Comparing auditory, visual and vibrotactile cues in individuals with Parkinson's disease for reducing risk of falling over different types of soil

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Abstract

Introduction*:* Several researches have demonstrated the positive benefits of auditory and visual cueing in the gait improvements among individuals with Parkinson's disease (PD). However, few studies have evaluated the role of vibrotactile cueing when compared to auditory and visual cueing. In this paper, we compare how these stimuli affect the risk of falling while walking on six types of soil (concrete, sand, parquet, broken stone, and two types of carpet).

Methods*:* An instrumented Timed Up and Go (iTUG) test served to evaluate how audio, visual and vibrotactile cueing can affect the risk of falling of elderly. This pilot study proposes twelve participants with PD (67.7 ± 10.07 years) and nine age-matched controls (66.8 ± 8.0 years). Both groups performed the iTUG test with and without cueing. The cueing frequency was set at 10% above the cadence computed at the lower risk level of falling (walking over the concrete). A computed risk of falling (ROFA) index has been compared to the TUG time (total TUG duration).

Results*:* The index for evaluating the risk of falling appears to have a good reliability (ICC > 0.88) in this pilot study. In addition, the minimal detectable change (MDC) suggests that the proposed index could be more sensitive to the risk of falling variation compared to the TUG time. Moreover, while using the cueing, observed results suggest a significant decrease in the computed risk of falling compared to 'without cueing' for most of types of soil especially for deformable soils, which can lead to fall.

Conclusion: When compared to other cueing, it seems that audio could be a better neurofeedback for reducing the risk of falling over different walking surfaces, which represent important risk factors for persons with gait disorder or loss functional autonomy.

Key words: Falls, iTUG test, Parkinson's disease, cueing

Introduction

Parkinson's disease (PD) is one of the most common neurodegenerative disorders. Among PD population, gait is characterized by some impairments such as festination (a reduction of the step length, shuffling gait, an increase of the gait cadence) and frequently the freezing of gait (FOG) (Dibble and Lange 2006). People with PD may also have difficulties in starting and stopping due in part to muscle rigidity (Dibble and Lange 2006; Nieuwboer and Giladi 2013). Gait disorders worsen with the disease progression, limiting severely the functional autonomy and the person's quality of life. Considering that usage of drugs (e.g. the levodopa) comes with some drawbacks such as an increase of gait impairment (Băjenaru et al. 2016), the main objective of fall prevention is therefore to maintain balance and an independent lifestyle thanks to a non-pharmacological method. To achieve this goal, a person's functional ability is evaluated in early stage through the mean of clinical tests such as the Timed Up and Go (TUG) test (Frenken et al. 2013).

The TUG test is one of the clinical tests recently instrumented with wearable technologies in several studies summarized by Sprint et al. (Sprint et al. 2015), giving promising results towards the automation of clinical assessments. Various technologies (wearable inertial sensors, video-based or smartphone-based, among others) are exploited to gain a more objective or quantitative indication of gait disorders. However, many of these devices are affected by several constraints, such as the encumbrance, the weight and the lack of portability, which limit their usage in daily activities. To overcome these situations, recently, many other research works, summarized by Hedge et al. (Hegde et al. 2016) have implemented pressure-sensitive insoles for analyzing some gait parameters. Although these constraints are surmounted with instrumented insoles, the great challenge remains the cost reduction and a device able to warn a user from a risk associated with gait disorders. In this context, and also for bringing a clinical test at home, we propose to use, in this present study, an enactive insole labelled ACtive Human computer Interaction for Locomotion Enhancement (ACHILE system). This enactive insole is used for the evaluation of the risk of falling and then for reducing the risk level over six types of soil using three cueing (auditory, visual, and vibratory).

Since 1967, visual cues have been reported as having positive effects on gait variability. Martin (Martin 1967) has showed the positive effects of transverse lines on floor by noting that persons with PD increase their stride length and gait velocity. Other researchers (Arias P. and Cudeiro 2010; Delval et al. 2014; Wright et al. 2016) have suggested that auditory cues provided by a metronome have resulted in improvements in velocity and cadence during gait, and reducing the FOG duration. Several studies continue to show the efficacy of auditory and visual cueing at improving specific impairments and functional limitations in healthy elderly or individuals with PD (Lim et al. 2005; Baker et al. 2008; Lohnes and Earhart 2011; Rocha et al. 2014; Schlick et al. 2015; Yogev-Seligmann et al. 2016; Young et al. 2016). In this line of thoughts, other studies (Galica et al. 2009 Oct; Yu et al. 2010; Yang et al. 2015; Basta et al. 2011) demonstrated that the vibrotactile feedbacks could be useful in correcting sway and balance of walkers. They used miniature vibrating apparatus, which were composed of sensor and stimulation components.

