RESEARCH ARTICLE

Pavement Patterns Can Be Designed to Improve Gait in Parkinson's Disease Patients

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ABSTRACT: Background: Public spaces are usually designed with respect to various patient populations, but not Parkinson's disease. The objective of this study was to explore what type of easily applicable visual cueing might be used in public spaces and some interiors to improve gait in people with Parkinson's disease.
Methods: Thirty-two patients with freezing of gait walked an 8-meter track on 6 different floor patterns in single- and dual-task conditions in random sequence. The reference pattern was a virtual large transverse chessboard, and the other patterns differed either in size (small floor stones), orientation (diagonal), nature (real paving), regularity (irregular), or no pattern. Time, number of steps, velocity, step length, cadence, and dual-task effect were calculated. The number and total duration of freezing episodes were analyzed.
Results: Virtual, large, transverse floor stones improve time (P = 0.0101), velocity (P = 0.0029), number of steps (P = 0.0291), and step length (P = 0.0254) in Parkinson's disease patients compared with walking on no pattern. Virtual floor stones were superior in time and velocity to the real ones. Transverse floor stones were better than diagonal, whereas regular pattern stones were superior to irregular in some gait parameters. Subjectively, the reference pattern was preferred to the irregular one and to no pattern. No direct effect on freezing of gait was observed.
Conclusions: Parkinson's disease patients may benefit from floor patterns incorporating transverse oriented large rectangular visual cues. Because public space can be regulated with respect to people with medical conditions, the relevant legislative documents should be extended to allow for parkinsonian gait disorder. © 2019 International Parkinson and Movement Disorder Society

Key Words: cueing; freezing; gait; Parkinson's disease; public space

Freezing of gait (FoG) is defined as a sudden inability to create effective stepping movements[1] despite the intention to walk,[2] and patients describe this experience as if their feet were glued to the ground.[3] FoG in Parkinson's disease (PD) is prevalent,[4] interferes with gait, leads to falls, and reduces quality of life.[5]

Rational FoG therapy is based on proper evaluation of the type of FoG present, that is, on deciding whether it is levodopa responsive, -resistant, or -induced.[6] In each case, either adjustments of pharmacological treatment or deep brain stimulation is recommended.[7-11] However, all types of FoG respond to various rehabilitation modalities. These can be used either as a rescue strategy when FoG occurs or to reduce the number of FoG episodes by optimizing spatiotemporal control of gait.[6,12] One of the most widely used techniques with good evidence is cueing,[12] defined as the use of a temporal or spatial stimulus to regulate movement.[13] The

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efficacy of cueing for FoG is based on shifting from habitual to goal-directed gait control.[12]

In previous studies, various parameters of cueing have been explored. Transverse lines seem to be more effective than parallel.[14] Similarly, regular (ie, predictable) are better than irregular and unpredictable,[15-17] and 3-dimensional visual cues are in some cases superior to 2-dimensional.[18,19] When one compares the effect of real and virtual cues, the former seem to produce greater effect in terms of stride length, cadence, and FoG frequency, but both are generally comparable.[20] However, most studies show that proper cueing parameters are highly individual.[21]

One of the easiest ways to apply cueing at home is to tape strips on the floor or to pave floor stones. When combined with general simplification of the interior (eg, getting rid of superfluous furniture and loose rugs), making narrow spaces wider if possible, and installing proper lightning, these strategies might greatly improve walking safety.[22] However, continual use of cueing has the disadvantage of inducing fatigue and may lead to cueing-dependence.[12] In the exterior, patients have to use portable audio players or devices able to generate augmented reality for visual ones, for example, Google Glass[23] or Cinoptics.[19] A more simple use of visual cues might be laser projectors installed on canes, walkers,[24] or shoes.[25] However, because of daylighting, not all laser projectors are able to function properly outdoors.

In most European countries, public spaces are designed and built with respect to wheelchair users and people with vision impairment.[26] Because PD patients both with and without FoG might also benefit from some environmental adjustments (eg, regular floor patterns that may easily be used in public spaces), more attention should be paid to this population. Therefore, we wanted to explore what type of visual cueing might be used in public spaces, especially in pavements and some interiors, for example, health-care facilities or PD specialized nursing homes. To our knowledge, this is the first study to explore various modalities of cueing with respect to usually employed floor patterns.

