Human Movement Science 58 (2018) 219–223

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

Effects of manipulated auditory information on local dynamic gait stability

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ARTICLE INFO

Keywords:
Gait stability
Gait automaticity
Dual-task
Acoustic information
Noise cancelling

ABSTRACT

Auditory information affects sensorimotor control of gait. Noise or active noise cancelling alters the perception of movement related sounds and, probably, gait stability. The aim of the current study was to evaluate the effects of noise cancelling on gait stability. Twenty-five healthy older subjects (70 ± 6 years) were included into a randomized cross-over study. Gait stability (largest Lyapunov exponent) in normal overground walking was determined for the following hearing conditions: no manipulation and active noise cancelling. To assess differences between the two hearing conditions (no manipulation vs. active noise cancelling), Student's repeated measures *t*-test was used. The results indicate an improvement of gait stability when using active noise cancelling compared to normal hearing. In conclusion, our results indicate that auditory information might not be needed for a stable gait in elderly.

1. Introduction

While walking, people are used to body-related and environmental sounds. The acoustic feedback is often diminished due to noise, noise reduction and diseases or age-related changes of hearing quality (e.g. presbyacusis). These hearing impairments are believed to influence automaticity of gait (Clark, 2015).

Even non-relevant information is integrated into the sensorimotor control of gait, and its influences are detectable in gait patterns (Hunt, McGrath, & Stergiou, 2014; Kaipust, McGrath, Mukherjee, & Stergiou, 2013). For instance, a recently published study (Hunt et al., 2014) examined the effects of several types of noise (white vs. pink vs. brown) on gait while subjects synchronized their steps to music. The results showed that when inter-beat intervals were manipulated with noise, the specific noise characteristics were represented in the sample entropy of their stride-time series. Another study revealed that even when the participants are not instructed to synchronize their steps to auditory stimuli, white noise and metronome ticks affect the structure of gait variability in the elderly (Kaipust et al., 2013). Thus, auditory information is processed and integrated into the sensorimotor control of gait.

"Agency processing" provides another perspective on sensorimotor control and the importance of auditory information. The observer framework theory (Wolpert, Ghahramani, & Jordan, 1995) models movement control by using the current movement state and the efferent motor commands to predict a subsequent movement state. Such internal models are expected to enable people to match their movements to themselves which results in the perception of being the agent controlling these particular movements (Kannape & Blanke, 2012). A frequently used study design in this research area provides some sort of delayed sensory feedback to the

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https://doi.org/10.1016/j.humov.2018.02.010
Received 17 August 2017; Received in revised form 16 February 2018; Accepted 19 February 2018
Available online 12 March 2018

participants and evaluates the effect on the self-attribution. In order to do this, participants are asked if they perceived the provided feedback to be their own movement. Besides visual feedback (Kannape & Blanke, 2013), auditory information (footstep sound) was identified as relevant for agency processing. Interestingly, delaying auditory feedback does also affect walking speed (Menzer et al., 2010) and, thus, motor control of gait.

A third research topic analyses the influence of self-generated sounds, such as breathing or movement related noise, on gait patterns. Under certain conditions subjects synchronize their footsteps subconsciously while walking side-by-side with another subject (Nessler & Gilliland, 2009, 2010). It has been assumed that self-generated sounds may mask critical environmental auditory information. Thus, interpersonal step entrainment may reduce those masking properties leading to a higher portion of silent periods in which, as a result, environmental sounds appear more noticeable (Larsson, 2014). Again, auditory information is obviously used in sensorimotor control of gait.

In addition, auditory cues change the non-linear dynamics of human gait (Terrier & Dériaz, 2012, 2013) and are also powerful in the rehabilitation of patients with different diseases. For example, cued gait improves sensorimotor control in patients with stroke or Parkinson's disease (Schaefer, 2014).

Thus, it is coherent to suppose that noise cancelling should result in a less stable gait pattern in older adults and unstable gait patterns are generally associated with a higher fall risk in elderly (Bruijn, Meijer, Beek, & Van Dieën, 2013; Hamacher, Singh, Van Dieën, Heller, & Taylor, 2011). However, to the best of our knowledge, no study previously examined the influence of noise cancelling on walking gait stability in older adults. Therefore, the aim of this study was to evaluate the effects of noise cancelling on gait stability in elderly. We hypothesise that noise cancelling impairs local dynamic gait stability (of foot kinematics) in older adults.

