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Research Article

Metronome-Cued Stepping in Place after Hemiparetic Stroke: Comparison of a One- and Two-Tone Beat

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Hemiparetic gait is characterised by temporal asymmetry and variability, and these variables are improved by auditory cueing. Stepping in place incorporates aspects of gait and may be a useful tool for locomotor training. The aim of this pilot study was to investigate the use of a single-tone and dual-tone metronome to cue stepping in place after hemiparetic stroke. Eight participants completed an uncued baseline stepping condition and two cued stepping conditions utilising a single-tone and a dual-tone metronome. Step times were determined from force plate data, and asymmetry and variability were calculated for the three conditions. Step time asymmetry was significantly reduced in the single-tone condition compared to baseline, and paretic step time variability was significantly reduced in both cued conditions. The single-tone metronome appeared to be preferred to the dual-tone metronome based on participant feedback. The results of this pilot study suggest that metronome cueing produces similar benefits on stepping in place to previously reported findings in walking. Further research on whether stepping in place to a metronome can be used for locomotor training is needed.

1. Introduction

Hemiparetic gait is characterised by several specific deficits, including decreased walking speed [1], increased variability [2], and asymmetrical stepping [3, 4]. Understanding and rehabilitating these features of hemiparetic gait are of paramount importance as walking affords a considerable level of independence and thus a better quality of life for many stroke survivors [5].

Temporal asymmetry is a common characteristic of hemiparetic walking, even amongst independent ambulators [6], is very resistant to rehabilitation efforts [7], and appears to progress in later stages after stroke [8]. Temporal asymmetry is associated with increased vertical ground reaction forces through the nonparetic limb [9], and repeated higher forces over prolonged periods increase the risk of joint pain [10] and degeneration [11]. Temporal asymmetry is associated with decreased performance on clinical balance tests [12] and therefore may be linked to the increased risk of falling observed after stroke.

Increases in the variability of gait parameters is of concern as only a small increase in stride time variability is associated with a risk of future falls [13]. Greater intraindividual variability in step length and double support time is linearly associated with increased risk of multiple falls in older adults, with a nonlinear association for step time variability [14]. Gait variability is higher after stroke than in healthy controls, and there is a direct association between underlying paretic limb impairment and step variability [2]. It is possible that this increased variability is linked to inferior dynamic balance after stroke.

The use of an auditory rhythm, such as a metronome, has been investigated as a means to improve hemiparetic gait [15]. Immediate effects of a metronome have been reported, with chronic stroke patients able to synchronise to a metronome during treadmill walking [14]. Improvements in temporal symmetry were observed with acoustic pacing, as was the ability to make gait adjustments in response to auditory cues [16]. Auditory cueing has also resulted in a decrease in swing time variability and muscle activation variability in the paretic limb during gait [17].

Cueing of each step has demonstrated stronger auditory-motor synchronisation as opposed to cueing only the paretic or nonparetic step [18], indicating that cueing both footfalls is important in metronome studies. The most beneficial metronome cueing rate for auditory-motor synchronisation is at the preferred cadence of the individual participant [19], and this is likely to be the most effective at improving gait symmetry. Gait has been cued with a different pitch for left and right footfalls [19], however it is unknown whether this approach has benefits over the use of a single pitch for both footfalls.

Stepping in place is a skill which requires reciprocal flexion and extension of the lower limbs by timely coordination and synchronisation to create a single limb support phase, a swing phase and a step frequency [20]. These components are also found in gait, and suggest stepping in place is an appropriate form of locomotor training. The temporal asymmetries typically seen in hemiparetic walking are also shown in stepping in place [20]. Therefore, it is possible that stepping in place to an auditory cue may provide an alternative to gait training, allowing stepping to be conducted in environments where space is restricted for walking training or as a precursor to overground walking training.