Methods

Patients

Thirty-two PD patients with FoG (median age, 67.5 years; median disease duration, 13 years; median MDS-UPDRS III, 24; median levodopa-equivalent daily dose,[27] 1155 mg) were recruited from the Movement Disorders Centre, Charles University, Prague. We recruited patients in the last quarter of 2017 and included all who were willing to participate on the grounds of the following criteria: a clinical diagnosis of PD according to UK Brain Bank diagnostic criteria,[28] age > 18 years, Hoehn and Yahr stage <5,[29] absence of severe cognitive impairment, and presence of FoG. For patients to be considered freezers, they either had to score ≥ 1 in question 3 of the Freezing of Gait Questionnaire (FoG-Q),[30] or FoG had to be present in the Rapid Turns test.[31] Patients were excluded if they suffered from other serious neurologic or orthopedic condition that could affect their gait, severe sensory deficits such as blindness, or peripheral neuropathy.

The study was approved by the Ethics Committee of General University Hospital in Prague (1247/17 S-IV). Written informed consent was obtained from all patients.

Experimental Protocol

All patients were assessed in the ON state by a movement disorders specialist (K.P.) who collected demographic and clinical information. After history taking and performing MDS-UPDRS,[32] the patients filled out a questionnaire consisting of the Parkinson's Disease Activities of Daily Living Scale (PADLS),[33] Gait and Falls Questionnaire, which comprises FoG-Q,[30] and questions related to the number of falls in past 12 months and to the patients' experiences of the effect of various architectonical elements on their gait (types of floor patterns, hallways, doors, narrow spaces, staircases, escalators, and elevators). Afterward, the Montreal Cognitive Assessment[34] was performed. In the subsequent subtraction task (backwards counting by 3s),[35] number of correct and incorrect answers in 10 seconds was recorded.

The patients were then asked to walk an 8-meter-long track, turn in the nonpreferred direction as established in the Rapid Turns test, and get back. They walked on 6 different floor patterns in single- and dual-task conditions (backwards counting by 3s) and could use walk aids if necessary. Both the floor patterns and single- and dual-task conditions were ordered randomly for each patient. We used the following 6 floor patterns. Four of these patterns were virtual, which enabled them to be easily switched (Fig. 1):

1. No pattern (gray carpet).
2. Real 50 × 50 cm transverse regular black-and-white (chessboard) floor stones.
3. Virtual 50 × 50 cm transverse regular black-and-white (chessboard) floor stones (reference pattern).
4. Virtual 5 × 5 cm transverse regular black-and-white (chessboard) floor stones.
5. Virtual 50 × 50 cm diagonal regular black-and-white floor stones.
6. Irregular virtual pattern, consisting of geometrical figures and signs.

We recorded the time, total number of steps, and number of steps in turning. We calculated gait speed, step length (without turning), and dual-task effect (DTE).[36] All gait trials were recorded using 3 cameras (fixed bird's eye, moving leg zoom, and moving frontolateral whole-body

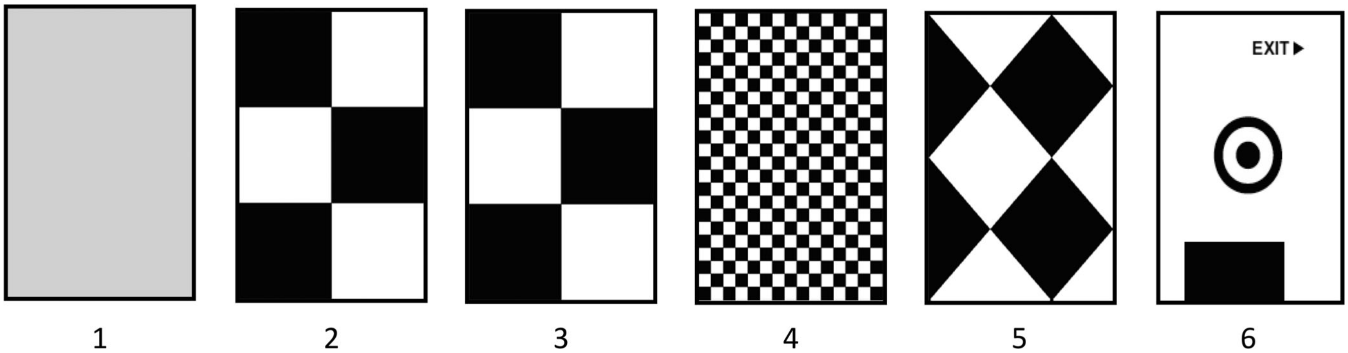

FIG. 1. Utilized patterns: 1: No pattern. 2: Real 50 x 50 cm chessboard. 3: Virtual 50 x 50 cm chessboard. 4: Virtual 5 x 5 cm chessboard. 5: Virtual 50 x 50 cm diagonal chessboard. 6: Irregular virtual pattern.

