RETURN TO SPORT TESTING IN FOOTBALL: IMPLEMENTING SPORTSPECIFITY BY A MIXED REALITY APPLICATION

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The purpose of this study was to identify, if a mixed reality gaming application (MOTUM XR), can be used for return to sport testing. Of specific interest was the influence of the standing position of the virtual non-contact player (left or right from the goal), on the movement pattern of the performing athlete. Kinematic and kinetic data were collected from nine healthy football players, who performed countermovement jumps and headers according to the game specification. For each jump condition three jumps were record. The headers showed significant movement adaptations with a shorter jump time (approx. 40%), increased vertical force peaks (between 25-42%) as well as less flexed knees (by 18-22°). The jumps that included heading for the ball, showed more sport specificity, the position of the thrower however had no significant influence on Limb Symmetry.

KEYWORDS: ACL-injury, football, soccer, header, countermovement jump.

INTRODUCTION: In the professional ACL-rehabilitation return to sport process biomechanical measurements of standardized tests batteries are usually conducted. The used test batteries as well as the time when these tests are executed vary immensely. Usually test that contain strength, mobility, stability and dynamic tasks such as horizontal and vertical maximal jump task and cuttings manoeuvres are recommended (Meredith, Rauer, Chmlelewski, Fink, Diermeier, Rothrauff et al., 2020). The prediction value of these tests with respect to the risk of potential further ACL-injury yet remains highly discussed (Schweizer, Strutzenberger, Franchi, Farshad, Sherr, Spörri, 2022)
Despite the possibility of high standardization and testing basic motor functions the test batteries might be improved by implementing more sport-specific tasks and tasks that also include the neurocognitive ability of the athlete by implementing tasks with external focus. Such tasks would stress the system from well planned and controlled movements to tasks in a shorter time domain and towards less controlled movements (Gokeler, McKeon, Hoch, 2020). In a football specific context, this would e.g. be the translation from a countermovement jump (CMJ) for maximal height to the task of heading a ball towards the goal (DiCesare, Kiefer, Bonnette, Myer, 2020). The CMJ is used to assess lower limb strength and limb symmetry.
Using Virtual reality and Mixed reality (MR) applications might help to overcome the difficulties usually coming with these tasks, such as e.g. space, standardization, including a ball and or opponents, and yet be able to test in laboratory conditions. MOTUM XR (MOTUM, Innsbruck, Austria) is a MR application, which enables the athlete to interact via an avatar, that he/she drives with the own movements, with a virtual surrounding displayed on a video wall in front of the motion capture area of the biomechanics lab. In Level I a non-player character (NPC) throws a virtual ball towards the avatar, who has the task to head the ball into a displayed goal (Figure 1) with varying movement difficulties.
Capturing the motion data enables on the one hand side the real time interaction with the MR application and on the other hand side allows to collect data on the performed movement.
While this approach seems promising to implement more sport specificity, little is known about the biomechanical movement adaptions induced by the game. In specific, the placement of the NPC, who throws the ball to the avatar, might induce movement adaptations. Due to gaming specifications the NPC is positioned left and right to the goal where the athlete has to head the

ball to, and it might be possible that the performing athlete might adapt the jump off movement to the side, where the header comes from.
Therefore, the aim of this study was a) to compare a MR header to a MR CMJ and b) whether a left versus right ball feed affects the player header biomechanics.

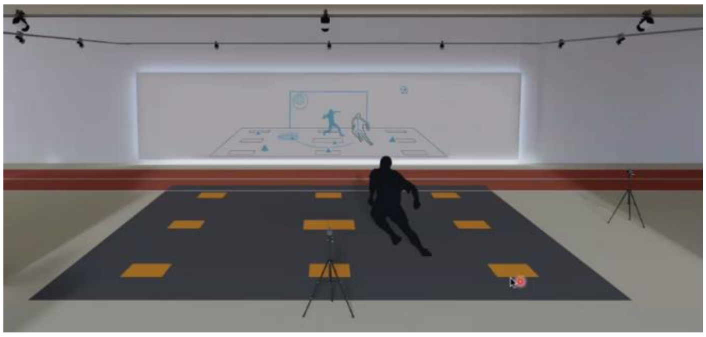

Figure 1: Schematic set-up of the MOTUM XR application in the laboratory

METHODS: Four female and five healthy male football players (21±5 years, 69±8 kg, 176 ± 10 cm) performed 3 maximal CMJs and 3 simulated head balls each from the left and right side (Headers left and right) using MOTUM XR displayed in figure 2. Movement instructions were a) CMJ: “Move the displayed bar as high as possible with your head”, b) Headers: “Head the ball into the goal”.
The participants were equipped with 61 reflective markers using a combination of the Qualisys Sports-Marker Set for the interaction with the real-time application and the cluster-based Cleveland Clinical Marker Set for data processing. A 14-camera motion system (Qualisys, Gothenburg, Sweden) collected the marker data with 100 Hz simultaneously with two force plates imbedded in the ground (AMTI Inc., Watertown, MA, USA), with a sampling frequency of 1000 Hz. The MOTUM XR Application was displayed 5 m in front of the players on a 5x3 m video wall.

