

# The Effects of Vertical Yoked Prisms on Gait

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**PURPOSE.** To investigate the influence of base down (BD) and base up (BU) yoked prism wear on gait.

**METHODS.** Gait was assessed in 31 young healthy adults (mean age,  $24.0 \pm 5.1$  years) during and after wearing 5 prism diopter ( $\Delta$ ) BU yoked prisms, 5 $\Delta$  BD yoked prisms, and plano (PL) (zero power; control condition) lenses, worn in a pseudorandom order. Velocity; cadence; step length; double support phase; step width; and variability in step time, step width, step length, and swing time were measured as participants walked at a freely chosen walking speed along a 5.3-m electronic mat placed in the center of a 7.5-m walkway. Gait parameters were analyzed for each viewing condition before, during, and after prism wear.

**RESULTS.** BD yoked prisms, when compared with PL, led to slower velocity, lower cadence, decreased step length, and increased step time variability ( $P \leq 0.001$ ). These gait parameters did not significantly differ between BU yoked prisms and PL lenses ( $P > 0.05$ ). Measurements taken immediately on removal did not differ from those taken after a time delay of 5 minutes.

**CONCLUSIONS.** BD yoked prisms affected gait in young healthy adults walking across an unobstructed path at their freely chosen walking speed, in that participants adopted a slower, apparently more cautious gait pattern; BU yoked prisms did not significantly affect gait. The effect of BD prism on gait may be due in part to a perception of increased height.

**Keywords:** vertical yoked prism, gait, prism adaptation

Yoked prisms are prisms of equal power positioned in front of both eyes such that their bases are oriented in the same direction. When looking through a pair of yoked prisms, the object of regard is perceived to have shifted toward the apices of the prisms by an amount proportional to the power of the prism and the viewing distance from the object.<sup>1</sup> Yoked prisms create no net power difference between the two eyes, but act to optically induce a change in the perception of space by shifting image location as well as by inducing greater magnification (along the base–apex axis) of objects viewed toward the apex than those viewed toward the base.<sup>2</sup> This effect is considered to be important by those practitioners who use vertical yoked prisms (VYPs) for potential therapeutic applications, which have been reported to range from treatment of oculomotor deviations to postural and movement (ball-catching) difficulties.<sup>3–5</sup>

Yoked prisms are recommended by behavioral optometrists for a range of visual problems, some of which relate to gait and posture.<sup>6</sup> One case report suggests the use of base down (BD) yoked prisms to modify the line of sight and aid mobility in a patient with a forward head tilt,<sup>7</sup> whereas another reports that a child with abnormal gait walked “normally” when wearing yoked prisms.<sup>8</sup> In a discussion on prescribing prism, Tea<sup>9</sup> advocated the use of VYP wear combined with active vision therapy for the treatment of abnormal head posture. Referring to chronic fatigue syndrome, Padula<sup>10</sup> noted that with yoked prism wear the patient will “shift his/her weight . . . and will have better balance.” Slavin and Gorsky<sup>11</sup> reported in one subject with severe postural and movement anomalies, that VYP had a positive influence on lateral body movement.

The evidence<sup>12</sup> for the use of VYP to overcome visual or postural problems is low level, primarily based on case studies and opinion.<sup>3,13,14</sup> This makes the use of VYP controversial. For example, Jennings<sup>15</sup> states that “There seems to be no evidence beyond the anecdotal as to its effectiveness. . . . In the absence of any supporting evidence the method cannot be recommended.” Although some research has been published into the effects of VYP on egocentric localization while sitting in a dark room,<sup>16</sup> there are few controlled studies to determine the visual, postural, or movement-related effects, if any, of VYP on participants with normal vision or on those for whom VYP would be prescribed. It should be noted, however, that there is more extensive evidence for the use of horizontally yoked prism in the treatment of hemispatial neglect.<sup>17</sup>

Kaplan<sup>14</sup> claimed (without publishing data) that VYP can effect immediate changes in posture and ball-catching behavior in those who have lateral vergence disorders. Kraskin<sup>13</sup> argued (without presenting data) that yoked prism wear results in eye movements that in turn induce a corresponding change in the position of the pelvis and thus body movements to maintain balance. Gizzi et al.<sup>18</sup> used the objective method of moving platform posturography to measure shifts in the center of gravity with 15 prism diopter ( $\Delta$ ) horizontal yoked prism wear. Participants stood on a platform that could be either still or could tilt, and the shifts associated with horizontal yoked prism were statistically significant but at 1° or less the clinical significance of this postural change is likely to be small. Suttle and colleagues<sup>19</sup> found no effect of VYP on posture as measured by hip joint angle, torso angle, and neck joint angle

in a pilot study in which six participants were required to stand still for a series of 30-second trials.

