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Using rhythmic auditory stimuli to modulate resilience to perturbations during walking in healthy young adults V.2

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Troubleshooting

Using rhythmic auditory stimuli to modulate resilience to perturbations during walking in healthy young adults

Abstract

We aimed to determine the relationship between the structure of movement variability and resilience to perturbations during walking in humans. This protocol outlines the procedures and evaluations performed in our study to test this notion. The study induces an unexpected mechanical perturbation during treadmill walking in healthy, young adults (N = 15) as they synchronize their walking patterns to auditory stimuli that are composed of either periodic or 1/f structure. We calculated the time to recover to steady-state movement patterns after a perturbation from the horizontal velocity of body's center of mass. We tested the hypothesis that individuals walking with periodic stimulus would exhibit prolonged recovery time compared to those synchronizing with 1/f stimulus.

Participants

Fifteen healthy young adults (ages: 19-30 years; height: mean 1.76 ± standard deviation 0.18 m; mass: 72.5 ± 7.5 kg; sex: 6 females, 9 males) with no history of neurological, vestibular or movement disorders or other problems that could alter typical walking patterns participated in this study. The protocol was approved by the local institutional review board (protocol #189-16-EP). All subjects provided written informed consent prior to participating.

Inclusion criteria:

- Between the ages of 19 and 35
- Normal or corrected-to-normal vision
- Normal or corrected-to-normal hearing
- Capable of walking for 70 minutes total, up to 45 consecutive minutes

Exclusion criteria:

- Neurological disorder
- Movement disorder
- History of cardiovascular events
- Currently pregnant
- Currently have a musculoskeletal injury
- Surgery within the past 6 months
- Hearing impairment
- Vision impairment

- Current pain
- Vestibular disorder
- History of dizziness

Preparation

An athletic training suit was worn, and retroreflective markers placed on the feet, shank, thigh, pelvis, trunk, hands and head in order to track the movements of the segments during treadmill walking (split belt treadmill, Bertec Corp., USA). Handrails were removed from the treadmill and a ceiling-mounted harness with chest and pelvis straps was worn (Solo-Step, North Sioux City, SD, USA). Prior to data collection, movement was checked to ensure the harness was comfortable and not restricting the natural walking patterns. Kinematic data were collected at 100 Hz with an eight-camera motion capture system (T-series, Vicon Motion Systems Ltd., Oxford, UK). A static image of the lab was projected onto a 120˚ semi-cylindrical screen situated in front of the treadmill, along with a fixed visual point that participants were asked to fixate on. Control of visuals and treadmill actions was performed using D-flow software (Motek Force Link, Amsterdam, The Netherlands).

Self-selected walking speed was determined by progressively increasing and decreasing the velocity of the treadmill (intervals of 0.01 meter/second) until the participant reported that the velocity was 'faster than comfortable' or 'slower than comfortable'. The mean of the first three 'too fast' and three 'too slow' velocities was taken as the self-selected comfortable velocity and used for the duration of the session (Dingwell et. al. 2006). Participants were asked to identify the leg they would choose to kick a ball with (the ‘dominant leg’). The contralateral side (the ‘support leg’) was selected to be perturbed.

Baseline and stimulus creation

Subjects participated in two walking trials. For the first trial (baseline), participants walked for 25 minutes at their pre-determined self-selected walking velocity with no stimulus. Right foot contact events were estimated from the final 3 minutes of recorded data based on the trajectory of the anterior-posterior velocity of the right heel marker. The mean and standard deviation of their inter-stride intervals was calculated using MATLAB (The MathWorks Inc, Natick, MA, USA). Participants then took a seated rest break for 20 minutes.

For the second walking trial (cued), participants were placed into one of two groups, corresponding to two stimulus conditions; periodic (N=7) and 1/f (N=8), the order of which was randomized using a random number generator.

Stimulus tracks appropriate to group, approximately 45 minutes in length were created based on the baseline stride characteristics of each participant. For the periodic condition, stimulus were set with an inter-beat interval that matched the participants’ mean inter-stride interval. For the 1/f condition, time series were generated using custom MATLAB code and similarly normalized to the mean and variance of the baseline walking trials. The stimulus patterns were translated into 4-beat drum patterns within which every beat was sounded by a closed hi-hat and the first and third of every four beats sounded by a bass drum and snare drum respectively. The bass drum indicated the onset of a stride, and the snare drum the foot contact of the contralateral limb. Stimuli were saved as MIDI files, and the patterns were transmitted to a drum generator app (Drum Studio, Rollerchimp, Sydney, Australia) for playback.

Participants in the stimulus condition groups were instructed to step in time to the beat of the stimulus of their respective condition. Prior to the recorded trial they were asked to demonstrate stepping in place in synchronization with the beat. Those who were initially unable to synchronize were coached and practiced for up to 2 minutes. All participants were able to recognize and walk to the beat, if after a small amount of coaching.

Perturbation trial

Participants completed a 45-minutes walking trial in their group condition, i.e. with a 1/f or periodic auditory stimulus. Stimulus drumbeats were played through audio speakers at a volume that was maintained consistent for all sessions. The inter-beat timing was monitored using a uniaxial accelerometer mounted on the subwoofer speaker of the system, which, when connected via signal conditioner into the motion capture software, provided a clear indication of the onset of the bass drum that could be captured simultaneously with the motion data.

At minute 25, one treadmill belt was arrested for 500 milliseconds, delivering a brief perturbation that emulated a trip. This occurred at the instant at which the ankle of the kick limb in swing passed the ankle of the support limb in stance. The timing and length of this interruption were controlled by the D-Flow. The acceleration and deceleration of the treadmill was set to maximum (3 meter per second squared). After normal belt movement had resumed the participant was asked to "Please keep walking" and the trial continued for a further 20 minutes. Participants underwent one perturbation only due to known learning effects (Pater et. al. 2015).

Processing

The kinematics of about 2 minutes before and after the perturbation was analyzed for each participant in order to identify the time that is needed to recover walking balance after the perturbation (Visual 3D, Germantown, Maryland). Position-time data “smoothing” was carried out by quintic splines according to the ‘Generalized, Cross-Validation’ criterion (Woltring 1986). The center of mass (COM) was calculated using gender-dependent inertial parameters (De Leva 1996). The model did not include the markers defining the arm segments which could be a limitation (Bruijn 2010). The anterior-posterior COM velocity of two minutes pre- and post-perturbation was estimated. The velocity of the base of support (approximated as the treadmill belt velocity) was then added to the time series and used for the quantification of resilience using the proposed methodology.

Data Availability

The datasets analysed during the current study are not publicly available but are available from the corresponding author (Dr Nick Stergiou: nstergiou@unomaha.edu) on reasonable request.

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