PRINCIPAL COMPONENT ANALYSIS OF NEURAL AND KINEMATIC PARAMETERS OF FORWARD AND BACKWARD WALKING ACROSS DIFFERENT INCLINES

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The purpose of this study was to identify whether the motor pattern of forward walking (FW) and backward walking (BW) affects the neural control and kinematics of lower limbs. A 21-camera 3D motion analysis system was used for the examination of locomotion. The activation of seven muscles of the right leg was recorded. The motion analysis was performed during FW and BW on a treadmill with the subjects (n=15) walking at four different inclines. The primary analysis of the complexity of variability of the kinematics and neural data was assessed using Principal Component Analysis (PCA). The complexity of gait pattern during FW appears more varied than during BW across all inclines. The associated muscles with each component were different during FW and BW.

KEY WORDS: biomechanical analysis, motor control, gait analysis.

INTRODUCTION: The exercise, as the BW is a physical activity appeared recently. Nevertheless, there is a limitation of the existing studies regarding neuromuscular and kinematic characteristics of human gait cycle during FW in compare with the movement of BW. The behaviour of human motor control essentially varies both within the individual motion characteristics and between human beings (Daffertshofer, Lamoth, Meijer, & Beek, 2004). It has been argued that a high important number of studies have considered that the variability phenomenon of mechanical characteristics of human movement is not a reflective noise, which has been randomly identified. This noise usually provides a number of important information and characteristics based on the behaviour of the motor control and the functionality of this data probably is highly valuable. (Priplata et al., 2002). Therefore, it is a highly important need to emphasize the signals, which have been randomly identified from the principal components. The solution of this issue could be given in the event that the terms and design of biomechanical research complemented with a scientific procedure which will have as a purpose the determination of muscle synergy as well as the influence of kinematic characteristics in the motor behaviour (Daffertshofer et al., 2004). In this study, it has been hypothesised that even though the movement pattern of FW and BW is substantially reversal and identical (Winter, Pluck, & Yang, 1989), the synergistic muscle groups (agonists/antagonists), the muscular activation and kinematic parameters of lower extremities are possibly different between both directions of the gait event, as well as across the different inclinations of the treadmill. The aim of the present study was to identify whether the motor pattern and the gait event of FW and BW affects the neural and kinematic mechanisms of lower limbs at four treadmill inclinations, focusing on the differentiation of muscular synergies and kinematic parameters of lower extremities.

METHODS: Initially, regarding the research design a motion analysis protocol has been applied. After institutional ethical approval along with providing written informed consent fifteen healthy adults (11 M and 4 F; age = 26 ± 6 y, height = 1.73 ± 0.17 m, mass = 68 ± 25 kg) participated in the present study with no medical history and free from neuromuscular diseases. A 21-infrared camera three-dimensional motion capture system (500 Hz; Qualisys Opus 300+) was used for the examination of locomotion during forward and backward walking. The kinematic analysis during forward and backward walking was performed on a treadmill with the subjects walking at a fixed speed of 4km/h, at four treadmill inclinations (-5%, 0%, 5% and 10%) up to 20 seconds for each incline. A total of 36 retro-reflective markers were placed bilaterally on anatomical landmarks of the lower limbs and pelvis, Acromion Process, 4th Lumbar Vertebrae, Xiphoid Process, along with four technical clusters on the thighs and shanks (De Groote, De Laet, Jonkers, & De Schutter, 2008).

EMG: The neuromuscular activity was measured for Vastus Lateralis (VL), Rectus Femoris (RF), Gastrocnemius Medialis (GM), Tibialis Anterior (TA), Biceps Femoris (BF), Soleus (SOL) and Gastrocnemius Lateralis (GL) muscles of the right leg, using a wireless EMG system (1000 Hz; Delsys Trigno Lab, 2012). The electrodes surface was positioned on the belly of each muscle, following recommendations from SENIAM (2016). The EMG signals were bandpass filtered (10 and 500 Hz) using a fourth-order digital Butterworth filter and root mean square was calculated using a 50-ms time window. A measurement of maximum EMG activity was made during maximal voluntary isometric contractions (MVIC).