Sheedy and Parsons,<sup>20</sup> in a randomized cross-over study, found that 2 weeks of 4<sup>Δ</sup> BD wear resulted in significant head elevation, an angular measure of the head tilting back. This elevation essentially counteracted 75% of the visual displacement induced by the prisms, and did not occur immediately upon wearing the prism. Moreover, the 24 participants almost universally rejected the wear of 4<sup>Δ</sup> BD prism while 46% accepted 2<sup>Δ</sup> BD prism (which had no significant impact on posture), when given a choice of prismatic or no prismatic correction. The reasons for rejection of the 4<sup>Δ</sup> prism included headaches and eyestrain, seeing distortion and reflections, and spatial disorientation. The reasons for preference of the 2<sup>Δ</sup> are unclear, and may include a placebo effect.

Gottshall and colleagues<sup>21</sup> found, in 80 young adult participants, that the introduction of spatial displacement using combined vertical and lateral prisms had no significant effect on center of pressure measurements obtained using computerized dynamic posturography, but did cause mild to moderate gait impairments in various walking conditions of the Dynamic Gait Index, a clinical test based on subjective ratings. Because posturography provides a measure of balance, it may be that the participants adjusted their posture to keep their balance, resulting in no significant change in the center of pressure.

Several researchers<sup>22-24</sup> have observed that gait difficulties, including hesitancy, stumbling and reduced velocity, were immediately apparent with the wear of horizontally yoked prisms, but that within minutes adaptation occurred and eliminated these effects. Horizontal yoked prisms have been used to investigate the visual factors that influence heading direction when walking.<sup>25</sup> However, there is no clear reason to suppose that VYP would affect lateral heading, since the scene is shifted vertically rather than sideways.

Perception and action are linked,<sup>26</sup> and it is well established that actions such as walking use visual information to coordinate motor systems. Visually guided movement such as walking is thought to be mediated in part by the dorsal visual pathway, with visual functions related to perception such as object identification being mediated by the ventral pathway (e.g., Milner and Goodale<sup>27</sup>). The hypothesis of two distinct separate systems has proven controversial, and recent work suggests that processing of vision for action (e.g., walking) and vision for perception (e.g., identification) is more integrated than initially thought. For example, perceived step height differences influence stepping behavior, suggesting interaction between perception and action.<sup>28</sup> This interaction leads to the suggestion that perceptual distortion in yoked prism wear could affect walking behavior.

The current study was performed primarily to assess which, if any, temporospatial parameters of gait are influenced by VYP wear, and to consider whether any adjustments to gait are maintained either during or following VYP wear.

On the basis of work with horizontally yoked prisms and the known link between perception and action, it was hypothesized that, when wearing the BU or BD VYP compared with PL lenses, participants would: (1) show reduced walking stability evidenced by increased variability in step time, step width, step length, and swing time; and (2) adopt a conservative gait pattern including slower walking velocity, slower cadence, shorter step length, increased step width, and longer double-support phase of gait, to safely navigate their way through the environment.

## METHODS

### Participants

Thirty-one healthy adults (13 males and 18 females), 19 to 49 years of age (mean [SD]: 24.0 [5.1] years), participated in the study. They were a convenience sample recruited from among staff and students from Neuroscience Research Australia and the University of New South Wales. The University of New South Wales Human Research Ethics Committee approved the study and informed consent was obtained from each individual prior to participating, in accordance with the Declaration of Helsinki. The inclusion criteria were as follows: (1) 18 to 50 years of age, (2) corrected to normal monocular visual acuity of 6/9 or better each eye using a high-contrast logMAR acuity chart at 3 m, and (3) corrected to normal binocular visual acuity of 6/7.5 or better. Exclusion criteria were the following: (1) presence of neurological disorders or diseases that could affect gait; (2) intake of medications that could affect walking or balance; (3) presence/history of eye diseases, surgery, or injury affecting eye movement; and (4) presence of strabismus. Exclusion criteria (1) to (3) were self-reported. A cover test at 3 m was performed to exclude heterotropia (criterion 4).

