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SOME PROPERTIES OF THE INTRA-INDIVIDUAL TEMPORAL COVARIABILITY OF JUMP HEIGHT AND LOWER-LIMBS FREQUENCY MEASURES. A PILOT STUDY

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Abstract

In this pilot study our aim was to test the possibility of existence of contemporaneous as well as lagged relations among time series representing the rate of change of jump height and leg movement frequency- measures in students from the Faculty of Physical education, Sports and Health, in Skopje. To achieve this goal, we used a sample of 5 volunteers (N =5; 4 male and 1 female, aged 24.6 years). Measurements were conducted twice each day with length of 30 days. The sample of measures consisted of 4 power variables: 1. Counter-movement jump (CMJ); 2. Counter-movement jump with free arms (CMJFA); 3. Squat jump (SJ); 4. Squat jump with free arms (SJFA); and 5. Stepping frequency (SF). All were measured using MicroGate OptoJump RX10. The daily measurements were separated at least 3 hours. The collected time series with length of n = 61 data points contained indications of non-stationarity such as local trends. In order to obtain stationarity, we applied order 1 differencing of time series with lag 1. With aim to check for the existence of statistically significant contemporaneous as well as lagged bi-variate relations among the collected intra-individual time series we applied a cross-correlation analysis. 50 within-person cross- correlations were estimated. The most consistently present statistically significant contemporaneous relation was the lag 0 correlation between the (CMJ) and (CMJFA) variables $r = 0.48 \pm 0.02$; $p < 0.001$. It was present in all participants. Somewhat less consistently present and with smaller although significant correlation values were the contemporaneous (i.e. lag 0) cross-correlations among the pair of variables (SJ) and (SJFA); $r = 0.31 \pm 0.08$; $p < 0.02$. Lagged cross-correlations with lags 1-7 were also present with even less consistency and they were individually-specific. From methodological point of view, this study revealed the existence of contemporaneous as well as lagged relations among the time series representing the rate of change of power- and frequency-measures in students. This result is promising with respect to application of more informationally rich statistical methods such as the Group-Iterative-Multiple-Model- Estimation (GIMME). From the perspective of the intra-individual co-variability of motor-ability-measures the results showed that some contemporaneous relations may be persistent across all individuals and some contemporaneous as well as lagged relations are individual-specific. These results point to the possibility of existence of more general and individual-specific, time-distributed, relations among specific neuro- musculo-tendinous-skeletal mechanisms responsible for generating the power performance. The pilot study showed promising results with respect to the future modelling of the intra-individual co-variability in the space of motor abilities in humans.

Key words: *intensive longitudinal analysis, human performance, motor abilities, cross-correlation, power, coordination*

Introduction

Within the newly emerging field of Network Physiology of Exercise (Balague et al, 2020), the analysis of time series and mutual temporal couplings of multivariate processes plays a central role. Previous research (Balague et al, 2022) has already shown how the analysis and modelling of temporally-distributed processes, such as the maximal motor performance measures in humans (Hristovski & Balague, 2010; Vasquez et al., 2016; Vázquez, et al., 2021), may be an important complement, and in

some cases corrective, to the more traditional methods in the Kinesiology which are based solely on group-pooled statistical analysis models. By continuing this line of research, the purpose of this paper is to conduct a preliminary analysis of the bivariate temporal couplings between variables that measure the maximal performance in jump height and movement frequency of legs. The activation patterns that bring-up the performance in these variables differ in the degree of involvement of the underlying neuro-musculo-tendino-skeletal generative processes such as: the supraspinal influences, the stretch-shortening cycle, the intra- and inter-muscular as well as the inter- limbic coordination (Komi, 2003; Taube et al., 2012). The difference is particularly present between the jump height variables and the frequency of leg movement variables, due to their motor control differences (i.e. discrete vs. rhythmic movements) (Degallier, & Ijspeert, 2010; Jirsa & Kelso, 2005).

