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Do performers' experience and sex affect their performance?

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Abstract

This cross-sectional study aimed at developing a biomechanical method to objectify voluntary and unpredictable movements, using an automated three-dimensional motion capture system and surface electromyography. Fourteen experienced theatre performers were tested while executing the old man exercise, wherein they have to walk like an old man, building up a sustained high intensive muscular activity and tremor. Less experienced performed showed a different kinematics of movement, a slower speed of progression and more variable EMG signals at higher intensity. Female performers also differed from males in movement kinematics and muscular activity. The number of the trial only influenced the speed of progression. The performers showed results which could be well placed within the stages of learning and the degrees of freedom problem.

Over the last decades, the importance of biomechanical movement analysis of athletes and dancers has grown (Cannell, Taunton, Clement, Smith, & Khan, 2001; Koutedakis, Owolabi, & Apostolos, 2008; Padulo, Powell, Milia, & Ardigò, 2013; Petersen, Nielsen, Rasmussen, & Sørensen, 2014; Pfile et al., 2013). Many factors, such as experience, sex and emotional factors may influence movement characteristics. However, these influencing factors have not been fully explored yet.

The majority of the studies evaluating biomechanical movement analyses were performed to examine the link with injury prevention and/or treatment (Cannell et al., 2001; Koutedakis et al., 2008; Padulo et al., 2013; Petersen et al., 2014; Pfile et al., 2013). Many injuries or physical complaints appear to be related to maladaptive biomechanical factors, local to the injury site as well as at remote locations (Koutedakis & Jamurtas, 2004; Munro, Herrington, & Comfort, 2012; Nishikawa et al., 2007). A prospective biomechanical-epidemiologic study revealed for example that deficits in motor control of the trunk predict knee injury risk in female athletes (Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007). In addition to injury prevention, biomechanical movement analyses are also used to understand physical performance. Athletes as well as dancers are increasingly analyzed in order to gain knowledge about specific physical tasks (Johnston, Butler, Sparling, & Queen, 2015; Stuelcken, Greene, Smith, & Vanwanseele, 2013). For example, a biomechanical evaluation of standardized ballet movements allows the quantification of joint angles and/or specific muscle activity.

Comparison of these muscular patterns in experienced and inexperienced dancers lead to increased insight in artistic optimal performances. Overall these studies revealed that inexperienced dancers show more variability in their movement patterns than experienced

dancers (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2009; Twitchett, Angioi, Koutedakis, & Wyon, 2011).

Dance movements, but also functional movements are often characterized by highly variable and complex movement patterns (Harbourne & Stergiou, 2009). Biomechanical analyses performed thus far have mainly researched cyclical and predictable simple movements, as for example stereotyped ballet movements, reaching exercises or gait analysis in healthy and patient populations (Hallemans, Ortibus, Truijen, & Meire, 2011; Krasnow, Wilmerding, Stecyk, Wyon, & Koutedakis, 2011; Louw & Deary, 2014). Voluntary and unpredictable movements, however, have not been examined yet, although they more closely represent the natural movement repertoire of an individual, be it patient, athlete or dancer. In contradiction to ballet dancers who execute a strictly predetermined movement pattern in time and space, so-called performers (physical/ corporal actors and dancers with clear acting skills) receive no strict choreography for their performances, and therefore show more variability in their movement pattern. Since the increasing interest regarding physicality in theatre (Clark, Gupta, & Ho, 2014; Clark, Williamon, & Redding, 2013; Van den Dries, 2004; Manchester, 2014), performers can be considered a highly relevant population to examine the use of unpredictable movements.

Until now, studies examining complex human movements, especially in the arts domain, are lacking. For example, it could be hypothesized that experienced theatre performers (more often just called 'performers') show other biomechanical characteristics as less experienced performers, as it is the case in dancers. However, since previous research in dancers only focused on cyclical or non-voluntary movements, this hypothesis has not been proven yet in theatre performers who use voluntary and non-cyclical movements.

By combining biomechanical modeling and statistical analysis methods that take variability into consideration, such as factor analysis (Van Dam, Hallemans, & Aerts, 2009), it is possible to unravel the motor control mechanisms behind functional or unpredictable movements. As such, these advanced methods enable us to gain more insight into the physical aspects of the movements of dancers and theatre performers. For Jan Fabre, Belgian stage director and visual artist (Antwerp, 1958), physical activity is considered the foundation of his "guiding lines for the performer", an extensive set of preparatory training exercises focusing on creating physical awareness and presence on stage (Roussel et al., 2014). Therefore, it is interesting and might be useful to perform biomechanical research on Fabre's performers, since they are submitted to high physical loads (e.g. stage performances lasting 4, 8 or even 24 hours).

The first aim of this study is to provide an objective research method for future analysis, description, and comprehension of unpredictable movements. The method is developed by investigating a highly variably exercise requiring voluntary control of almost all degrees of freedom of the musculoskeletal system. Kinematic analysis of the movement patterns and registration of muscular actions during the execution of this exercise, will allow us to understand the biomechanical characteristics of voluntary and variable movement. The second aim of the present study is to use this objective research method to gain insight in the voluntary control of movement of Fabre's performers during unpredictable, non-cyclical exercise movements. We expect that more experienced theatre performers will show less variability in movement characteristics (Lu, Kincl, Lowe, Succop, & Bhattacharya, 2015) as well as less intensive muscular activity (Ohata, Matsuo, Ban, Shiba, & Yasunaga, 2013), and that the kinematics of movement is also affected by experience. Movement patterns might

also differ between male and female performers. Furthermore, due to the required enduring muscle activity, we hypothesize that the intensity muscular activity will show a decrease as a result from fatigue.

Methods

Study design and experimental set-up

Using a cross-sectional study design, participants were observed in a multi-disciplinary, motion analysis laboratory (M²OCEAN), equipped with an automatic three-dimensional motion capture system and surface electromyography. The period of data collection was between June 2012 and April 2013. All participants read and signed an informed consent form previous to the measurements. After a five minutes warming-up session, participants were asked to perform two of the exercises from Jan Fabre's masterclass (Van den Dries, 2004) while registering total body kinematics and EMG activity of 12 independent muscles. The first exercise was the *Cat exercise*, where the participants were asked to behave as a feline, i.e. to move with extreme precision, to be aware of the spatial occupation of their movements (Roussel et al., 2014). After a resting period of five minutes, the second exercise, *the Old Man exercise,* was performed. This exercise is characterized by an inner tremor and extremely slow movements, demanding tremendous physical concentration from the participants (Roussel et al., 2014). In this last exercise, Fabre asks his performers to build up a high load muscular tension and tremor over the entire body. The exercise takes approximately 20 minutes to perform. Ten trials of 30 seconds were registered per performed exercise, all separated by a period of one minute without registering (during which the exercise was continued).

An instructor of the team of Jan Fabre was present and gave all the performers an identical short instruction, explaining the exercises one more time, without giving any further

information that might constrain the artistic liberty of the performers. This instructors were further not involved in the data processing and statistic processes. They asked the performers to mentally prepare by conjuring an inner tremor. Once the whole inner being is filled with this quaking, the body can begin to vibrate. The idea is that the shaking moves from the inside to the outside of the body, a metaphor that is often used in instructions. Slowly, the performers have to move through the room, as if walking through an imaginary apartment (occasionally grasping imaginary furniture), conquering the space millimeter by millimeter. The performers need to give themselves an (imaginary) concrete goal, for example reaching the television at the end of the room. This process can easily take 20 minutes. Only the *Old Man exercise* will be analysed and discussed in this paper. In this exercise, the performers are required to consciously control almost all degrees of freedom of the musculoskeletal system. Therefore, this exercise is very useful for this explorative research, creating a standardized method to analyse, comprehend and describe voluntary, non-cyclical and unpredictable movements,

Participants

Participants with a wide range of experience (N = 15) were recruited from Jan Fabre's acting company, existing of trained/schooled actors and dancers. The Fabre's company consists of 20 theatre performers, of which 15 performers met the inclusion criteria: having participated in at least one workshop and one production of Jan Fabre. The experience of the performers was expressed in number of productions they participated in. The outcome assessors were blinded to the degree of experience of the performers. No exclusion criteria were used.