### Apparatus

Participants wore plastic safety goggles (Uvex Safety, Parramatta, Australia) equipped with a clip-in lens capability, enabling the prism to be placed over the participants' habitual distance spectacles, if any (no participants wore multifocals). Three plastic inserts could be clipped into the goggles: 5<sup>Δ</sup> base up (BU), 5<sup>Δ</sup> base down (BD), or PL power. Five prism diopters was selected since it is between those powers recommended for constant wear (2-3<sup>Δ</sup>) and those for in-office therapy (6-20<sup>Δ</sup>).<sup>4,14</sup> The difference between the magnification of the prismatic lenses and the PL lenses at their centers was 0.05%.

### Procedure

Each participant was tested in one 75-minute session, wearing their own flat footwear.

Temporospatial variables of gait were recorded using an electronic mat (GAITRite mat; CIR Systems, Sparta, NJ)<sup>29</sup> placed in the middle 5.3 m of a 7.5-m walkway. This ensured that acceleration and deceleration phases of gait associated with the first few and last few steps were excluded from the measures.

In each session, participants performed walking trials along the walkway at a self-selected pace, in the three lens conditions presented in a random order. Participants were given the following instruction: "Walk forward toward the other end of the room and stop once you are past the white line." Just walk normally like you are walking down the street. Participants, but not experimenters, were masked to the lens condition.

Once the subjects reached the end of the walkway, they turned around and walked back along the walkway constituting the next trial. Thus at the end of the fifth trial the participant was standing at the far end of the walkway. Subjects waited approximately 15 to 20 seconds between trials.

The procedure undertaken for each lens condition is outlined in Figure 1. Baseline gait measurement involved two walks without goggles. The goggles, with a lens/prism insert, were then placed on participants' faces as they stood behind a white line marker with their eyes closed. Upon opening their eyes, participants immediately walked along the walkway five times (ON Initial). This was done in an attempt to reduce any rapid lens/prism adaptation that may have taken place prior to walking. (Here we define *adaptation* as a return toward

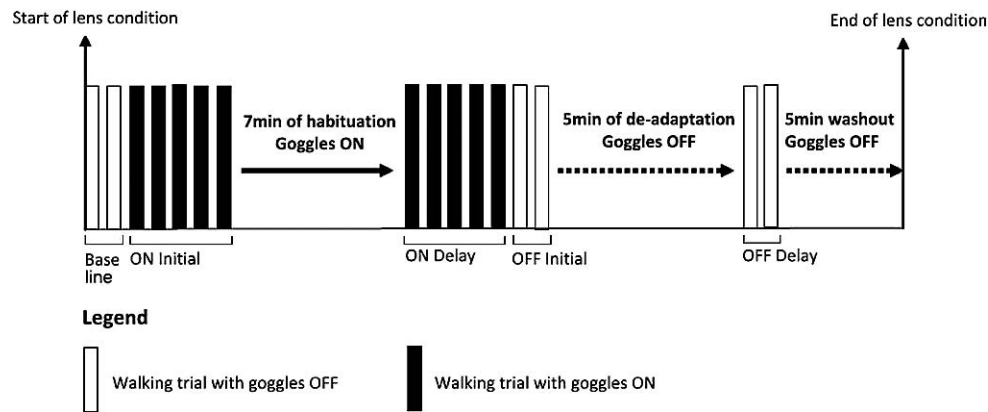


FIGURE 1. Procedure. Filled bars indicate walking trials with lenses on and white bars indicate walking trials without goggles or lenses.

baseline values. The term “adjustment” is used here to refer to any change in values, whether toward or away from a baseline value.) After 7 minutes of prism exposure, during which time participants were asked to walk up and down along a well-lit corridor, another five walking trials (ON Delay) were recorded to determine if there was any effect of the prisms over time. (The corridor was 45 m long, 2.1 m wide, with light levels varying from 490 to 1880 lux [the latter near a window], artwork on the walls, and a small number of people walking along its length.) After those five trials, the goggles were removed, and participants immediately performed another two walking trials followed 5 minutes later by another two walking trials (OFF Initial and Delay). An additional 5 minutes without lens wear elapsed (a washout period) before the process was repeated for the next lens condition. Participants were permitted to walk, sit, read, or use a computer during the deadaptation and washout phases.