The main characteristic of the maximal performance tests is that they fluctuate on many scales under repeated measurements. These fluctuations (i.e. temporal variability) are a consequence of the differences in the organization of the movement's energetic and coordinative patterns under repetitive measurements. In other words, it means that each repetition of the movement contains a set of stable self-organizing processes (Degallier, & Ijspeert, 2010; Jirsa & Kelso, 2005), however also some situational adaptive processes which depend on a large number of interacting constraints (Balague et al., 2019). Hence, the temporal behavior as well as the relations of these multivariate fluctuations may contain important information about the couplings of shared and specific processes that generate the performance in each of these variables (Hristovski et al,.2010) at intra-individual level. In other words, they convey information about the common and shared variance among the maximal performance variables. Furthermore, the covariance among the variables may be not only contemporaneous, but may also include inter-variable influences that temporally predate or postdate the current performance in some variable (so called - lagged relations). The aim of this paper is to make the first insights of the above discussed possible relations and orient the future work based on these insights.

Material & methods

Participants, measures and test protocol

In order to investigate the above-mentioned possible relations, for our pilot study, we used a sample of 5 volunteers (N =5; 4 male and 1 female, average aged 24.6; maximum 31 minimum 21). The sample of measures consisted of 4 jump height variables measured in centimetres with accuracy to second decimal place: 1. Counter-movement jump (CMJ); 2. Counter-movement jump with free arms (CMJFA); 3. Squat jump (SJ); 4. Squat jump with free arms (SJFA); and 5. Stepping frequency (SF) variable, measured in number of steps performed. All tests were conducted on Opto-jump version 1.13.24 installed on Windows 10 operative system with excellent statistical metric characteristics (Glathorn, 2011; Condello, et al., 2020). Participants were tested by the following order: CMJ test, CMJFA test, SJ test, SJFA, test, SF test. Each participant has at least 2 minutes pause between the tests. The measurements lasted for 30 days and were conducted twice a day. The daily measurements were conducted in the time interval from 9.00 AM-14.00 PM, and separated at least 2 hours. In this way we obtained time series of 5 measures with length of n = 61 data points.

Data pre-processing and statistical analysis

The collected multivariate time series contained indications of non-stationarity such as local trends. In order to obtain stationarity, we applied order 1 differencing of time series with lag-1. The new differenced time series had a length of n – 1, i.e. 60 data points. The differenced data were informative of the direction and rate of change of the measured variables. Because the aim was to check for the existence of statistically significant contemporaneous as well as lagged bi-variate relations among the differenced intra-individual time series, we applied a cross-correlation analysis. Hence, the cross-correlations were informative about the contemporaneous and lagged covariations of the rate and direction of change of the measured variables.

Lag-0 cross-correlations give information about the strength of relatedness of variables at the same measurement session (i.e. contemporaneous relations) (see Fig.1). Lag-o cross-correlations are identical to the. ordinary Pearson correlation coefficient. Lags with values ± 1-7 inform about the strength of relations between two variables when one of them is lagged for a certain amount. For example, lag±1 cross- correlation, in this investigation, informs about the relation of the values of one variable on the previous or the next measurement with the value of the second variable on the current measurement.

Analogously, lag±5 cross-correlation informs how strong is the relation of one variable measured 2 days ago or 2 days after the current session with the value of the other variable measured on the current session (see Fig. 1). Fifty within-person cross-correlations were estimated. We set the statistical significance threshold on p=0.05 which for 60 data points corresponds to a cross-correlation of r = 0.25.