A shortcoming of the previous works has been the limitation to a clinical or laboratory setting that does not consider the patient's environment such as the type of soil. In fact, some studies (Menant et al. 2009; Sprager and Zazula 2011; Muaaz and Nickel 2012) related the effects of different types of soil on the gait parameters. Furthermore, it is known by Maki that variability in gait parameters is indicated as an important factor in fall prediction (Maki 1997). Therefore, the type of soil can lead to an increase of the risk of falling. Thereby, this paper evaluates the possibility of reducing the risk of falling while walking over different surfaces (concrete, parquet, broken stone, carpet living room, carpet foam and sand) with different sensory feedbacks: visual, auditory and vibrotactile. We compare the impact of these different cueing modalities on the value of the risk of falling. Unlike using the TUG time (total TUG duration) as a threshold for differentiating faller from non-faller, we also introduce a new approach for evaluating a risk of falling in an instrumented TUG test with an enactive insole designed for the ACHILE research project.

Materials and methods

Suggested insole technology

The suggested insole technology is an intelligent system developed in our laboratory (Figure 1). It is used for preventing falls related to extrinsic factors such as the types of soil and intrinsic factors such as the gait parameters. This device counts a set of non-invasive sensors which include an accelerometer for evaluating cadence, stride time, duty cycle; and force sensors for measuring the center of pressure position (COP) and motion (computed as a local barycenter under the foot). Force Sensitive Resistors (FSRs) manufactured by Interlink Electronics were used for assessing the force distribution under the foot. Two of FSRs (diameter, 15 mm, FSR402) were placed underneath the heel pad, one medially and the other laterally. The two others were placed under the first and fifth metatarsal approximately. Overall, this device measures the forces applied at four points under the foot. Using these sensors, the enactive insole is exploited to compute the risk of falling level associated to human balance. Furthermore, this insole contains one Eccentric Rotating Mass (ERM, a VPM2 manufactured by Solarbotics) actuator (the vibrating motor) located under the Plantar Fat Pad which enables vibrotactile cueing in order to reduce the risk of falling level. The battery used for the power supply has a lifetime, which depends essentially on the use of the actuators.

Two schematics of the enactive insole (depending on the size of the feet) and a Smartphone for data recording are presented in Figure 1. During the iTUG test, the data are sent in real time via Bluetooth to an Android application at a sampling rate of 100 Hz. A user-friendly interface was designed using the TUG procedure. The software is running as a serious game for training elderly performance. The TUG time and the cadence computed by our Android application are displayed for user and can be improved at each usage.

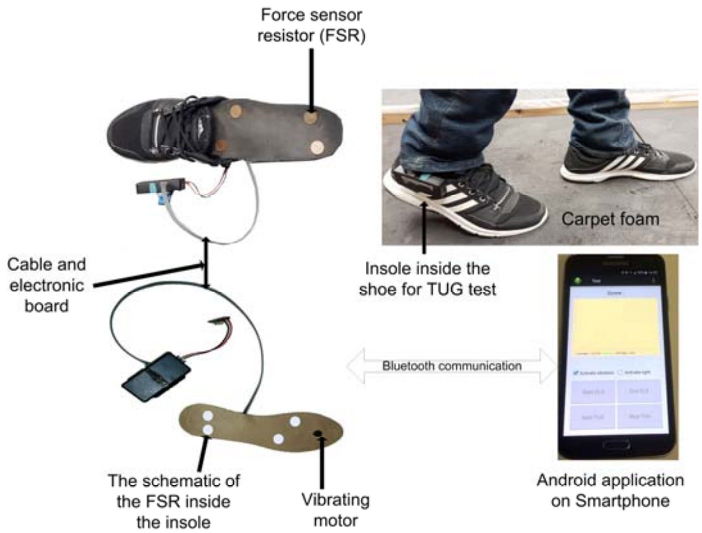

Figure 1. The ACHILE system (two types of enactive insole and Android application)

Proposed risk of falling (ROFA) index

The risk of falling proposed in this study is based on the results described by Noshadi et al. (Noshadi et al. Jan 2010). For a better clinical assessment tests, the aim was to combine into a single score, the most significant gait parameters known to be related to the falls. Accordingly, we used the concept of the Coefficient of Variation (CV) of gait parameters as suggested by Lewis et al. (Lewis et al. 2000 Oct). Then, the ROFA index (labeled I_{ROFA}) is expressed as follows (Otis et al. 2016):

$$I_{ROFA} = \alpha * (\mathrm{CV_{cad}} + \mathrm{CV_{SL}})$$

where CV_{cad} and CV_{SL} are respectively the CV of instantaneous cadence and stride length; and α represents the coefficient attributed to the variability of the gait parameter. This coefficient can be adjusted by physicians or clinicians in order to tailor the instability assessment for a personalized analysis (Noshadi et al. Jan 2010). In our study, this coefficient is inversely equal to the walking velocity value v ($\alpha = 1/v$).

We hypothesize that ROFA index, including some gait parameters, can be a better indication than the clinical TUG time.

Table 1

Table 1. Demographic information and clinical characteristics of the participants.