It was determined that only two walking trials would be required for the baseline and OFF conditions, given that walking patterns of healthy participants on a standard surface are highly repeatable, and the electronic mat has high test-retest reliability.<sup>30,31</sup> Five walking trials were undertaken for the ON measurements, as greater intrasubject variability was expected when wearing the prisms. A 7-minute period of prism wear was selected since previous prism adaptation studies’ findings suggested that this was sufficient time for rapid adaptation to occur.<sup>24,32–35</sup> Similarly, a 5-minute deadaptation and washout time was chosen given that previous research has shown this process to occur rapidly.<sup>36</sup>

The following variables were computed for each walk and averaged across each walk series for each lens condition:

- walking velocity (cm/s)
- cadence (steps/min)
- step length (cm)
- double support phase (% of gait cycle duration; the proportion of the gait cycle during which both feet were in contact with the mat)
- step width (cm; distance between the left and right heels at respective heel contact with the ground, in the direction tangential to the progression of walking [this is the variable GAITRite name “H-H Base of Support”])
- step time variability (s; SD of mean step time; time between first contact of one foot and the contralateral foot)
- step width variability (cm; SD of mean step width)
- step length variability (cm; SD of mean step length)
- swing time variability (s; SD of mean swing time [time elapsed between the last contact of the current footfall to

the first contact of the next footfall on the same foot]). According to previous research<sup>37</sup> swing time variability is a measure of dynamic balance that is not influenced by gait speed.

## Statistical Analysis

Statistical analyses were performed using a commercial software program (SPSS, version 10.0 for Windows; IBM SPSS Software, Chicago, IL).

A one-way repeated-measures ANOVA was conducted with lens condition as the within-subjects factor to determine whether gait parameters were different at each baseline (see Fig. 1).

A three-way repeated-measures ANOVA was conducted with wearing condition (ON or OFF), lens condition (BU, PL, or BD), and time (Initial or Delay) as within-subject factors.

Simple contrasts to the PL lens condition were performed when the main effect of lens condition was significant, and pairwise comparisons were performed for significant interactions. Since multiple comparisons were made, a Bonferroni correction was used and, for significance, an alpha level of 0.05 was chosen.

It is possible that some adaptation occurred to lens wear within the first five walking trials and that the averaging of the results of these trials resulted in the loss of this information. Therefore, the first five (ON) walking trials were investigated by means of a repeated-measures ANOVA with two within-subjects factors: lens condition (BU, PL, or BD) and walking trial (1–5). One single trial (second walk with BD prism) for one participant was found to be an outlier and was removed from the analysis.

