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Influence of a rhythmic auditory stimulation on asymptomatic gait

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ABSTRACT

The direct effects of a rhythmic auditory stimulation (RAS) on the gait of asymptomatic subjects are not clear. Previous studies only showed modifications in the gastrocnemius activity, inconsistent effects on temporal parameters, and no modification of spatial parameters. Furthermore, the influence of RAS on kinematics and kinetics has only been reported in pathological gait. The objective of this study was to perform a full comparison of gait characteristics in asymptomatic subjects at preferred and reduced walking speed between without and with RAS conditions. Spatiotemporal parameters, kinematics, kinetics and EMG signals datasets were collected for each condition. RAS conditions were obtained by asking subjects to walk on metronomic beats. 17 asymptomatic subjects were included in the study (12M/5W, 37.4 ± 15.7 years, 74.0 ± 14.8 kg, 1.77 ± 0.09 m). Comparisons between without and with RAS conditions were then performed using the Statistical Parametric Mapping method. For all combined subjects, the effect of RAS was limited whatever the walking speed. Meanwhile, global effects were observed for kinematics, kinetics and EMG at both spontaneous and reduced walking speed, which can only be explained by covariances (*i.e.*, no effect on individual time-series). The use of RAS to impose a specific cadence matching the desired walking speed (*e.g.*, to collect normative data) appears thus possible, as none parameters were modified individually. However, RAS should be used with caution taking into account covariances (*i.e.*, muscle synergy or joint coordination patterns). This study has to be extended to a larger number of subjects to confirm these observations.

1. Introduction

It's well known that gait characteristics, including spatiotemporal parameters, kinematics, kinetics and electromyographic (EMG), vary with walking speed [1]. It is then questionable if patients, often walking at reduced speed, should be compared to normative data recorded on asymptomatic subjects walking at a preferred speed often higher than the patients' one. Several studies have thus made the choice to use normative data obtained at a walking speed contained in a range close to the explored population's walking speed [2–4]. In these studies, the walking speed of the asymptomatic subjects composing the normative data was often controlled using rhythmic auditory stimulation (RAS), for example by asking subjects to walk on metronomic beats [4].

However, it's not clear how RAS influences the gait of asymptomatic subjects. Since the auditory and motor systems share connections through a variety of cortical, subcortical and spinal pathways [5], some impacts might nevertheless exist. In this sense, several studies tried to investigate the effect of RAS on spatiotemporal parameters in asymptomatic subjects at preferred walking speed [6–8]. While the use of RAS did not demonstrate significant variation on walking speed [6–8] and stride length [6,8], its impact on stride duration or stride interval variability (SIV) is much more questionable. Indeed, Wittwer et al. [8] showed stride and double support durations significantly reduced, while other studies showed no difference in stride duration [6,7] due to RAS. Moreover, while Wittwer et al. [8] did not show significant difference on SIV between the two conditions without and with RAS, Hausdorff et al. [6] and Sejdic et al. [7] observed differences on this parameter with an opposite effect. The effect of RAS on kinematics, kinetics and EMG has much more rarely been studied. To our knowledge, only sagittal kinematic parameters in pathological populations have been investigated [9,10]. Concerning EMG, only Thaut et al. [11] have investigated the effects of RAS (*i.e.*, musical RAS) on EMG envelopes patterns in an asymptomatic population. For that, gait records at preferred, reduced and increased walking speeds were compared to gait records conditioned by a musical rhythm. For each walking speed, the second

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RAS condition cadence was adjusted to the first condition cadence to get comparable datasets. At the three walking speeds, they found modifications in the gastrocnemius activity under RAS, consisting in a delayed and shortened contraction associated to increased amplitude of the signal. This effect was more pronounced during the preferred walking condition. However, only the activity of the gastrocnemius was reported in this study. On the whole, in all studies mentioned above, conclusions appear sometimes conflicting and, in any case, only partially answer to the question whether the use of RAS influences or not gait characteristics in asymptomatic subjects.

The first aim of this study was thus to report the differences observed during preferred and reduced walking speed, without and with RAS, on spatiotemporal parameters, kinematics, kinetics and EMG in asymptomatic subjects. In order to manage these highly multivariate datasets, composed of not independent parameters [12,13], the method called Statistical Parametric Mapping (SPM) was used. Briefly, this method is based on the random field theory that allows studying a set of scalars or time-series (*i.e*., temporal curves) as a unique unit of observations by referring to their vector field [12,13]. In other words, by studying this multivariate space (*i.e*., the vector field), this method allows taking into account both temporal correlation and vector covariance. Another aim of this study was to validate or not the use of tools such as a metronome in gait acquisition protocols to impose cadence and thus indirectly walking speed, for example when defining a normative database.

2. Methods

2.1. Subjects

This study included 17 subjects (5W/12M, 37.4 ± 15.7 yrs, 1.77 ± 0.09 m, 74.0 ± 14.8 kg). The data were extracted from an on-going internal measurement campaign in CNRFR – Rehazenter (Luxembourg) aiming to provide a normative database for the clinical practice. All subjects did not present any motor trouble or neurological disease as well as any recent traumatic trouble. The protocol was approved by the Institutional Review Board, all data were anonymised, and subjects all gave their informed consent prior to their participation to this study.