Variables	PD participants Mean ± SD (Range)	Healthy elderly Mean ± SD (Range)
No. of participants	N=12	N=9
Age (years)	67.7 ± 10.07 (53-77)	66.8 ± 8.0 (57-77)
Male/Female	10M /2F	1M / 8F
Height (cm)	169.5 ± 21.5	146.6 ± 21.76
Duration of the disease (years)	10.67 ± 6.05 (1-20)	------
Hoehn and Yahr scale	2.5 ± 0.88 (1-4)	------
Taking of medication	11/12#	------
UPDRS score	43.42 ± 14.9 (16-72)	------
UPDRS motor score	20.6 ± 6.5 (9-31)	------
TUG time in sec (on concrete)	12.7 ± 1.99 (8-17)	8.9 ± 0.89 (7-10)
Fear of falling	33.83 ± 14.75 (16-57)	------
PDQ-39	53.58 ± 29.9 (70-116)	------

SD: Standard deviation; UPDRS: Unified Parkinson's Disease Rating Scale; TUG: Timed Up and Go; PDQ: Parkinson's disease Questionnaire; # mainly Levodopa

Participants

This study was approved by the local Ethical Committee of UQAC (certificate number 602.434.01). Diagnostics of idiopathic PD, presented as an ability to ambulate independently without assistive device were performed by a neurologist. After that, PD participants were recruited from a convenience sample at Parkinson Society of Saguenay and the control participants were spouses or kinships of PD participants. Twelve participants with PD (moderate, under medication and predominantly fallers) and nine age-matched controls (elderly without PD) have participated in this study (Table 1). The dominance of the right limb was 11/12 (92%) for PD participants and 9/9 (100%) for healthy elderly. The side showing more impairment was measured directly on the PD participant during the Unified Parkinson's Disease Rating Scale (UPDRS). Eleven were affected bilaterally and one unilaterally. In participants with bilaterally side affected, 73% were more marked at right; 9% more marked at left and 18% on both sides equally.

The inclusion criteria for all participants were: 1) ability to walk over different surfaces; 2) an adequate vision and a sufficient hearing acuity; and 3) an apparent somatosensory perception of the lower limb. The cognitive impairment was verified in unpublished study (preliminary study) before this present study. Then, the exclusion criteria for all participants were the existence of a cognitive impairment, an uncontrolled health such as orthopedic disorders, joint prosthesis, or others. Based on 30-point global, none participant involved have presented a cognitive impairment. Furthermore, PD participants were excluded if they presented any other neurological disorders or any comorbidity that may affect gait.

Clinical evaluation

Each participant was informed about the experimental protocol and signed the informed consent form. The PD participant was rated by the UPDRS (Fahn and Elton 1987), the Parkinson's disease Questionnaire, PDQ-39 (Bushnell and Martin 1999) and the fear of falling (Tinetti et al. 1990).

It is known that the fear of falling (FOF) influences spatial and temporal gait parameters in elderly persons which consist in slower gait speed, shorter stride length or increase stride width (Chamberlin et al. 2005). However, the prevalence of fear of falling of healthy elderly, by gender and age groups, is around: 86% (no fear); 10% (moderately fearful) and 3% very fearful (Arfken et al. 1994). Moreover, based on the many studies summarized by Scheffer et al. (Scheffer et al. 2008), the reported prevalence of FOF varied between 3% and 85% (Binda et al. 2003; Rochat et al. 2010). Since the FOF score is usually close to a low score (less than 10%) for some healthy people, we have only conducted the FOF questionnaire with PD participants because our study is mainly focused on them. We summarized the results of these tests (UPDRS, PDQ-39 and FOF) in Table 1.

Experimental protocol

Most of the participants have had one fall in the last six months. From the Parkinson society of Saguenay where the participants were recruited, three of them used walking aids (2 cans, one walker), but only at home and outside summer. However, during the experimentation performed for this study, none of participants has used walking aids implying devices except one PD's participant who received sometimes a physiotherapist aid with attached belt. The enactive insole of ACHILE system (Figure 1) was introduced in the shoe of the right foot. Given that the PD participants are reached mostly bilaterally, we think that a single insole placed on the right foot (usually the dominant foot) could measure the complete cycle of the participant's walking. This also makes it possible to reduce the production cost of the ACHILE device.

Before the evaluation (data recording), each participant (PD participant and healthy elderly) comfortably performed two or more walking trials across three meters along a walkway. The goal was to ensure that the participant understood the test. Then, the test recording by the Android application can begin. For each participant, the experimental procedure listed below was done at the same day. The procedure has performed as follows as:

1) two or more iTUG tests without cueing over the baseline soil (walking over concrete). After that, an average value of cadence has been computed.

2) the iTUG test on the five other types of soil (parquet, sand, broken stone and two types of carpet) without cueing.

3) the iTUG test over the six types of soil in each of the following conditions: auditory, visual, and vibratory cueing at 10% above baseline cadence computed in the case 1.