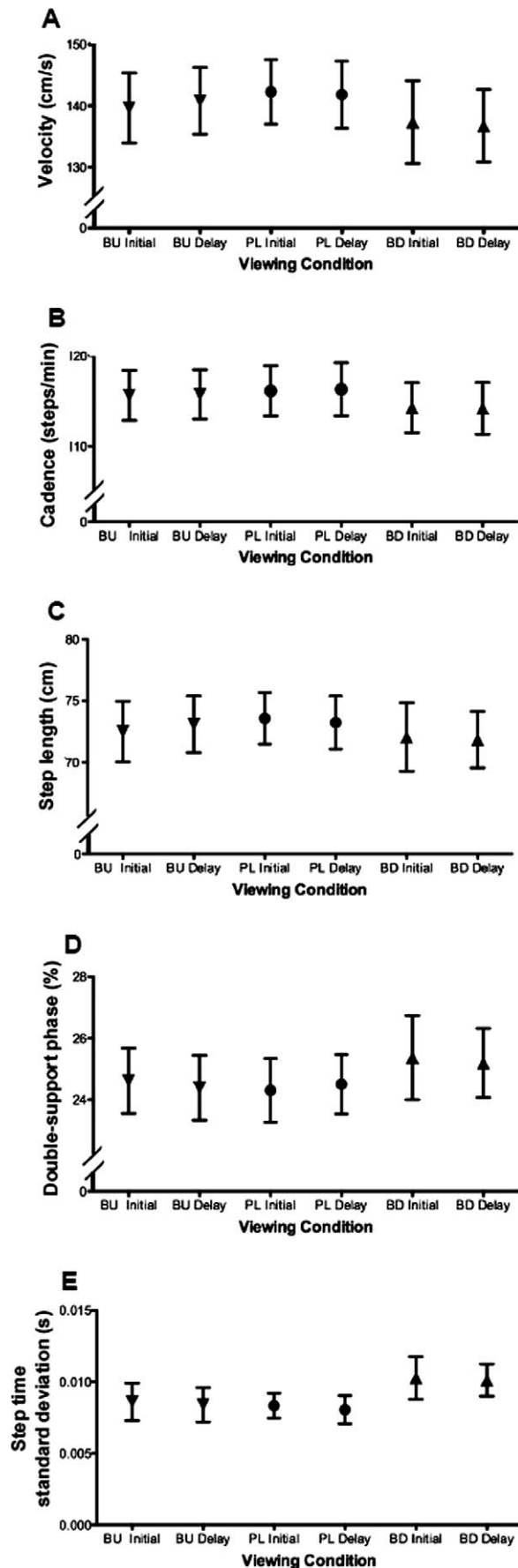
## RESULTS

### Baseline Measurements

Across all parameters evaluated, baseline measurements prior to each lens condition were not significantly different across lens conditions (all  $P > 0.05$ ). This indicates that the deadaptation and washout times were sufficient to allow return to baseline level. Thus, these baseline values were not considered in further comparisons.

### Effects of Lens Condition

A significant three-way interaction between lens condition (PL, BD, BU), wearing condition (ON/OFF), and time condition



(Initial/Delay) was found only for step width ( $F_{2,60} = 10.86$ ,  $P < 0.001$ ). Significant two-way interactions between lens condition and wearing condition were found for walking velocity ( $F_{2,60} = 13.85$ ,  $P < 0.001$ ), cadence ( $F_{2,60} = 17.40$ ,  $P < 0.001$ ), step length ( $F_{2,60} = 7.43$ ,  $P < 0.001$ ), double-support phase ( $F_{2,60} = 3.54$ ,  $P = 0.035$ ), and step time variability ( $F_{2,60} = 5.27$ ,  $P = 0.008$ ). There was no significant interaction for variability in step width, step length, or swing time ( $P > 0.05$ ).

These three-way and two-way interactions reflect the comparisons outlined below in each lens condition (Fig. 2).

### Plano Lens Condition

For PL lenses, there was a small (<6 mm) but statistically significant shortening of step length in the ON condition compared with the OFF condition ( $P = 0.045$ ). There was no significant difference between the ON and OFF conditions for any of the other eight variables ( $P > 0.05$ ). Thus the effect of the goggles that held the lenses was minimal.

### Base Up Prism Condition

There were no significant differences in the ON lens wear condition between the BU prism and the PL lens conditions, for any of the gait parameters assessed ( $P > 0.05$ ). This indicates no effect of wearing the BU prism.

### Base Down Prism Condition

There were significant differences in the ON lens wear condition between the BD prism and the PL lens conditions, with slower velocity (mean reduction: 5.0 cm/s), lower cadence (mean reduction: 2.0 steps/min), shorter step length (mean reduction: 1.4 cm), increased double-support phase (mean increase: <1% of gait cycle), and increased step time variability (mean increase SD of 0.002) in the BD condition ( $P \leq 0.001$  for all the above). There was no significant difference between the BD and PL lens conditions with regard to step width, step width variability, step length variability, or swing time variability ( $P > 0.05$ ).

### Initial and Delay Measurements

For step length only, the difference between initial and delay measurements was found to depend on lens condition ( $F_{2,60} = 3.73$ ,  $P = 0.03$ ). For step width, this comparison depended on both lens and wearing conditions ( $F_{2,60} = 10.86$ ,  $P < 0.001$ ). Post hoc pairwise comparisons indicated that there was a small (<7 mm) but statistically significant ( $P = 0.049$ ) increase in step length at the delay time compared with the initial time for BU prism wear. There was also a significant decrease in step width ( $P = 0.003$ ) at the delay time (mean [SD] 8.6 [2.2] cm) compared with the initial time (mean [SD] 9.3 [2.3] cm) for BU wear. There was no significant difference with regard to step length or width between initial and delay times for either PL or for BD prism wear ( $P > 0.05$ ).

There was no significant lens condition by time interaction and no significant main effect of time for any of the other gait parameters assessed ( $P > 0.05$ ). This indicated a lack of gait adjustment in terms of these variables to the lens condition over time.

**FIGURE 2.** Mean and 95% confidence intervals for each of the five variables: (A) Velocity; (B) Cadence; (C) Step length; (D) Double-support phase; (E) Step time variability. Only the "ON" condition is portrayed.

