The effects of listening to music or viewing television on human gait

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Abstract

This paper presents a two-part study with walking conditions involving music and television (TV) to investigate their effects on human gait. In the first part, we observed seventeen able-bodied adults as they participated in three 15-minute walking trials: 1. without music, 2. with music and 3. without music again. In the second part, we observed fifteen able-bodied adults as they walked on a treadmill for fifteen minutes while watching 1. TV with sound 2. TV without sound and 3. TV with subtitles but no sound. Gait timing was recorded via bilateral heel sensors and center-of-mass accelerations were measured by tri-axial accelerometers. Measures of statistical persistence, dynamic stability and gait variability were calculated. Our results showed that none of the considered gait measures were statistically different when comparing music with no-music trials. Therefore, walking to music

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did not appear to affect intrinsic walking dynamics in the able-bodied adult population. However, stride interval variability and stride interval dynamics were significantly greater in the TV with sound walking condition when compared to the TV with subtitles condition. Treadmill walking while watching TV with subtitles alters intinsic gait dynamics but potentially offers greater gait stability.
Keywords: Gait, statistical persistence, Lyapunov exponents, stride interval variability, music, television.

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1. Introduction

Extraneous interferences during walking such as music and television have become an increasingly integral part of today's culture. People listen to music when they are exercising, walking their dog and going for an evening stroll. Meanwhile, watching television, long thought to be a sedentary activity, has become commonplace at gyms and screens are often attached to treadmills and other exercise machines. In other words, music and television increasingly make up the backdrop of everyday activities, although their effects on gait are not well understood.

Music consists of a beat that may subconsciously alter an individual's intrinsic walking pace, a phenomenon that has been seen when individuals walk to rhythmic auditory stimuli (e.g., McIntosh et al. (1997), Willems et al. (2006), Sejdić et al. (2012a), Sejdić et al. (2012b)). It is well documented that rhythmic auditory stimuli impact variables of human gait (e.g., McIntosh et al. (1997), Willems et al. (2006)) and in particular the gait patterns for patients with Parkinson's disease (e.g., Willems et al. (2006), Rochester et al. (2009)). Similarly, music has been shown to impact gait patterns (e.g., Janssen et al. (2008), Brown et al. (2009), Styns et al. (2007)). Television also contains an auditory component that may affect gait in a similar way. Furthermore, the visual component of television may act as an additional distraction further disrupting natural gait dynamics. Specifically, reading tasks and gaze-stabilization tasks while treadmill walking have been shown to alter human gait (Mulavara and Bloomberg (2002)); however, the different ways to watch TV (sound vs. subtitles) have not yet been analyzed.

Assessing the stability of the human gait under various walking conditions involving music and/or television may have clinical applications in rehabilitation programs. It may also have safety implications in compromised populations such as people with Parkinson's disease, Huntington's disease, frail older adults and people with a history of falling. Specifically, it is important to observe the effect of music and TV on human gait in order to ensure safety of patients with compromised gait patterns and in the creation of gait interventions and rehabilitation programs. We hypothesize that the exposure to both music and television will have negative effects on stride interval dynamics, since the exposure to these additional sources of information will invoke processing from multiple brain centers, activity which may disrupt gait pattern generation. To investigate the effect of these external sources of information, we are going to explore the temporal dynamics of human gait as measured by the fractal scaling exponent (e.g., Chau (2001), Terrier et al. (2005)) and the maximum Lyapunov exponent (e.g., Dingwell and Cusumano (2000)).

2. Methodology

2.1. Data Collection

The study was divided into two: a music part and a TV part. For each part, participants performed two sessions of three walking trials. Stride interval time series and acceleration time series were collected. The protocol was approved by the Research Ethics Board of Holland Bloorview Kids Rehabilitation Hospital (Toronto, Ontario, Canada). All participants provided written consent. Additionally, all participants had normal eye-sight and hearing and did not have any known neurological or musculoskeletal disorders.

Seventeen participants of mean age 25.9 ± 2.76 years (9 male) were involved in the music part (please see Table 1). Participants completed two sessions. Each session involved a sequence of three 15 minute trials: over ground walking (OG1), over ground walking while listening to music through standard headphones (OG2) and over ground walking without music once again (OG3). OG3 was used to assess any carry-over effect music has on gait. The participants were instructed to walk at a comfortable pace and were permitted a self-regulated rest period between each trial. The participants walked in a rectangular path along a sparsely populated hallway (of approximate length 85 m and width 2.5 m). Any stumbles or falls were noted by an investigator, who walked slightly behind each participant. Each session was separated by at least 24 hours and took place at approximately the same time of day.

