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Markerless motion capture: What clinician-scientists need to know right now

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Abstract

Markerless motion capture (mocap) could be the future of motion analysis. The purpose of this report was to describe our team of clinicians and scientists' exploration of markerless mocap (Theia 3D) and share data for others to explore (link: https://osf.io/6vh7z/?view_only=c0e00984e94a48f28c8d987a2127339d). Simultaneous mocap was performed using markerless and marker-based systems for walking, squatting, and forward hopping. Segment lengths were more variable between trials using markerless mocap compared to marker-based mocap. Sagittal plane angles were most comparable between systems at the knee joint followed by the ankle and hip. Frontal and transverse plane angles were not comparable between systems. The data collection experience using markerless mocap was simpler, faster, and user friendly. The ease of collection was in part offset by the added data transfer and processing times, and the lack of troubleshooting flexibility. If used selectively with proper understanding of limitations, markerless mocap can be exciting technology to advance the field of motion analysis.

Keywords

Markerless motion capture; 3D modeling; Lower extremity; Kinematics

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1. Introduction

As Clinician-Scientists, we love 3D motion capture (mocap). This technology has aided movement science since the 1970s [1], and the techniques are well documented [2,3]. There are, however, aspects of traditional 3D mocap that make its use challenging. The time-consuming placement of retroreflective markers, for example, requires extensive training [4], and the markers themselves may impede natural movement. We have, therefore, watched with interest the emerging technology of markerless mocap as a potential replacement for traditional marker-based mocap.

Trusting new technology can be difficult for scientists, especially when good methods already exist. A single study comparing treadmill walking kinematics from commercially available 3D markerless (Theia3D) and marker-based mocap systems has been published [5,6]. Consistency between the systems is promising, but the reported joint angle differences of 5° are not trivial. Currently, no work has been done to validate markerless mocap against gold standard measures of kinematics (*e.g.*, biplanar fluoroscopy), leaving the accuracy of markerless mocap in question. An alternative for assessing markerless mocap's utility is to compare it to marker-based mocap for various movements that have yet to be tested. Theia3D uses a black box machine learning algorithm with few ‘knowns’ and many ‘unknowns’. Is it consistent? Does clothing matter? Will the model scale? These are questions that are difficult to address with traditional hypothesis-driven experiments.

As Clinician-Scientists with these burning questions, when given the opportunity to trial a markerless mocap system, we naturally jumped at the opportunity. We imagined the broader biomechanics community would appreciate insight into how this new, unexplored technology operates. The purpose of this short communication is to present perspectives of how our diverse team explored the technology and share data for others to explore (link: https://osf.io/6vh7z/?view_only=c0e00984e94a48f28c8d987a2127339d).

2. Methods

2.1. Movements of interest

Three members of the research team at the University of Delaware of varied skin color and sex performed movements which we expected would present different challenges for the system. Walking is an obvious standard. The unweighted squat was chosen as a stationary movement with a large range of joint excursion. The single leg forward hop is a quick movement with relevance to sports. Images for the participants and movements can be found in the shared link.

2.2. Data collection and processing

All movements were first performed three times without retroreflective markers using a commercially available markerless mocap system (Theia 3D, Theia Markerless Inc., Kingston, ON). Markers were then placed, and three static trials with arms across the chest were collected to create the model files applied to motion trials of the marker-based system. In contrast, no static calibration trial was collected for the markerless system, as independent model files are generated for and applied to each trial. Finally, three more trials of each movement were concurrently captured by both systems. Joint kinematics for the hip, knee, and ankle were analyzed for each movement. Detailed data collection and processing descriptions can be found in the shared link.

2.3. Statistics

The statistics are descriptive; we encourage readers to download and explore the full data set (link: https://osf.io/6vh7z/?view_only=c0e00984e94a48f28c8d987a2127339d). The data set includes all C3D and CMZ files, as well as the R [7] scripts used to generate some appropriate figures for interpretation of data. For kinematic comparisons, the average of three trials for each participant was used. Correlations and mean differences between markerless and marker-based kinematics along the waveform were calculated and used to identify agreement [8]. As marker placement required rolling up the shorts and securing elastic bands around the thighs, shanks, and pelvis, comparisons between trials with and without markers were used to evaluate the effect of clothing on the markerless system.