Figure 2: Video wall seen by the athlete with the avatar and the 3 conditions: a) maximal jump, b) header from left and c) header from right.

Data was labelled (QTM) and further processed with Visual 3D (C-Motion Inc., USA) using the Qualisys Functional Assessment pipeline for CMJs with the exemptions of a) the model calculation, which used the Cleveland Clinical Markerset for segment definitions and b) jump start event definition, which used the time instance, where the vertical force passed 95% of bodyweight for the first time. The jump height was defined using the vertical velocity of the center of mass at take-off. Maximum sagittal and frontal knee joint angle and moment were calculated using the 6 DOF Model implemented in Visual 3D and time normalized over the jump cycle. Joint Moment data was further normalized to body weight. From the force plate data, the time to take-off, the maximum rate of force development and the maximal force was calculated. A limb symmetry Index was defined as left parameter / right parameter*100. A one-factor ANOVA (CMJ, header from left, header from right) was used for statistical analysis with post-hoc t-tests.

RESULTS: While the jump height did not differ between the 3 CMJ-variations, significantly faster jump off time, increased peak vertical force and peak rate of force development as well as increased internal knee extension moments were shown for the jumps, where the athletes had to head the ball. Simultaneously the athletes displayed less flexed knees in these jumps. With respect to the position where the ball came from to be headed into the goal, no significant difference in the limb symmetry indices were found between the left and right ball feed position.

Table 1: Performance parameters for CMJ, header from left and header from right.

parameter	max CMJ	Header left	Header right	ANOVA	post-hoc
max jump hight [cm]	40.2 ± 7.1	36.8 ± 6.2	37.4 ± 7.2	0.10	--
time to take-off [s]	0.994 ± 0.208	0.619 ± 0.121	0.586 ± 0.115	**0.01***	**$0.001^{max\text{-}L}$, $0.002^{max\text{-}R}$**, $0.400^{L\text{-}R}$
Fz_{max} L [N/BW]	1.2 ± 0.1	1.5 ± 0.2	1.5 ± 0.2	**<0.01***	**$0.008^{max\text{-}L}$, $0.002^{max\text{-}R}$**, $0.400^{L\text{-}R}$
Fz_{max} R [N/BW]	1.2 ± 0.1	1.6 ± 0.3	1.7 ± 0.3	**<0.01***	**$0.008^{max\text{-}L}$, $0.003^{max\text{-}R}$**, $0.200^{L\text{-}R}$
Fz_{max} LSI [%]	97 ± 5.1	95 ± 8.2	93 ± 8.9	0.20	--
RFD_{max} L [N/BW]	6.3 ± 1.9	11.6 ± 5.9	12.2 ± 4.9	**0.02***	**$0.010^{max\text{-}L}$, $0.010^{max\text{-}R}$**, $0.600^{L\text{-}R}$
RFD_{max} R [N/BW]	7.5 ± 2.7	14.0 ± 8.1	14.7 ± 8.8	**0.05***	**$0.010^{max\text{-}L}$, $0.040^{max\text{-}R}$**, $0.700^{L\text{-}R}$
RFD_{max} LSI [%]	88 ± 18.4	90 ± 25.3	90 ± 21.2	0.90	--
A $Knee_{sag\ max}$ L [°]	96 ± 8.4	76.7 ± 5.1	74.8 ± 7.0	**<0.01***	**$0.010^{max\text{-}L}$, $0.010^{max\text{-}R}$**, $0.300^{L\text{-}R}$
A $Knee_{sag\ max}$ R [°]	94± 8.6	76.5 ± 6.3	74.5 ± 7.7	**<0.01***	**$0.010^{max\text{-}L}$, $0.010^{max\text{-}R}$**, $0.200^{L\text{-}R}$
A $Knee_{sag\ max}$ LSI [%]	103 ± 2.4	101 ± 4.4	101 ± 4.4	0.11	--
A $Knee_{front\ max}$ L [°]	-10 ± 11.2	-12.7 ± 5.7	-12.3 ± 4.9	0.30	--
A $Knee_{front\ max}$ R [°]	-6 ± 13.8	-8.1 ± 10.2	-6.7 ± 10.7	0.50	--
A $Knee_{front\ max}$ LSI [%]	99 ± 35.5	138 ± 66.7	128 ± 45.9	0.30	--
M $Knee_{sag\ max}$ L [Nm/BW]	1.5 ± 0.3	1.9 ± 0.3	2.0 ± 0.3	**<0.01***	**$0.010^{max\text{-}L}$, $0.010^{max\text{-}R}$**, $0.200^{L\text{-}R}$
M $Knee_{sag\ max}$ R [Nm/BW]	1.4 ± 0.2	1.9 ± 0.3	2.0 ± 0.2	**<0.01***	**$0.010^{max\text{-}L}$, $0.010^{max\text{-}R}$**, $0.200^{L\text{-}R}$
M $Knee_{sag\ max}$ LSI [%]	111 ± 16.6	101 ± 15.5	100 ± 14.7	**0.01***	**$0.007^{max\text{-}L}$, $0.025^{max\text{-}R}$**, $0.600^{L\text{-}R}$
M $Knee_{front\ max}$ L [Nm/BW]	-0.3 ± 0.4	-0.5 ± 0.4	-0.5 ± 0.4	0.08	--
M $Knee_{front\ max}$ R [Nm/BW]	-0.1 ± 0.5	-0.3 ± 0.5	-0.3 ± 0.5	0.10	--
M $Knee_{front\ max}$ LSI [%]	113 ± 57.4	118 ± 48.0	134 ± 57.2	0.30	--