The television part of the study involved fifteen young adults (7 male) with a mean age of 25.4 ± 2.69 years (please see Table 1). Again, two sessions were completed by each participant, separated by at least 24 hours.

Table 1: A summary of anthropometric measurements.

Part	Age (yrs)	Height (m)	Weight (kg)
Music	25.9 ± 2.76	173 ± 8.16	70.2 ± 12.3
TV	25.4 ± 2.69	173 ± 8.95	69.3 ± 12.2

Each session involved three 15 minute trials performed in a random order: walking on a treadmill while watching television with sound (TV-S), walking on a treadmill while viewing television without sound (TV-NS), and walking on a treadmill while watching television with subtitles without sound (TV-SUB). Participants were instructed to walk at a pace that they considered comfortable. The sessions were conducted as follows: a 5 minute warm-up at the self-selected, comfortable speed, a 2 minute warm-up under the trial condition, quiet standing for 45 seconds, and finally, the 15 minute trial from standing to the self-selected pace.

2.2. Equipment

An ultra-thin force-sensitive resistor (FSR) (Model 406, Interlink Electronics) was taped beneath the insoles of each of the subject's shoes at the heel. The FSRs measured the heel-strikes of each foot. Voltage changes in FSRs were directly captured by a datalogger (programmable R-Engine- A processor board manufactured by Tern Inc.) which was worn around the participant's waist in a small fanny pack and collected all signals at a frequency of 200Hz.

A tri-axial accelerometer (Freescale Semiconductor Inc.; model number: MMA7260Q) measured the acceleration of the participants' approximate center of mass in the anterior-posterior (AP), medial-lateral (ML) and vertical

(VT) axes. The accelerometer was secured to the small pack over the L3 segment of the lumbar spine and was powered by a small battery carried within the pack. A continuous voltage output of acceleration was also collected and stored by the datalogger.

2.3. Data analysis

2.3.1. Stride intervals

A probabilistic stride interval extraction algorithm from Chau and Rizvi (2002) was used to extract the stride intervals. First, the gait signals were trimmed to 15 minutes in order to exclude the extraneous signals of the participants as they began to walk (i.e. the 2 minute warm up and the 45 second quiet standing periods). In order to ensure that the analysis represented participants' 'intrinsic' walking dynamics, atypical strides, identified as stride intervals that fell outside of the 0.01 and 99.99% of a gamma distribution fit, were removed from the time series (Fairley et al. (2010b)). A previous study found that removing segments from a signal had no effect on the scaling for positively correlated signals ($\alpha > 0.5$), such as gait signals, even when up to 50% of the points in the signals were removed (Chen et al. (2002)). Only a small fraction of stride intervals were removed from the time series in the present study.

2.3.2. Statistical persistence

Stride interval dynamics incorporate temporal information into the analysis of the stride interval time series and reveals statistical persistence. Detrended fluctuation analysis (DFA) is used in order to estimate the scaling exponent, α, as described in previous studies (e.g., Chau (2001), Terrier et al.

(2005), Damouras et al. (2010)). For each signal, $\alpha > 0.5$ indicates the signal is statistically persistent; $\alpha = 0.5$ indicates random, uncorrelated behavior (a.k.a. white Gaussian noise) and $\alpha < 0.5$ means that the signal is anti-persistent (Chau (2001)). DFA involves fitting a power law across different box sizes, n, of a series' mean fluctuations, $F(n)$, and finds α as the slope of $\log F(n)$ vs. $\log n$ (Chau (2001), Damouras et al. (2010)). The box size range used for DFA analysis was $[16, N/9]$ as recommended in Damouras et al. (2010) where N represents the number of stride intervals. The number of stride intervals included in the analysis ranged from 616 to 965.

2.3.3. COM acceleration

A procedure outlined in Chang et al. (2010) was used to filter the accelerometer data, calibrate the data to within 0.1g of acceleration due to gravity, calibrate for tilt and calculate the root-mean-square (RMS) of the acceleration variability for each of the three axes. The RMS of the acceleration variability acts as an estimate for COM variability (Chang et al. (2010)).

