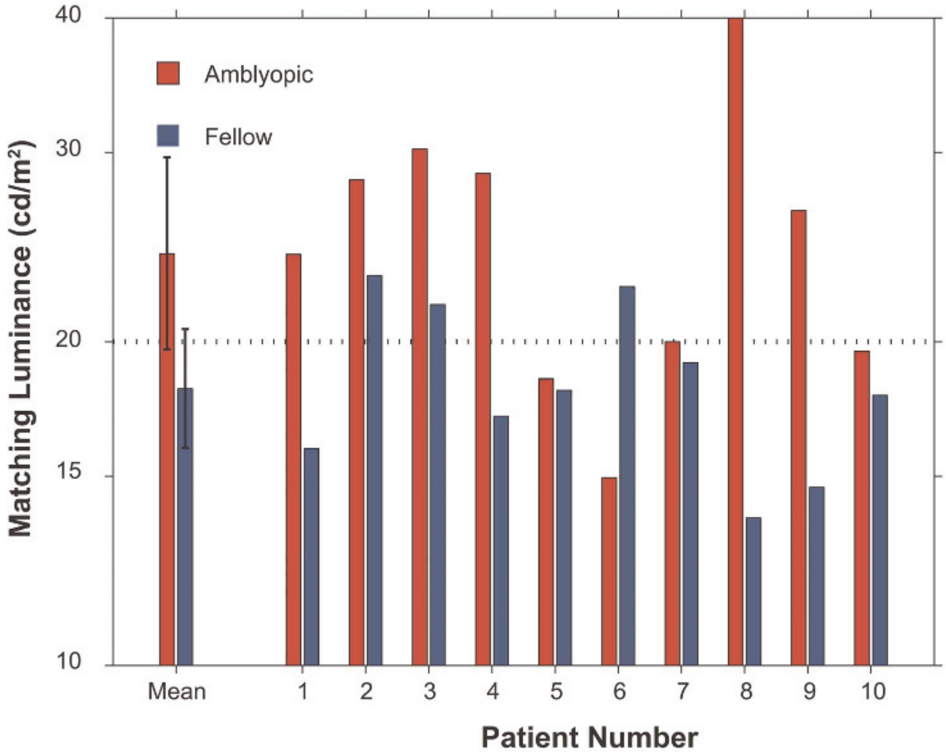

FIGURE 4. The mean matching luminance and the individual results (medians) in patients with amblyopia. The mean matching luminance was higher for the amblyopic eye (red bar) than for the fellow eye (blue bar), although there was individual variability. The dashed line represents the standard luminance. Error bars show 95% confidence interval.

evidence for spontaneous Pulfrich effects in patients with amblyopia, which might be expected if the perceived luminance reduction in the amblyopic eye acted in the same way as a neutral density filter. On the other hand, it is possible that the reduction in amblyopic eye–perceived luminance was simply too small to produce any speed bias. In support of this idea, there was no speed bias for controls when a weak (0.3-strength) neutral density filter was placed over one eye.

The mismatch in perceived speed induced in control observers when a neutral density filter was placed over the nondominant eye is consistent with previous results indicating a reduction in perceived speed at scotopic light levels.[33] However, increases in perceived speed have been reported when luminance is lowered but maintained within the mesopic or photopic range.[34,35] The 2.0-log-unit strength of the neutral density filter used in the present study reduced luminance to the low photopic range (dots, 0.04 cd/m^2; background, 0.02 cd/m^2). Therefore, the reduction in perceived speed we observed for the filtered eye may be due to interocular suppression or changes in gain induced by the unilateral neutral density filter[39–41] rather than a direct effect of reduced luminance on speed perception.

In agreement with previous work,[8] we found that matching luminance was higher for the amblyopic eye than for the fellow eye, indicating lower perceived luminance for the amblyopic eye. However, compared with the previous findings, we found somewhat larger individual differences. We speculate that the individual differences might be due to amblyopia etiology. Most of our patients had anisometropic amblyopia, and there were no patients with purely strabismic amblyopia (Table 1). In contrast, most of patients in the previous study had strabismic amblyopia, but no patient had purely anisometropic amblyopia.[8] Behavioral and functional magnetic resonance imaging studies have suggested that the mechanisms and effects of interocular suppression may differ between strabismic and anisometropic amblyopia,[42,43] although other studies have found no differences in suppression between these two groups.[44] A direct luminance matching comparison between strabismic and anisometropic amblyopia groups is required to address this question.

No patients with amblyopia reported a spontaneous Pulfrich effect, despite having a perceived luminance difference between the two eyes. This is contrary to Tredici and von Noorden,[30] who reported a spontaneous Pulfrich effect in three patients with anisometropic amblyopia. Our results indicate that the perceived luminance

TABLE 2. Perceived rotation of the Pulfrich stimulus and the corresponding ND filter strength in patients with amblyopia

Patient no.	Filter over the fellow eye	Filter over the amblyopic eye
1	Anticlockwise, ND 0.9	Clockwise, ND 0.9
4	No rotation	No rotation
7	Clockwise, ND 1.3	Anticlockwise, ND 1.0
8	No rotation	No rotation
9	No rotation	Anticlockwise,* ND 1.0
10	Anticlockwise,* ND 1.3	No rotation
11	No rotation	Anticlockwise,* ND 2.5

*The rotation direction was opposite to that predicted by the standard Pulfrich effect. ND = neutral density.

mismatch between the amblyopic and fellow eyes does not influence binocular motion perception. One possible explanation relates to the way that our stimuli were presented. For the matching experiments, stimuli were presented to different quadrants in each eye and therefore did not overlap. Interocular suppression may only be partially active under these conditions, allowing for simultaneous perception of all four quadrants. In contrast, the Pulfrich stimulus was presented to the same retinal location in both eyes, presumably activating maximal suppression. If the Pulfrich stimulus was suppressed in the amblyopic eye, no motion in depth effects would be expected. In addition, as for perceived speed, it is possible that the interocular difference in perceived luminance may not be sufficiently large to induce a spontaneous Pulfrich effect in amblyopia. Our observation that a median neutral density filter strength of 1.0 log unit was required to induce a Pulfrich effect in our control observers supports this possibility. This strength of neutral density filter produces a much larger interocular difference in luminance than the perceived luminance differences we observed for our patients with amblyopia (~15% reduction in the amblyopic eye). It should be noted that patients 7 and 11 reported a Pulfrich effect, although they had no measurable stereopsis with the TNO (Netherlands Organization for Applied Scientific Research) test. This raises the interesting possibility that the Pulfrich effect is a more sensitive measure of stereo performance than current clinical tests.

Overall, our results indicate that the difference in perceived luminance between the amblyopic and fellow eyes that is present under dichoptic viewing conditions does not affect the perceived speed of suprathreshold motion stimuli. Therefore, interocular suppression mechanisms engaged during dichoptic viewing seem to affect luminance but not temporal processing for suprathreshold stimuli. Amblyopia may affect processing within the lateral geniculate nucleus in which neurons are sensitive to luminance contrast.[45–47] Therefore, lateral geniculate nucleus anomalies may be the source of the perceived luminance mismatch between the amblyopic and fellow eyes. We note that our random-dot kinematograms stimuli were fully coherent. Previous studies have suggested that motion perception deficits in amblyopia involve the segregation of signal from noise.[23,48–50] The effect of interocular suppression on signal noise segregation in amblyopia remains to be examined in future studies.

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