The ideal frequency of cueing has yet to be fully defined, but it is known that auditory cues ranging from 90% to 125% of preferred cadence have shown benefit in terms of gait velocity (McIntosh et al. 1997; Howe et al. 2003; Suteerawattananon et al. 2004; Willems et al. 2006), stride length (Thaut et al. 1996; McIntosh et al. 1997; Willems et al. 2006; Arias Pablo and Cudeiro 2008) and cadence (McIntosh et al. 1997; Howe et al. 2003; Suteerawattananon et al. 2004; Willems et al. 2006; Arias Pablo and Cudeiro 2008). In addition, Moreau et al. (Moreau et al. 2008) who used higher auditory frequencies (20% and 40% above the preferred walking cadence) have found an increase of FOG in PD subjects. Therefore, the use of 10% above the cadence of the walker was based on previous results (Hausdorff JM et al. 2007; Arias Pablo and Cudeiro 2008; Arias P. and Cudeiro 2010). Stimulation at this frequency is known to reduce the coefficient of variation of stride time (Hausdorff JM et al. 2007; Arias Pablo and Cudeiro 2008; Arias P. and Cudeiro 2010) which is associated with FOG (Hausdorff J et al. 2003). Our research hypothesis is that cueing stimulation at the frequency proposed modifies the walking pattern, reducing the risk of falling level over different types of soil.

The presentation order of the types of soil and cues were randomized. The five different types of soil such as parquet, sand, broken stone, carpet foam and carpet living room were brought from their natural environment to our laboratory. The vibrotactile cueing was delivered by the vibrating actuator (vibrating motor) of the ACHILE system in pulses of fifty milliseconds. The auditory cueing was delivered through a stationary metronome while the visual one was rendered via a computer monitor located in front of and behind the participant. Participants were given as much time as requested to rest between trials, and fatigue did not appear to limit them. Due to the mechanoreceptor dysfunctions, few participants reported being unable to feel the vibrotactile cueing (one healthy elderly and five PD participants) resulting in the rejection of their results for the vibrating cueing condition. In this situation, we didn’t change the vibrotactile actuator since the aims of the study is to use low cost insole with small actuator (low current consumption) and then using very low amplitude vibration (near the perception threshold). Thus, it's normal for some participants to be withdrawn from the study.

Statistical analysis

Statistical analysis was performed using the software PRIMS-5 by Graph Pad Co San Diego USA. All outcomes (TUG time and ROFA index) were normalized for each experimental condition by using individual baseline value (walking over concrete without cueing). These relative values were compared across conditions using a one-way analysis of variance (ANOVA) with Tukey's pairwise comparisons. Also, the relationship between the TUG time and the ROFA index was assessed with a t-test and the Pearson's correlation. Finally, the minimum detectable change was computed and analyzed as suggested by Pardo et al. (Pardo et al. 2013).

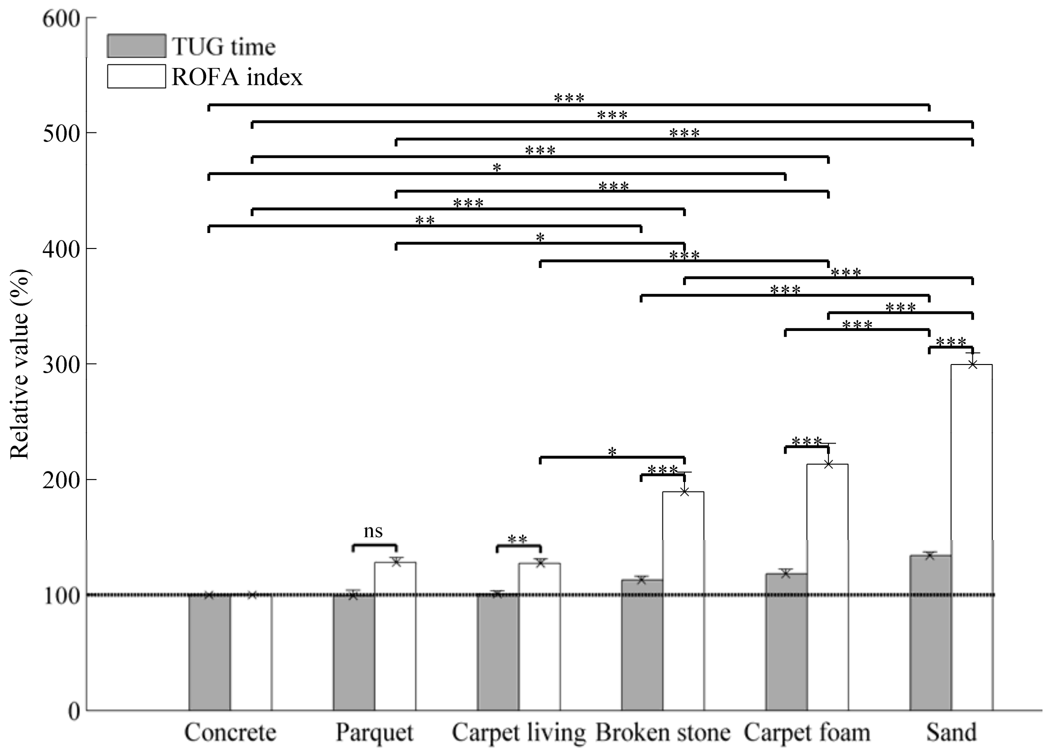

Figure 2. Relative values of TUG times and risk of falling (ROFA) index without cueing over different types of soil among healthy elderly.