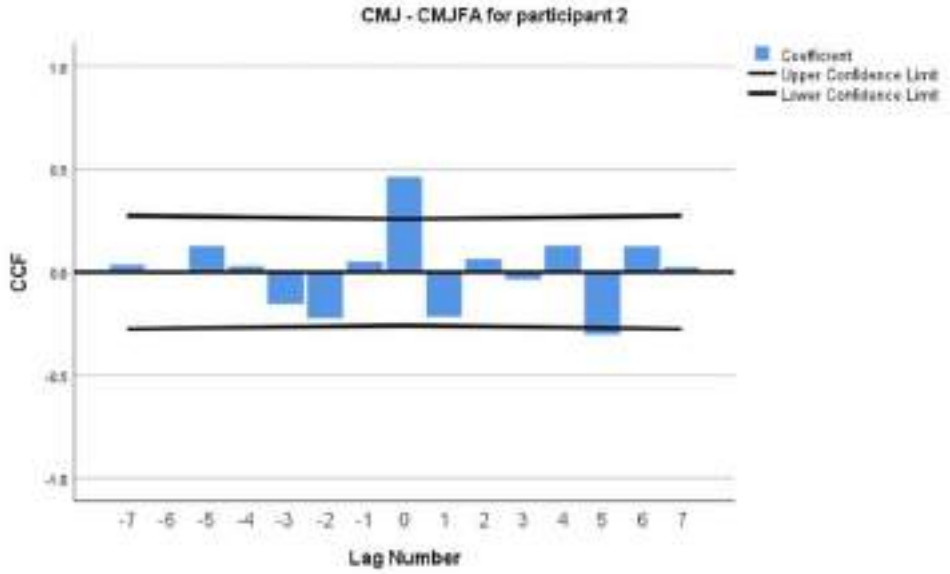

Figure 1. An example of cross-correlation function (CCF) with statistically significant positive medium lag-0 value and statistically significant weak lag+5 negative value.

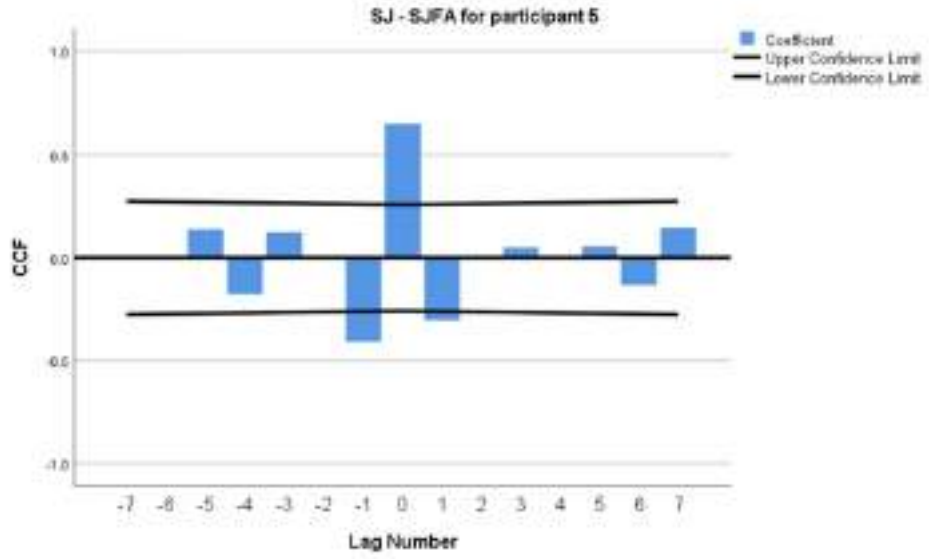

Figure 2. An example of cross-correlation function (CCF) with statistically significant positive and high lag-0 value and statistically significant weak lag± 1 negative values.

Results

The most consistently present statistically significant contemporaneous relation was the lag-0 cross- correlation between the CMJ and CMJFA variables r = 0.48±0.02; p < 0.001. It was statistically significant and with medium hight in all participants. Somewhat less consistently present and with smaller although significant correlation values were the contemporaneous (i.e. lag-0) cross-correlations among the pair of variables (SJ) and (SJFA); r = 0.31±0.08; p < 0.02. The average lag-0 cross-correlation between CMJ and squat-jump variables (SJ) and (SJFA) was statistically significant

but low: $r = 0.26 \pm 0.01$; $p < 0.05$ and $r = 0.27 \pm 0.04$, respectively. Statistically significant but weak lag-0 cross-correlations, i.e. $r = 0.35 \pm 0.01$; $p < 0.04$ and $r = 0.32 \pm 0.1$; $p < 0.01$, were found for CMJFA and SJ and CMJFA and SJFA, respectively. The average lag-0 cross-correlations between all power variables (CMJ, CMJFA, SJ and SJFA) and the stepping frequency variable (SF) were non-significant, however in some participants there were weak to medium statistically significant relations for higher ±lags.

In general, lagged cross-correlations, with lags ± 1 to 7, were also present with even less consistency and they were eminently individual-specific. A general characteristic was that more often higher lagged cross-correlations were noticed for smaller lags, e.g. 1-4 (see Fig. 2), and smaller cross-correlations were present for higher lags (see Fig 1).