Data Analysis: A Statistical Package for the Social Science (SPSS) and Microsoft Excel (2011) were used for the analysis of collected data. The primary analysis of the complexity of variability of the kinematic motion and neural control was assessed using Principal Component Analysis (PCA). A 95% threshold was used to determine the number of components to retain. Additionally, for the identification of joint angles, it has been defined by one segment (shank) relative to the proximal segment (foot). Visual3D software (C-Motion) was used for the analysis and normalisation of kinematic and EMG data. The kinematics and neural data of the FW condition were normalized from the right heel strike (RHS, 0%) to the next RHS (100%) and the data of BW condition was normalized from the right toe on (RTO, 0%) to the next RTO (100%). Also, an additional normalization procedure was used for the EMG signal in order to identify the percentage of muscular activation $\left(\frac{\text{EMGmean}}{\text{EMGmax}} \times 100\right)$.

RESULTS: A description of the neural data set variability is shown visually in Fig 1. Initially, a number of important values of the EMG variability were identified by four PCs. However, for all seven muscles, it has been counted the mean and SD values over 95% PCs scores of variance across all conditions.

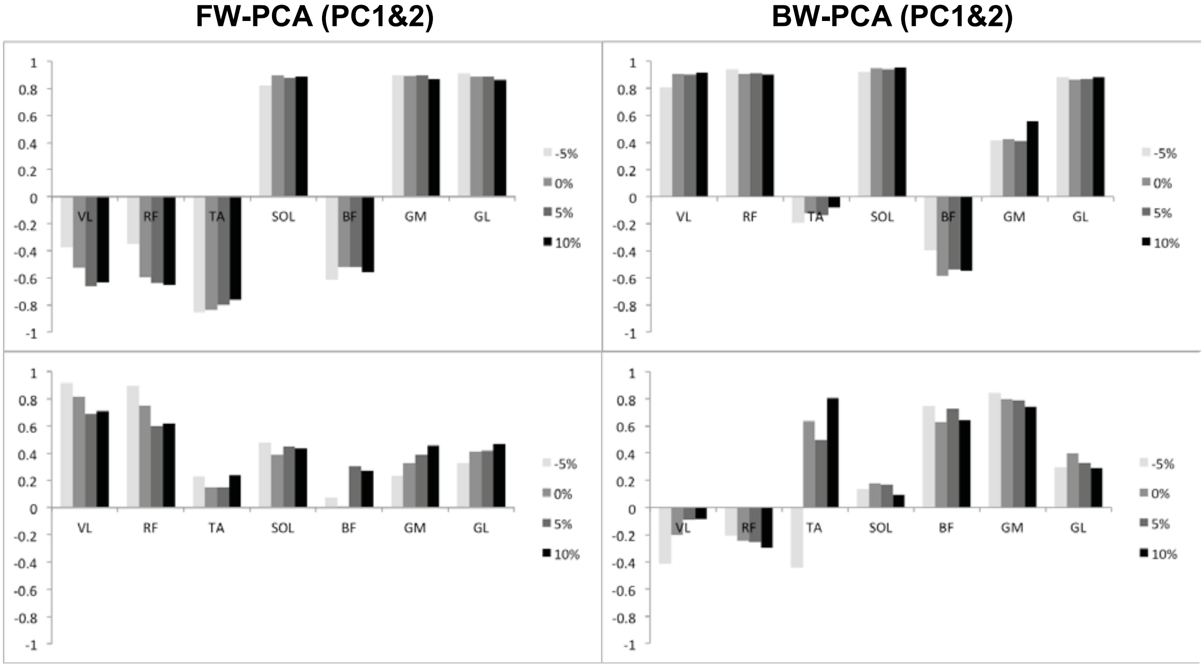

Figure 1: The variability of the neural data set interpreted by the first two principal components for FW (left) and BW (right) in four treadmill inclinations for VL, RF, GM, TA, BF, SOL and GL.