A non-linear method of demonstrating stability is based on estimating maximum finite-time Lyapunov exponents. It has been previously found that, compared to stride-to-stride variability, average maximum finite-time Lyapunov exponents were able to characterize dynamic stability more precisely and provided additional insight into human gait (Dingwell and Cusumano (2000), Chang et al. (2010)). The maximum Lyapunov exponent quantifies local stability, which is defined as a system's sensitivity to extremely small perturbations (Dingwell and Cusumano (2000)). The Lyapunov exponents were calculated using the protocol carried out by Dingwell and Cusumano

(2000) and Rosenstein et al. (1993). Briefly, the approach involved reconstructing a state-space from the original time series and time-delayed coordinates. This entailed the estimation of the minimum embedding dimension and the time delay. Time delays were estimated by the autocorrelation function (Chang et al. (2010), Rosenstein et al. (1993)) and the embedding dimension was computed through a global false nearest neighbors analysis (Dingwell and Cusumano (2000), Chang et al. (2010)). The short-term exponents (λ_{ST}) and long-term exponents (λ_{LT}) were calculated and the reported values represent their means.

2.3.4. Statistics

Mean gait velocity in m/s was calculated for the over ground walking trials (with and without music) using the distance travelled (number of laps completed multiplied by the perimeter of the hallway) and time spent walking. For the treadmill trials, mean gait speed (m/s) was obtained from the treadmill's digital spedometer. The stride interval variability was determined by σ/μ where σ and μ represent the standard deviation and mean of the stride interval time series, respectively. The Kruskal-Wallis one-way analysis of variance, a non-parametric test for equality of group medians, was used to test for statistical differences among the mean values for each gait parameter across the walking conditions. The Wilcoxon rank sum test, a non-parametric test, was subsequently used to identify between-group differences. $p < 0.05$ was considered significant.

3. Results

According to the results of a Wilcoxon rank sum test, Session 1 measures did not differ statistically from session 2 measures in both music part and TV parts of the study ($p > 0.05$). Data from the two sessions were subsequently analyzed collectively. Additionally, the right and left foot values were not found to differ statistically in either the music or TV sessions ($p > 0.05$) for all measured parameters. All tables thus display the values from the right foot.

3.1. Effect of music

3.1.1. Stride interval analysis

The results of the stride interval analysis for the music part are summarized in Table 2. Three of the participants were excluded from the analysis due technological problems with the FSRs at the time of testing. All considered gait parameters were statistically equal. Note, however, that the greatest α and stride interval variability were observed for the OG2 (music) trial, while participants had the slowest gait speed and fewest number of strides during OG1.

3.1.2. COM acceleration analysis

Tables 3 and 4 summarize the results of the COM acceleration analysis. Note that the RMS acceleration values were not significantly different across the walking trials for any of the axes of movement ($p > 0.05$). Likewise, the Lyapunov exponents (λ) were not significantly different between the different walking trials ($p > 0.05$). The Pearson's correlation between RMS accelera-

Table 2: Characteristics of gait for different over ground walking trials. OG1 and OG3 represent overground walking trials with no music, while OG2 represent an overground walking trial with music. ‡ denotes multiplication by 10^{-1}.

	OG1	OG2	OG3	p-value
Scaling exponent (α)	0.76 ± 0.16	0.81 ± 0.17	0.79 ± 0.14	0.58
Stride interval variability‡	1.75 ± 0.41	1.83 ± 0.36	1.68 ± 0.33	0.24
Mean stride interval (s)	1.08 ± 0.08	1.08 ± 0.09	1.08 ± 0.09	0.97
Gait speed (m/s)	1.44 ± 0.16	1.48 ± 0.15	1.49 ± 0.15	0.34
Number of strides	839 ± 60	841 ± 56	844 ± 55	0.96

Table 3: RMS acceleration values for three axes of movement for different over ground walking trials.

	OG1	OG2	OG3	p-value
Antero-posterior RMS	0.17 ± 0.05	0.18 ± 0.06	0.18 ± 0.06	0.47
Medio-lateral RMS	0.16 ± 0.03	0.17 ± 0.04	0.18 ± 0.03	0.45
Vertical RMS	0.25 ± 0.07	0.27 ± 0.06	0.27 ± 0.07	0.24

tion and α values was negligible ($p > 0.05$) for all walking trials and all areas of motion.