Data measurement

Eight Vicon T10 cameras (Vicon® Oxford, UK, 100 fps, resolution 1 Megapixel) were used to measure kinematics of movement. Data were captured and reconstructed to a 3D

image using the Vicon Nexus 1.8 software. Reflective markers were placed over anatomical reference points according to the Plug-In-Gait marker set-up (Kadaba, Ramakrishnan, & Wootten, 1990).

Muscle activation patterns were recorded using a 16-channel wireless Noraxon ZeroWire EMG system (1000 Hz). Surface EMG electrodes (Kendall H124SG Ag/AgCl 24 mm) were placed on the right side of the body over the Erector Spinae (ES) and Rectus Abdominis (RA) for the trunk muscles. For the right lower extremity, they were placed on the Rectus Femoris (RF), Vastus Lateralis of the Quadriceps (VLQ), Biceps Femoris (BF), Tibialis Anterior (TA) and Triceps Surae (TS). For the right upper extremity, the electrodes were placed over the Deltoideus (D), Biceps Brachii (BB) and Triceps Brachii (TB). All electrodes were placed according to the SENIAM guidelines (Hermens & Freriks). Prior to electrode placement, the skin was prepared through shaving and cleaning with diethyl ether.

Kinematic data analysis

After reconstruction and tracking, the marker coordinates were filtered using a second order zero phase-shift low-pass Butterworth filter (cut-off frequency 6 Hz.). The conventional gait model (Baker, 2006) was used to obtain 3D kinematic data of the lower extremity joints from the 3D coordinates of the individual markers. Joint angular time profiles are expressed in Euler/Cardan rotations of the more distal relative to the more proximal segment. Following kinematic time profiles were selected for further analysis: hip flexion/extension, hip ad/abduction, hip external/internal rotation, knee flexion/extension, ankle dorsiflexion/plantar flexion and internal/external rotation. Additionally to the conventional gait model, two segmental angles were measured.

The kyphosis angle of the spine was characterised as the 3D angle between the markers on C7, T10 and the sacrum (SACR) according to formula $\cos\alpha = (A^2 + B^2/2AB) - C^2$ (1). In this formula, A is representing a vector between the markers of C7 and T10, B is a similar vector between the markers of T10 and SACR and C is a similar vector between the markers of C7 and SACR. Similarly a Shoulder Bend Angle was characterised as the 3D angle between the markers on C7, the left acromion and right acromion (formula 1). The Shoulder Bend Angle characterised equally, but with A representing a vector between the marker of the left acromion and C7, B representing a vector between the right acromion and C7 and C representing a vector between both acromions. For each kinematic time profile, the maximum, minimum and average value over the performed step was calculated. The range of motion was calculated as the difference between maximum and minimum values. The mean speed of progression was calculated by the product of stride length and stride frequency, based on the progression of the ankle marker.

EMG data analysis

The raw EMG signal was processed using a custom made Matlab (R2013a) model. After a full wave rectification, the signal was filtered using a second order zero phase-shift band-pass filter (10 – 300 Hz.). Next, a moving average window of 50 msec was applied to the filtered EMG signal in order to calculate the linear envelope (E). Intensity of muscle activation was characterized as the integrated linear envelope (I) of the EMG signal over the entire 30 seconds of each trial, according to formula $I = \sum \Delta E \times \Delta t$ (2).

Statistical analyses

Statistical analysis was performed in IBM/SPSS version 22 for Windows. The data were explored using boxplots, in order to identify any extreme values. Mistakes (missing markers) were corrected or values were deleted if necessary. Missing data were treated as missing. The variables selected for further analysis were mean speed of progression, the

range of motion of all measured joint angles (dynamic aspects of the exercise) and the mean joint angular position over the performed step (static/posture during the exercise). A Principal Component Analysis (PCA) was performed in order to explore the variance in the selected kinematic variables and to reduce the high number of available parameters. A 'varimax' (orthogonal) rotation was chosen for the PCA, to minimize the number of variables with high loadings on each factor. Newly composed variables of principal components were only represented if they explained a sufficient part of the variance (eigenvalue > 1). A scree plot was used to determine the optimal numbers of components for the further analysis. Only the factors left from the last steel slope of the scree plot were further included (Grover & Vriens, 2006).

To investigate the effect of fatigue and the performers' experience (number of performances in which they participated) on the kinematics and muscle intensity a linear mixed model was designed. The newly composed variables from the PCA and the integrated linear envelope of the EMG signal of each muscle were added to the model as dependent variables. Experience (number of productions), sex of the performer and trial number were independents. Of each trial, one gait cycle consisting of two steps was analysed. The trial number was used to trace time effects, since it represents progression of exercise over time. Both main effects and interaction effects were investigated. Non-significant two-way interactions were left out of the model. The level of significance was determined at $p<0,05$.

Results

Descriptive statistics

Demographic information of this study's population is shown in table 1. In this table, males and females are discussed separately, since sex could possibly influence the biomechanical properties of the performers (Bruening, Frimenko, Goodyear, Bowden, &

Fullenkamp, 2015). One performer was excluded out of the study, due to methodological issues (missing markers).

Principal Component Analysis

The PCA resulted in seven principal components with an EigenValue being greater than one, explaining up to 76.7% of variance. A scree plot showed a last steel slope between the fourth and fifth factor. The first four factors from the PCA explain 57.9% of the variance in the dataset (see figure 1) and will be discussed further.

Total initial EigenValue, % of variance, Cumulative % of variance and factor scores for each variable on each principal component axis can be found in table 2. The factor scores are the loadings of the variables on the Principal Component axes and can be used to calculate the component scores per performer on the Principal Component axes.

The first component consists of mean hip flexion-extension, mean knee flexion-extension and mean pelvic tilt. Positive values of mean hip flexion together with positive values of mean knee flexion and positive values of mean anterior pelvic tilt show strong loadings on the first principal component. This indicates that the first component describes the variation in the *Bended Posture*. The second component (termed *Twisting*) shows high loading from positive values of ROM of hip abduction/adduction, hip rotation and pelvis rotation. A high loading could be found on the third component (*Swinging*) from positive values of ROM of hip flexion/extension, ROM of pelvic tilt and ROM of pelvic obliquity, together with positive values of the mean Shoulder Bend Angle. Higher values of Shoulder Bend Angle indicate a more straightened posture, since this parameter measures the anterior angle between the left and right shoulder girdle. The fourth component can be defined as *Speed of Progression.* A strong loading could be found on this factor from positive values of mean speed and ROM of knee flexion/extension.

Mixed Linear Model

The overall model showed significant effects of experience (number of productions) and sex on the performance of the *Old Man exercise*. The sex of the performer significantly influenced factor 2 (Twisting: *P=0.002; F=9.989; 1-β=0,597)*. Female performers showed higher values for factor 2 than male performers. No significant influence could be found on factor 1 (Bended Posture), factor 3 (Swinging) and factor 4 (Speed of Progression).

The experience of the performers showed a significant influence on factor 2 (Twisting: *P=0.002; F=9.989; 1-β=0,879*), factor 3 (Swinging: *P=0.012; F=6.582; 1-β=0,720*) and factor 4 (Speed of Progression: *P=0.004; F=8.737; 1-β=0,833*). Figure 2 shows the differences in movement patterns between performers with high and low experience (respectively *Swingers* and *Twisters*). Figure 3 shows the trend lines of each factor. No significant influence could be found on factor 1 (Bended Posture).
Only factor 4 (Speed of Progression: *P=0.004; F=2.634; 1-β=0,970*) showed a significant effect of trial number, with a slightly positive evolution during the execution exercise. This effect of time could not be found in factor 1 (Bended Posture), factor 2 (Twisting) and factor 3 (Swinging).