Essentially, it has been observed the dominant role of TA, SOL, GM and GL as the synergistic muscles during FW in compare with BW, where the domination of VL, RF, SOL and GL has been clearly identified. Additionally, it was determined the synergy of SOL and GL during both FW and BW, whilst the absence of TA from the synergistic muscle group during BW was also found. Moreover, regarding the variability of co-activation and domination for VL, RF and SOL during FW has been visually represented, in contradiction to

BW where the important role of TA, BF and GM has been clearly determined. However, the intricacy of the neural synergy presents similarities across inclinations and directions (four components). In spite of this similarity in the comprehensive complexity of neuromuscular behaviour, the associated muscles with each component were different during FW and BW.

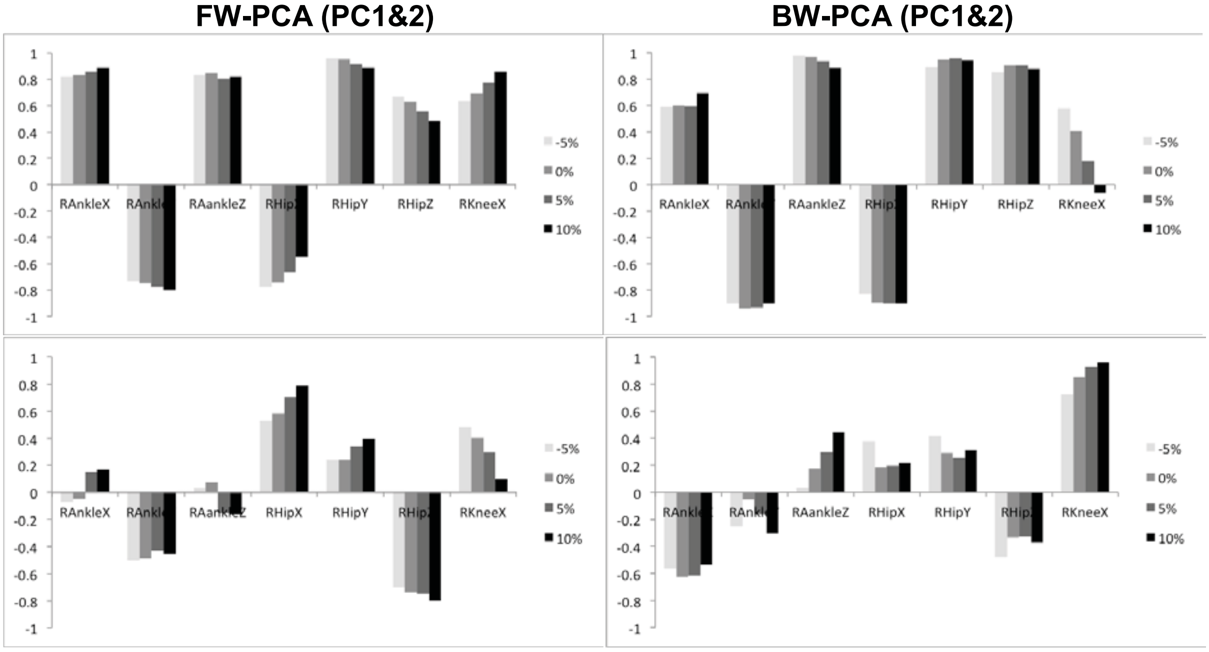
FW-PCA (PC1&2) **BW-PCA (PC1&2)**

Figure 2: The variability of the kinematic data set interpreted by the first two principal components for FW (left) and BW (right) in four treadmill inclinations for the right hip (RHip), right knee (RKnee) and right ankle (RAnkle).

