Title:
Kinematics and loading conditions between the left and right wrist during the forward, forward ulnar deviated and backward handspring

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Abstract:
Introduction:
The forward handspring, the forward handspring with ulnar deviated hand position and the backward handspring are common elements in gymnastics and artistic gymnastics. The wrist joint plays a prominent role in the force transmission and is exposed to great loads while performing these elements. Excessive and repetitively compressive forces acting on the wrist joint can lead to acute and chronic injuries of the wrist (DiFiori, Puffer, Mandelbaum, & Mar, 1996). An earlier study demonstrated that wrist pain is a common problem among none-elite young gymnasts. Wrist pain was prevalent in 73 % of the tested gymnasts who attended this study (De Smet, Claessens, & Fabry, 1993; Dobyns & Gabel, 1990). An asymmetry between the right and left wrist can be assumed to lead to long-term damages in the wrist that is more loaded. Furthermore differences between the left and right wrist such as different joint forces, moments and angles can result in an asymmetrical execution of the three handspring variations, which leads to a compensation in other body segments or to discounts of the gymnasts’ performance in a competition. The purpose of the present investigation is to detect differences of the kinematics and the load condition between the left and right wrist during the forward, forward ulnar deviated and backward handspring.

Methods:

Seven female and seven male gymnasts performed five forward, forward with ulnar deviated hands and backward handsprings. The backward handspring was generated after a round off. The subjects could participate if they did not have any problems or medical condition with their musculoskeletal system. They were excluded if they had had surgeries or other medical interventions at the wrist. They had to be of age as well. To perform the handsprings floor mats were laid out so that there was enough space for the run in and the landing (see Figure 1). Since the wrist joint was exposed to high loadings, the two force plates which acquired the kinetic data were covered by seven-centimeter thick floor mats. Therefore the test arrangement was in accordance with the conditions the subjects normally exercise in (see Figure 1). The kinematics was tracked with skin markers and a motion analysis system. This system consists of 12 infrared cameras. A floating, a forearm fixed axis was used, allowing a clinical interpretation of the results for the wrist joint angles. This convention of the joint coordinate system was introduced by Grood and Suntay (1983) on the knee joint and adapted for several other joints as well as the wrist by Wu et al. (2005). In all of the dynamic motion tasks the period where the force acted on the hands and therefore on the wrist joints was defined as the support phase. The kinetic data was normalized over the subject’s body weight. The wrist joint force was calculated by means of an inverse approach with a quasi-static solution (Lorenzetti et al., 2012) and then split in three forces acting in three orthogonal directions defined by the forearm segment coordinate system. The forces were named $F_{i}$, $F_{j}$ and $F_{k}$ and acted along the $i$-axis, $j$-axis and $k$-axis. The sum of the absolute value of these three forces was considered the absolute force $F_{abs}$. The same was done for the wrist moments. Therefore the moments were...
named $M_\text{ij}$, $M_\text{jf}$ and $M_\text{kf}$ and acted along the $i$-axis, $j$-axis and $k$-axis. The sum of the absolute value of the three moments was considered the absolute moment $M_{\text{abs}}$. The mean and standard deviation of the kinematic and kinetic data of the five repetitions were calculated for each subject. This procedure was done for the forward handspring, the forward handspring with ulnar deviated hand position and the backward handspring. The mean and standard deviation of the 14 established means were computed for the three motion variations and the joint angles, forces and moments and compared between the right and the left wrist for each execution form.

The 0.05 level was used to indicate statistical significance. All parameters were tested by the Kolmogorov-Smirnov and the Shapiro-Wilk test to test if the data was normally distributed. In that case the T-test was conducted to find significant differences between the left and right wrist. For not normally distributed parameters the Friedman test which is a non-parametric test was conducted for the specific parameters. If the Friedman-test showed significant differences the Wilcoxon-test was chosen to find which parameters significantly differed between the left and right side during the three executions. All $p$-values were corrected by the Bonferroni adjustment.

**Results:**

There was no difference found in this study between the right and the left wrist for the kinematic parameters, which concerned three clinically defined wrist angles during all execution forms. The kinetic parameters, which included the forces and moments acting along the three coordinate axis of the forearm segment system and the absolute wrist force and moment didn’t show any left-right asymmetries either.

**Discussion/Conclusion:**

For the first time research on the load condition of the wrist during the forward, forward with ulnar deviated hand positioning and backward handspring was conducted, considering the force and moment acting on the wrist as well as the wrist angles. Former studies investigated the ground reaction forces acting on both hands and found no significant differences between the left and right hand (DeGoede & Ashton-Miller, 2002; Koh, Grabener, & Weiker, 1992). In this study no significant differences concerning the wrist forces and angles were found. The symmetric performance shows that the attending subjects were experienced enough to perform technically good handsprings. Worse gymnasts or gymnasts in the process of learning these tasks could show more asymmetries. It is important for coaches and athletes to eliminate left and right asymmetries in the wrist to prevent long-term damages or overcompensating muscles from injuries.

**References:**