For seven muscles, the integrated linear envelope of the NEMG (normalised EMG) signal showed a significant relationship to the performers' sex: Rectus Abdominis *(P=0.001; F=11.506; 1-β=0,919)*, Adductors *(P=0.005; F=9.195; 1-β=0,835)*, Hamstrings Lateral Part *(P=0.032; F=4.865; 1-β=0,581)*, Hamstrings Medial Part *(P=0.026; F=5.170; 1-β=0,610)* and Gastrocnemius *(P=0.037; F=4.490; 1-β=0,555)* showed more activity in female performers than male performers. Triceps Brachii *(P=0.005; F=8.157; 1-β=0,807)* and Erector Spinae *(P=0.049; F=3.969; 1-β=0,505)* showed more activity in male performers

than female performers. NEMG of the other muscles showed no significant relationship to the performers' sex: Biceps Brachii *(P=0.746; F=0.105; 1-β=0,062)*, Deltoideus *(P=0.721; F=0.128; 1-β=0,065)*, Rectus Femoris *(P=0.883; F=0.022; 1-β=0,052),* Vastus Lateralis *(P=0.085; F=3.030; 1-β=0,406)*, Tibialis Anterior *(P=0.847; F=0.037; 1-β=0,054)*.

Except for two muscles, i.e. the Adductors (*P=0.519; F=0.426; 1-β=0,097*) and Rectus Abdominis (*P=0.558; F=0.345; 1-β=0,090*), all muscles showed a significant relationship between their activity and the experience of the performer. A negative relationship was found between experience and the activity of the Biceps Brachii *(P=0.000; F=16.805; 1-β=0,982)*, Triceps Brachii *(P=0.000; F=17.388; 1-β=0,985)*, Deltoideus *(P=0.003; F=9.140; 1-β=0,849)*, Erector Spinae (P=0.000; F=16.560; *1-β=0,981*), Rectus Femoris *(P=0.000; F=37.931; 1-β=1,000)*, Vastus Lateralis *(P=0.000; F=28.492; 1-β=1,000)*, Hamstrings Lateral Part *(P=0.004; F=8.970; 1-β=0,836)*, Hamstrings Medial Part *(P=0.000; F=16.151; 1-β=0,554)*, Gastrocnemius *(P=0.000; F=23.716; 1-β=0,998)* and Tibialis Anterior *(P=0.000; F=16.151; 1-β=0,978)*. The scatter plots show a remarkable decrease in variability of muscle contraction in the performers with more experience.

Only for the Biceps Brachii *(P=0.041; F=2.060; 1-β=0,838)*, a reduction in muscle activity was shown during the execution of the exercise. For all other muscles, no effect of trial number could be found: Adductors *(P=0.336; F=1.192; 1-β=0,471)*, Triceps Brachii *(P=0.548; F=0.878; 1-β=0,411)*, Deltoideus *(P=0.529; F=0.899; 1-β=0,420)*, Erector Spinae *(P=0.604; F=0.814; 1-β=0,380)*, Rectus Abdominis *(P=0.790; F=0.605; 1-β=0,281)*, Rectus Femoris *(P=0.358; F=1.118; 1-β=0,522)*, Vastus Lateralis *(P=0.142; F=1.550; 1-β=0,695)*, Hamstrings Lateral Part *(P=0.229; F=1.364; 1-β=0,590)*, Hamstrings

Medial Part *(P=0.860; F=0.513; 1-β=0,229)*, Gastrocnemius *(P=0.097; F=1.712; 1-β=0,748)* and Tibialis Anterior *(P=0.175; F=1.459; 1-β=0,663)*.

Discussion

The first aim of this study was to provide an objective research method for future analysis, description, and comprehension of unpredictable movements. This was done by combining biomechanical analysis with statistical techniques for data reduction. The PCA of explained 57.9% of the variance in the biomechanical data of the members of the Jan Fabre Company, performing the *Old man exercise*. This means that together, the four newly composed factors (i.e. Bended Posture, Twisting, Swinging and Speed of Progression), account for almost 60% of the biomechanical phenomena shown by the performers. It can therefore be assumed that with these four components, we are able to describe and investigate the *Old man exercise* properly. Actually, based on the PCA results, two movement strategies can be identified. The first pattern is determined by a strongly bended position (mainly in the shoulders, hips and knees). In this moving pattern, progression is mainly achieved by twisting movements while the other joints show less dynamic activity. Especially less experienced and female performers tend to use (parts of) this strategy while performing the exercise. The second pattern shows a less bended position (mainly in the shoulders). Progression is achieved through sagittal hip movements and pelvic dynamics. More experienced performers tend to use this strategy while performing the exercise. Thus, this study's method hereby provides us a useful tool to reduce the serious amount of biomechanical data from unpredictable movements to a more comprehensive and manageable amount, without any loss of information (as mentioned in the aims of the study).

The second aim of this study was to gain insight in the motor control of performers and to investigate whether the already known principles of motor control and motor learning

can be recognized in the so far unresearched population of performers. The experience of the performers, as well as their sex seems to play a major role in the execution of the exercise. Theatre performers with less experience show more Twisting, less Swinging and lower Speed of Progression while executing the exercise. Regarding muscle activity, it appears that more experienced theatre performers show less intense muscle activity, but a more homogeneous pattern of muscular activity. Female theatre performers show overall more muscle activity and Twisting than males. No fatigue effect could be found in this population of experienced theatre performers.

The observation that less experienced performers show more Twisting, might be related to a movement strategy that is well known within the domain of motor control and motor learning, being the principle of the reduction in *degrees of freedom* (McCollum, Holroyd, & Castelfranco, 1995; Sporns & Edelman, 1993) and the strategy of freezing (Sporns & Edelman, 1993). Humans, when learning a new motor task, tend to move with less flexibility and variation in movement than when the motor task is automated at the end of the learning process. We hypothesize that the Twisting is seen in less experienced performers because they tend to "freeze" their trunk and extremities. Twisting is consequently necessary to generate propulsion. The phenomenon of Twisting is comparable to one of the forms of early walking (McCollum et al., 1995); infants in their first weeks of independent locomotion sometimes seem to walk while showing an increased pelvic rotation in the transverse plane (i.e. Twisting). This form of early walking is frequently associated with an increased stiffness of the trunk, as is observed in the performers (McCollum et al., 1995). Swinging, on the other hand, is considered as a more functional gait pattern, characterized by more motion in the sagittal plane than the transverse plane (Lin, Gfoehler, & Pandy, 2014). However, this

strategy requires control over adequate degrees of freedom and thus requires sufficient experience.

In contrast to our hypothesis, flexion of the lower body seemed not to be related to the performers' experience but the upper body upright posture was (included in factor 3). Performers with more experience tend to perform the *Old Man exercise* in a more straightened position. Expressivity of the more experienced performer might play a role in the posture during the exercise (Van Zijl, 2014), as well as the overall more natural gait pattern which is used in more experienced performers, leading to a more straightened position and more movement in the sagittal plane of the lower limbs.