Consequently, it can be argued that the direction of gait can influence the neural control of muscles. A visual determination of the variability of kinematic data set is shown in Fig. 2. The complexity of the movement pattern during FW appears more varied (four components) than during BW (three components) across all inclines. Regarding the kinematics variability of PC1, the values of variance show that a differentiation, which has been observed was the high scores in Rknee values during FW and the values of RHip in BW that is significantly higher than for FW. Furthermore, according to the scores of PC2, it has been determined that the FW has highly affected the values of RAnkle and RHip whilst, it was identified that the BW has highly influenced the values of RAnkle and Rknee. Overall, it can be argued that the synergy of some muscles differs in each condition, regarding the direction of walking. Also, it can be considered that the walking conditions have affected differently the joint kinematic parameters.

DISCUSSION: The principal laboratory findings were a major portion of the variance (> 95%) using essentially four PCs for each data set. The neural data set has shown the presence of differentiations between FW and BW regarding the synergy of the muscle group. The muscular activation pattern that has the dominant role during FW appears substantially different than during BW. Moreover, the neural variability for FW and BW has shown a different variance in numerous variables across all treadmill inclines. These findings advocate in our proposed hypothesis that the muscular activation pattern possibly varies both in the direction of the gait event and between the inclinations on which the gait movement has been performed. This may strengthen the findings of previous studies, which have argued that the variability phenomenon of mechanical characteristics of muscular synergy is not a reflective noise. Instead, this has been identified as indicative of true movement, and the functionality of this is considered highly valuable regarding the behaviour of the motor control (Huber et al., 2013). Especially, the dominant role of SOL and GL has been identified in both directions of the gait event. However, SOL and GM had been supplemented with TA and GM as synergistic muscles, responsible for the FW, whilst the same muscles (TA & GM) were complemented with VL and RF for the performance of BW. The concentric activity of GM and SOL during FW was identified into our findings. Also, a significant feature of our findings is the absence of TA during BW, whilst the TA has been identified as a dominant muscle, which is responsible for FW. This can be easily explained using the theory of Winter et al. (1989, p. 304), who argued that the gait pattern of FW is essentially a reversal of BW. Subsequently, this may suggest the presence of dorsiflexion during heel strike for FW, whilst during the period of time between toe on and heel off for BW. Therefore, TA can be probably identified as a dominant muscle for the gait event in both directions, as a responsible muscle for the dorsiflexion. The inactivation of TA during BW may be due to the hip and ankle kinematic parameters. Overall, in spite of a number of similarities in the neuromuscular behaviour of FW and BW, the presence of numerous differences in the complexities of the resultant movement patterns has been intrinsically identified. This possibly is as a result of the action of bi-articular muscles, which are working across both joints in BW, but not during FW. Essentially, The neural pattern of those muscles would be activated at different periods of time (i.e. knee flexion and plantarflexion for the GM) but the kinematic pattern of the resultant joint would be similar. Consequently, this may advocate the presence of a remarkably complex motor control strategy occupied due to the number of pairings of agonist and antagonist as well as uni- and bi-articulators pairings. Additionally, in this study, a PCA has been applied to a number of varied biomechanical analyses focusing on the neural and kinematic characteristics of the gait. In contradiction to normal gait analysis, the PCA applies a quantification of the differentiation of coordinated variables for the determination of the multidimensionality of different signals.

CONCLUSION: The present study has determined whether the motor pattern of FW and BW affects the neural and kinematic mechanisms of lower limbs, using a number of biomechanical analyses and it can be suggested that the functionality of the principal findings of this research are highly valuable. Specifically, this study has identified that the behaviour of human motor control is essentially varied both within the individual motion characteristics and between the conditions. Additionally, through this study, it has been sufficiently determined an even more complex indicative strategy related to motor control. Accordingly, PCA and associated analyses are considerably valuable for the identification of determining features motor control. The outcomes of the present study provide a number of features and formalities regarding the motor control of human locomotion. Moreover, the functionality of those findings probably is highly valuable for the development of effective rehabilitation methods. As a result, the present study displays an advanced approach and analysis of identification of neural and kinematic variability that is responsible for the motor control of forward and backward walking.

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