3.2. Effects of TV on human gait

3.2.1. Stride interval analysis

Table 5 summarizes the results for stride interval analysis for the TV part of the study. The highest α values were observed for TV-S and lowest for TV-SUB. The α value for TV-SUB was the smallest amongst considered conditions and was significantly different from the TV-S condition ($p < 0.05$). Likewise, the stride interval variability was smaller for the subtitles condition

Table 4: Lyapunov exponents for different over ground walking trials. ‡ denotes multiplication by 10^{-1}.

	OG1	OG2	OG3	p-value
Antero-posterior λ_{ST}	0.47 ± 0.07	0.49 ± 0.08	0.49 ± 0.07	0.41
Medio-lateral λ_{ST}	0.49 ± 0.10	0.49 ± 0.12	0.49 ± 0.11	0.88
Vertical λ_{ST}	0.60 ± 0.12	0.63 ± 0.13	0.62 ± 0.12	0.63
Antero-posterior λ_{LT} ‡	0.44 ± 0.12	0.45 ± 0.10	0.45 ± 0.09	0.91
Medio-lateral λ_{LT} ‡	0.19 ± 0.09	0.20 ± 0.09	0.20 ± 0.09	0.77
Vertical λ_{LT} ‡	0.47 ± 0.15	0.50 ± 0.13	0.50 ± 0.13	0.61

Table 5: Characteristics of gait for different treadmill walking trials. † denotes that $p < 0.05$ when performing the pairwise comparison with TV-SUB. ‡ denotes multiplication by 10^{-1}.

	TV-S	TV-NS	TV-SUB	p-value
Scaling exponent (α)	0.90 ± 0.11†	0.86 ± 0.12	0.83 ± 0.12	0.15
Stride interval variability‡	1.64 ± 0.53†	1.39 ± 0.28	1.37 ± 0.25	0.07
Mean stride interval (s)	1.10 ± 0.09	1.10 ± 0.08	1.10 ± 0.09	0.97
Gait speed (m/s)	2.80 ± 0.43	2.91 ± 0.38	2.86 ± 0.38	0.46
Number of strides	817 ± 57	821 ± 52	811 ± 51	0.96

when compared with TV-S ($p < 0.05$). The different TV walking conditions did not appear to affect the mean stride interval or number of strides.

3.2.2. COM acceleration analysis

RMS acceleration values were not found to be statistically different ($p > 0.05$) across TV walking conditions (Table 6). Likewise, Lyapunov exponents failed to indicate significant differences across the axes of movement ($p >$

0.05) (Table 7). There were small correlations between α and the RMS

Table 6: RMS acceleration for three axes of movement for different treadmill walking conditions.

	TV-S	TV-NS	TV-SUB	p-value
Antero-posterior RMS	0.18 ± 0.03	0.20 ± 0.03	0.19 ± 0.04	0.20
Medio-lateral RMS	0.14 ± 0.05	0.15 ± 0.05	0.15 ± 0.05	0.63
Vertical RMS	0.23 ± 0.06	0.25 ± 0.06	0.24 ± 0.06	0.55

Table 7: Lyapunov exponents for different treadmill walking trials. ‡ denotes multiplication by 10^{-1}.

	TV-S	TV-NS	TV-SUB	p-value
Antero-posterior λ_{ST}	0.41 ± 0.07	0.41 ± 0.08	0.40 ± 0.08	0.98
Medio-lateral λ_{ST}	0.42 ± 0.12	0.40 ± 0.12	0.40 ± 0.13	0.88
Vertical λ_{ST}	0.52 ± 0.10	0.50 ± 0.11	0.48 ± 0.10	0.42
Antero-posterior λ_{LT} ‡	0.44 ± 0.09	0.43 ± 0.09	0.40 ± 0.09	0.53
Medio-lateral λ_{LT} ‡	0.18 ± 0.07	0.20 ± 0.09	0.20 ± 0.09	0.71
Vertical λ_{LT} ‡	0.48 ± 0.10	0.48 ± 0.11	0.46 ± 0.10	0.59

values for all trials except for in the ML axis for TV-NS and TV-SUB. TV-S indicated a small negative correlation ($r = -0.27$, $r = -0.29$ and $r = -0.16$ for AP, ML and VT) with acceleration, while both TV-NS and TV-SUB had small positive correlations with acceleration in the AP and VT axes.

