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A preliminary investigation of a novel design of visual cue glasses that aid gait in Parkinson's disease

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Objective: Parkinson's disease is a relatively common progressive neurodegenerative disorder, one of whose main features is difficulty with walking. This can be partially corrected by providing cues for the placement of each step. We piloted the potential benefit of simple custom-designed 'walking glasses' worn by the patient that provide visual and auditory cues to aid in step placement.
Design: We used a repeated measures design to compare gait performance when unaided and when using the walking glasses with different patterns of visual and auditory stimulation by timing patients' walking over a 'real-life' predefined 30-m course.
Setting: Hospital outpatient clinic.
Subjects: Fifteen patients with idiopathic Parkinson's disease who had significant gait problems and no other condition affecting gait performance.
Main measures: Timed walk.
Results: Using the glasses, 8 of 15 patients achieved a significant and meaningful average improvement in walking time of at least 10% (mean (95% confidence interval) improvement in these patients was 21.5% (3.9%)), while a further 2 had subjective and modest objective benefit. Different patterns of visual and auditory cues suited different patients. Visual cueing alone with a fixed horizontal cue line present all the time statistically resulted in the greatest improvement in walking time.
Conclusions: This pilot study shows promising improvement in the gait of a significant proportion of Parkinson's disease patients through the use of a simple, inexpensive and robust design of walking glasses, suggesting practical applicability in a therapy setting to large numbers of such patients.

Introduction

Gait disturbance is an almost universal complaint suffered by patients with Parkinson's disease as they inevitably progress to its more severe stages. It characteristically becomes stooped and shuffling, with particular difficulty in initiating gait and in navigating obstacles. Sometimes such difficulty may be so severe that the patient 'freezes' to the spot, unable to move either foot from the floor.

External cues that guide walking, such as auditory cues pacing individual steps, are well recognized to improve the shuffling and freezing phenomena,[1,2] sometimes even when the patient is

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distracted by performing concurrent activities.[3] However, quantitative randomized studies on the use of such cues do not always show benefit. For example, use of auditory cueing metronomes in one controlled study actually slowed gait, and did not improve freezing in the 'on' state even after training.[4]

Cues for walking that provide direct positional information, such as visible markers on the floor, might be thought to be more effective than rhythmic auditory cues but have obvious disadvantages in terms of requiring special floors. Patients may instead be trained to use a walking stick or frame placed where the next step should be; recently such aids have been developed to incorporate a laser line projected in front of the patient's feet.[5] However, placement of the stick or frame is itself a movement that might be underestimated in magnitude and also places additional demands upon the patient's already stretched 'programming' resources (performing two tasks simultaneously is another particular impairment in Parkinson's disease).[6] In fact, while they may increase confidence and stability, such devices when studied systematically may not reduce gait freezing and sometimes actually reduce walking speed.[7,8] Other studies indicate that, while some Parkinson's disease patients with freezing do respond to visual walking stick cues, most do not.[5] The lack of consistent benefit from visual cueing has been highlighted in a recent systematic review that stressed the importance of translating findings in the laboratory to those that have practical applicability.[9]

Recently, devices called 'walking glasses' have been developed and piloted. These provide visual cues during walking wherever the patient may be and without necessitating the performance of any simultaneous task.[10] Ferrarin *et al.*[11] reported up to 11% gait speed improvement in three Parkinson's disease patients using glasses with 70 light emitting diodes (LEDs) and a programmable microprocessor to generate a backwards 'flow' across the peripheral vision triggered by foot pressure to occur during the swing phase. A different device using flashing LEDs to provide rhythmic rather than spatial visual cues was shown to provide benefit with a carry-over training effect when used by therapists as part of a home training programme.[12]

In developing aids for walking in Parkinson's disease, it is clearly important to have a device that is simple to use and to demonstrate its utility in a proper systematic study. Since previous studies show variable effects depending on the patient and the particular cues, it is also important to explore the effects of different patterns of cues in different patients. Finally, given the large number of potential candidates who may benefit from the device, and the wear and tear that it is likely to suffer in the hands of patients with severe motor impairment, a cheap and sturdy device will also be greatly advantageous.

