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Manipulating the stride length/stride velocity relationship of walking using a treadmill and rhythmic auditory cueing in non-disabled older individuals. A short-term feasibility study.

Diderik Jan A. Eikema Dr.,

Biomechanics Research Building, University of Nebraska at Omaha, Omaha, NE 68182, US

Larry W. Forrester Dr., and

Department of Physical Therapy & Rehabilitation Science, University of Maryland, Baltimore, Baltimore, MD 21201, US

Jill Whittall Dr.

Department of Physical Therapy & Rehabilitation Science, University of Maryland, Baltimore, Baltimore, MD 21201, US

Abstract

One target for rehabilitating locomotor disorders in older adults is to increase mobility by improving walking velocity. Combining rhythmic auditory cueing (RAC) and treadmill training permits the study of the stride length/stride velocity ratio (SL/SV), often reduced in those with mobility deficits. We investigated the use of RAC to increase velocity by manipulating the SL/SV ratio in older adults. Nine participants (6 female; age: 61.1 ± 8.8 yrs.) walked overground on a gait mat at preferred and fast speeds. After acclimatization to comfortable speed on a treadmill, participants adjusted their cadence to match the cue for 3 minutes at 115% of preferred speed by either a) increasing stride length only or b) increasing stride frequency only. Following training, participants walked across the gait mat at preferred velocity without, and then with, RAC. Group analysis determined no immediate overground velocity increase, but reintroducing RAC did produce an increase in velocity after both conditions. Group and single subject analysis determined that the SL/SV ratio changed in the intended direction only in the stride length condition. We conclude that RAC is a powerful organizer of gait parameters, evidenced by its induced after-effects following short duration training.

Keywords

aging; rhythmic auditory cueing; gait rehabilitation; treadmill training

Introduction

Safe community ambulation is essential to participation in daily life. As we age, gait becomes slower, more effortful and less consistent [1], contributing to restricted mobility and potentially a loss of independence. Importantly, it is the reduction of stride length rather than cadence that is the more significant predictor of poor outcomes associated with gait speed [2, 3]. One plausible and novel strategy is to increase gait speed by increasing the SL/SV ratio.

In this feasibility study we examined a training period of 8 minutes on the treadmill (TM) including 3 minutes at increased velocity designed to elicit a different SL/SV ratio using rhythmic auditory cueing (RAC). Our goal was to demonstrate the power of cueing in **increasing or decreasing** SL/SV ratios, not necessarily for an immediate carryover effect, given the short adaptation time, but as a mechanism of re-triggering the adaptation and demonstrating the association of the cue.

Our primary hypothesis was that 3 minutes of treadmill and RAC manipulation would be too brief for immediate SL/SV overground effects without RAC, but that changes in the SL/SV ratio at a given velocity would be directionally apparent after the cue was re-introduced because of association with the training adaptation. Our secondary hypothesis was that the increased velocity training might independently cause increased overground velocity, but again we theorized that this would only be observed when RAC was re-introduced.

Methods

Participants

Nine individuals (six female, mean age = 61.1; SD = 8.8 yrs.) participated with informed consent (Institutional Review Board, UMB). Inclusion criteria were: 50 to 80 years, adequate cognitive function (Mini Mental Status Exam ≥ 23) and minimum gait velocity of 0.8km/h. Exclusion criterion: no history of neurological or orthopedic impairments.

Apparatus

Manipulation of walking speed took place on a treadmill. For safety a suspension harness was used, but it did not support the participant's body weight. Pre/post-training trials were measured overground using an 8-meter gait mat with pressure sensors embedded throughout its surface area. The auditory cue was generated using an amplified electronic metronome.