Also muscular activity is influenced by experience. Almost all muscles showed a decrease in the integrated linear envelope of the EMG with increasing experience. This might suggest that more experienced performers perform the exercise with less muscle tension. Previous research already showed that the performance of a new or challenging task requires more muscle tension (Ohata et al., 2013), although this effect could not be generalized (Hu, Su, & Hsu, 2014). The EMG scatter plots in attachment also reveal a remarkable decrease in inter-individual variability of the EMG integrated envelope and a more uniform muscle activity in performers with more experience. Comparable results could be found when investigating the effect of experience on activity of postural muscles in the lower limbs in varying balance aspects (Lu et al., 2015). When challenging professional roofers' balance, they showed a significant increase in Normalised EMG (NEMG) data of all postural muscles of the lower limb. When providing visual cues, these NEMG data decreased. Nevertheless, the observed relationships between experience and the EMG data in this study need to be interpreted with caution. The EMG data were not normalized to some standard such as a

Maximum Voluntary Contraction (MVC). This decision was based on previous research which showed that the use of a MVC has many statistical and methodological impairments (Sousa & Tavares, 2012). But consequently, comparison of EMG data between individuals remains difficult. The observed differences can be related to different motor control strategies, but changes in musculature or physiology might also play a role.

To summarise, experience affects the execution of the *Old Man* exercise. A possible hypothesis is that these changes indicate a process of motor learning leading to changes in motor control. Indeed, the observations in this study can be placed within the well-accepted two-stages model (Gentile) or three-stages models (Fitts & Posner) of motor learning that discuss the different stages in a motor learning process. These models predict a decrease in variability when learning a new motor task. It is interesting to note that this study's results reveal remarkable similarities between the principles of motor learning and the effect of experience on the execution of unpredictable voluntary movements. Although no standardization exists between the learning process of performers and other disciplines (such as dancers, athletes, infants learning to walk, rehabilitating stroke patients,…), comparable results can be found in their biomechanics. As well performers as other populations in education of a new motor task show a clear shift of conscious movement to unconscious movement during their intrinsic learning process, leading to changes in their kinematic and dynamic movement patterns (McCollum et al., 1995; Sporns & Edelman, 1993). On the other hand, experience can also lead to different aesthetic impressions or physical characteristics that may also affect the execution of the *Old man exercise*.

A second and important factor influencing the execution of the *Old Man exercise* is the sex of the performer. Female performers show more Twisting than male performers. This

phenomenon could possibly be explained by the biomechanical differences between male and female hips, such as higher femoral anteversion angles, resulting in a more endorotated position of the hip (Peterson et al., 2014). Also natural differences in the gait pattern between males and females could possibly explain these results (Bruening et al., 2015). Another interesting observation is that the activity of the paravertebral muscles (Erector Spinae) differs significantly between male and female performers. This might be related to the observed differences in pelvic mobility.

_____Sex had furthermore a significant effect on EMG activity. Women overall seem to perform the *Old Man exercise* with a higher amount of muscular activity than male performers. Different other studies (Clark, Manini, Thé, Doldo, & Ploutz-Snyder, 2003; Umezu, Kawazu, Tajima, & Ogata, 1998) already pointed out differences between trunk muscle activity of males and females while performing physical tasks, such as a higher endurance of the Erector Spinae in women (Umezu et al., 1998) and a higher fatigue in the lumbar muscles (Clark et al., 2003). Not only trunk muscles, but also muscles of the extremities already showed sex related differences in previous studies (Inglis, Vandenboom, & Gabriel, 2013; Senefeld, Yoon, Bement, & Hunter, 2013; Szucs & Borstad, 2013). However, it cannot be ruled out that sex related differences in biometry and physiological factors (e.g. subcutaneous fat) have influenced the EMG results in this study. Furthermore, a large variance could be found in the EMG data, which could possibly have influenced the analysis of these data.

This study hypothesized that a fatigue effect would be found, since the high physical requirements of the exercise. The fourth factor, *Speed of Progression*, was significantly influenced by the number of trials during the data collection, with a slightly positive trend. A

negative evolution in the EMG data would possibly indicate a fatigue effect. However, in this data set no evolution in EMG data could be found between the trials (during the exercise), and therefore no fatigue effect could be found in these performers. Since the population of this study consists of experienced theatre performers, this result seems plausible. It can be assumed that the performers in this population show large endurance in performing this exercise, since a good physical endurance fits within the vision of Jan Fabre (van den Dries & Crombez, 2010).

Despite the interesting results, some methodological issues and possible sources of bias need to be considered. Given the exploratory nature of this study, without comparing populations or diagnostic aims, 14 participants seem an adequate sample size. Participants were addressed directly by the Jan Fabre Company, and participated on a voluntary basis. Therefore this study's population can be considered a sample of convenience, and it is possible that performers with more experience in this exercise were more likely to participate, introducing some form of selection bias positively influencing the execution of the exercise. Nevertheless, this sample comprises 70% of Jan Fabre's company, suggesting that the sample is representative for the population of performers of the Jan Fabre Company. But, since only performers from the Jan Fabre Company were selected, and due to the small sample size and the specific nature of the exercise, generalization of our findings is limited towards performing artists from other companies. However, the used method for the biomechanical analysis of unpredictable movements can be generalized towards other study's.

Performance bias might result from the fact that participants of this study kept on participating in workshops from Jan Fabre during the data collection period, which could positively influence the execution of the exercise. On the other hand, this study was

performed in a laboratory and not in a theatre context or at the regular training facilities, which might have negatively influenced the performances of the participants. A third possible source of bias is that the first exercise (the *cat exercise*) might have influenced the second exercise. The performers might have built up a fatigue when performing the first exercise, which could have influenced the execution of the second exercise. However, the *cat exercise* is far more focused on explosive muscle strength and flexible movement patterns, in contrast to the *old man exercise* wherein especially muscle endurance is important. Furthermore the *cat exercise* has a much shorter duration than the *old man exercise.* A short resting period between both exercises was used for the performers in order to reduce the effect of the first exercise on the second. Finally, the influence of emotions on movement needs to be discussed. From literature, the influence of emotional factors on the execution of motor tasks in musical performers, athletes, patients and healthy populations is well known. (Barliya, Omlor, Giese, Berthoz, & Flash, 2013; Foster, Knuiman, Hooper, Christian, & Giles-Corti, 2014; Naruse, 2004; Rathschlag & Memmert, 2013; Yiou, Gendre, Deroche, & Le Bozec, 2014; Van Zijl, 2014). It therefore cannot be ruled out that the performers researched in this study experienced any influence of emotional factors, such as fear of failing the exercise, eagerness to perform the exercise correctly, emotional associations of the exercise with previous experiences,… However, the effects of emotion on movement were not the primary goal of this study.

Despite these methodological issues, this biomechanical study offers a contribution to the field of the performing arts, given its fundamental character; performers were investigated for the first time in a biomechanical context. Unlike previous research on control of movement in dancers (Roussel et al., 2009; Roussel et al., 2013), no strict guidelines were given concerning the movement outcome, therefore leading to unpredictable and voluntary

movements. This study however managed to reduce the high amount of data from unpredictable movements to a comprehensive description of these movements. Several principles of motor learning can be recognized in this study, which could lead to the conclusion that the used method in this study provides a valid analysis of voluntary, unpredictable movements.

This study's results highlight the importance of physicality in the *Old Man exercise*, frequently used in training sessions of the Jan Fabre Company. A biomechanical analysis of this exercise showed that male and female performers execute the exercise in a different way, although they received the same instructions. One hypothesis could be that a training of Jan Fabre has different effects on male or female performers. Due to this hypothesis as well as the resemblance between this study and the actual known aspects of motor learning, a longitudinal study could be indicated to examine the effect of a specific training according the principles of Jan Fabre. Future studies in this domain could usefully include other parameters such as emotional factors (e.g. the Positive and Negative Affect Schedule -PANAS-) (Watson, Clark, & Tellegen, 1988), in order to enlarge the knowledge regarding a performance and its influencing parameters. It could also be a useful contribution to integrate qualitative data when researching performers.