The mean of relative values is reported. The errors bars indicate the standard error of mean (SEM)

***** indicates significantly different with p < 0.05. ****** indicates significantly different with p < 0.001. ******* indicates significantly different with p < 0.0001. ^{ns} indicates non-significantly different with p > 0.05.

ROFA: Risk of falling from gait parameters; TUG: Timed Up and Go

The dashed line represents the baseline.

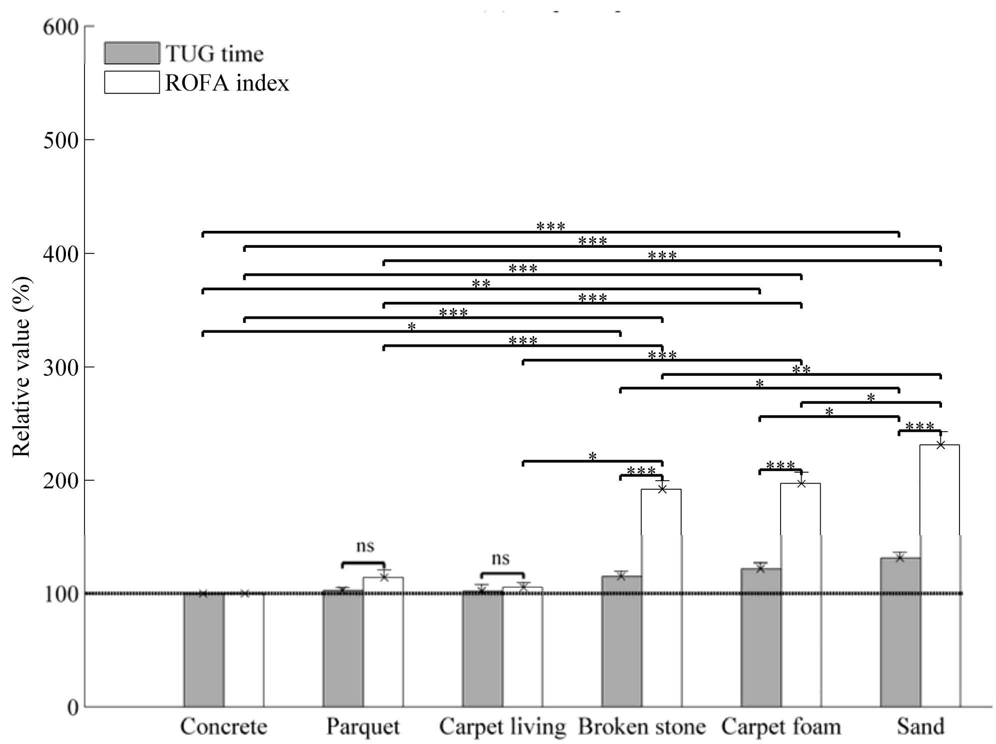

Figure 3. Relative values of TUG times and risk of falling (ROFA) index without cueing over different types of soil among PD participants.

The mean of relative values is reported. The errors bars indicate the standard error of mean (SEM)

* indicates significantly different with $p < 0.05$. ** indicates significantly different with $p < 0.001$. *** indicates significantly different with $p < 0.0001$. ^{ns} indicates non-significantly different with $p > 0.05$.

ROFA: Risk of falling from gait parameters; TUG: Timed Up and Go

Results

Walking without cueing and minimum detectable change

As seen in Figures 2 and 3, after ANOVA analysis, the multiple pairwise comparisons showed that the TUG times are similar and non-significant *($p > 0.05$)* for concrete, parquet and carpet-living-room, respectively (100%; 99.0 ± 5.1%; 100.7 ± 2.8%) for healthy elderly, shown in Figure 2; and (100%; 102.8 ± 2.3%; 102.0 ± 5.8%) for PD participants, shown in Figure 3. However, the results for broken stone, carpet-foam and sand, respectively (113.0 ± 3.2%; 118.3 ± 4.1%; 134.0 ± 3.2%) for healthy elderly and (115.2 ± 4.5%; 122 ± 5%; 131 ± 5.1%) for PD participants were significant ($p < 0.0001$).

PD participants have taken 50% more time to complete the iTUG on concrete soil without stimulation (Table 1). Moreover, it was only on broken stone, carpet-foam and sand that the average of their TUG time overpass 14 seconds (the threshold used by the literature (Shumway-Cook et al. 2000 Sep) for distinguishing faller from non-faller). The minimum detectable change (MDC) was close or around to 1 sec. or 10% for healthy elderly (0.83 sec. over concrete) and it has doubled for PD participants (1.78 sec. over concrete). We observed similar results for ROFA testing (0.78 sec. for healthy elderly and 3.96 sec. for PD participants over concrete).