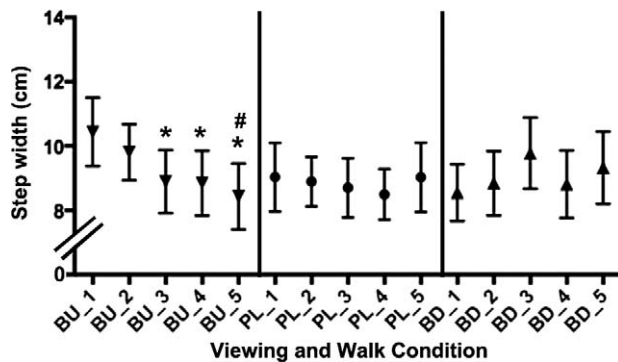


FIGURE 3. Step width mean and 95% confidence intervals for first five walking trials in each lens condition. \*indicates a significance difference with BU\_1 at  $P < 0.05$ ; #indicates a significance difference with BU\_2 at  $P < 0.05$ .

### Investigation of Possible Short-Term Adaptation

A significant interaction between lens condition and the five ON Initial walking trials was found for step width only ( $F_{8,240} = 5.20$ ,  $P < 0.001$ ). Pairwise comparisons indicated that, for BU lens wear only, step width narrowed significantly over those five walks, with most change occurring in the first three walking trials (see Fig. 3). This narrowing of step width was not evident in the averaged data. No such effect was found in PL or BD prism wear ( $P > 0.05$ ).

There was no lens condition by walking trial interaction and no main effect of walking trial for any of the other gait parameters ( $P > 0.05$ ).

### DISCUSSION

The primary aim of this study was to determine whether VYP wear has an effect on temporospatial gait parameters. We found that healthy young adults demonstrated significant changes in their gait patterns while wearing 5 $\Delta$  BD VYP. Specifically, BD prism wear compared with PL lens wear slowed velocity, reduced cadence, shortened step length, increased double-support phase, and increased step time variability. Surprisingly, these effects were not evident in the BU condition. The only gait parameter that changed in the BU condition was step width, which narrowed during the first three walks. These changes could be related to perceptual effects and physiological mechanisms such as proprioception.

The participants in our study were masked to the type of lens housed in the goggles they wore, yet many reported that they felt “taller” when wearing the BD prism. This observation is consistent with the perceptual effect of objects viewed toward the prism base appearing minified<sup>2</sup> and therefore creating a perception of increased distance from the ground. Both virtual and real heights have been shown to increase fear of falling in younger adults,<sup>38</sup> and Delbaere and colleagues<sup>39</sup> found that anxiety about falling is associated with slower walking velocity, decreased cadence, and increased double support phase in older adults. This supports the possibility that when participants were confronted with a perception of increased height, they may have moved with greater caution and hesitancy.

Another possible explanation for the gait changes found with BD VYP is related to the fact that step time variability was increased in this lens condition. Increased step time variability is associated with an increased risk of falling in older adults.<sup>40,41</sup> Participants may have walked slower with shorter steps and slower cadence, tending to keep both feet on the

ground for longer (increased double-support phase) to compensate for poorer walking stability (indicated by increased step time variability); alternatively, the increased gait variability may be a result of the slow walking pace. The fact that other variability measures in step width, step length, and swing time were not affected by prism wear suggests that this variability is more likely due to the slow walking pace than overall instability.<sup>41</sup>

In addition to feeling taller, subjects reported the floor appearing to slant slightly upward from them when wearing BD prism, and slanting downward when wearing BU prism. Kawamura et al.<sup>42</sup> found gait adjustment when subjects walked uphill or downhill, with lower cadence on uphill walks and shortened step length on downhill walks. Whereas any perceived “hill” was virtual in the present study, previous findings on virtual height and gait adjustment<sup>28</sup> support the possibility that our findings of reduced velocity with BD prism wear may be related to this perceptual distortion. However, the absence of any such effect in BU prism wear indicates that distortion of this kind cannot entirely explain the findings.

The secondary aim of this study was to consider the changes that would occur with prism wear over a short period of time, as well as those following their removal. Other than a small increase in step length with BU prism wear, we found no difference in any parameter between measurements taken upon initial wearing of the lenses and those taken after a 7-minute wearing period, suggesting that any gait changes occurred immediately on lens wear, and there was minimal or no further change during this period. The gait parameters following removal of the BD lenses returned immediately to baseline values, suggesting that there was no long-term “recalibration,”<sup>34</sup> with regard to gait as a result of the prism wear, consistent with the lack of adaptation (return toward baseline values during wear) to the prisms.