However, we must emphasize that for many of these bi-variate relations the participants showed high degree of heterogeneity. In other words, whereas one participant may show a high cross-correlation between some variables, other participants may show non-significant or close-to non-significant relation for the same pair of variables and on average the sample would show non-significant covariation at the certain lag.

Discussion

We conducted a preliminary investigation on the possible contemporaneous and lagged relations within a set of 4 jump height variables and one variable that measures the stepping frequency. This pilot study, to our knowledge, is the first that studies the temporal relations among the said set of variables and possibly has a relevance for the studies of the structure of the space of motor abilities in general. The results suggest some more stable (possibly general) contemporaneous temporal bi-variate relations and also highly heterogeneous, and hence individual-specific, lagged temporal bi-variate relations. The high heterogeneity was very much detectable when sample averaged cross-correlations were compared to individual cross- correlations and was also detectable in the difference between the standard deviations of the averaged cross- correlations. This result, inter alia, signifies that statistical approaches based on pooling-over-subjects may give sometimes a wrong information about the real covariation of within-subject processes (see e.g. Molenaar, 2003). In other words, results point to the possibility of existence of more general as well as individual-specific, time-distributed, relations among specific neuro-musculo-tendinous-skeletal mechanisms responsible for generating the jump height and leg movement frequency performance.

The higher and fully consistent, contemporaneous, sample averaged cross-correlations of the counter- movement jumps (without and with arm movement), i.e. CMJ and CMJFA respectively, with respect to sample averaged cross-correlations between squat jumps (without and with arm movements) possibly points to a more stable relationship between the former pair. This may be a consequence of the more stabilized motor control and biomechanics of the counter-movement jumps, since in all individuals being an initial upright stance, in order to maximize the jump hight, they naturally perform quick counter- movement with aim of the engagement of the stretch- shortening cycle (Komi, 2003). With respect to the ‘naturalness’ of the jump the squat jumps, which do not significantly engage the stretch-shortening cycle, are less frequent, and hence, less stabilized patterns. A careful reader will notice in the results section that the counter-movement with free arms variable (CMJFA) variable has highest sample-averaged temporal relations with other 3 jump height variables when mutually compared. This points to the possibility that this variable (i.e. CMJFA) is the most complex one and hence, contains and coordinates all the sub- processes which are partly present in other variables. This comes as no surprise, since the said variable performance depends on the fine coordinated use of both: a. the stretch-shortening cycle (Komi, 2003, Taube et al, 2012) and b. the quick and coordinated upward upper-limb movement. Additionally, it contains the processes that produce the coordinated intra- and inter muscular synchronization (Taube et al, 2012) in the relevant leg muscles, which is common also for the rest 3 variables. However, the other 3 jump height variables lack an emphasized use of one of the first two processes (either a or b).

The non-existent sample-averaged cross-correlations of the rate of change of jump performance variables with the stepping frequence variable shows the task specificity of this variable with respect to the former variables. However, the statistically significant and medium cross-correlation found in one of the five participants shows that this non-existent relation may be a mere statistical artifact produced by sample- averaging. Concerning the lagged relations among the variables with positive and negative directions, they may reflect the enhancing or suppressing processes that predate or postdate

the current measurements. A crucial test for the practical use of these lagged relations and the information they reveal will be the degree of stability of these relations at intra-individual level. These results show that a more subtle approach may be needed when searching for the real (i.e. intra-individual) structure of motor abilities. In this sense, this pilot study showed promising results with respect to the future modelling of the intra-individual co- variability in the space of motor abilities in humans. On the other hand, these results are promising concerning the application of more informationally rich statistical methods such as the Group-Iterative- Multiple-Model-Estimation (GIMME) (Beltz et al., 2016) which will be used in our further studies.

Conclusions

This pilot study showed that some contemporaneous relations may be persistent across all individuals and some contemporaneous as well as temporally lagged relations are individually-specific. Results point to the possibility of existence of populationally general as well as individually-specific, temporally-distributed, relations among specific motor control processes responsible for generating the jump height and leg movement frequency performance. The pilot study showed promising results with respect to the future understanding of the intra-individual co-variability in the space of maximum performance variables in humans. It opens possibilities of using intensive longitudinal analysis of motor abilities at intra-individual level.

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