This study explored a novel design of walking glasses, worn alone or over prescription glasses, that generate a virtual image of a horizontal line on the floor below the patient's main field of view. This is done by a pair of two LEDs at the top of each lens reflecting off the angled lower surface of the lens. The lines projected from each lens may be switched on together or alternately according to a left–right gait pattern, or combined with auditory clicks to provide simultaneous rhythmic cueing. The glasses design is simple and cheap so that they may be readily available to a large patient population. We tested patients' walking speed over a defined 'realistic' 30-m course, with and without the glasses and using different combinations of visuospatial and rhythmic cues, to see if the glasses result in reliable improvements in walking in Parkinson's disease.

Methods

Fifteen patients (14 men and 1 woman (patient UP in Table 1)) with idiopathic Parkinson's disease were studied. The inclusion criteria were:

- Moderate to severe stage disease (Hoehn and Yahr[13] stage III or worse).
- Able to walk 30 m without aid.
- No other conditions that would adversely affect walking (e.g. cervical myelopathy, lumbar radiculopathy, lower limb arthritis).
- Problems with slow, shuffling gait and/or 'freezing' of gait for a significant proportion of the day (not just during brief 'wearing-off' periods).

Table 1 Responders vs. non-responders when using walking glasses

Patient	Age	UPD RS	Subjective benefit (%)	Visual alone (% faster)	Audio alone (% faster)	Visual + audio (% faster)	Alternating (% faster)
RK	67	19	70	20.8	12.8	20.8	24.0
HJ	74	29	50	18.4	8.8	17.0	19.7
TC	79	28	50	24.3	11.1	11.1	12.3
UP	63	14	25	10.5	–5.3	–4.8	–5.0
LC	83	34	50	27.9	19.2	29.3	19.7
BA	82	35	75	21.3	13.7	21.4	16.1
GP	47	27	75	27.8	11.6	28.4	29.3
AH	71	29	50	21.0	–0.5	16.1	13.0
PM	70	25	50	–0.9	8.5	9.4	9.4
MH	65	11	30	3.9	6.1	–1.1	2.6
JO	82	11	0	3.5	–11.5	–10.9	–11.5
PMc	64	9	0	2.9	2.1	2.2	3.6
CF	86	32	0	–1.6	2.6	–2.1	–1.6
PC	72	28	0	–0.6	0	–0.6	0.6
TR	63	41	0	1.5	–0.6	0.4	–2.9

Effect of walking glasses on mean walking time over a 30-m defined course. Patients' ages and Unified Parkinson's Disease Rating Scale (UPDRS) motor severity scores at the time of testing are shown. Four different aided conditions were tested and compared with unaided walking: (1) visual alone: fixed horizontal cue lines displayed in both glasses lenses, (2) audio alone: auditory brief clicks at the patient's preferred cadence frequency heard through headphones, (3) visual + audio: glasses and headphones used together, (4) alternating: horizontal cue lines switching between left and right glasses lenses at the patient's preferred cadence frequency to trigger left and right steps respectively. Eight of fifteen patients (shown above broken lines on table) had clear improvement in walking compared to unaided walking, as defined empirically by at least 10% faster than unaided walking time in at least one of the four aided conditions. A further two patients reported subjective benefit (between broken lines); one of these (PM) had almost 10% improvement in walking time when there were timed visual or auditory cues as opposed to fixed visual cues while the other had a modest objective benefit.

- On examination by the neurologist, a typical festinant Parkinsonian gait and no clinical features suggestive of a non-idiopathic parkinsonian condition.

Patients were recruited from the local neurology clinic and given informed consent. The study was conducted with local ethics committee approval. All patients' motor Unified Parkinson's Disease Rating Scale[14] (UPDRS) scores were determined immediately before and after assessment.

The walking glasses system consists of a pocket-sized control unit and the LED visual cue glasses (Figure 1).

