LOAD CONDITION OF THE WRIST DURING THE FORWARD HANDSPRING, THE FORWARD HANDSPRING WITH ULNAR DEVIATED HAND POSITIONING AND THE BACKWARD HANDSPRING

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The aim of this research was to deterime the loading conditions throughout the forward handspring, the forward handspring with ulnar deviated hand positioning and the backward handspring using an inverse dynamics approach based on simultaneously acquired kinetic and kinematic data. 14 gymnasts performed five of each movement. The range of motion (ROM) around the pronation/supination axis in the forward handspring with ulnar deviated hands was significantly higher than in the two other executions. The calculated moment acting on the wrist during backward handsprings exceeded the ones during the forward executions significantly. Due to the knowledge of the loading conditions, long-term damages can be estimated and minimized in such repetitively excessive motions.

KEY WORDS: gymnastics, kinematics, kinetics, video-photogrammetry.

INTRODUCTION: The forward and backward handsprings are common movement elements in gymnastics and apparatus gymnastics. The wrist plays a prominent role in the force transmission and is thought to be exposed to extreme loads while performing these elements. Since excessive and repetitive compressive forces acting on the wrist are known to lead to acute and chronic injuries (DiFiori, Puffer, Mandelbaum, & Mar, 1996), it is clear that an understanding of the forces that act in the wrist is necessary in order to reduce the occurrence of injuries during gymnastics.(De Smet, Claessens, & Fabry, 1993; Dobyns & Gabel, 1990). The aim of this research was to determine the loading conditions throughout the forward handspring, including the variant with the hands ulnar deviated, as well as the backward handspring, using an inverse dynamics approach based on simultaneously acquired kinetic and kinematic data.

METHODS: 14 healthy, national competing gymnasts (7m, 7f) performed five valid handsprings in a neutral hand position, in an ulnar deviated hand position (Fig. 1) and backward handsprings after a round off. The study was approved by the ethics committee of the ETH Zurich.
The run in and landing were laid out with 7 cm thick floor mats (Alder and Eisenhut AG, Ebnat-Kappel, Switzerland). The two force plates (Kistler, Winterthur, Switzerland) which measured ground reaction forces of one hand each with a sampling frequency of 2000 Hz(Bachmann, Gerber, & Stacoff, 2008), were covered by mats with the same dimensions as the force plates (Fig. 1).
Kinematic data was recorded with the 12 camera video photogrammetric system (VICON, Oxford Metrics Group, UK) using a frequency of 200 Hz. Based on literature (Murgia, Kyberd, Chappell, & Light, 2004; Rab, Petuskey, & Bagley, 2002), 14 reflective markers were additionally to Vicon’s plug-in-gait marker set(Vicon®, 2002) attached on arms and hands. The kinetic and kinematic analysis was done in Matlab (R2011a, The MathWorks, Inc., Natwick, USA).
The support phase was defined as the period where the force acted on the palms regarding a threshold of 25 N. Wrist kinematics were calculated throughout the loaded phase, as well as 20 % before.
To determine the wrist joint center (WJC) a functional approach using a least-square fit of the corresponding marker point clouds (Gander & Hrebicek, 1997) based on basic motion tasks, as previously described in List et al.,(List, Gerber, Foresti, Rippstein, & Goldhahn, 2012) was

used. The lateral and medial epicondyle markers were used to determine the elbow joint center (EJC) based on a geometrical approach.(Roux, Bouilland, Godillon-Maquinghen, & Bouttens, 2002; Williams, Schmidt, Disselhorst-Klug, & Rau, 2006) The relative hand to forearm rotations were computed according to the conventions of the joint coordinate system introduced by Grood and Suntay(Grood & Suntay, 1983) to calculate the wrist angles.

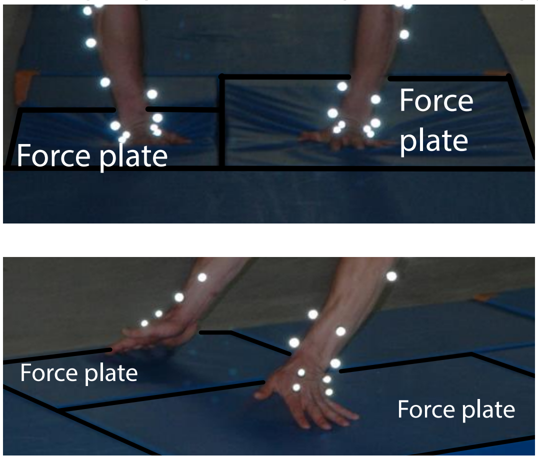

Figure 1: neutral hand position (on the top), ulnar deviated hand position (on the bottom).