Previous work using horizontally yoked prisms indicates that some adaptation may occur nearly instantly.<sup>34,43,44</sup> In the present study, however, gait parameters changed on initial BD lens wear, with no sign of adaptation after 7 minutes, whereas in BU lens wear gait parameters were similar to baseline values.

To investigate the possibility that adaptation may have occurred within the first five walking trials, we analyzed these trials separately. In the BU lens condition, there was a significant narrowing of step width over the first three walks. There was no evidence of change in any other variable over these trials, in any lens condition. It remains possible that rapid adjustment with regard to these other variables may have occurred within the first few steps of the first walking trial, prior to reaching the mat, which may have masked an initial effect of the prism (with the effect and adaptation both occurring in the first few unmeasured steps). However, the lack of adjustment to BD prisms over the first five walking trials suggests that there was no early rapid adaptation. We are unable to confirm this because no measurements were taken in the first few steps.

Step width reduced across walking trials in the BU condition only. This may reflect that in this viewing condition subjects felt the need for a wide base of support initially, with this need diminishing with time and walking trials. In the BD viewing condition, no such finding was evident for step width.

This lack of adjustment over time with regard to most variables was unexpected. Previous studies have demonstrated adaptation to horizontally yoked prisms such that over a time period of up to 7 minutes, participants' walking path approached that of the baseline condition.<sup>33,45</sup> This was also the case when measurements involved walking speed and obstacle contacts while negotiating an obstacle course, where after approximately three or four walking trials with prisms, improvement plateaued to match the control condition.<sup>24</sup> The

main difference between those previous studies and the present study is the yoked prism base direction, being horizontal in previous studies showing adaptation and vertical in the present study showing no adaptation. Our finding suggests no adaptation of the effect on gait over a period of at least 7 minutes.

Although some adjustment over time was found in terms of step width reduction in the BU condition, no other such adjustment or adaptation was found. The lack of adaptation to the prisms in this experiment may have been due to the relatively short time period permitted for this. In a task assessing perceived sense of “straight ahead” in total darkness, Huang and Ciuffreda<sup>16</sup> found that adaptation occurred after 15 minutes of VYP wear, although no measurement had been taken at earlier time points. Perhaps, then, the critical time for adaptation lies somewhere between 7 and 15 minutes, or is different for different task types. However, our findings that step width adjusted in the BU condition suggest that sufficient time was allowed.

Testing involved a sample of young, healthy adults and cannot be generalized reliably to other populations. Aside from measuring visual acuity and performing a cover test to determine the absence of strabismus, we did not assess other aspects of visual function such as heterophoria, fixation disparity, vergence ranges, or eye movements, which might influence outcomes with VYP.

It is possible that VYPs exert an effect on lateral heterophoria due to the change in vertical gaze. However, a landmark study by Stuart and Burian<sup>46</sup> found that 66% of participants demonstrated less than 1 $\Delta$  difference in heterophoria magnitude with a change in vertical gaze of 20°. Of the participants who did demonstrate a larger exophoria in upgaze, a change in vertical gaze of 20 degrees resulted in a mean change in phoria of less than 2 $\Delta$ , and a maximum change of 5 $\Delta$ . Thus the 5 $\Delta$  (roughly 3°) prisms used in this current experiment would be expected to change the heterophoria by much less than 2 $\Delta$ . It is doubtful that this would have a significant effect on gait.

Horizontal vergence changes accompany vertical saccades. Upward vertical saccades are initially accompanied by divergence, followed by convergence toward the end of the saccade and during the postsaccadic drift. Likewise, downward saccades are accompanied by convergence followed by divergence.<sup>47</sup> Although saccadic suppression may diminish (not block; see Ilg and Hoffmann<sup>48</sup>) perception during saccades, any changes in retinal disparity due to vergence variations during the postsaccadic drift could very well affect spatial localization and gait.

The change in initial eye position or a change in ocular motility characteristics may have had an impact on gait. Participants may have responded to the shift in their visual world by a combination of eye and postural movements.<sup>20</sup> The eye's position within the orbit has been shown to contribute to the correct perception of space, specifically slant.<sup>49</sup> Saccadic eye movements also affect spatial localization (for review, see Leigh and Zee<sup>50</sup>). Collewijn and colleagues<sup>47</sup> found that the speed and waveform of upward saccades depended on initial eye position. Thus, the VYP used herein could have changed the nature and pattern of saccades via an effect on initial eye position. Saccadic eye movements contribute to one's perception of where things are in space relative to the eye, head, and body,<sup>50</sup> so interference or changes in saccades could lead to gait changes.