view; Suppl. 1), and answers in dual-task conditions were recorded using a portable microphone device. A blinded movement disorders specialist (H.B.) then reviewed all gaits and confirmed the presence of FoG during gait, counted the number of FoG episodes, and timed the total duration of all FoG episodes. We counted the number of correct and incorrect answers in dual task from the audio recordings. After walking the tracks, patients were asked to evaluate on a visual analog scale, how the patterns influenced their walking (Suppl. 2).

Finally, patients were assessed using the Short Falls Efficacy Scale-International,[37] Beck Depression Inventory,[38] STAI X-1, and STAI X-2,[39] by a movement disorders specialist (K.P.).

Gait speed and step length were selected as primary outcome measures and FoG, DTE, number of correct answers per second in dual-task conditions, number of steps when turning, and subjective evaluation as secondary. Our hypotheses were that visual cueing would improve primary and secondary outcomes compared with no cueing (pattern 1 vs 3). Second, we expected only regular pattern to be effective (pattern 3 vs 6). Third, we anticipated large floor stones to be efficient as opposed to small ones (pattern 3 vs 4). Fourth, we hypothesized that transverse floor stones would be superior to diagonal (pattern 3 vs 5). Finally, we assumed that the effect of virtual floor stones would be similar to the real ones (pattern 2 vs 3).

TABLE 1. Clinical and demographic characteristics of PD patients

	Patients with PD	
	(n = 32, 10 ♀, 22 ♂)	
	Mean (SD)	Range
Age (years)	65.4 (7.2)	46–75
Disease duration (years)	13.5 (5.6)	2–25
Hoehn and Yahr stage	2.5 (0.6)	2–4
MDS-UPDRS Total	64.3 (32.3)	29–158
MDS-UPDRS III	27.9 (18.7)	4–91
GFQ	17 (10)	3–42
FoG-Q	11.6 (6)	1–23
Short FES-I	12.8 (4.4)	7–28
MoCa	25.6 (3.8)	14–31
BDI	9.4 (6.2)	2–30
STAI X-1	42.5 (5.6)	26–51
STAI X-2	41.1 (5.3)	30–56

PD, Parkinson's disease; MDS-UPDRS, Movement Disorder Society Unified Parkinson's Disease Rating Scale; GFQ, Gait and Falls Questionnaire; FoG-Q, Freezing of Gait Questionnaire; Short FES-I, shortened version of the Falls Efficacy Scale-International; MoCA, Montreal Cognitive Assessment; BDI, Beck Depression Inventory; STAI, State-Trait Anxiety Inventory.

Virtual Reality Equipment

A system projecting virtual patterns on the floor was fixed on a 5-m-high ceiling. As the projected pattern was too long to be created by only 1 projector, the projected image was assembled using 3 Digital Light Processing (DLP) projectors. The projection was controlled by an application we developed in the software environment called VVVV (vvvv.org). This application allowed for the control of light conditions at 150 l× (recommended light level for halls and corridors), as well as of all projected content, and for the blending of the projected images. The projection system configuration is shown in Suppl. 3.

Statistical Analysis

Because of the nature of observed variables (counts, scales, and velocities), the nonparametric Mann-Whitney-Wilcoxon test was adopted to study the effects of floor patterns. P values were adjusted for multiple comparisons by a Holm method per each gait parameter. Effect size was evaluated using Cohen's d. Analysis was performed using R statistical package version 3.4.4.[40] $P < 0.05$ was considered statistically significant.

Results

Demographic subject data are shown in Table 1. The distribution of answers in PADLS was near normal, that is, 83% of the patients chose answer "b" (mild difficulties, 43.8%), "c" (moderate difficulties, 28.1%), or "d" (high level of difficulties, 12.5%).