3. Results and discussion

3.1. User experience and logistics

Collecting data with markerless mocap was less time-consuming and more user-friendly compared to marker-based mocap. The reduced set up time while participants are present in the lab was a positive feature. The total file sizes for all videos collected with markerless mocap, however, required approximately 160 times more storage space (Marker-based: 0.22 GB, Markerless: 34.9 GB) with subsequently longer data transfer times compared to the files from the marker-based system. This is not something that can be ignored, especially if one plans on using this system for large studies. Post-processing time is dependent on computer specifications, and Theia3D has a minimum requirement beyond those required for marker-based mocap. Our system, equipped with a 10-core Intel i9-10900k central processing unit, NVIDIA RTX 3090 graphics processing unit, and 32 GB of random-access memory, took approximately 87 s to process 8.4 s of video. The C3D files created through this process are final and, unlike marker-based mocap, no corrections can be made once data are collected. In other words, with markerless mocap you cannot check for “good” trials during a data collection, so you should collect additional trials to maximize the likelihood of having a complete dataset for analysis. Advancements in technology may improve some of the discussed downsides of using markerless mocap in the future.

3.2. Model scaling

Marker-based model files captured via static trials demonstrated consistent segment lengths across trials in the thigh and shank, as expected (Fig. 1). In contrast, the model files created using the markerless system showed variability in segment lengths between trials and movements with no systematic offset across participants (Fig. 1). The model files created during static trials created longer segment lengths in the thigh after retroreflective markers were placed. Participants A and C had their shorts tied up and all three participants had bands strapped around the waist to secure the pelvic marker cluster for the marker-based system. These clothing changes resulted in up to 4 cm differences in segment lengths within the markerless system: roughly 10% of the participants’ thigh segment length. This variability based on attire alone emphasize the importance of controlling for clothing when using Theia3D.

3.3. Lower extremity joint angles

3.3.1. Flexion-extension angles (x-axis)—

Hip, knee, and ankle angles all showed similar waveforms with strong correlations between markerless and marker-based systems across movements (Table 1). The mean difference, however, was large at the hip (10–22°) and the ankle (3–8°), with knee angles demonstrating the most comparable results between the two systems (1–3°) (Table 1). The mean difference was offset systematically, with smaller angles across all three joints, using the markerless system. Mean differences in hip joint angles varied between participants, with participant C demonstrating the best agreement between systems. It's plausible that body type, skin color, and clothing all contributed to kinematics being more comparable at the hip joint in participant C compared to participants A and B.

3.3.2. Abduction-adduction angles (y-axis) and internal-external rotation angles (z-axis)—

Hip, knee, and ankle angles between the two systems demonstrated much weaker correlations across movements (Table 1). The findings in the y and z axes were disappointing, but also difficult to draw conclusions from, since validity in y and z axes are less than optimal in marker-based mocap as well.

3.4. Markerless mocap knee flexion angles

Knee flexion angles collected using the markerless system during walking and hopping had similar waveforms and magnitudes across participants regardless of retroreflective marker placement. During squats, however, knee flexion angles were smaller when retroreflective markers were placed on participants (Fig. 2). This was due to movement restrictions from the straps placed on the lower body, which function to affix rigid clusters to the thigh and shank segments. No instructions were given for squat depth during this task, yet all participants squatted lower without markers; highlighting the restrictions imposed by markers when moving through large ranges of motion. This limitation can be partially offset by less restrictive marker placement protocols or more specific instructions regarding squat depth.

3.5. Summary

Theia3D is easy to set up, saves participants' time, and requires little skill to successfully execute a data collection session. Large file sizes, long data transfer times, and lack of flexibility in trial troubleshooting are drawbacks to the markerless system.

Markerless mocap seems to be a great tool for assessing sagittal plane kinematics. Unsurprisingly, knee flexion-extension angles were the most comparable to marker-based mocap (1–3°). The knee has the greatest amount of skin exposed, providing the machine learning algorithm the most consistent view of the joint center. Hip and ankle angle waveforms were comparable, but users should keep in mind the systematic offset between systems that was much greater than what was observed at the knee. In the frontal and transverse plane, we hesitate to draw any conclusions on the utility of Theia3D (Table 1).

The kinematics collected from the two systems in our study are not comparable outside the sagittal plane, however, further analysis with a larger sample size is necessary.

We remain enthusiastic and excited by this new technology. If applied in a suitable setting, it can make a large impact on biomechanics. The differences in measurements compared to traditional marker-based mocap, however, dampen the enthusiasm. Clinicians and scientists must, at a minimum, understand and weigh the pros and cons of each system. We hope our perspectives have provided some food for thought for those who are contemplating integrating emerging markerless mocap technology into their research and clinical care.