The first aim of this pilot study was to assess whether immediate improvements in step timing and variability observed in metronome-cued walking could be elicited by metronome-cued stepping in place. The second aim was to investigate whether the use of a single-tone to cue both limbs or a separate tone to cue each limb provided any additional advantage.

2. Materials and Methods

2.1. Participants. Ten community-dwelling adults (four female) with chronic hemiparesis (see Table 1), gave written informed consent to participate. Favourable ethical opinion was granted by the Local Research Ethics Committee and was carried out in accordance with the principles laid down by the Declaration of Helsinki. Participants were recruited through local media publicity. Inclusion criteria were at least 6 months afterstroke, walking disability but retained ability to stand and transfer, and a Rivermead Motor Assessment Gross Function (RMA GF) scale score [21] of 6–12. Participants were excluded if they had cognitive impairments preventing understanding of the task or hearing impairments reducing ability to hear the metronome.

2.2. Data Collection. All testing occurred during a single session and consisted both of uncued and cued stepping in place. Participants stepped on two force plates (Bertec 4060 H, Ohio, USA), placed side by side, with one foot on each force plate. Participants were asked to step in place at their comfortable speed to obtain baseline measures. Their average step time at baseline was determined and used to determine the interresponse interval (IRI) for the metronome. In the cued trials, participants were instructed to listen to the first 5 tones before initiating their first step response. Participants were instructed to time their footfalls to the metronome beep. In the dual-tone condition, they were instructed to time their left footfall to the high beep and their right footfall to the low beep (see Figure 1). Each baseline and cued trial lasted 30 s, and participants were given breaks between trials to minimise fatigue.

Table 1: Demographic information.

Demographic information	
Age	61 ± 16 years
Time since stroke	6 ± 2 years
Gender	6 male, 4 female
Paretic side	6 right, 4 left
RMA GF (maximum 13)	10 ± 1

Participants synchronised their footfalls to the pulse of a metronome programme running on a PC which played at a regular IRI. The single-tone metronome and the first pitch of the dual-tone metronome were set to a frequency of 700 Hz, whereas the second pitch of the dual-tone metronome was set to 1400 Hz. The tone duration was 100 ms. The IRI of the metronome pulse was created based on the participants' individual uncued stepping times (average of left and right step time) and presented using the MatTAP toolbox [22].

Five baseline stepping trials were conducted, followed by 5 stepping trials in each cued condition. A crossover design was adopted so that half the participants were randomly assigned condition 1 followed by condition 2 and vice versa. A familiarisation period of 30 s stepping to the cue was utilised prior to data collection in the cued conditions. The Timed Up and Go (TUG) test [23, 24] was conducted after each stepping condition as a functional mobility test. A rest period of 10 minutes was given between the two cueing conditions to minimise crossover effects.

2.3. Data Analysis. Data were sampled at 2000 Hz and filtered using a 2nd-order, multipass Butterworth filter with a cut-off frequency of 15 Hz. Paretic and nonparetic step timings were determined from initial footfall contact on the force plates using a custom analysis script in MatLab (MathWorks, Natick, MA, USA). Paretic step time was defined as the time between a nonparetic foot contact to the next paretic foot contact, whereas nonparetic step time was defined as the time between a paretic foot contact to the next nonparetic foot contact. The first 5 step times were discounted from analysis. Step time asymmetry was determined using a step time ratio, where paretic step time was divided by nonparetic step time. The coefficient of variation (CoV) was calculated as a measure of variability for step time for the paretic and nonparetic sides. Over 24 steps of data were collected for each condition, meeting the recommendations for gait variability studies [25].

Differences between cued and baseline conditions were examined using a Friedman test. Posthoc analysis using

Table 2: Step time asymmetry and variability and Timed Up and Go times for the three conditions.