In the single task, we found significant differences in time (P = 0.0101; d = 0.052), gait speed (P = 0.0029; d = 0.116), number of steps (P = 0.0291; d = 0.052), and step length (P = 0.0254; d = 0.143) between reference and no pattern. Patients had a significantly increased step length (P = 0.0395; d = 0.165) when walking on the reference pattern, compared with the irregular virtual pattern. We found no differences between walking on small and large floor patterns. However, differences in time (P = 0.0092; d = 0.173), gait speed (P = 0.0070; d = 0.082), number of steps (P = 0.0008; d = 0.118), and step length (P = 0.0033; d = 0.158) were significant for the reference pattern using transverse floor stones compared with diagonal ones. Finally, there were significant differences in time (P = 0.0160; d = 0.043) and gait speed (P = 0.0024; d = 0.122) in favor of the reference pattern with virtual floor stones, compared with real ones. Subjectively, significant differences of the patients' evaluation of floor patterns were found only in favor of the reference pattern compared with the irregular (P = 0.0066; d = 0.756) or no pattern (P = 0.0136; d = 0.939). These results are summarized in Table 2, and key results are shown in Figure 2. With respect to the number of FoG episodes and total FoG episodes duration, we found no differences between the 6 floor patterns. Indeed, 68%–91% of the patients did not experience FoG when walking on the 8-m-long track depending on the pattern and single- or dual-task conditions. This was the case even though they reported FoG in FoG-Q (see Table 1), and in 64% of the patients, FoG was also present in the Rapid Turns test.

Both the mean and median gait speed and step length decreased in the dual task regardless of the pattern. In the case involving the number of steps when turning, the median DTE was 0.0 for all patterns, but the mean varied from -31.3% to -0.2%. Similarly, the median number of correct answers per second decreased significantly in the dual task (pattern 1, P = 0.0126; pattern 2, P = 0.0126; pattern 3, P = 0.0126; pattern 4, P = 0.0044; pattern 5, P = 0.0126; pattern 6, P = 0.0126). Details are provided in Suppl. 4.

Discussion

The results of this study show that large, virtual, transverse floor stones improve some gait parameters such as time, gait speed, number of steps, and step length in PD patients compared with walking on no pattern. Moreover, the improvement in step length compared with no pattern, irregular pattern, or diagonal floor stones greatly exceeded the minimal clinically important difference (MCID) established for older adults.[40] In the case of gait speed, MCID is also available for PD patients.[41] Our results did not reach the threshold for small MCID established by distribution-based analyses, effect size metrics, and sample variability within gait speed. However, applying established cut points in the UPDRS motor scale, the improvement in gait speed when walking on large, virtual, transverse floor stones was slightly above the associated small MCIDs compared with no pattern and diagonal and real floor stones. Moreover, the MCID values established by Hass et al are derived from a slightly less affected PD population compared with ours, and they only walked straight ahead, whereas our patients also had to turn. Therefore, MCID for gait speed comprising a turn has not been to our knowledge established yet.

TABLE 2. Significance of gait parameter differences depending on task (single × dual) and on floor pattern in a single task

	ST vs DT	Real vs reference	Small vs reference	Diagonal vs reference	Irregular vs reference	No pattern vs reference
Time	$P < 0.0000$	P = 0.0160; R shorter; d = 0.043	NS; d = 0.039	P = 0.0092; R shorter; d = 0.173	NS; d = 0.008	P = 0.0101; R shorter; d = 0.052
Gait speed	$P < 0.0000$	P = 0.0024; R faster; d = 0.122	NS; d = 0.053	P = 0.0070; R faster; d = 0.082	NS; d = -0.105	P = 0.0029; R faster; d = 0.116
Total number of steps	$P < 0.0000$	NS; d = 0.051	NS; d = 0.055	P = 0.0008; R lower; d = 0.118	NS; d = 0.038	P = 0.0291; R lower; d = -0.052
Number of steps without turn	$P < 0.0000$	NS; d = 0.048	NS; d = 0.052	P = 0.0444; R lower; d = 0.152	NS; d = 0.020	P = 0.0239; R lower; d = -0.023
Step length	$P < 0.0000$	NS; d = -0.059	NS; d = -0.090	P = 0.0033; R larger; d = 0.158	P = 0.0395; R larger; d = -0.165	P = 0.0254; R larger; d = 0.143
Step length without turn	$P < 0.0000$	NS; d = -0.079	NS; d = -0.125	NS; d = 0.092	NS; d = -0.149	P = 0.0220; R larger; d = 0.145
Subjective evaluation	—	NS; d = 0.210	NS; d = -0.495	NS; d = 0.087	P = 0.0066; R preferred; d = -0.756	P = 0.0136; R preferred; d = 0.939

ST: single-task; DT: dual-task; Real = real 50 x 50 cm transversal regular black and white floor stones; Small: virtual 5 x 5 cm transversal regular black and white floor stones; Diagonal: virtual 50 x 50 cm diagonal regular black and white floor stones; Irregular: irregular virtual pattern consisting of geometrical figures and signs; No pattern: no pattern (grey carpet); Reference: virtual 50 x 50 cm transversal regular black and white floor stones; R: reference pattern; NS: not significant, d: Cohen's d.