The control unit measures 90 × 65 × 28 mm, weighs 150 g and contains the battery, drive electronics and user controls (function switches and a variable cadence potentiometer). It may be clipped to a belt or placed in a trouser or breast pocket. An interconnecting cable passes around the back of the wearer's neck, leading over the right ear, and plugs into the socket located on the right arm of the glasses frame.

The LED visual cue glasses consist of clear plastic lenses and a lightweight frame containing the wiring for the LEDs. On the top edge of both left and right lenses are fixed two LEDs connected in series. The straight horizontal bottom edge of each lens is chamfered to a 45 degree angle and polished to a mirror finish. The light from the LEDs shines down to illuminate this bottom edge and thereby creates a virtual horizontal cue line below the field of vision. The nose position of the glasses may be adjusted to alter the position of the cue line relative to the field of vision to suit the desired stride length of the individual (a parkinsonian stoop may shift habitual direction of gaze downward). The glasses can fit over normal spectacles so that prescription spectacle wearers can also use them.

The control box can be set to provide fixed cue lines, or lines alternating from left to right lens.

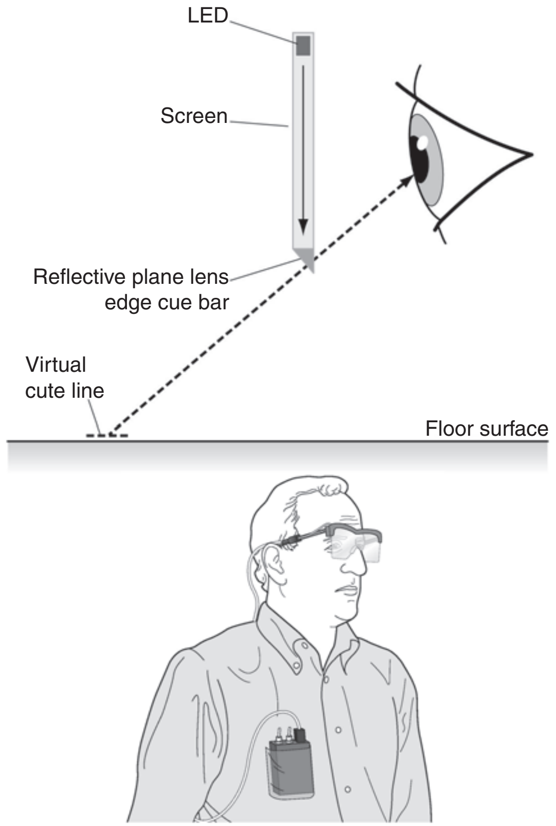

Figure 1 The walking glasses project light from light emitting diodes (LEDs) down through each lens to the straight chamfered lower edge of the lens where it is reflected and so appears to the wearer as a straight horizontal 'cue line' in the lower visual field. Auditory cues may be provided by a pair of standard headphones (not illustrated) connecting to the same battery box.

The frequency of alternation can be continuously adjusted to suit the patient's preferred cadence.

Where auditory cues are used, these are provided by personal stereo headphones connected to an output of the control box that produces clicks at the same frequency as that for the alternating cue lines.

Each patient was initially fitted with the walking glasses adjusted so that the cue line was positioned in the lower visual field to remain easily visible without requiring the patient to tilt their gaze too far downward to match a step to the line. Patients practised with the glasses for several minutes. Then they were fitted with the click-emitting headphones, practising again to determine an ideal clicking cadence.

Walking speed was determined over a standardized 15-m corridor course that included walking through a doorway, round a corner and turning back again (30 m total). Patients started on a 'go' command and were timed with a stopwatch.

Several conditions were tested in random order, timing three walking trials for each condition. Randomization was by drawing out unseen from a bag, one at a time, pieces of paper marked with the five conditions. Patients were given 5 minutes' rest between trials. The conditions were:

(1) Unaided
(2) Wearing walking glasses with fixed cue lines
(3) Using the auditory cue headphones emitting clicks at the preferred auditory cadence
(4) Wearing both walking glasses with fixed cue lines and the headphones clicking at the preferred auditory cadence
(5) Wearing walking glasses with cue lines alternating between left and right lenses at the preferred auditory cadence.