Conclusion

This study provides a useful method to adequately analyse, describe and comprehend biomechanical data about complex unpredictable movements. It can be used for future study's which need to decrease their amount of variables (e.g. biomechanical data of voluntary movements) without any loss of information. Theatre performers of Jan Fabre show less Twisting, more Swinging and a higher Speed of Progression with increasing experience (number of performances). They also show a less intensive and more

homogeneous muscle activity when they are more experienced. Female performers twist more while performing the exercise and show overall more muscle activity (especially in the posterior leg muscles). During an exercise, the performers show a slightly higher moving speed, but no fatigue effect.

References

Angioi, M., Metsios, G. S., Twitchett, E., Koutedakis, Y., & Wyon, M. (2009). Association between selected physical fitness parameters and esthetic competence in contemporary dancers. *Journal of dance medicine & science : official publication of the International Association for Dance Medicine & Science*, *13*(4), 115–123. United States.

Baker, R. (2006). Gait analysis methods in rehabilitation. *Journal of neuroengineering and rehabilitation*, *3*, 4. England.

Barliya, A., Omlor, L., Giese, M. a, Berthoz, A., & Flash, T. (2013). Expression of emotion in the kinematics of locomotion. *Experimental brain research*, *225*(2), 159–76. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23250443

Bruening, D. a., Frimenko, R. E., Goodyear, C. D., Bowden, D. R., & Fullenkamp, A. M. (2015). Sex differences in whole body gait kinematics at preferred speeds. *Gait & Posture*, *41*(2), 540–545. Elsevier B.V. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0966636214007942

Cannell, L. J., Taunton, J. E., Clement, D. B., Smith, C., & Khan, K. M. (2001). A randomised clinical trial of the efficacy of drop squats or leg extension/leg curl exercises to treat clinically diagnosed jumper's knee in athletes: pilot study. *British journal of sports medicine*, *35*(1), 60–64.

Clark, B. C., Manini, T. M., Thé, D. J., Doldo, N. A., & Ploutz-Snyder, L. L. (2003). Gender differences in skeletal muscle fatigability are related to contraction type and EMG spectral compression. *Journal of applied physiology (Bethesda, Md. : 1985)*, *94*(6), 2263–2272.

Clark, T., Gupta, A., & Ho, C. H. (2014). Developing a dancer wellness program employing developmental evaluation. *Frontiers in psychology*, *5*(July), 731. Retrieved from

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4090754&tool=pmcentrez&rendertype=abstract

Clark, T., Williamon, A., & Redding, E. (2013). The value of health screening in music schools and conservatoires. *Clinical Rheumatology*, *32*(4), 497–500.

Van Dam, M., Hallemans, A., & Aerts, P. (2009). Growth of segment parameters and a morphological classification for children between 15 and 36 months. *Journal of Anatomy*, *214*(1), 79–90.

Van den Dries, L. (2004). *CORPUS JAN FABRE Observations of a creative process*. Gent: Uitgeverij Imschoot.

van den Dries, L., & Crombez, T. (2010). Jan Fabre and tg STAN: Two Models of Postdramatic Theatre in the Avant-Garde Tradition. *Contemporary Theatre Review*.

Foster, S., Knuiman, M., Hooper, P., Christian, H., & Giles-Corti, B. (2014). Do changes in residents' fear of crime impact their walking? Longitudinal results from RESIDE. *Preventive medicine*, *62*, 161–6. Elsevier Inc. Retrieved from http://www.sciencedirect.com/science/article/pii/S0091743514000760

Grover, R., & Vriens, M. (2006). *The Handbook of Marketing Research*. SAGE Publications, Inc.

Hallemans, A., Ortibus, E., Truijen, S., & Meire, F. (2011). Development of independent locomotion in children with a severe visual impairment. *Research in developmental disabilities*, *32*(6), 2069–2074. United States.

Harbourne, R. T., & Stergiou, N. (2009). Movement variability and the use of nonlinear tools: principles to guide physical therapist practice. *Physical therapy*, *89*(3), 267–282. United States.

Hermens, H. J., & Freriks, B. (n.d.). Seniam. *www.seniam.org*. Retrieved from www.seniam.org

Hu, M.-T., Su, F.-C., & Hsu, A.-T. (2014). Effect of prior experience and task stability on the intrinsic muscle activity of the thumb. *Manual therapy*, *19*(5), 484–489. Scotland.

Inglis, J. G., Vandenboom, R., & Gabriel, D. A. (2013). Sex-related differences in maximal rate of isometric torque development. *Journal of Electromyography and Kinesiology*, *23*(6), 1289–1294. Elsevier Ltd. Retrieved from http://dx.doi.org/10.1016/j.jelekin.2013.09.005

Johnston, L. A., Butler, R. J., Sparling, T. L., & Queen, R. . (2015). A Single Set of Biomechanical Variables cannot predict jump performances across various jumping tasks. *Journal of Strength & Conditioning Research*, *29*(2), 396–407.

Kadaba, M. P., Ramakrishnan, H. K., & Wootten, M. E. (1990). Measurement of lower extremity kinematics during level walking. *Journal of orthopaedic research : official publication of the Orthopaedic Research Society*, *8*(3), 383–392. UNITED STATES.

Koutedakis, Y., & Jamurtas, A. (2004). The dancer as a performing athlete: Physiological considerations. *Sports Medicine*.

Koutedakis, Y., Owolabi, E. O., & Apostolos, M. (2008). Dance biomechanics: a tool for controlling health, fitness, and training. *Journal of dance medicine & science : official publication of the International Association for Dance Medicine & Science*, *12*(3), 83–90.

Krasnow, D., Wilmerding, M. V., Stecyk, S., Wyon, M., & Koutedakis, Y. (2011). Biomechanical research in dance: a literature review. *Medical problems of performing artists*, *26*(1), 3–23.

Lin, Y., Gfoehler, M., & Pandy, M. G. (2014). Quantitative evaluation of the major

determinants of human gait. *Journal of biomechanics*, *47*(6), 1324–31. Elsevier. Retrieved from http://dx.doi.org/10.1016/j.jbiomech.2014.02.002

Louw, M., & Deary, C. (2014). The biomechanical variables involved in the aetiology of iliotibial band syndrome in distance runners - A systematic review of the literature. *Physical therapy in sport : official journal of the Association of Chartered Physiotherapists in Sports Medicine*, *15*(1), 64–75. England.

Lu, M.-L., Kincl, L., Lowe, B., Succop, P., & Bhattacharya, A. (2015). Muscular activity of lower limb muscles associated with working on inclined surfaces. *Ergonomics*, *58*(2), 278–290. England.

Manchester, R. A. (2014). Prevention of Performance-Related Musculoskeletal Disorders, (December), 179–180.

McCollum, G., Holroyd, C., & Castelfranco, a M. (1995). Forms of early walking. *Journal of theoretical biology*, *176*(3), 373–390.

Munro, A., Herrington, L., & Comfort, P. (2012). Comparison of landing knee valgus angle between female basketball and football athletes: Possible implications for anterior cruciate ligament and patellofemoral joint injury rates. *Physical Therapy in Sport*, *13*(4), 259–264. Elsevier Ltd. Retrieved from http://dx.doi.org/10.1016/j.ptsp.2012.01.005

Naruse, K. (2004). RELATIONSHIPS BETWEEN MOOD STATE, TIME ESTIMATION, AND SELECTED MOVEMENT SPEED. *Perceptual and Motor Skills*, *99*(2), 618–620. Ammons Scientific. Retrieved from http://dx.doi.org/10.2466/pms.99.2.618-620

Nishikawa, K., Biewener, A. A., Aerts, P., Ahn, A. N., Chiel, H. J., Daley, M. A., Daniel, T. L., et al. (2007). Neuromechanics: An integrative approach for understanding motor control. *Integrative and Comparative Biology*, *47*(1), 16–54.

Ohata, E., Matsuo, K., Ban, R., Shiba, M., & Yasunaga, Y. (2013). Electromyographic

comparison of forearm muscle movements for fine skin suturing between an enlarged pen needle holder and a webster needle holder. *Eplasty*, *13*, e22. United States.