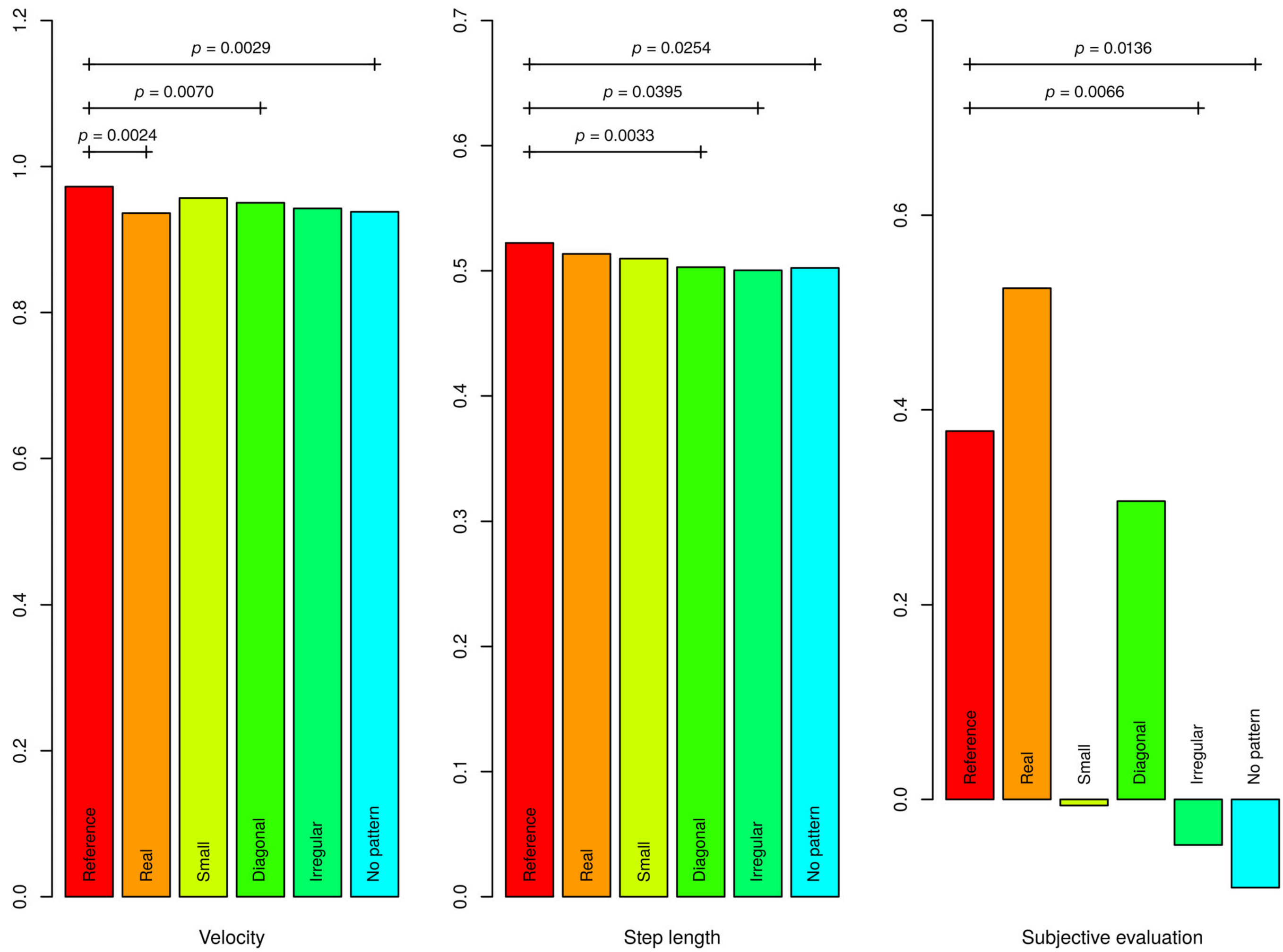

FIG. 2. Differences in velocity, step length and subjective evaluation between the six utilized floor patterns in single task. [Color figure can be viewed at wileyonlinelibrary.com]