Data analysis

Differences between unaided vs. cued conditions, between trials vs. conditions, and between the different cued conditions were analysed by a repeated measures analysis of variance (ANOVA) design (SPSS). Correlations were determined by Spearman and Pearson coefficient calculations as appropriate.

Results

The patients were of mean (SD) age 71 (10.3) years and their mean motor UPDRS score at the time of assessment (SD) was 25 (9.8). There was no change in patients' UPDRS score when assessed again just after the half-hour study period.

Effect of visual cue glasses

Subjectively according to patients' own reports, 10 of 15 patients reported benefit from using the walking glasses. When expressed as a range from achieving perfect walking (100%) to no improvement at all (0%), these patients reported a mean (SD) improvement of 52.5% (17.0%).

On objective assessment across all 15 patients, significant differences were found in walking time within subjects between the five walking conditions (Wilk's lambda 0.603; $P = 0.005$). In contrast, there was no evidence for a within-subject effect between the three trials under each condition (Wilk's lambda 0.837; $P = 0.915$). Across all subjects and conditions, the mean coefficient of variation between the three identical trials was only 2.85%. The walking test therefore proved to be a reliable and repeatable test, with little random variation and no consistent variation due to learning or fatigue effects.

The mean (SD) unaided walking time across all subjects was 46.4 s (15.8). Taking the mean walking time of the three identical 30-m trials, and subtracting the values for the cued conditions for each subject from the unaided condition for that subject, mean (95% CI) improvements across all 15 subjects were (1) 12.1% (6.3%) using walking glasses with fixed cue lines, (2) 5.2% (4.6%) using auditory clicks at preferred cadence, (3) 9.1% (7.0%) using both fixed cue line walking glasses and auditory clicks, and (4) 8.6% (6.6%) using walking glasses with cue lines alternating between right and left glasses lenses at preferred cadence. Simple contrasts indicated that all four aided conditions were significantly better than unaided walking (glasses only, $P = 0.004$; audio only, $P = 0.024$; both glasses and audio, $P = 0.017$; alternating visual cues, $P = 0.013$).

There were significant correlations between (worse) unaided walking time and the amount of benefit from external cues for all conditions except alternating visual cues (glasses only Pearson $r^2 = 0.532$, $P = 0.02$; audio only Pearson $r^2 = 0.639$, $P = 0.005$; both glasses and audio Pearson $r^2 = 0.605$, $P = 0.03$). As expected, there was a strong correlation between unaided baseline walking time and UPDRS score (Spearman rho $= 0.906$, $P < 0.001$).

Responders vs. non-responders

The overall statistically significant benefit actually reflected benefit in only a subset of the 15 patients. It was empirically considered that for a clinically meaningful objective benefit, there should be at least a 10% reduction in walking time from using at least one type of cueing pattern (Table 1). Eight patients satisfied such criteria. As a illustration of the magnitude of benefit in these 'responder' patients, their mean walking time improved from 50.8 s unaided to 39.5 s using fixed visual cue lines alone, representing a mean (95% confidence interval) improvement in walking time of 21.5% (3.9%).

A further two patients reported subjective improvement without fulfilling the criteria for objective improvement (Table 1). One had almost 10% improvement using all types of rhythmic cues, whether auditory or alternating horizontal cue lines, but no improvement when the only cue was visual and non-rhythmic (i.e. the fixed cue line condition). The other had a modest benefit ranging from 2.6 to 6.1% for all cued conditions except where cue lines and auditory clicks were presented together.

Observations on effect of walking glasses in individual patients

Observation of the patients suggested that there were two main factors required for benefit to be gained from using the glasses. First, the patient's walking at the time of the test had to be impaired to a major degree by freezing spontaneously, on gait initiation or on negotiating turns and obstacles. Some patients at the particular time of testing did not display much freezing behaviour, while others appeared to derive benefit compared with their habitual walking performance simply from having practised the course and the motivation of being timed. Second, the patients had to be able to manage looking ahead while simultaneously being aware of the horizontal line across their lower field of vision. There were two patients who had particular difficulty with this. In the case of walking to auditory rhythmic cues, those that failed to respond tended not to be able to walk to the rhythm at all.