2.2. Protocol

The subjects were asked to walk on a 10-m straight level walkway. Four gait conditions were investigated: gait without RAS at preferred (C1) and reduced walking speed (C2), and gait with RAS at preferred (C3) and reduced walking speed (C4). These conditions were randomised across subjects. In C3 and C4, subjects were asked to step in time with the beat of an electronic metronome set to induce cadences matching preferred and reduced walking speeds. For each condition, a 3-step procedure was applied. Firstly, a trial was used to find the cadence that match the required range of walking speed for each condition, by adjusting the beat to the walking speed computed in real time. Secondly, a 4-trial training was performed by the subjects in order to adjust their steps to the beat. Finally, 5 gait trials were recorded on each subject and for each condition.

2.3. Data acquisition

Spatiotemporal parameters, kinematics, kinetics and EMG signals were acquired simultaneously. For that, kinematics was recorded using an optoelectronic system composed of 10 cameras (OQUS, Qualisys AB, Sweden) sampled at 100 Hz. The markerset, composed of 26 cutaneous markers placed on anatomical landmarks on pelvis and lower limbs, was based on the Leardini's protocol [14]. Markers placement remains unchanged during the whole session recording (*i.e*., the markers placement remained the same for all conditions). Kinematics thus included the movement of pelvis, hips, knees and ankles in the sagittal, frontal and transversal planes. Kinetics was recorded by 2 forceplates (OR6-5, AMTI, USA) sampled at 1500 Hz. The EMG activity of 8 right muscles (*i.e*., tibialis anterior, soleus, gastrocnemius medialis, vastus medialis, rectus femoris, semitendinosus, gluteus medius and gluteus maximus) was collected with a 16-channel wireless electromyographic system (DTS clinic, Noraxon, USA) sampled at 1500 Hz. The EMG surface electrodes were placed following the recommended standard of the Surface EMG for a Non-Invasive Assessment of Muscles (SENIAM) project [15].

2.4. Data processing

All data were then imported under Matlab R2011b using the Biomechanical ToolKit (BTK) [16]. Kinematic time-series were interpolated when necessary using a cubic spline and smoothed by a 4th-order lowpass Butterworth filter with a cutoff frequency of 6 Hz. Similarly, kinetic time-series were smoothed by a 4th-order lowpass Butterworth filter with a cut-off frequency of 20 Hz. Raw EMG signals were first high pass filtered at 30 Hz cut-off frequency to reduce baseline shift due to motion artefacts. Then, the signals were rectified and EMG envelops were obtained by a 4th-order low pass Butterworth filter, applied in forward and backward directions, at 6 Hz cut-off frequency. Finally, kinematic and kinetic data were normalised using the procedure described by Hof [17], EMG envelops were normalised by the maximum of the mean without RAS, and all data were time-normalised to a 100% gait cycle.

Temporal (*i.e*., rhythmicity defined as ratio between right and left stance times) and spatial symmetry (*i.e*., ratio between right and left step lengths) ratios were added to conventional spatiotemporal parameters [18]. For two-side spatiotemporal parameters (*e.g*., step length), only right side parameters were used in this study ($m = 1$). Kinematics and kinetics were obtained for both right and left sides and were merged in this study under the assumption that asymptomatic gait is symmetrical ($m = 2$). EMG signals were only recorded on the right side ($m = 1$).

2.5. Statistical parametric mapping (SPM)

In order to assess the differences existing between matched cadence conditions without and with RAS (*i.e*., C1 *vs*. C3 and C2 *vs*. C4), both scalars, obtained for spatiotemporal parameters, and time-series, obtained for kinematics, kinetics and EMG envelops, were compared using SPM [12]. For each of these four datasets, a $I \times J \times Q$ vector field was defined, where I was the number of vector components, J the number of gait cycles studied, and Q the time points. I was set to 9 for spatiotemporal parameters (*i.e*., cadence, walking speed, rhythmicity, stance time, double support time, symmetry, step length, stride length, step width), 12 for the kinematic dataset (*i.e*., pelvic, hip, knee and ankle angles in the sagittal, frontal and transversal planes), 6 for the kinetic dataset (*i.e*., hip, knee and ankle moments in the sagittal plane as well as ground reaction forces in the three planes) and 8 for the EMG envelops dataset (*i.e*., the envelops of the 8 recorded muscles). For each dataset, J was set to $n \times 5 \times m$ (*i.e*., n representing the number of subject included in the analysis, 5 gait cycles per condition, m representing the number of sides used per dataset). Q was set to 1 for the spatiotemporal parameters dataset (*i.e*., scalars) and to 101 for the three other datasets (*i.e*., time-series normalised to a 100% gait cycle).

This experiment was designed as a two-way MANOVA including two experimental factors (*i.e*., RAS and walking speed)