Note: Fz: Vertical foce, L: left, R: right, LSI: Limb symmetry index, RFD: rate of force development, A $Knee_{sag}$: sagittal knee angle, A $Knee_{front}$: frontal knee angle, M $Knee_{sag}$: sagittal knee moment, M $Knee_{front}$: frontal knee moment. Post-hoc p-value between conditions: max-L max CMJ – Header left, max-R: maxi CMJ – Header right, L-R: Header left – Header right

DISCUSSION: The CMJ is a classical performance test used in standardized test situations. In football the CMJ can be seen e.g. in situations where the athlete has to head the ball, however within different framework conditions. As such in the real time situation the athlete might compete against an opponent, there is little time to plan and execute the movement, the ball comes from different unstandardized directions and heights, the player might be in movement or perform the jump from a standing position. Therefore, conclusions drawn from a standardized test, where the player is focused on a "good" jump, towards how the player acts in a sport-specific situation might give limited information, about the habitual movement pattern. With the introduction of an external focus in the test situation this natural movement pattern might be better reflected, and the athlete has to perform the movement with increased perceptive-cognitive load and a less pre planned movement strategy (Gokeler et al. 2020). The data of this study showed indeed, that participants displayed altered movement strategies, despite a similar jump height. Most notably the jump-off time was significantly reduced. To generate a similar jump height athletes performed the jump with an increased maximal vertical force and consequently an increased rate of force development. As there is less time to execute the jump, also the players displayed less flexed knees, which indicates a reduced

lowering of the center of mass during the countermovement. Interestingly no significant differences were found in the frontal plane knee angle and moment. These movement alterations are comparable to DiCesare et al. (2020), who compared headings performed with an virtual reality (VR)-headset to basketball drop jumps, and also found increased peak forces along with reduced knee flexion angles in the VR-szenario. Additionally, Gokeler et al., (2020) explored the influence of XR immersion on knee biomechanics in individuals who had undergone ACL reconstruction in a stepping down task and concluded, that a VR surrounding might distract the user as such, that cautious movement patterns are omitted.
With respect to the influence of the throw-in position of the virtual ball on the heading movement strategy, no adaptations were identified in our sample group. The limb symmetry index remained similar between the two throw-in positions. This indicates that the athletes displayed an inherent movement pattern which was not affected by different throw-in positions. The LSI however did show one significant difference between the standardized situation and the header jumps: The internal sagittal knee extension angle displayed in the standardized CMJ situation an increased moment at the left side, while in the header conditions no tendency toward a limb side was identified, which again highlights the influence of external distraction already in a healthy population. This study is a first step to evaluate the influence of external focus using a mixed reality application and sets the ground for the interpretation of findings for ACL-injury assessments. The apparent insensitivity of the influence of throw-in sides indicates, that the throw-in position does not have to be considered as a cofounding parameter in the data-processing and hence all trials can be analysed together. Future steps will need to include ACL-injured participants.

CONCLUSION: These findings suggest that the jumping strategy was adapted to the task and that the head-ball situation in the MR environment may provide a more realistic test environment. Additionally, this movement pattern displayed strategies, that are generally associated to an increased ACL-injury risk mechanism, such a stiff knee movement combined with an increased vertical force (Bahr, Avela, Perttunen, 2017). With respect to ACL-injury monitoring using tasks, which induce movement strategies that are closer to the identified risky movement strategies might improve the efficacy of screening tests. In the MR application the position of the thrower does not affect leg symmetry. These results suggest that the MOTUM XR application has the potential to induce an external focus in a yet standardized testing scenario and might implement a more sport-specific testing. However, further research involving individuals after an ACL-injury and follow up data is needed to critically evaluate the results of this pilot study.

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