We did not observe any direct effect on FoG when walking on any of the 6 patterns. This was probably because most patients did not experience FoG in the laboratory settings, even though they reported FoG in FoG-Q, and in approximately two-thirds, FoG was present in the Rapid Turns test. Such discrepancy has already been noted.[6,31,42] Nevertheless, the positive effect of large, virtual, transverse floor stones on step length was significant and is probably related to FoG. Several studies have shown that factors such as diminished step length and step-to-step reduction in amplitude may lead to FOG,[43] and stabilizing these gait parameters by visual cues might prevent its occurrence.[12,13] Therefore, it seems reasonable to suppose that visual cues help to increase and maintain step length and thus alleviate FoG.

Surprisingly, there were no significant differences in any spatiotemporal parameters between large and small floor stones. This might suggest that regularity and transverse orientation common to both patterns are more important than size. However, this should be further investigated because it contradicts to some extent the findings of Chee et al.[27] In their study, however, decreased step length was imposed on the patients, which was not the case in our experiment. The only effect of small floor stones that could be observed was the increase of mean DTE with respect to the number of steps when turning discussed below.

A further interesting result is that virtual floor stones were superior in time and gait speed to the real ones of the same size and orientation. This is probably because walking in a virtual reality environment was so unusual for the patients that it drew more attention to the cues given than the real ones. The importance of paying attention to the cues has already been described.[13,44] In time, however, patients will probably adapt to virtual cues so that their effect will diminish and will probably become equally as effective as real cues. Nevertheless, our results are in contrast with the findings of previous research in which real cues resulted in similar or even greater improvement of various gait parameters.[20,45] However, it is not specified in these studies, whether environmental light conditions were adapted when using virtual cues. If not, real cues could have been seen more sharply. Moreover, patients in these studies used either laser lines[45] or virtual reality glasses.[20] In the former case, laser lines might not have been extraordinary enough to attract more attention than real cues. In the latter case, the use of virtual reality glasses might have been even more unusual than the virtual environment in our study. However, virtual reality glasses have been reported to distract patients and narrow their field of view, thus blocking sensory visual feedback needed for gait.[19] Such a negative impact might have been the cause of the superiority of real cues in this study.

Large, real, transverse floor stones might be easily used on pavements and floors, be it in private houses of PD patients or in public spaces such as hospitals, nursing houses, public offices, and so forth. In most European cities, however, pavements are made of concrete without any pattern. In historical city parts, cobblestones are used and ordered into various shapes, often diagonal. In public interiors, various patterns are being used, usually based on aesthetic reasons. The findings of this study suggest that the current architectonical practice might be optimized to meet the needs of PD patients similarly to how it takes into consideration other disabilities (eg, wheelchair users or people with vision impairment).

Two objections may be raised against this suggestion. First, because the height of each individual varies, so does the step length, and consequently also the requirements with respect to the floor stone size, that is,. cueing frequency. However, assuming people's height is normally distributed, that is, 68% is to be found within 1 standard deviation of the mean and 99.7% within 3, choosing cueing frequency on the grounds of mean height might be more efficient.[46] Furthermore, because cobblestones are often used and their size is completely inappropriate and concrete pavements lack any pattern, any change might be considered an improvement.

Second, one might object that the effect of cueing fades in time[12] so that the effectiveness of floor stones might be questioned. However, this is true for all cueing, which is nevertheless still used. Theoretically, the habituation of cues might be diminished by changing various pattern characteristics, for example, its color. Therefore, if pavements were not built uniformly, the effect of floor stone cueing might be prolonged. However, the effect of non-uniform pavements would have to be studied because irregularity might cause FoG.

Large, virtual, transverse floor stones are rather suitable for the interior because of the negative impact of daylight on projected images. In the interior, however, the advantage of virtual floor stones lies in the modifiability of their characteristics: their frequency might be tailored to the user and their color and other characteristics changed to prevent habituation. Therefore, a device capable of projecting such modifiable patterns should be developed for commercial use.