Comparison between different cue paradigms

Further comparisons were made between the different aided conditions in the responder patients.

Overall, there was a significant within-subjects difference between these aided conditions ($P < 0.001$). Pairwise comparisons between the individual conditions highlighted particular differences, but with Bonferroni correction for the 6 degrees of freedom, the only significant differences were that using fixed visual cue glasses alone or with audio was clearly better than using audio alone (visual alone vs. audio alone, $P < 0.001$; visual + audio vs. audio alone, $P = 0.036$).

It should be noted that such comparisons between different cue devices must be interpreted with caution in the light of the limited number of patients studied, and also because grouping patients together may mask the fact that individual patients may respond better to different cueing aids (Table 1). For example, patient LC had a mean 22.3 s benefit versus unaided walking when using fixed cue glasses and only a 15.0 s benefit when using cues alternating between lenses, while patient RK had only a 8.7 s benefit using fixed cue glasses and a 10.0 s benefit using alternating cues.

Further observations and discussion with patients indicated that different aspects of gait impairment could be helped by different cueing systems. For example, for gait initiation failure and freezing, the auditory or alternating visual temporal cues tended to be effective in initiating walking. Once patients were walking, they tended either to ignore such rhythmic cues or become fixed to them, which obviously limited cadence speed and in some cases appeared to become a further complicating task. Such cues did not help in turning or in negotiating obstacles. On the other hand, fixed cue lines tended to help both initiation and maintenance of walking, especially when navigating obstacles or turning. It was remarkable how little conscious attention needed to be diverted to concentrating upon the cue lines to achieve this benefit, especially after practice. There was a suggestion of a ‘carry-over’ type learning effect after using the glasses; since the order of trials was randomized, this would tend to reduce the measured benefit of the glasses in this study.

Discussion

Despite the generally accepted belief that external cues aid parkinsonian gait, when studied systematically the effect of using such aids has often been disappointing.[4,5,7–9] It was therefore encouraging that we were able to demonstrate significant improvements in waking time from using the walking glasses in our assessed population of moderately to severely affected Parkinson’s disease patients with gait problems.

The clear improvement noted in this study may partly reflect experimental design. Patients were selected who had significant walking impairment. It was found in this study that worse initial walking time correlated with greater improvement, suggesting that the worse the walking time, the greater the room for improvement. Conversely, there will be a limit effect with little room for improvement as patients approach a normal walking time (around 20 s for the course used in this study), even though there might be other circumstances where external cues may be of meaningful benefit to those individuals. Other studies on patients with only mild deficits may have suffered from this limit effect. In addition, patients in this study walked a 30-m course with a turn, a corner and a doorway. The importance of assessing turning and other real-life tasks in such circumstances has already been emphasized.[15]

Other aspects of study design may have lessened observed benefit. First, improvements may have been greater if all patients had their medication withdrawn, but the purpose of this study was to assess benefit to patients in their normal day-to-day life. The patients were therefore kept on their normal medication. They had been optimized on their medication so that they had little in the way of on–off fluctuations within the relatively short period of the study that might otherwise have confounded the findings. Second, motivation is an important factor improving gait in Parkinson’s disease, so that timed trials even without walking glasses appeared better than the patients’ normal walking. Approaching a limit effect in this way, combined with a carry-over effect after having practised with the glasses, would tend to reduce observed benefits. Finally, the statistical improvement from using the walking glasses was largely accounted for by a subset of responder patients. In these eight patients (out of 15), walking time improvements were of meaningful magnitude (on average 21.5% faster than unaided walking).