2. Methods

Thirty healthy, community-dwelling older adults were screened and 25 (12 males, 13 females, mean age: 70 ± SD 6 years, mean weight: 77 ± SD 13 kg, mean height: 1.68 ± SD 0.08 m) were included into a randomized cross-over study. The participants were recruited with a newspaper advertisement. A minimum age of 60 years and the self-reported ability to walk continuously for at least 10 min without assistance represented the inclusion criteria. Acute motor-functional or acute hearing impairments (but one subject had a hearing aid device) that could affect gait lead to exclusion. All participants provided their written informed consent after they were informed about the research protocol, which was in accordance to the Declaration of Helsinki and approved by the local board of the ethical committee (No. FSV 16/01).

Wireless inertial sensors (MTW2 Awinda 3DOF Motion Tracker, Xsens Technologies B.V., The Netherlands, sampling rate 100 Hz) were fixed to the forefoot of the dominant leg. The dominant leg was identified by asking the participant with which foot they would shoot a ball into a goal. To improve between-day test-retest reliability of variability measures (Hamacher, Hamacher, Krowicki, & Schega, 2017), all subjects walked back and forth on a 22-m long track in a sports hall to familiarize to the test situation. They walked with their preferred pace which they normally used for comfortable walking for three minutes. Thereafter, data was registered for each of the following hearing conditions in randomized and counterbalanced order: a) no manipulation and b) active noise cancelling using headphones (QuietComfort 25, Bose Corporation, USA). However, in the noise cancelling condition (probably due to bone conduction), the participants were still able to perceive their foot strikes.

In all test conditions, the local dynamic gait stability was analysed. After having removed the first and last 22-m bouts of each gait and 2.5 m prior to and after each turning, strides were detected as local minima of the foot's angular velocity in the sagittal plane (Hamacher, Hamacher, Taylor, Singh, & Schega, 2014). For every gait condition, at least 80 strides were available.

As a measure of local dynamic gait stability, the largest Lyapunov exponent was calculated. Since for normal overground walking, the highest effects comparing the local dynamic gait stability of young vs. older adults were observed when analysing time series derived from angular velocity data of the foot (Hamacher, Hamacher, Singh, Taylor, & Schega, 2015), we used those time series, too. Hence, the norm of the angular velocity data of the 80 strides was time-normalised to 8.000 samples. The angular velocity data and their time-delayed copies (embedded dimension $dE = 7$ according to the false nearest neighbours analysis, Kennel, Brown, & Abarbanel, 1992; time delay = 19 samples according to the first minimum mutual information analysis, Fraser & Swinney, 1986) were used to reconstruct the state space. Thereafter, the largest Lyapunov exponent was calculated with Rosenstein and co-workers' algorithm (Rosenstein, Collins, & De Luca, 1993) which we implemented in MATLAB (version 2014a, The MathWorks BV, Natrick, USA). The divergence of each nearest neighbour (Euclidean distance) in the state space was tracked and the mean of the logarithm of the divergence curve was calculated. The largest Lyapunov exponent was then defined as the slope of the linear fit through 0–0.5 strides. Larger positive exponents indicate a less stable gait and greater sensitivity to small perturbation that occurred during walking (Bruijn et al., 2013).

SPSS version 23.0 (SPSS, Armonk, NY, USA) was used for statistical analyses. To assess differences comparing the two hearing conditions (no manipulation vs. active noise cancelling), Student's repeated measures *t*-test was used. All results are presented as means ± standard deviations (SDs).

3. Results

All subjects completed the tests, successfully. Compared to normal walking, local dynamic gait stability was improved from a largest Lyapunov exponent of 0.649 (SD: 0.079, 95% confidence interval: 0.617–0.682) in normal walking to 0.626 (SD: 0.074, 95% confidence interval: 0.595–0.656) in the noise cancelling condition. The *t*-test revealed a significant difference (*t*-value = 2.319, df = 24, $p = .029$, Cohen's d = 0.46, Fig. 1).