	Baseline	Single tone	Dual tone	P
Step time asymmetry	1.24 ± 0.24	1.16 ± 0.15	1.19 ± 0.18	0.048
Paretic step time variability (%)	11.31 ± 0.05	9.04 ± 0.03	9.53 ± 0.03	0.034
Nonparetic step time variability (%)	12.02 ± 0.07	7.89 ± 0.03	8.62 ± 0.03	0.135
Timed Up and Go (s)	23.8 ± 15.2	20.8 ± 12.1	24.5 ± 16.2	0.089

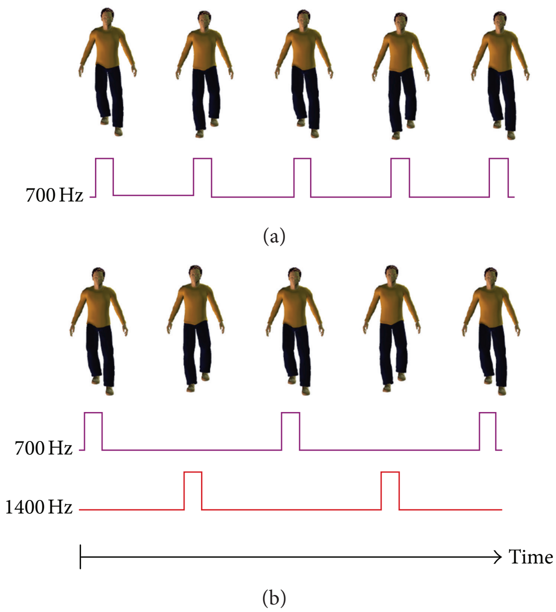

Figure 1: Illustration of metronome-cued stepping in (a) the single-tone condition and (b) the dual-tone condition.

Wilcoxon signed-rank tests identified the location of any differences from baseline. A Bonferroni adjustment for multiple testing was also investigated, resulting in $\alpha = 0.025$ for the post hoc analysis.

3. Results

One participant withdrew due to lacking confidence in stepping in place, whilst another participant withdrew due to a dislike of the dual-tone metronome; therefore, 8 participants completed the study.

Six of the eight participants displayed mild asymmetry (step time ratio 1.10–1.50) and two displayed severe asymmetry at baseline (>1.50). For these two participants with severe asymmetry, the use of a metronome reduced their asymmetry to <1.50. There was a significant main effect for condition ($\chi^2(2) = 6.077$, $P = 0.048$) for step time asymmetry (see Table 2). Post hoc analysis revealed this difference to be between baseline and the single-tone condition ($Z = -2.207$, $P = 0.027$); however, this was not significant with the application of a Bonferroni adjustment.

There was a significant main effect of condition for paretic step time variability ($\chi^2(2) = 6.750$, $P = 0.034$). Post hoc analysis showed these differences to be between baseline and both the single- ($Z = -2.240$, $P = 0.025$) and dual-tone conditions ($Z = -2.173$, $P = 0.030$). However, only the difference between baseline and the single-tone condition remained significant with the application of a Bonferroni adjustment. Nonparetic step time variability was lower in the two cued conditions compared to baseline; however, there was no significant main effect for this variable ($\chi^2(2) = 4.000$, $P = 0.135$). There was a trend for quicker TUG times after the single-tone condition, but this did not reach significance ($\chi^2(2) = 4.839$, $P = 0.089$).

4. Discussion

The aim of this pilot study was to examine the use of a single- and dual-tone metronome to cue stepping in place. The results indicate a trend towards better symmetry of step time during cueing and significantly reduced paretic step time variability, with the improvements being slightly more pronounced for the single- than the dual-tone cue. There was also a trend towards improved TUG times after the single-tone cueing condition. This provides an early indication that a single-tone cue may be more efficient than a dual-tone cue at eliciting improvements when stepping in place in a stroke population.