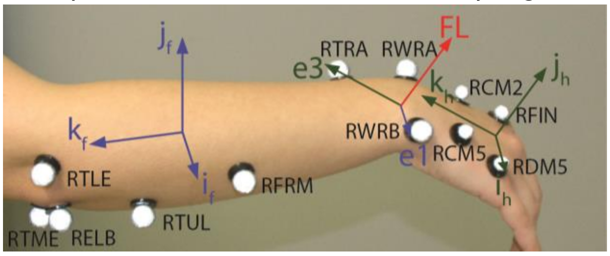

Figure 2: *RTME:* right medial epicondyle, *RTLE:* right lateral epicondyle, *RELB:* right elbow, *RTUL:* right ulna, *RFRM:* right forearm, *RTRA:* right radius, *RWRA:* right medial wrist marker, *RWRB:* right lateral wrist marker, *RCM2:* right second carpometacarpal joint, *RCM5:* right fifth carpometacarpal joint, *RDM5:* right fifth distal metacarpal joint, *RFIN:* right second distal metacarpal joint; i_f, j_f, k_f: forearm coordinate system, i_h, j_h, k_h: hand coordinate system; *e1*: proximal segment fixed axis, *e3*: distal segment fixed axis, *FL*: floating axis

The force and moment calculation was done by means of an inverse approach with a quasi-static solution adapted to the method that was used for the knee by Lorenzetti et al.(Lorenzetti et al., 2012) The kinetic data was normalized over the subject's body weight (BW). The absolute wrist force F_{abs} was split in three forces (F_{if}, F_{jf}, and F_{kf}) acting in three orthogonal directions(i_f-axis, j_f-axis and k_f-axis) defined by the forearm segment coordinate system (Fig. 2). The anterior, medial and proximal directions were defined as positive. The absolute wrist joint moment M_{abs} was projected in the directions of the forearm coordinate system (i_f-axis, j_f-axis and k_f-axis) and were named M_{if}, M_{jf}, and M_{kf} . The sign convention was determined by the direction of the corresponding axis of the forearm coordinate system along which the moments acted.

The one-way analysis of variance (ANOVA) was conducted in SPSS (version 20, SPSS Inc., Chicaco) with the chosen parameters of each execution form and was corrected by the Bonferroni adjustment. For not normally distributed parameters the Friedman-test was chosen to indicate significant differences before using the Wilcoxon-test to distinguish between execution forms (p<0.05).

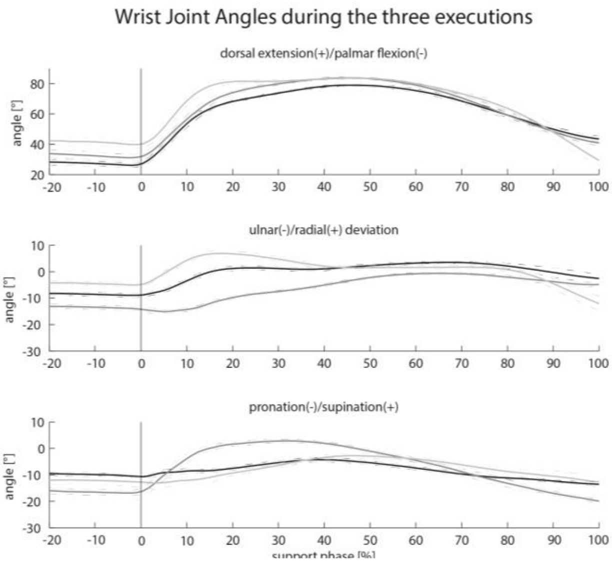

Figure 3: Mean (solid lines)and standard deviation (dashed lines) of the right wrist angles over all subjects. During the support phase of the forward handspring: black lines, forward handspring ulnar deviated: grey lines, backward handspring: light grey lines

RESULTS AND DISCUSSION: This study, as well as former investigations, (Davidson, Mahar, Chalmers, & Wilson, 2005; DeGoede & Ashton-Miller, 2002; Koh, Grabiner, & Weiker, 1992) found no significant differences in the force and kinematic data between the left and right side. Therefore only results of the right side are presented (Tab. 1).

Kinematics: No significant differences in maximal and minimal wrist angles were found between the three movements (Fig. 3). This leads to the assumption that in all three executions the maximally possible dorsal extension angle was reached and restricted by passive structures. The pronation/supination ROM was significantly larger in the ulnar deviated forward handspring in comparison to the forward as well as the backward handspring (Tab. 1). This could be an indication that this motion task moved more around the k_h-axis of the hand than the other two tasks. This rises up the question if a higher pronation/supination range of motion (ROM) during the forward ulnar deviated handspring leads to a long-term damage of the wrist or to a less loaded dorsal extended wrist preventing long-term damages.