Protocol

Two systematically re-ordered training conditions, tested whether the SL/SV ratio can be increased or decreased (Figure 1). A 30-minute rest occurred between conditions to prevent fatigue and provide a washout period. Baseline parameters were recorded during 5 walks: two self-selected speed trials (pre-comfortable: PrC) determined comfortable walking speed (CWS) and the associated step rate (RAC frequency); two fast but safe speed trials determined the available velocity range. The instruction was "When I say begin, please walk at your normal comfortable speed (or "at a fast but safe speed") until I say stop". Finally, a trial with RAC set at the CWS step rate was used to familiarize the participant with the

auditory cue: “You will hear a beat for a few seconds, then when I say begin, please try to time your footsteps with the beat as you walk, until I say stop.” Participants started behind the mat and continued walking off the other end.

The eight-minute training trials began with 60s to familiarize the participant to TM walking at 0.85CWS. After familiarization, the belt speed was increased to 1.0CWS for another 60s. During the following 180s the belt speed was held at 1.0CWS and the pre-determined RAC introduced. Participants were instructed to step in time with the metronome to establish synchronizing their footsteps to the beat while on the treadmill. In the final 180s adaptation phase, one of two conditions occurred. For the stride lengthening condition (SLC) the belt speed was increased to 1.15CWS while RAC rate remained constant. For the stride frequency condition (SFC) the belt speed was increased to 1.15CWS while RAC was increased to 1.15 preferred step rate to manipulate step frequency. After either condition, training effects were measured overground. Participants walked approximately 3-4 steps between the treadmill and gait mat, and overground walking was initiated within one minute of the treadmill training. Two comfortable speed trials (post-comfortable: PoC) were performed first to measure whether the treadmill-induced SL/SV adaptation at 1.15 CWS carried over to overground. Secondly, two trials with RAC (post-RAC: PoR) were performed to observe the effects of reintroducing the same auditory cue rate experienced on the treadmill during the adaptation phase.

Data processing and analysis

Dependent variables were stride length, stride time, cadence, and stride velocity. On average, walks consisted of six-seven strides with initial and last steps eliminated to further remove acceleration/deceleration effects. Each condition was analyzed independently. First, we performed single subject analyses on SL/SV ratios by means of non-parametric model statistical analyses [4, 5].

Second, using individual strides of comfortable and fast pre-training trials, for each participant, a regression line was obtained to provide slope parameters of stride length over stride velocity across the natural range of walking speeds. From the derived slopes we compared observed vs. predicted stride lengths in the post-training trials. A training effect was defined as a significant deviation between observed and expected stride lengths. One-sample t-tests determined whether observed minus expected stride lengths differed from 0 as a reference value, with 0 indicating no training effect.

Third, to test whether velocity changed regardless of the SL/SV ratio, a one-way repeated measures ANOVA at three time-points (PrC; PoC; PoR) was employed with post-hoc paired t-tests as required. Type I error was controlled using Holm-Bonferroni corrections, and Cohen's d effect sizes were calculated. Alpha was set at 0.05.

Results

Changes in SL/SV ratios were evaluated across PrC to PoC and PoR for each condition (Table 1). In the SLC five participants increased the ratio at PoC, and six participants did so

at PoR. For group data (Figure 2), observed stride lengths increased relative to expected only when RAC was present ($t(8) = 2.504$, $d = 0.29$).

In the SFC, only two participants decreased the SL/SV ratio at PoC. At PoR two different participants decreased the ratio as intended. Group data revealed no difference between the observed and expected stride lengths at PoC or PoR (Figure 2).

For velocity, there was a main effect of trial in both conditions (SLC: $F(2,16) = 4.978$; SFC: $F(2,14) = 5.223$) with the effect only significant at PoR (SLC: $t(8) = 6.201$, $d = 0.63$; SFC: $t(7) = 7.693$; $d = 0.50$).

Discussion

We investigated the effect of manipulating RAC relative to treadmill velocity. Increasing stride length relative to velocity appears more feasible than decreasing stride length (increasing cadence) possibly because the latter is influenced by the pendular mechanics of the leg [6], which are essentially constant over the lifespan. In contrast, stride length is reduced relative to velocity with aging [3], perhaps allowing more flexibility for modulating stride length.

