CONCURRENT VALIDITY OF LOWER LIMB KINEMATICS BETWEEN MARKERLESS AND MARKER-BASED MOTION CAPTURE SYSTEMS IN GAIT AND RUNNING.

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The goal of this study was to evaluate the accuracy of a markerless silhouette-based tracking and hybrid tracking against traditional marker tracking. Different speeds in gait and running conditions were analysed. In the literature, studies most often make use of low cost rather than high performance systems. Markerless systems allow us to evaluate in the most natural conditions. Very high correlations were obtained depending on the joint. The use of markerless tracking is still new regarding motion analysis in sports or for clinical purposes. This technology could be a very good solution for clinical rehabilitation and real sports situations.

KEY WORDS: MOCAP 3D, gait analysis, running analysis, markerless.

INTRODUCTION: The analysis of human motions is a highly relevant topics in many fields of applications. Three-dimensional kinematic systems are considered as the non-invasive gold standard of motion analysis (Gu, Sowulewski, Yun, Flisberg & Thordstein, 2016). For medical purposes, gait analyses are conducted to detect reasons for movement disorders and to help finding appropriate therapy methods or medical solutions (Klenow, Kahle & Highsmith, 2016). In sports biomechanics the motion analysis is decisive for high performance. Not only improving performance but also preventing injuries and rehabilitation by avoiding inappropriate physical stress is an important topic (Suberi, Razman, & Callow, 2017). Running is a motor skill present in many sports, as football, basketball, handball tennis, etc. For both medical and sports applications these instrumental methods are used to gain objective data.

Marker based systems are the most widespread and used method, due to its high quality of precision in the data. They provide valid kinematic data but are time consuming to setup and process data (McLean, Walker, Ford, Myer, Hewett, van den Bogert, 2005), limiting their use in large studies. The time taken to prepare a participant is very high. In contrast, markerless systems require less participant preparation and data processing time. It does not spend time on the placement of skin markers, neither will you have marker drops during the trials. The recognition of body silhouettes is being increasingly used and companies are working to improve detection algorithms. Athletes can be analysed in real competition or training situations.

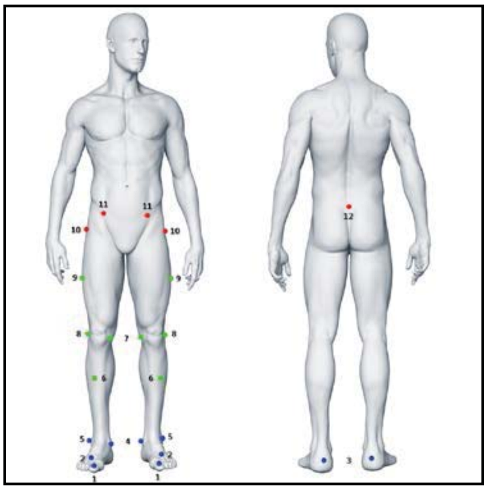

Figure 1: Lower extremities model.

The aim of the study was to compare the accuracy of lower limbs kinematics between markerless and marker-based motion capture systems in gait and running analysis.

METHODS: For the study, six conditions were recorded on a treadmill for gait and running (gait: 2km/h, 4km/h and 6km/h; running: 8km/h, 10km/h and 12km/h). For each condition 20 seconds were recorded. We used eight cameras, model mvBlueCOUGAR-XD104C (MATRIX VISION GmbH Germany), with a resolution of 2048 x 1088 pixels, the sampling frequency was fixed to 100Hz and

LED ringlights were mounted on the cameras. The same camera ring was used for the two methods of motion tracking, although two software were used.

The software used for the marker-based motion capture system was Simi Motion v.9.2.0. (Simi Reality Motion Systems GmbH, Germany). The lower limb model used had 23 reflective markers (Figure 1). The joint centers of ankle, knee are defined as center of the connection line between the medial and lateral markers of the particular joint. Hip and shoulder joints are calculated in a more complex way according to the works of Bell, Pedersen and Brand (1990) and De Leva (1996). According to the International Society of Biomechanics (ISB) standard (Wu, Siegler, Allard, Kirtley, Leardini, Rosenbaum, Whittle, D'Lima, Cristofolini, Witte & Schmid, 2002) and, Grood and Suntay (1983), special joint coordinate systems are defined to describe joint rotations. Markerless silhouette-based model was obtained by using Simi Shape v.2.2.0. (Simi Reality Motion Systems GmbH, Germany). This software is an upgrade of Simi Motion.
The subject wear an orange suit in addition to reflective markers (Figure 2), this allowed us to measure simultaneously. Therefore Simi Motion tracked the marker positions and Simi Shape analysed the silhouettes.

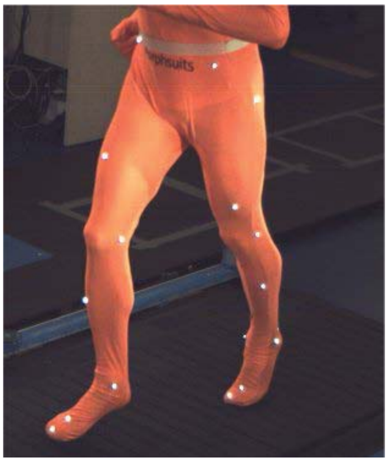

Figure 2: Body suit and reflective markers.

We collected a total 1.000 samples per each speed/condition. To quantify the accuracy of markerless against marker-based tracking, we used Spearman correlation coefficient with IBM SPSS Statistics 20 (table 1), and the standard deviation of the angle difference with Microsoft Excel 2010 (table 2). The interpretation of the correlations coefficient was: very high (r ≥ 0.9); high (0.7 ≤ r < 0.9); moderately (0.5 ≤ r < 0.9); and weak (r < 0.5).