Table 1
Mean of the ROM, minimal and maximal forces and moments of the wrist

		Forward handspring	Forward ulnar deviated handspring	Backward handspring
dorsal extension/palmar flexionl [°]		55.1 ± 12.2	56.1 ± 12.0	59.7 ± 14.7
ulnar/radial deviation [°]		17.5 ± 7.5	20.8 ± 6.3	21.3 ± 7.2
supination/pronation [°]		13.3 ± 5.1[*1]	21.3 ± 7.2[*1,2]	16.0 ± 6.4[*2]
F_{if} [N/BW]	max	0.35 ± 0.11	0.34 ± 0.13	0.38 ± 0.09
	min	-0.06 ± 0.04[*3]	-0.02 ± 0.02[*3,4]	-0.06 ± 0.03[*4]
F_{jf} [N/BW]	max	0.09 ± 0.05[*5]	0.09 ± 0.07[*6]	0.21 ± 0.10[*5,6]
	min	-0.16 ± 0.09	-0.25 ± 0.18	-0.23 ± 0.07
F_{kf} [N/BW]	max	1.46 ± 0.26	1.57 ± 0.36	1.50 ± 0.20
F_{abs} [N/BW]	max	1.48 ± 0.26	1.60 ± 0.37	1.53 ± 0.19
M_{if} [Nm/BW]	max	0.049 ± 0.016	0.047 ± 0.020	0.090 ± 0.096
	min	0.0024 ± 0.0026[*7]	0.0019 ± 0.0029[*8]	-0.167 ± 0.140[*7, 8]
M_{jf} [Nm/BW]	max	0.0061 ± 0.0049[*9, 10]	0.026 ± 0.0149[*9, 11]	-0.032 ± 0.009[*10 11]
	min	-0.0081± 0.0076[*12, 13]	0.001 ± 0.0039[*12, 14]	-0.674 ± 0.090[*13, 14]
M_{kf} [Nm/BW]	max	0.0027 ± 0.0017[*15]	0.0043 ± 0.0059[*16]	0.115 ± 0.046[*15, 16]
	min	-0.016 ± 0.009[*17]	-0.011 ± 0.007[*18]	-0.139 ± 0.047[*17, 18,10]
M_{abs} [Nm/BW]	max	0.052 ± 0.017[*19]	0.053 ± 0.022[*20]	0.722 ± 0.081[*19,20]

Kinetics: The maximal absolute (F_{abs}) and the maximal proximal-distal (F_{kf}) force during the three execution forms did not significantly differ (Tab. 1). The maximal value of the F_{jf} during the backward handspring was more than twice as large as during the other handspring executions. The vertical velocity of the subject has to be greater during the first flight phase before touch-down of the hands to perform a proper backward handspring than performing a forward or forward ulnar deviated handspring. At take-off of the hands the gymnasts try to push themselves in the moving direction to gain a further second flight phase. The minimal value of F_{if} is higher during the forward ulnar deviated handspring than during the other two executions. It has to be construed cautiously, since the ulnar deviation leads to a gyration of the forearm coordinate system, on which the force vector was projected. Thus the anterior-posterior force direction is not anymore directed more or less in the anterior-posterior direction of the movement, which is the case for the other two execution forms. However, it has to be noted that all forces are measured below the mat and therefore the damping properties are influencing the resulting forces.

For the first time wrist moments were computed during forward, forward ulnar deviated and backward handsprings. The mean maximal absolute moment during the backward handspring was more than ten times greater than during the other execution forms (Tab. 1). Since F_{abs} did not differ the lever arm can be assumed to be the crucial factor. This external moment has to be compensated by internal structures such as muscles and bones and will therefore lead to a larger internal loading of the wrist joint and the embracing tendons and muscles. A further interesting fact is that performing the backward handspring no positive moment along the j_f-axis (M_{jf}), considered as an ulnar deviation moment, was detected (Tab. 1). Furthermore the backward handspring was the only exercise resulting also in a great moment along the i_f-axis (M_{if}), determined as a palmar flexion moment, probably due to the significantly higher maximal value of F_{jf} and the bigger lever arm compared to the other executions. Therefore the wrist is stressed more by the wrist moments especially around the dorsal flexion/palmar extension and ulnar/radial deviation axis during the backward handspring than during the forward and forward ulnar deviated handspring.

CONCLUSION: The pronation/supination ROM was significantly higher in the forward handspring with ulnar deviated hands. There was no significant difference detected in the maximal absolute force applied to the wrist between the three motion tasks. Nevertheless there were significantly higher wrist moments during the backward handspring. Due to the knowledge of the load condition of the wrist during these tasks the risk of long-term damage can be estimated and minimized in such repetitively excessive motions. It cannot be recommended to athletes and coaches to perform the forward handspring with ulnar deviated hand position.

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