The explanation for gait and other deficits in Parkinson's disease may lie in a quantitative failure in selectively activating neural processes required for performing movement or cognitive tasks.[16] Thus, although the walking pattern is normal, the lack of sufficient activation of each muscle contraction results in a gross shortening of step size. Since internally cued tasks require a greater activation of processing or attentional resources than do externally cued tasks, the deficit can be partly compensated by changing steps from being internally cued by an in-built gait pattern to being externally cued by visible markers for each step position. This explanation, as opposed to one where there is a specific dependence on visual information rather than kinaesthetic information,[2] is supported by the fact that continuing to focus mentally on stride length after withdrawal of visual cues may still normalise stride length.[17] Increased mental vigilance instead of external cues may here be compensating for the internal cueing deficit.

In this study, fixed visual cues were statistically more beneficial than auditory cues. Using visual and auditory cues together resulted in no additional benefit over using fixed visual cues alone, nor did using alternating visual cues to present both visual spatial and visual rhythmic stimuli together. A previous comparison of visual cues of stripes on the floor and a metronome providing auditory cues showed a similar lack of additive effect.[18] This perhaps reflects the balance between external cues aiding a task and the additional cognitive resources required to direct attention to such cues, with the potential for task interference.[19]

Previous studies give differing reports on which cues are most effective, most likely reflecting that they have either set up their cues slightly differently or tested different aspects of gait performance. On detailed kinematic analysis of gait initiation on a forceplate, visual cues of transverse lines on the floor were found to improve initiation while auditory cues did not.[20] A recent similar study showed an improvement in single step parameters from auditory cues but not from non-spatial rhythmic visual cues.[21] Finally, a study conducted in the home environment found that auditory and not visual cues were helpful, and even then only when the subjects were performing another interfering task while walking.[8,22] The latter situation is nevertheless a realistic practical issue, as patients do report particular gait problems while talking or holding objects, and a device that helped to refocus attention on their gait would clearly be useful.

Azulay *et al.* considered that the best visual cue was one that provided perceived motion (i.e. dynamic)[2]; when stripes on the floor were lit not continuously but stroboscopically they were no longer helpful. Ferrarin *et al.* recently reported that patients with different disease severity may respond differently to walking glasses generating steadily streaming versus swing phase linked cues.[23] Once the patient is moving (after gait initiation), the cue line of our walking glasses is static relative to the patient and thus unlike more complex designs of walking glasses that generate a moving visual field. They nevertheless appear to be at least as effective. Like the proverbial carrot on a stick, they provide a cue perpetually signalling a target to aim towards.

Observation of the patients in our study indicated that, with remarkably little conscious diversion of attention, the fixed cue lines tended to help both initiation and maintenance of walking, especially when navigating obstacles or turning. In contrast, auditory or alternating visual temporal cues tended to be specifically effective in initiating walking or restarting after 'freezing'. Once patients were walking, they tended either to ignore such rhythmic cues or become fixed to them, the latter strategy perhaps limiting rather than improving cadence and constituting a complicating task.

A practical point in relation to choice of cues is that, at least in this pilot study, different cues appear to suit different patients. A flexible system that allows patients the option to *select* auditory, fixed visual or alternating visual cues according to preference or to changing circumstances may prove to be of greatest day-to-day use.

Given the simplicity, resilience and cueing flexibility of the walking glasses, the fact that over 50% of candidate patients may respond while continuing on their normal medication, and that this response can easily be determined over a half-hour experimental trial, patients could easily be directly tested for benefit from the walking glasses on a routine basis in a movement disorder or therapist clinic. Further studies, perhaps including direct or telemetric monitoring as part of a home-based training programme, are required to assess how a positive trial in this study setting relates to practical utility over a longer period.[24,25]

Clinical messages

- This novel design of visual and auditory cue glasses ('walking glasses') afforded a clear objective improvement in walking speed over a 'real-life' 30 m course by a mean of 21.5% in 8 of 15 Parkinson's disease patients and a subjective improvement in a further 2 patients.
- The glasses could be set up to provide fixed visual spatial cues, auditory rhythmic cues or visual spatial and rhythmic cues. Fixed visual cues were statistically superior, but different cue systems suited different patients.
- The inexpensive design of the glasses, and the ease of determining benefit to individual patients in a therapy outpatients setting, makes them promising as a practical aid.

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