RESULTS: Gait and running showed very high correlations for the sagittal plane. Except for the ankle, in the plantar / dorsal flexion movement in gait condition (table 1). The eversion / inversion of the ankle showed very high correlation in 4km/h and 6km/h speed. We found differences in order of 3-6° for gait, and 5-7° for running. Except ankle abduction / adduction that showed more than 15° and 21° for gait and running respectively.

Table 1
Gait condition: correlations of joint angles and standard deviations of angle difference. Interpretation of the correlation coefficient: Very high correlation = **, and High correlation =*

Joint	Movement	Gait					
		Correlation			SD of angle difference [°]		
		2km/h (0.56 m/s)	4km/h (1.11 m/s)	6km/h (1.67 m/s)	2km/h (0.56 m/s)	4km/h (1.11 m/s)	6km/h (1.67 m/s)
Hip	flexion/extension	0.97**	0.98**	0.97**	3.47	2.21	3.07
	abduction/adduction	0.66	0.60	0.65	4.49	4.22	5.24
	rotation	0.55	0.73*	0.76*	6.77	4.22	4.35
Knee	flexion/extension	0.98**	0.98**	0.99**	2.67	2.57	2.85
Ankle	plantar/dorsal flexion	0.58	0.71*	0.59	5.96	5.67	5.73
	eversion/inversion	0.89*	0.90**	0.92**	4.78	4.44	4.62
	abduction/adduction	0.36	0.03	-0.83*	15.86	18.01	19.16

Table 2
Running condition: correlations of joint angles and standard deviations of angle difference. Interpretation of the correlation coefficient: Very high correlation = **, and High correlation=*

Joint	Movement	Running					
		Correlation			SD of angle difference [°]		
		8km/h (2.22 m/s)	10 km/h (2.78 m/s)	12 km/h (3.33 m/s)	8 km/h (2.22 m/s)	10 km/h (2.78 m/s)	12 km/h (3.33 m/s)
Hip	flexion/extension	0.90**	0.99**	0.97**	7.30	4.33	6.12
	abduction/adduction	0.37	0.31	0.30	5.11	8.86	5.76
	rotation	0.56	0.58	0.76*	8.67	9.76	6.79
Knee	flexion/extension	0.996**	0.99**	0.997**	3.07	5.53	3.37
Ankle	plantar/dorsal flexion	0.93**	0.83*	0.91**	5.20	6.21	5.94
	eversion/inversion	0.88*	0.79*	0.76*	6.21	7.20	7.07
	abduction/adduction	-0.22	-0.24	-0.33	21.64	21.37	22.33

DISCUSSION: This study has evaluated whether a markerless motion capturing system is feasible as a complementary tool for common situation in gait and running analysis.

In the clinical setting, marker-based systems could contaminate the movements of patients, who suffer from certain limiting movement pathologies. For sporting purposes something similar occurs, sports professionals want to observe and analyse their athletes in real rather than simulated situations, and even better in competitive situations. There are many advantages of markerless tracking compared to marker-based tracking. First, much time can be saved if no markers have to be attached. Second, subjects are captured in free conditions with no restrictions of movement. Third, there are no human failures in the placement of the markers. And fourth, there are no marker movements as a result of soft tissues such as fat thickness and our skin.

The use of markerless tracking in motion analysis in sport with clinical purpose is not widespread. Markerless advances are already commonly used in the film and computer game industry. The aim of these systems was not placed on high precision, (Corazza, Mündermann, Gambaretto, Ferrigno, & Andriacchi, 2010), but on low costs and the use of uncalibrated cameras. In the literature, low-cost markerless systems, as MATLAB Kinect Skeletal Tracking System are able to measure the gait parameters, though there was a substantial error in accuracy (Abiddin, Jailani, Omar & Yassin, 2016).

Moreover, there are a few studies which test the accuracy of markerless tracking in clinical or sports situations, where precision has to be much higher. Perrott, Pizzari, Cook, & McClelland (2017) evaluated the accuracy of the markerless tracking software (Organic Motion) against a marker-based motion capture system (Vicon). They found systematic differences or relatively small differences in the order of 3–6º, just as we have found differences of 3-6º degrees for gait (table 1) and 5-7º for running (table 2). We have found similar results but in different conditions. Their conditions were knee flexion test and single leg squat. We tested the system in gait analysis, which is an activity with a higher gestural speed. Therefore, it is more difficult to analyse the algorithms. However, Xu, McGorry, Chou, Lin & Chang (2015) suggest that Kinect sensor may be used as an alternative device to measure some gait parameters for treadmill walking. In this case, we add sports conditions like running at 12 km / h with very high accuracy for the sagittal plane and high for eversion / inversion of the ankle (table 2).

We found exceptional results for the sagittal plane in all joints, although not as good results for plantar / dorsal flexion for gait. The sagittal plane obtained better results because the algorithms more easily recognize an intersection of two large segments than the rotational movements, because the geometry of a rotating segment remains intact.

CONCLUSIONS: The 3D analysis systems based on markers have long been used over decades. They are the technology that allow us to have the best precision for kinematic parameters. They all require us to always evaluate in laboratory conditions, with an expensive and sensitive preparation. This has been one of the major limitations that these systems have always had. Marker-based systems are considered the goal-standard non-invasive photogrammetric analysis, but markerless systems are much less invasive. Our purpose study was not to compare this system with a low-cost solution, hence in the future the improvement of artificial vision algorithms and the combination with other models such as IMUs and reduced hybrid models with markers will allow to increase the accuracy of this system. Especially to improve results in the frontal and transverse plane. Markerless systems would be a powerful tool in real situations of patients and athletes, and we could evaluate in a more natural context.

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