Temporal asymmetry has a high prevalence after stroke [6], shows resilience to rehabilitation [7], and progresses over time [8]. Temporal asymmetry is associated with poorer results in clinical balance tests [12]; therefore, any improvement might be expected to have benefits for balance after stroke. The reduction in step time asymmetry observed here with the single-tone metronome is of a similar magnitude to that previously observed with auditory-cued treadmill walking [14]; however, the mean temporal asymmetry in the current study is milder at baseline than the mean asymmetry for the study population in [14]. Two of the participants in the current study would be classified as having severe asymmetry at baseline, and for both participants, the asymmetry was reduced with the metronome cue. This suggests that cueing is effective and immediate even in those with a high level of asymmetry. Future research is needed to see if these improvements in temporal asymmetry can be elicited in a larger sample stroke population with severe temporal asymmetry.

The variability in step time on both the paretic and nonparetic steps was reduced in both cueing conditions compared to baseline, although this was only statistically significant for the paretic step. This reduction in variability with auditory cueing is consistent with gait studies involving participants with stroke [17] and Parkinson's disease [26]. Increased step time variability is associated with a risk of multiple future falls in older adults [13], and stroke survivors are over twice as likely to experience at least one fall than population controls [27]. Therefore, these reductions in variability may have benefits for balance control after stroke.

Some of the participants commented on how the dual tone metronome did not sound like a regular beat, and one participant withdrew from the study because he/she did not like the dual-tone. It is possible that there was superior detection of gaps between stimuli in the single-tone condition compared to the dual-tone condition where the tones were dissimilar, which may cause a slight illusion in the perception of the gaps between stimuli [28]. Caution needs to be employed when using a different tone to cue the footfall of the left and right limbs that the tones themselves do not cause a distortion in the perception of the timing intervals.

Stepping in place incorporates many of the aspects of walking gait. Temporal asymmetries displayed during stepping are consistent with those present during walking [20]. Step time variability during stepping in a virtual reality environment has also been found to be similar to stride time variability during gait, although that was for a Parkinson's disease population [29]. The immediate improvements in both asymmetry and variability, when stepping was cued to a metronome, were consistent with those previously reported for cued walking [14]. In addition, the trend for improved TUG times after the single-cue condition suggests that there may be an immediate carry-over effect on functional mobility. Therefore, auditory-cued stepping may be a useful tool for locomotor training in rehabilitation.

Individuals with chronic stroke perform notably reduced amounts of daily stepping than sedentary older adults, even in those receiving physiotherapy [30]. This suggests that individuals after stroke are not performing enough repetitions for optimal benefits in locomotor training, and sedentary behaviour is associated with multiple adverse health outcomes [31]. Intensive locomotor training has shown improvements in walking performance after discharge from rehabilitation for reaching a "recovery plateau," and this was likely to be related to the dose of training [32]. If a metronome could be adapted for step training at home, then this could be a rehabilitation tool that could be utilised daily and therefore provides a much higher dosage of step training than clinic-based training alone.

The 10-minute break between cueing conditions may not have been sufficiently long enough to exclude an effect of the first condition on the second one. However, the use of a crossover design should have reduced the tendency for any carryover or fatigue that could influence the findings. Although improvements were seen in stepping during the cued conditions, we did not find a significant improvement in the TUG, and we did not specifically examine the transfer of these skills to everyday, community walking. Therefore, future study is required to examine whether improvements in stepping in place are carried into functional walking improvement in hemiparetic stroke.

5. Conclusions

Early evidence from this pilot study suggests that the use of a metronome for stepping in place has benefits for step time asymmetry and variability after hemiparetic stroke. These modifications in the step pattern are immediate and not the result of a training effect. Caution needs to be applied if a dual tone is used for cueing, as this may not optimise rehabilitation as the effects do not appear as strong as for a single-tone metronome; plus, not all participants liked the dual tone as they thought that it did not sound like a regular beat. This may have an effect on compliance if used as a training tool in rehabilitation. Further research is needed to assess whether auditory-cued step training results in significant improvements in functional walking and whether any improvements are maintained after a follow-up period.