Fox<sup>5</sup> suggests that any impact of yoked prisms on behavior reflects a change in attention triggered by altered perception of the visual scene and mismatches between visual and other sensory inputs. A general change of this kind is likely to be nonspecific and may be expected to vary within and between

individuals depending on motivation and other behavioral factors. It seems plausible that attention could vary between BU and BD prisms of the same power if the two have perceptual effects that engage attention to differing extents. As explained above, since BD prism creates a perception of increased height and BU prism does not have this effect, attentional effects on gait may differ between the two.

VYP may interfere with the calibration of the oculomotor system. There is evidence<sup>51</sup> that a 3-dimensional, adaptable brain “map” develops for coordination and “automatic” control of binocular vertical saccadic movements. Both the image shift and the magnification differential described earlier could have interfered with such a map that would in theory require an adjustment of ocular movements. This altered ocular motility pattern and altered spatial map could require a subsequent adjustment of the motor responses required for walking.

Walking is guided to some extent by optic flow.<sup>52</sup> It seems likely that VYP could alter optic flow by magnification toward the prism apex. This combination of differential magnification and known asymmetries between the upper and lower visual fields (e.g., ganglion cell topography<sup>53</sup>; visual attention<sup>54</sup>; and saccade reaction time<sup>55</sup>) may account in part for the differential effects we found in yoked prism wear.

When our subjects opened their eyes and started to walk across the path in front of them, they would have been using visual information (distorted to some extent as described above) as well as vestibular and proprioceptive signals. The vestibular system provides information about translation and rotation of the head and body, and about their orientation and position with respect to gravity. Vestibular signals of this kind may have been mismatched with visual signals, for example, when walking along a level path that appears to be inclined. There is controversy over whether extraocular muscles send proprioceptive signals (reviewed by Ruskell<sup>56</sup>), but it is thought that ocular proprioception contributes to at least some extent to our sense of object location with respect to our position.<sup>57</sup> Gaze direction in VYP wear would be expected to have some effect on signals of this kind. Similarly, efferent signals to extraocular muscles may be different due to altered gaze direction in VYP wear, and this may have some impact on the wearer's sense of spatial localization. Extraretinal signals of this kind may all have had some impact on walking behavior.

The link between perception and action is apparent in locomotion, which is largely guided by peripheral visual information and in particular the lower visual field (reviewed by Marigold<sup>58</sup>). In view of this, it seems feasible that in the present study participants' gait was influenced by perceptual distortion. In other words, any uncertainty about aspects of the scene relevant to walking, such as floor position relative to foot position while walking, was processed by the visual system and used together with proprioceptive information in an attempt to make safe steps in the required direction.

Our findings apply to gait in young healthy individuals and do not imply that BD prism would affect other behavioral measures, such as visuomotor function in seated positions. The findings suggest that any effect of BD VYP on gait is not sustained, since the effect found here was lost immediately on prism removal.

What are the clinical implications of these findings, if any? As discussed earlier, VYP have been advocated for use in patients with disorders thought to be related to posture and in some cases gait. We find that in visually normal participants, gait is different in BD yoked prism wear than in BU yoked prism or PL lens wear. This indicates that the information provided by the visual system to guide walking was sufficiently different in the BD prism case to have a significant effect on gait parameters, including an increase in step time variability.

Gait variability is associated with risk of falling in older adults, and this association is thought to be related to physical and executive function in those individuals, rather than age per se.<sup>40</sup> With this in mind, our findings that step time variability increases and other gait parameters change in BD VYP wear raises questions about their use in patients with physical or cognitive anomalies. Further research would be needed to address this issue and to investigate whether VYPs are helpful or harmful in clinical populations.

In conclusion, a short period of BD VYP wear led to a more cautious walking pattern characterized by slower walking velocity, lower cadence, increased double support phase, shorter step length, and impaired walking stability, as suggested by increased step time variability compared with PL lens wear. With BU prism these effects were not found, but step width was found to decrease during the first five walking trials. Further research should focus on possible effects of longer-term wear and different prism magnitudes as well as investigating possible interactions between binocular status and any effects of the prism.

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