Padulo, J., Powell, D., Milia, R., & Ardigò, L. P. (2013). A Paradigm of Uphill Running. *PLoS ONE*, *8*(7), 1–8.

Petersen, J., Nielsen, R. O., Rasmussen, S., & Sørensen, H. (2014). Comparisons of increases in knee and ankle joint moments following an increase in running speed from 8 to 12 to 16km·h−1. *Clinical Biomechanics*, *29*(9), 959–964. Elsevier Ltd. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0268003314002150

Peterson, J. B., Doan, J., Bomar, J. D., Wenger, D. R., Pennock, A. T., & Upasani, V. V. (2014). Sex Differences in Cartilage Topography and Orientation of the Developing Acetabulum: Implications for Hip Preservation Surgery. *Clinical orthopaedics and related research*.

Pfile, K. R., Hart, J. M., Herman, D. C., Hertel, J., Kerrigan, D. C., & Ingersoll, C. D. (2013). Different exercise training interventions and drop-landing biomechanics in high school female athletes. *Journal of Athletic Training*, *48*(4), 450–462.

Rathschlag, M., & Memmert, D. (2013). The influence of self-generated emotions on physical performance: an investigation of happiness, anger, anxiety, and sadness. *Journal of sport & exercise psychology*, *35*(2), 197–210. United States.

Roussel, N. A., Nijs, J., Mottram, S., Van Moorsel, A., Truijen, S., & Stassijns, G. (2009). Altered lumbopelvic movement control but not generalized joint hypermobility is associated with increased injury in dancers. A prospective study. *Manual therapy*, *14*(6), 630–635. Scotland.

Roussel, N., Hallemans, A., Rutgeerts, J., Gielen, J., & Dries, L. Van Den. (2014). Exploring the Biomedical Paradigm in the Work of Jan Fabre Exploring the Biomedical Paradigm

in the Work of Jan Fabre. *PERFORMANCE RESEARCH*, (October), 37–41.

Roussel, N., De Kooning, M., Schutt, A., Mottram, S., Truijen, S., Nijs, J., & Daenen, L. (2013). Motor control and low back pain in dancers. *International journal of sports medicine*, *34*(2), 138–143. Germany.

Senefeld, J., Yoon, T., Bement, M. H., & Hunter, S. K. (2013). Fatigue and recovery from dynamic contractions in men and women differ for arm and leg muscles. *Muscle & nerve*, *48*(3), 436–439. United States.

Sousa, A. S. P., & Tavares, J. M. R. S. (2012). Surface electromyographic amplitude normalization methods : A review. *Electromyography: New Developments, Procedures and Applications*, 85–102. Retrieved from http://repositorio-aberto.up.pt/bitstream/10216/64430/2/949666.pdf

Sporns, O., & Edelman, G. M. (1993). Solving Bernstein's problem: a proposal for the development of coordinated movement by selection. *Child development*, *64*(4), 960–981.

Stuelcken, M., Greene, A., Smith, R., & Vanwanseele, B. (2013). Knee loading patterns in a simulated netball landing task. *European journal of sport science*, *13*(5), 475–482. England.

Szucs, K. A., & Borstad, J. D. (2013). Gender differences between muscle activation and onset timing of the four subdivisions of trapezius during humerothoracic elevation. *Human Movement Science*, *32*(6), 1288–1298. Elsevier B.V. Retrieved from http://dx.doi.org/10.1016/j.humov.2013.05.003

Twitchett, E. A., Angioi, M., Koutedakis, Y., & Wyon, M. (2011). Do increases in selected fitness parameters affect the aesthetic aspects of classical ballet performance? *Medical problems of performing artists*, *26*(1), 35–38. United States.

Umezu, Y., Kawazu, T., Tajima, F., & Ogata, H. (1998). Spectral electromyographic fatigue analysis of back muscles in healthy adult women compared with men. *Archives of Physical Medicine and Rehabilitation*, *79*(5), 536–538.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*. US: American Psychological Association.

Yiou, E., Gendre, M., Deroche, T., & Le Bozec, S. (2014). Influence of emotion on the biomechanical organization of backward and forward step initiation. *Motor control*, *18*(4), 368–382. United States.

Zazulak, B. T., Hewett, T. E., Reeves, N. P., Goldberg, B., & Cholewicki, J. (2007). Deficits in neuromuscular control of the trunk predict knee injury risk: a prospective biomechanical-epidemiologic study. *The American journal of sports medicine*, *35*(7), 1123–1130. United States.

Van Zijl, A. G. W. (2014). *Performers' Emotions in Expressive Performance: Sound, Movement , and Perception*.

Figure captions

FIGURE 1 - Scree plot Principal Component Analysis

This scree plot visualizes the Eigenvalue for each component distracted from the PCA. The curve shows a last steel slope between the fourth and the fifth factor. Therefore only the first four factors should be further used in the analysis.

FIGURE 2 – Twisters and swingers

These graphs show the differences in moving patterns between twisters (low experience) and swingers (high experience), considering the pelvic and hip motion in the sagittal, frontal and sagittal plane. The x-axis shows the trial number of which a step was selected, which belongs to the joint angles at that moment.

FIGURE 3 - Scatter plots linear mixed model

The first three scatter plots show the spreading of significant factors 2, 3 and 4 by experience. The x-axis represents the experience (number of performances) and the y-axis the factor values. A regression line shows the relationship between these variables. The last scatter plot shows the spreading of factor 4 by step number. The X-axis represents the trial number of which a step was selected, the y-axis represents factor 4 (Speed of Progression).

VARIABLE	Male (N = 6)	Female (N = 8)
	Median (min-max)	Median (min-max)
Age (years)	31 (24-41)	33 (23-48)
Experience in Fabre's company (number of productions)	4 (1-10)	3 (1-11)
BMI (kg/m²)	22.53 (21.14-26.42)	20.53 (19.01-21.98)

TABLE 1 – Descriptive characteristics of the participants

This table shows the demographic variables of this study's population. Median, as well as minimum and maximum age (years), experience (number of productions) and BMI (kg/m²) are shown.

VARIABLE	FACTOR 1 *Bended Posture*	FACTOR 2 *Twisting*	FACTOR 3 *Swinging*	FACTOR 4 *Speed of Progression*
Total initial EigenValue	4.613	2.770	2.419	2.356
% of variance	21.969	13.191	11.517	11.218
Cumulative % of variance	21.969	35.160	46.677	57.895
Factor Scores				
Mean speed	-0.223	-0.037	-0.087	**0,841**
ROM Hip Flex/Ext	0.109	0.3	**0.767**	0,346
ROM Hip Abd/Add	0.174	**0.744**	0.222	0,131
ROM Hip Rot	0.089	**0.759**	0.281	0,271
ROM Knee Flex/Ext	-0.018	0.34	0.324	**0,654**
ROM Ankle PF/DF	0.083	0.119	0.396	0,387
ROM Foot Int/Ext	0.121	0.41	0.142	0,202
ROM Pelvis Tilt	-0.105	0.217	**0.762**	-0,366
ROM Pelvis Obl	0.394	0.134	**0.771**	0,062
ROM Pelvis Rot	0.017	**0.729**	0.059	-0,124
M Hip Flex/Ext	**0.955**	0.172	0.071	-0,067
M Hip Abd/Add	-0.017	0.039	-0.078	0,004
M Hip Rot	0.038	-0.021	0.113	0,048
M Knee Flex/Ext	**0.673**	0.018	0.142	0,047
M Ankle PF/DF	-0.03	-0.059	0.162	-0,012
M Foot Int/Ext	-0.194	-0.413	0.13	0,061
M Pelvis Tilt	**0.865**	0.07	0.088	-0,168

M Pelvis Obl	-0.013	0.001	-0.024	-0,012
M Pelvis Rot	-0.106	-0.002	-0.035	-0,271
M Shoulder bend angle	-0.379	-0.399	**0.454**	0,251
M Kyfosis	0.188	-0.14	0.014	-0,065

TABLE 2 - Principal Component Analysis

Eigenvalues, percentages of the variance in the population explained by each component and the cumulative variance that is explained by the eight components of the PCA. Numbers in bold indicate which parameters represent each component. Flex/Ext = Flexion extension; Abd/Add = Abduction/Adduction; Rot = Rotation; PF/DF = Plantar Flexion/Dorsal Flexion; Int/Ext = Internal Rotation/External Rotation; Obl = Obliquity. The factor scores show the loading of each variable on the concerning principal component axis.