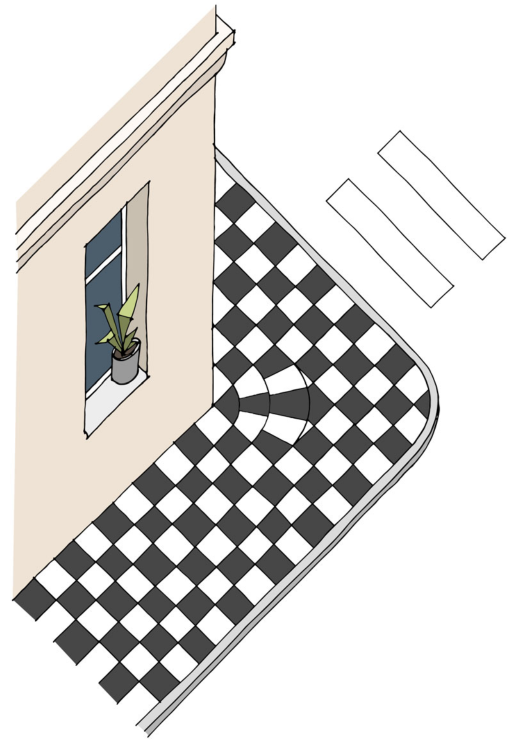

FIG. 3. Possible way how to utilize floor stones in corners to help with turning. [Color figure can be viewed at wileyonlinelibrary.com]

The beneficial effect of visual cues used in this study was only observed under single-task conditions and was lost while dual-tasking. This might be explained by impaired ability to prioritize, which is common in PD and especially in freezers.[47,48] To evaluate the effect of cueing as it could be expected in real-life situations, patients were not instructed what to focus on either in single-task or in dual-task situations. Although single-task patients spontaneously used cues, dual-task patients probably lost their focus on the provided cues and paid attention to counting. This suggests that in clinical practice, dual-task gait training should be introduced in patients with FoG with the goal of improving dual-task gait performance and possibly increasing the patients' attentional capacity to be able to use cueing.[49] Moreover, it is reasonable to instruct the patients to try to avoid unnecessary dual-tasking during walking (eg, using a mobile phone or carrying objects instead of putting them into a backpack).

Furthermore, our results differ from those of other studies[36,50-53] and even from the conclusion of a systematic review,[54] which claims that visual cueing does improve gait performance in dual-tasking. However, Galletly et al[50] investigated the effect of cueing in a population with mild deficits (mean UPDRS III score, 14.4 ± 6.1; mean MMSE score, 28 ± 3), which could also suggest better ability to dual-task. In the 3 other studies,[36,51,53] patients were asked to synchronize their steps to a flash of light generated by a light-emitting diode attached to glasses. Such a use of visual cues differs from the one employed in this study, so that the results cannot be easily compared. Moreover, they used a motor dual task, which is less demanding in terms of attention than a cognitive one.[50] Finally, in Rochester (2010),[52] the effect of a 3-week cued gait training and not the immediate effect of cues was investigated.

Therefore in dual-task conditions, auditory cueing[36,51,53,55] or self-instruction strategies[56] might be more effective than visual cueing. However, Lohnes et al[56] did not confirm the effect of auditory cues in dual-tasking probably because they used a more challenging cognitive secondary task. Therefore, the issue remains controversial.

Even though the median DTE with respect to number of steps when turning was 0.0 for all floor patterns, its mean might indicate some effect of virtual diagonal floor stones and virtual small ones. In the former case, the mean DTE was the lowest, whereas in the latter case the highest (Suppl. 4). DTE with respect to number of steps when turning was positive in 45% of the patients and in 29% equaled 0.0. This might suggest that some patients used the diagonal floor stones as cues when turning. Consequently, such floor stones might be incorporated into corners, as suggested in Figure 3. In contrast, mean DTE with respect to number of steps when turning increased by more than 50% in nearly 47% of the patients (or even by more than 100% in 5 patients and by 200% in 1 patient). This might indicate that small floor stones are the least appropriate probably because they put too much load on attention.

The limitations of this study include a relatively small number of patients and testing in laboratory settings. Therefore, future studies should verify the present findings in real-world situations and in a larger sample size. Moreover, because most of the patterns used in this study were virtual, their positive effect should be tested in real ones.

Conclusions

The present findings suggest that PD patients benefit from using large transversal visual cues, which might be incorporated in floor patterns in both the exterior and the interior. Because public indoor and outdoor space can be and is regulated with respect to people with some medical conditions, the relevant legislative documents should be extended to allow for parkinsonian gait disorder.

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Supporting Data

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