A t-test performed between the TUG time and the ROFA index showed a significant effect when the participant walked on deformable soils (broken stone, carpet-foam and sand) but no significant difference was found as regards the rigid soils except over carpet-living-room in healthy elderly (Figure 2). The better sensibility for risk of falling measurement is the existence of Pearson correlation (r) between TUG time and ROFA index ($r = 0.56$, $p < 0.05$ among PD participants) over baseline soil. In addition, the similarity of the results from TUG time and ROFA index are these significant Pearson correlations: ($r = 0.75$, $p < 0.0009$); ($r = 0.82$, $p < 0.001$); and ($r = 0.74$, $p < 0.001$), respectively for UPDRS/ROFA, stage H &Y/ UPDRS motor, and UPDRS/fear of falling.

Clinicians and researchers usually focus on a measure of relative reliability, the intraclass correlation coefficient (ICC). The ICC is reported as a coefficient ranging from 0 (no reliability) to 1.0 (maximum reliability). It has been suggested that ICC values above 0.75 are indicative of good reliability. The relative reliability coefficient reported here is above 0.88 for ROFA testing.

Effects of cueing (10% above the cadence) over concrete

ANOVA analysis and pairwise comparisons indicated that no significant effet of cueing was observed on TUG time with healthy elderly ($p > 0.05$, Figure 4-a). In PD participants, a significant effect of visual cueing was observed compared to uncued situation ($p < 0.022$, Figure 4-b). As regards the ROFA measurement, Tukey tests confirmed a significant effect of cueing for the two groups.

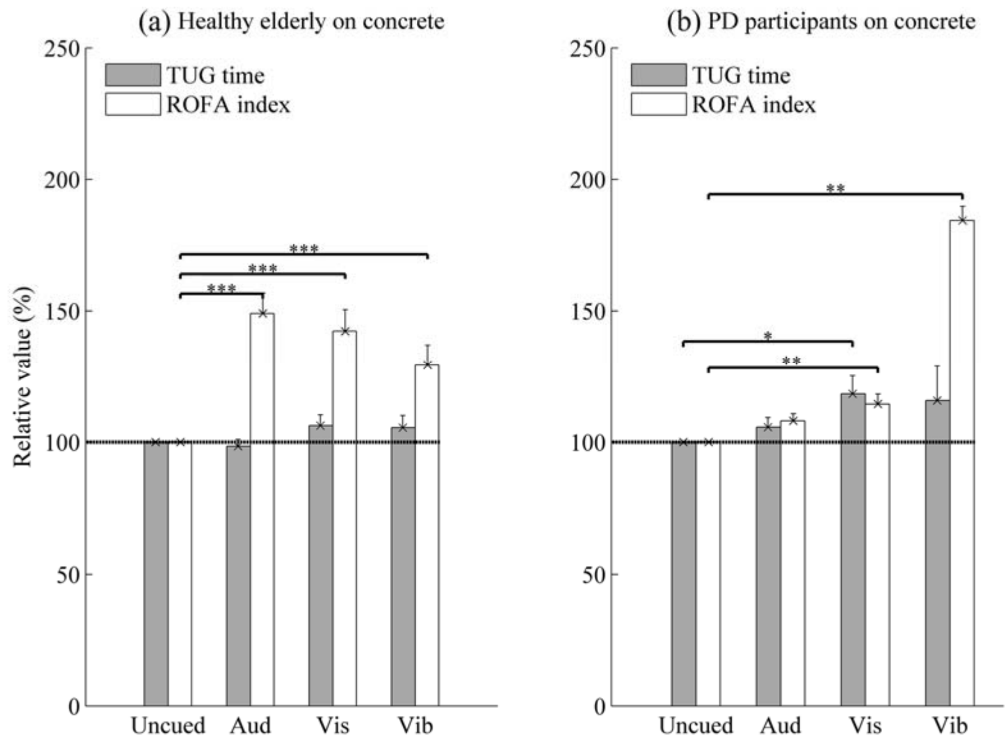

Figure 4. Effects of 10% above the cadence over concrete

The mean of relative values is reported. The errors bars indicate the standard error of mean (SEM)

* indicates significantly different with $p < 0.05$. ** indicates significantly different with $p < 0.001$. *** indicates significantly different with $p < 0.0001$.

Note: In vibrotactile condition, the data were represented for seven PD participants and eight healthy elderly (HE). For other cueing conditions, it was 12 PD participants and 9 HE.