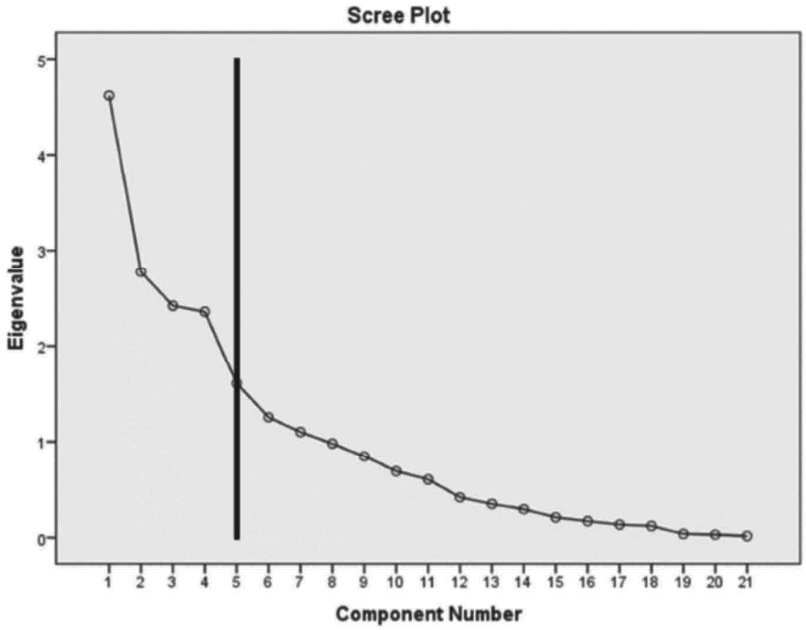


FIGURE 1 - Scree plot Principal Component Analysis

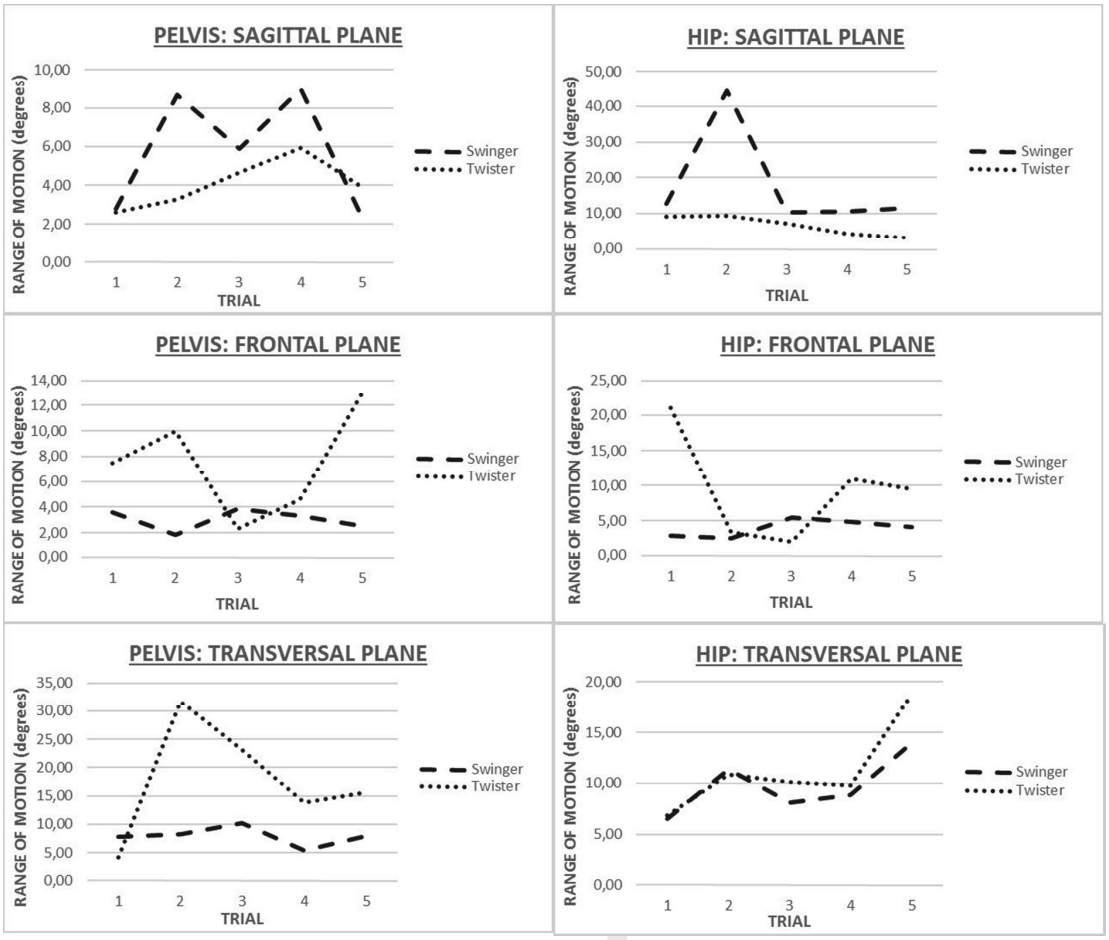
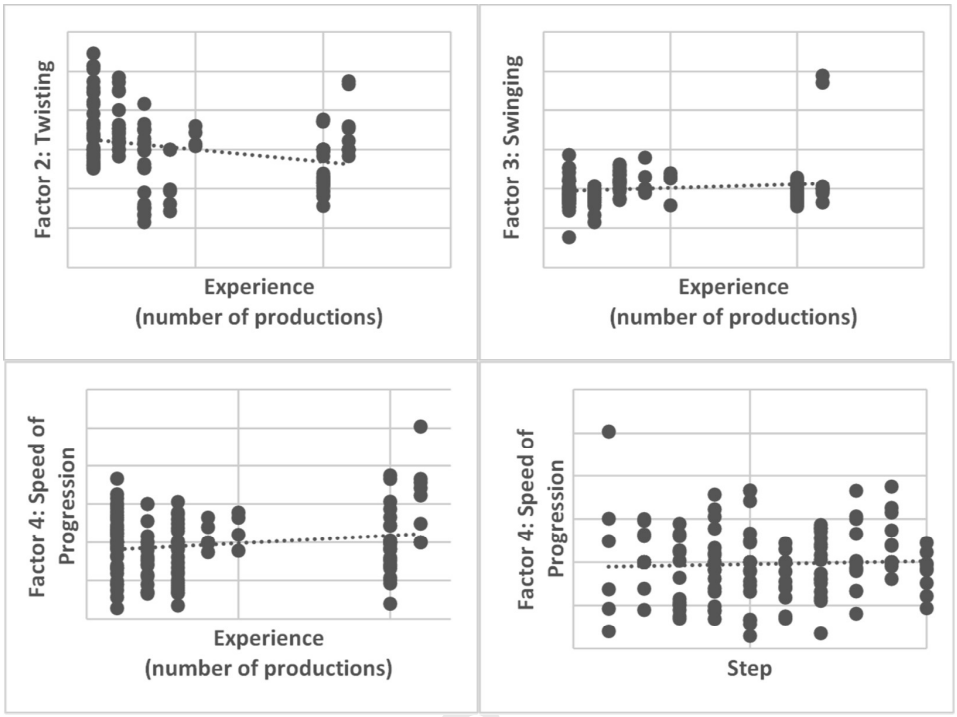