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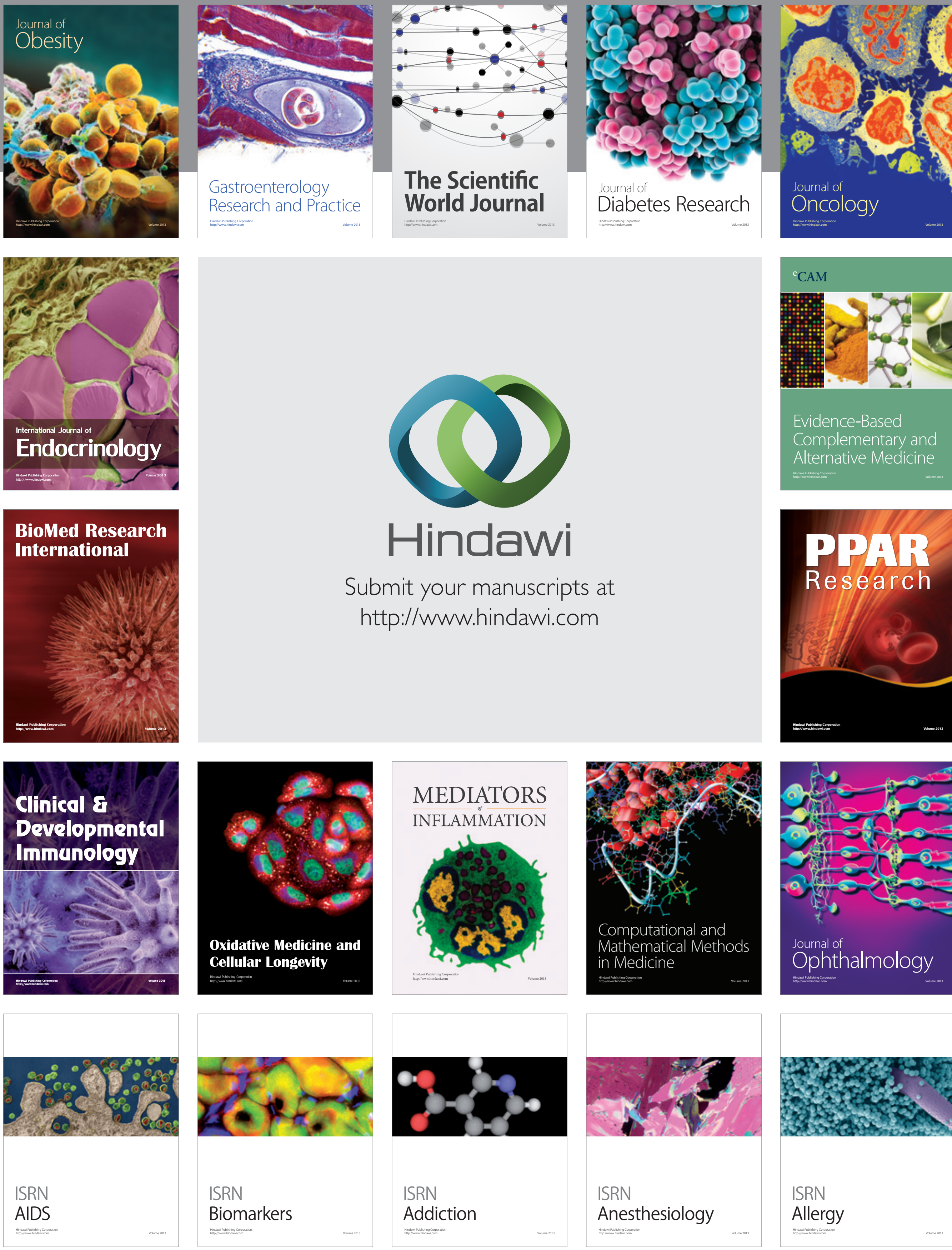
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