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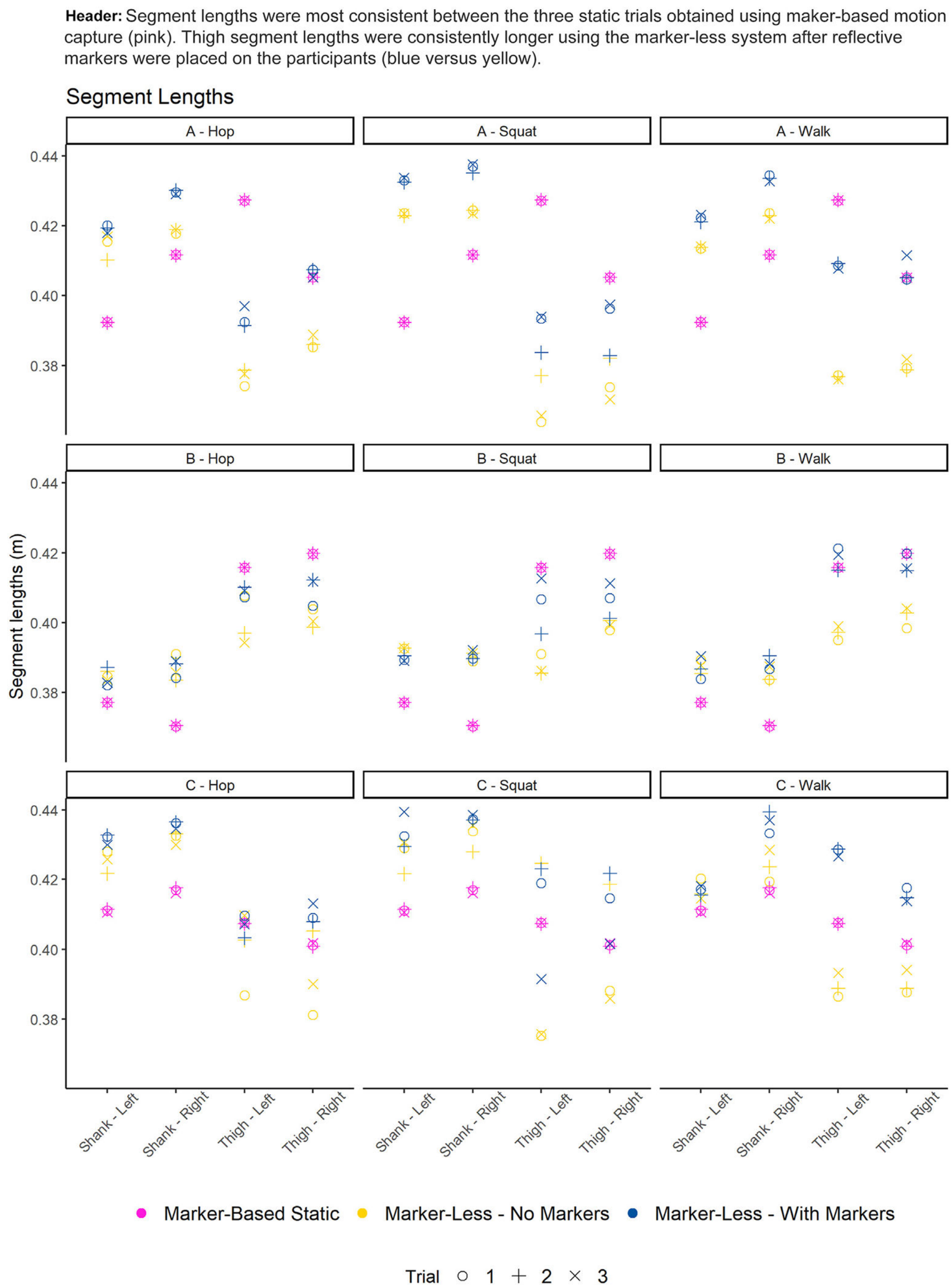

Fig. 1.

Foot note: Subheadings: "participant ID – movement". e.g., "A-Hop" is participant A performing the hop. Images of each participant and marker placement can be found under "Methods" in the OSF link (https://osf.io/6vh7z/?view_only¼c0e00984e94a48f28c8d987a2127339d).