Compared to gait adaptation studies with 10 minutes training [7, 8], we found after effects after only 3 minutes training. This was sufficient to build a feed-forward mechanism that was strong enough in the short term not to require a cue for some individuals and was reinstituted in the majority by the cue. Further studies will determine ideal durations of cued adaptive training over multiple training periods and in patient populations.

In conclusion, manipulating the SL/SV ratio of overground walking is achieved by manipulating RAC and treadmill speed; however with a short training duration, proof of concept was only seen in the increasing stride length condition.

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Research Highlights

Use of auditory cue and treadmill to manipulate the stride length/stride velocity of older adults when increasing velocity since loss of velocity and particularly decrease in stride lengths are found in older adults.

Two adaptation conditions of 3 minutes where treadmill speed was changed and (a) cue frequency kept constant so that stride length increased or (b) cue frequency increased so that stride length was constant.

Pre-post assessment on a gait mat with 9 adults and testing whether carryover of the new gait velocity and stride length/stride velocity ratio was observed under conditions of (1) no auditory cue followed by (2) re-instatement of the auditory cue.

Group and single subject analysis determined that the SL/SV ratio changed in the intended direction only in the stride length condition.

Group results for velocity were significant only after cue was re-introduced.

We conclude that auditory cueing is a powerful organizer of adaptive response and should be investigated in clinical populations over longer time periods

Figure 1.

The experimental design includes two randomly counter-balanced conditions that manipulate stride length (SLC-left column) and stride frequency (SFC-right column). Conditions were separated by 30-min. rest. Pre-training gait assessments (top panels) were followed by 8-min. treadmill training (middle panels), and immediately after post-training, overground walking was performed without and then with RAC (bottom panels). The main difference between the two conditions is illustrated in the last 180s block of the treadmill training phase. CWS = Comfortable Walking Speed. FWS = Fast Walking Speed, RAC = Rhythmic Auditory Cue.

Figure 2.

(A) Stride-length difference between observed and predicted stride lengths at post-training velocity for each condition (stride length on left and stride frequency on right) showing the predicted direction of positive for the stride length condition only after RAC was introduced. Note that the increase in stride length for the stride frequency condition explains the increase in velocity found after RAC was introduced but it is not in the manipulated direction of decreasing stride length at a given velocity.

Table 1

Single subject listing of parameters and values used for the calculation of the model statistic.

Subject	Stride Length Condition				Stride Frequency Condition					
	PrC	PoC	Obs	PoR	Obs	PrC	PoC	Obs	PoR	Obs
1	0.471	0.470	0.001	0.424	0.046	0.350	0.467	0.117	0.419	0.048↓*
2	0.322	0.348	0.026†*	0.849	0.501†*	0.279	0.344	0.047	0.608	0.264
3	0.340	0.390	0.050†*	0.724	0.023†*	0.426	0.376	0.050↓*	0.619	0.243
4	0.388	0.523	0.135†*	0.851	0.328†*	0.457	0.556	0.099	0.611	0.055
5	0.504	0.510	0.006	0.963	0.453†*	0.524	0.384	0.140↓*	−0.228	0.612
6	0.534	0.539	0.005†*	0.739	0.200†*	0.518	0.544	0.026	0.205	0.339↓*
7	0.554	0.559	0.005	0.555	0.004					
8	0.722	0.770	0.048†*	0.456	0.314	0.686	0.750	0.064	0.743	0.007
9	0.486	0.488	0.002	1.157	0.669†*	0.478	0.497	0.019	1.163	0.666

PrC = Pre-treadmill, comfortable trial. PoC = Post-treadmill, comfortable trial without RAC. PoR = Post-treadmill with RAC. Obs = Observed ratio. An asterisk indicates a significant effect in the intended direction. The upward arrow † indicates the stride length/velocity ratio increases as a result of a greater stride length increase relative to stride velocity. The downward pointing arrow ↓ indicates the ratio is decreasing, meaning stride length is decreasing relative to stride velocity. Data are missing for #7 in SFC.