4. Discussion

In this experiment, we examined different overground and treadmill walking conditions. We assessed traditional gait variables including mean stride intervals, gait speed and a number of strides in addition to quantifications of gait variability in the form of stride interval variability and COM RMS acceleration values. Finally, nonlinear methods of analysis were used to quantify gait dynamics, specifically through the computation of α and maximum Lyapunov exponents.

4.1. The effect of music

For the music part of our study, none of the measured characteristics of gait exhibited significant differences across the walking trials, although 59% of participants stated that they believed the music affected the way they walked in at least one of the sessions.

In our study, the participants listened to music that did not have an amplified beat or metronomic rhythm. Although previous research has determined that walking to rhythmic auditory stimuli (RAS), usually in the form of a metronome, results in a less persistent gait (e.g., Sejdić et al. (2012a)), Thaut and colleagues determined that music and metronomes have different affects on the gait of patients with Huntington's disease (Thaut et al. (1999)). They proposed that music involves complex auditory pattern perception and using music as motor timing cues involves frontostriatal circuitry that is not recruited when using metronomic cues. Since the participants in our study were simply told to listen to the music and not specifically to walk to the beat, it is possible that they did not recruit these additional parts of the brain to synchronize their walking to the music (Thaut et al. (1999)).

In many studies, the effect of music and RAS is limited to those with neurological disorders like Parkinson's diseases (e.g., McIntosh et al. (1997), Willems et al. (2006), Brown et al. (2009)). It is believed that the beat (be it from RAS or music) acts as an external pacing cue and stabilizes the defective internal rhythm in the basal ganglia (Hove et al. (2012)). The participants chosen for this study were able-bodied and without any neurological disorders, perhaps limiting the effect of music on gait. Intrinsic pacing mechanisms in the healthy population may be more robust to the external cues presented by the music. It has been previously proposed that patients with Parkinson's diseases need to assign greater attentional resources to maintain gait because Parkinson's disease disrupts the automacity of their movement control (Brown et al. (2009)). Since the healthy population needs little attention to maintain the pacing of gait, they can listen to music without the added cognitive load affecting or taking away resources from their intrinsic pacing mechanisms (Brown et al. (2009)), thereby limiting the effect of music on gait.

In our study, songs with a variety of tempos were played over the course of the 15 minute walking trial. Perhaps gait parameters were unaltered by the music due to the changing tempos. Previous studies examining RAS or music on gait generally employed the stimuli at specific, pre-determined tempos. Styns and colleagues found that rhythmic auditory stimuli and background music can influence basic bodily activities such as gait in an unconscious way (Styns et al. (2007)). They determined the optimal tempo to achieve this synchronization is around 120 beats per minute. The tempo of the songs played in our study varied from 95 to 119 beats per minute and so the use of the songs at the lower end of the spectrum may have discouraged synchronicity between movement and music.

The use of music instead of a metronome, the physical condition of our participants, (namely that they were young, healthy and lacking any neurological disorders), the directive to walk at their own comfortable pace and the changing tempos of music over the course of the walking trial can potentially explain why music did not significantly affect gait patterns in the present study.

4.2. The effect of TV

Significant differences were observed for the α value and the stride interval variability when comparing the TV-S and TV-SUB treadmill walking conditions. Notably, neither condition was found to be different from the TV-NS walking trial. Therefore, the differences between these two conditions can be attributed to the combination of two variables: the presence/absence of sound and the presence/absence of subtitles.

TV with sound resulted in significantly greater stride-interval variability compared to the subtitles condition. The sound of the TV may have altered gait due to the rhythm of the conversation. It has been previously found that people synchronize their gait to the pace of conversation on a mobile phone (Murray-Smith et al. (2007)). The different rhythms/tempos of conversation occurring over the course of the 15 minute trial may have altered the pace of the participants' gait by overriding their internal rhythm. Since speed was constrained by the treadmill, any attempt to change pace would result in departures from the stride as set by the treadmill, thus resulting in higher stride-interval variability. The impact of the audio stimuli on concentration is a second cause of the increased variability. The sound of the TV can add to the participant's cognitive load and distract them from the walking task at hand. Brown and colleagues found that background music, when paired with a cognitive task, resulted in gait changes that were greater than with each of these conditions independently (Brown et al. (2009)). In the present study, the sound of the TV provided a changing audio tempo and distracted from the walking task, leading to greater variations in strides.