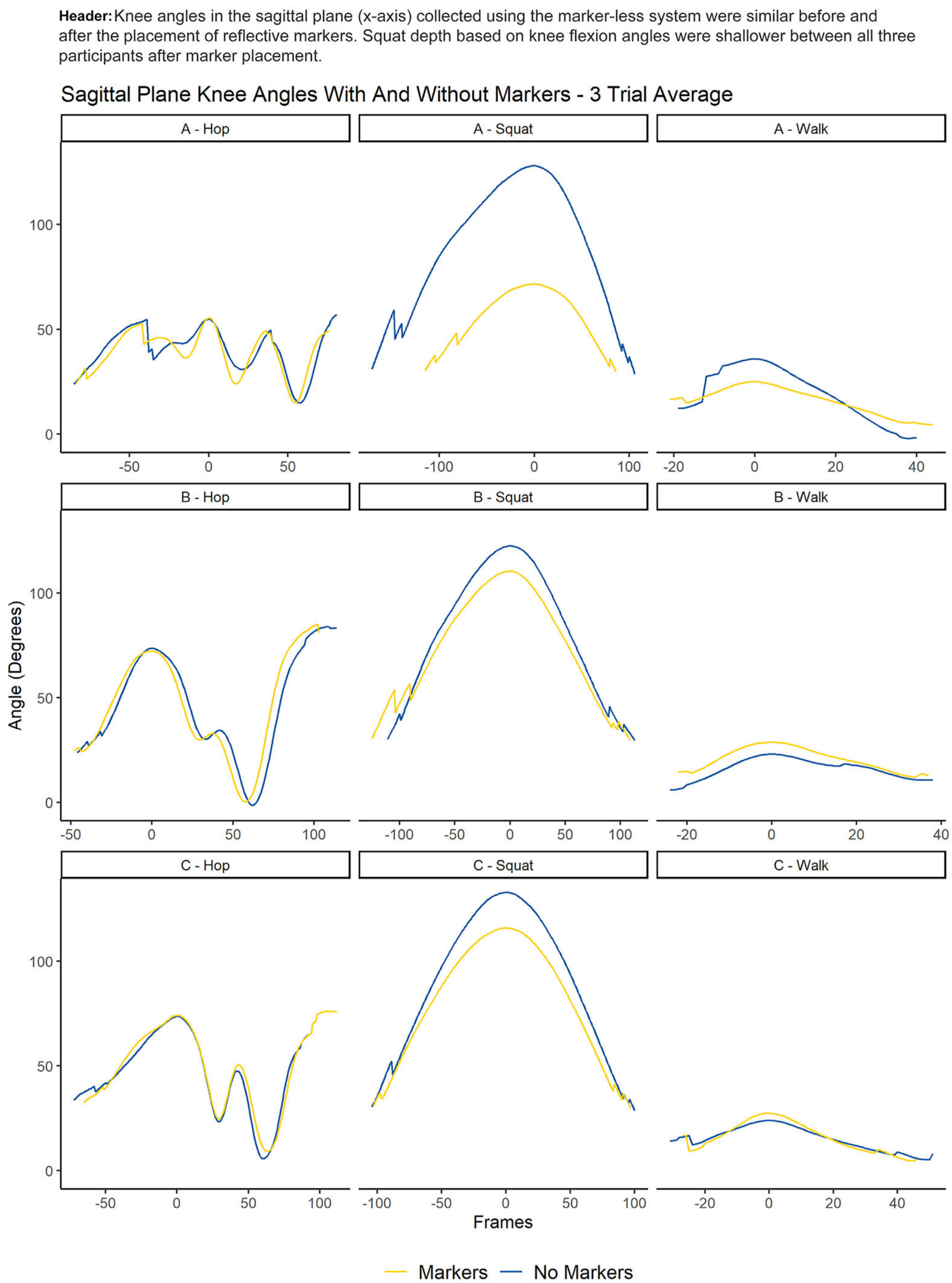

Fig. 2.

Foot note: Frames normalized to peak flexion angles at 0 frames. Subheadings: "participant ID – movement". e.g., "A-Hop" is participant A performing the hop.

Table 1

Pearson's correlation coefficients along the waveform between the marker-based and marker-less systems were largest in the sagittal plane (x-axis) for all three lower extremity joints across all three movements of interest. The knee joint had the smallest mean difference between the two waveforms, followed by the ankle and hip joint which demonstrated larger mean differences between systems. The frontal (y-axis) and transverse (z-axis) were much less comparable between the two systems across joints and movements.

Joint	Axis	Hop		Squat		Walk	
		Pearson's correlation coefficient	Mean difference (deg)	Pearson's correlation coefficient	Mean difference (deg)	Pearson's correlation coefficient	Mean difference (deg)
Hip	**x**	0.945	14.13	0.977	22.16	0.991	10.42
	y	0.525	−2.21	0.736	−4.59	0.142	−2.77
	z	0.307	5.31	0.208	2.65	−0.011	2.35
Knee	**x**	0.925	1.48	0.983	2.16	0.928	2.79
	y	0.278	5.99	0.463	5.49	0.378	4.67
	z	0.300	4.62	0.675	5.26	0.290	−2.62
Ankle	**x**	0.901	8.01	0.918	3.59	0.865	6.38
	y	0.430	−1.74	0.570	1.93	0.489	0.23
	z	0.434	−8.29	−0.222	−6.58	−0.194	−3.34

Mean difference = marker-based – marker-less systems.