Aud: Auditory; Vis: Visual; Vib: Vibrotactile; ROFA: Risk of falling from gait parameters; TUG: Timed Up and Go

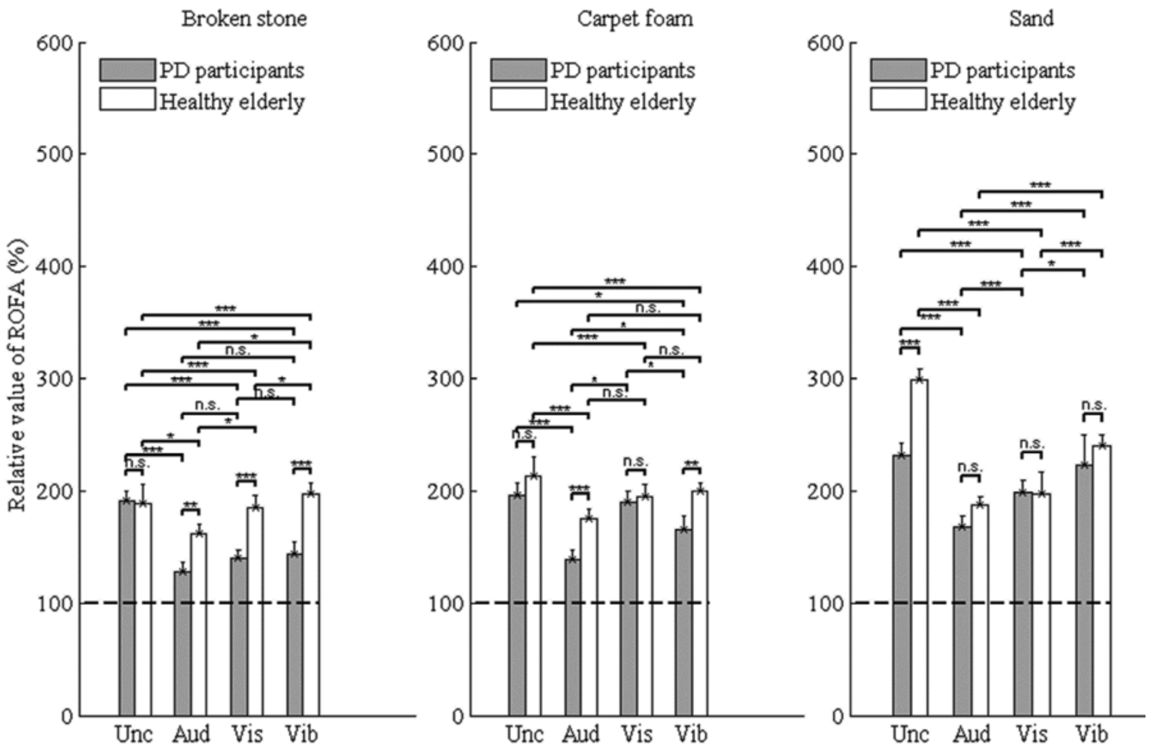

Figure 5. Relative values of the risk of falling under the following conditions: uncued, auditory, visual and vibrotactile

The mean of relative values is reported. The errors bars indicate the standard error of mean (SEM)

***** indicates significantly different with $p < 0.05$. ****** indicates significantly different with $p < 0.001$. ******* indicates significantly different with $p < 0.0001$. ^{ns} indicates non-significantly different with $p > 0.05$.

Note: In vibrotactile condition, the data were represented for seven PD participants and eight healthy elderly (HE). For other cueing conditions, it was 12 PD participants and 9 HE.

Unc: Uncued; Aud: Auditory; Vis: Visual; Vib: Vibrotactile; ROFA: Risk of falling from gait parameters; TUG: Timed Up and Go

Effects of cueing on the risk of falling over deformable soils

In Figure 5, there was no significant difference between the three cueing when PD participants walked over broken stone or when healthy elderly walked over carpet-foam ($p > 0.05$). By comparing the vibrotactile cueing with the uncued condition, no significant difference was found when PD participants and healthy elderly walked over the sand. Also, no significant difference was found for the visual cueing compared to the uncued condition when PD participants walked over carpet-foam. All other pairwise comparisons between cueing conditions have given a significant effect as shown in Figure 5.

Discussion

The main contribution of this paper is in three aspects. Firstly, the walking test on deformable soils, in particular over sand, carpet-foam and broken stone, represents a better model to differentiate the risk of falling in healthy elderly and PD participants. Secondly, the ROFA index proposed is more sensitive to differentiate levels of the gait disorders (and also probably to identify fallers from non-fallers) than the TUG time (see Figures 2 and 3). Thirdly, the use of cueing, mainly auditory, improves the walking by reducing the risk of falling among all participants (Figure 5).

Effects of no cueing on the risk of falling

The similarity of the results from TUG time, ROFA measurement and the significant Pearson correlations, suggested that ROFA index represents an interesting instrument to evaluate the risk of falling. From this pilot study, we think that ROFA measurement could become adequate to detect the risk of falling compared to the TUG time. Indeed, the ROFA measurement has shown a good reliability and a significant measure on carpet-living-room, broken stone, carpet-foam and sand contrary to the TUG time where the significant measures were only on broken stone, carpet-foam and sand (Figures 2 and 3).

Effects of cueing on the risk of falling

The most important results of this pilot study concern the positive impact of cueing on the risk of falling over different types of soil. However, over concrete, no significant positive effect of cueing was observed on TUG time testing for healthy elderly and PD participants (Figure 4). In fact, PD participants had taken more time to execute the TUG test in visual cueing. Moreover, in Figure 4, we observed that an increase of 10% above the cadence on concrete had the effect of increasing the gait parameters (Arias P. and Cudeiro 2010) and then the risk of falling on a rigid soil.