FIGURE 2 – Twisters and swingers



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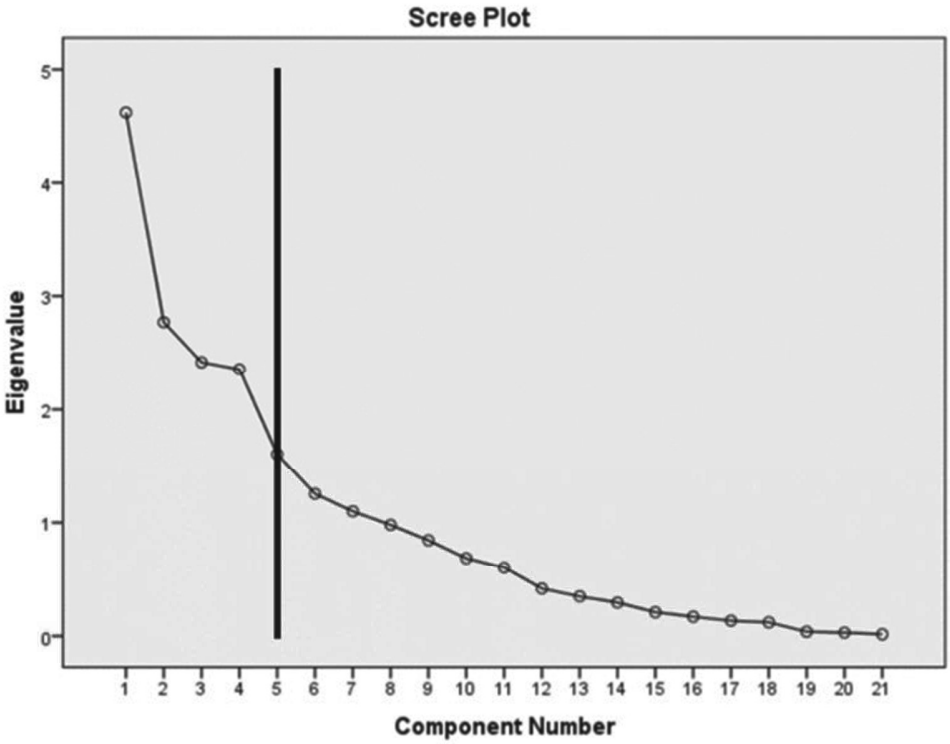

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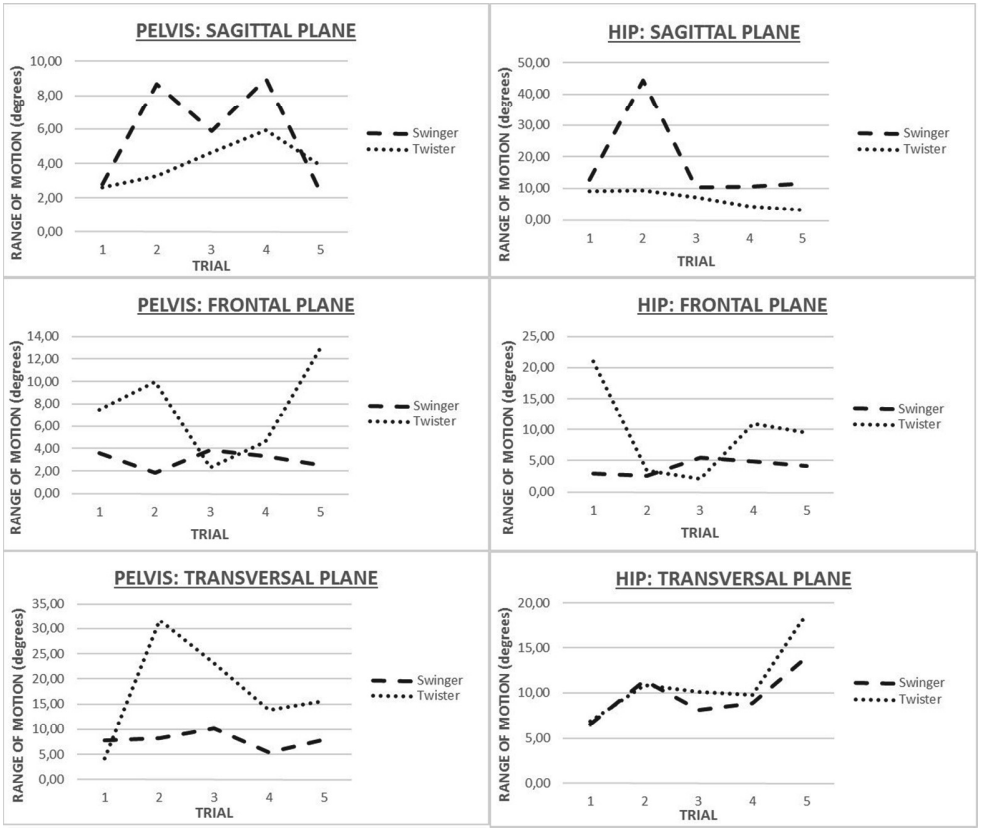
118x94mm (150 x 150 DPI)



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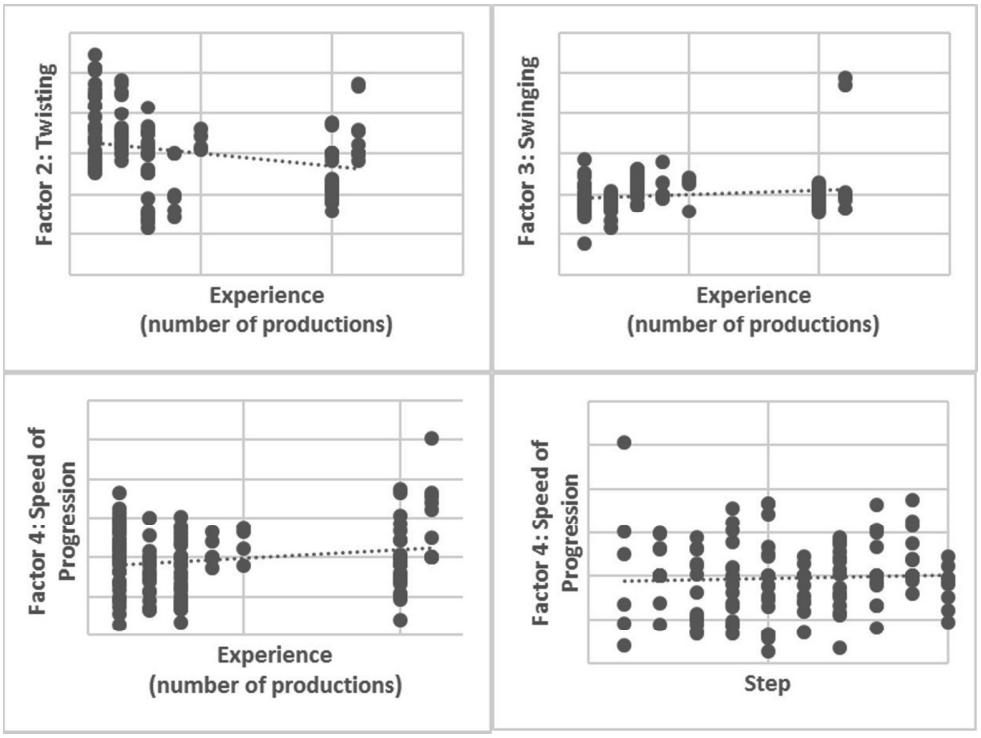

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212x158mm (150 x 150 DPI)