Reading subtitles while walking on a treadmill involves gaze-stabilization which demands higher visual acuity than simply watching the television without reading (Mulavara and Bloomberg (2002)). In a study by Mulavara and Bloomberg, participants who performed a reading task while on a treadmill experienced various changes in gait when compared with simple gaze fixation (Mulavara and Bloomberg (2002)). The reading task was associated with various kinematic changes such as increasing ankle joint and knee joint flexion as a shock absorption mechanism to prevent disturbances to the head position and subsequently the gaze. They speculated that these changes in gait increase stability. Therefore, biomechanical changes employed by the participants in this study to stabilize their gaze may have resulted in decreased stride interval variability.

In addition to lower stride-interval variability, TV-SUB exhibited a smaller α value ($\alpha = 0.83$), indicating a less persistent gait. To understand this finding, we should reflect back on previous contributions. Lower α values have been seen in the elderly and those with neurological diseases like Parkinson's and Huntington's diseases who have less stable walking patterns (Jordan et al. (2007), Bollens et al. (2012)). It has been also found that elevated values of α are associated with stride dynamics in children (Fairley et al. (2010a)). These results lead to the hypothesis that the higher values associated with the younger children may represent immature stride dynamics, suggesting that there is an optimal value for α, above which indicates immature stride dynamics and below which denotes impaired gait rhythmicity. It is plausible, then, that the higher α value of 0.90, seen in the TV with sound treadmill walking condition represents a less stable gait compared to the gait while reading the subtitles ($\alpha = 0.83$). These result mirror those of the stride-interval variability analysis. The presence of subtitles may act as such a constraint to human gait, because the participants must keep their head stable in order to be able to read and comprehend the subtitles (Mulavara and Bloomberg (2002)). This added restriction may limit the magnitude of the stride-to-stride fluctuations, thereby overriding the intrinsic statistical persistence.

COM has been described as an indicator of balance (Chang et al. (2010)). In the present study, the measures of COM stability (RMS acceleration and Lyapunov exponents) did not show significant differences across the treadmill walking trials, despite differences in stride-interval variability and stride interval dynamics. These results correspond with the conclusions of Dingwell and Cusumano that the stride-to-stride variability and Lyapunov exponents measure different aspects of human locomotion (Dingwell and Cusumano (2000)). The possibility exists that the distinct TV conditions may not have differed enough to affect balance in a significant way.

4.3. Treadmill and overground walking

Some general trends can be seen when comparing the treadmill walking trials and the overground walking trials. The α values were found to be lower and stride-interval variability values higher for the overground walking trials. This finding is similar to those made by Chang and colleagues who compared overground walking with treadmill walking while holding an arm rail (Chang et al. (2009)). Since lower α values and higher stride interval variability are indicative of various pathologies and gait instability, treadmill walking may provide individuals with impaired gait a training medium to practice persistent, stable gait patterns. Comparing the COM variability and Lyapunov exponents also indicate that overground walking may be less stable than treadmill walking.

4.4. Remarks

Given that this is a proof-of-concept study, its limitation is a small sample size. Our future research efforts will expand the number of participants in the study and the age span of these participants.

Our previous contribution has determined that stride interval time series acquired while walking to music or watching television can be nonstationary (Sejdić et al. (2012b)). Even though DFA can detect statistical persistence in nonstationary times series (e.g., (Peng et al. (1994)), (Chen et al. (2002))), time-evolving correlations or random spikes can introduce various artifacts that influence the accuracy of DFA (Chen et al. (2002)).

5. Conclusion

In this paper, we investigated the effects of music and TV on gait within the able-bodied population. From our experimental results, we observed that listening to music did not significantly affect intrinsic walking dynamics in the able-bodied adult population. On the other hand, treadmill walking while watching TV with subtitles resulted in a less persistent gait with lower variability compared to treadmill walking while watching TV with sound.

Compared to COM variability and Lyapunov exponents, stride interval variability and α were more sensitive to changes due to TV watching.

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