In literature (Azulay et al. 1999; Lee et al. 2012), both static and dynamic visual cues improve the spatiotemporal gait patterns of participants with PD. The difference found with our study can be explained by the design used for rendering the visual cueing. It was located at six meters from the participant at the eye level, and the participant has to watch the computer monitor without seeing the soil while walking. This cueing would have may be overloaded or shared the attention. We note that the healthy elderly participants have not presented this type of response (as shown in Figure 4-a). This means that the lack of visual stimulation effect is not entirely due to the design but the capacity of the participant. This design has also been chosen because it is closer to the realization of walking's activities of everyday life.

The auditory cueing has a significant positive effect on deformable soils such as the broken stone, carpet-foam and sand (Figure 5). This means that the use of cueing, mainly auditory, improves gait in a perturbed walking environment by reducing the risk of falling. This confirms the impression of participants that this type of cueing was comfortable and did not divide the attentional process as in the visual cueing situation. From a questionnaire, 70% of PD participants and 44.4% of healthy elderly preferred the auditory cueing and mentioned that this cueing induced a confidence to avoid fall compared to visual and vibrotactile cueing. The reduction of risk of falling observed over the deformable soils compared to the no-cueing situation was due to a regular stride length and cadence, and an increase of gait velocity, while walking under cueing conditions (Figure 5). Indeed, auditory feedbacks offer a rich augmented environment of sensory cues. This may have provided to PD participants more ways to enhance attention and focus on the required tasks and make them explicit by using the frontal lobe, motor-occulomotor, basal ganglia, cerebellum and limbic loops connectivity in internal cueing. Therefore, auditory cueing has improved the walking instability and mobility especially over deformable soils. These results are consistent with the findings reported in (Spaulding et al. 2013; Delval et al. 2014) which concluded that auditory cueing is more effective than visual cueing for treating gait disorders in PD and helping gait initiation.

The auditory cues provide an external rhythm, which is able to compensate the defective internal rhythm of the basal ganglia (McIntosh et al. 1997) whereas visual cues act on the visual-cerebellar motor pathway to facilitate a better gait pattern (Azulay et al. 1999; Lee et al. 2012). Thus, the difference observed between healthy elderly and PD participants can be explained by the fact that both populations treat sensory information differently.

The case of vibrotactile cueing is different and the results were inconsistent but interesting for future works. The variability observed in the figures 4 and 5 is due from the reduction of peripheral sensory information (proprioception, mechanoreceptors and skin information). For example, five of the twelve PD participants did not feel the vibrotactile feedback and three others barely feel it. Among healthy elderly, only one participant did not feel the vibrotactile cueing. In Figure 4-b, the use of vibrotactile cueing in PD participants increased the ROFA index above 150% compared to other situations. This can be explained by the fact that PD participants have probably tried to feel in mind the vibration while walking. The results with vibrotactile cueing (Figure 5), mainly over sand, show an increase of the risk for PD participants and were not significantly different from uncued condition. This can be explained by a perceptual conflict: the vibration of the sand at the heel strike could have augmented the unfelt of vibrotactile cueing. However, an important change in the gait parameters such as a regular stride length occurred when using a vibratory cueing, suggesting that this may be an effective tool for improving the regulation of gait of elderly or individuals with gait impairments.

For our present study, we didn't make a test-retest procedure elapsed by few days for each subject. Even if the number of subjects is low and in our knowledge, they can't be considered as normative values, we believe, in reason of some relation with TUG values, that these results suggest a generalization. Thus, of all the foregoing, ROFA testing computed by the ACHILE system contributed to a growing body of evidence showing that our system using cueing may be useful for reducing risk of falling of PD participants.

Conclusion and future works

We think that the ROFA index combined with TUG time should allow the clinician to better identify the patient at risk of falling. The ROFA index is computed by the ACHILE system and transmitted wirelessly to a mobile device. In this case, the information displayed on the mobile device can be understood easily by clinicians and patients. This monitoring is important to assess the progression of the disease and the improvement between the clinical visits. In addition, it can give information to the neurologist to adjust drug prescription as needed. The longitudinal change information is important for rehabilitation and probably can help to decrease the number of visits to physicians and clinicians. The collected data will be useful for extracting some information in real time to suggest a correction in regard of gait deficits and some other motor complications like motor fluctuations.

The limitation of this study is the generalization of finding to a wider population due to small sample size used. Also, for a better feeling and reducing perceptual conflict with the soil vibration at each heel strike, the vibrotactile cueing should be related to a different waveform easily differentiable and customizable from the other vibrations while remaining low cost and with low power consumption. Given that the fall is a multi-factorial phenomenon, the other limitations of this study are the combination and the generalization to all gait measures in a single index. However, our first evaluation reported in this study shows encouraging results. Our next paper will include several gait measures using an artificial neural network (ANN) which will be performed with more participants. The design of such an algorithm for more gaits features and for all activities is still an undergoing issue.

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Conflict of interest

None.

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