Lower Body Reaction Testing Using Ultrasonic Motion Capture

K. Taylor, O. Lennon, C. Blake, D. Fitzgerald, D. Fox, and C.J. Bleakley, *Senior Member IEEE*

Abstract— This paper presents a lower body reaction test that utilizes a new portable ultra-sound based motion capture system (MobiFit) combined with a synchronized visual stimulus. This novel system was tested first for criterion validity and agreement against a gold standard laboratory based optical motion capture system (CODA). It was subsequently tested in the field during Gaelic football (GAA) team gym sessions with 35 subjects to demonstrate its utility and versatility. The lower body reaction test itself is novel in that it can be applied to a gross motor task. During testing, participants had sensors attached to their lower limbs and trunk. The speed of movement for each sensor was monitored at 500Hz using the Mobifit motion capture system, and reaction time was measured as the elapsed time from the appearance of a green indicator on the screen to a sensor reaching a set threshold velocity as the participant raised the corresponding leg. Pearson's correlation coefficient tested criterion validity against the CODA system and Intra class correlation coefficients and Bland-Altman plots assessed agreement of velocity measures obtained from the MobiFit and CODA systems. Results indicate that the MobiFit system is an accurate device to assess lower body reaction time and has advantage over standard laboratory measures in terms of portability and ease of set-up.

I. INTRODUCTION

The ability to measure reaction time has various applications relating to sports. Most sporting activities require an athlete to respond to external stimuli, e.g. sprinter reacting to the umpire's gun, or a hockey goalkeeper reacting to a shot on goal. Simple reaction times are based on the length of time taken from the initial stimulus to the desired action. This involves the perception of the stimulus by the athlete, the transmission of the nerve impulse to the spinal cord, the processing of the stimulus at spinal cord level or in the brain, the transmission of the desired action impulse to the muscle, and finally, movement.

With this in mind, the measurement of reaction time is useful for a number of reasons. It gives a reference value for the athlete so that, for example, should they suffer a concussive head injury; they may repeat the test as a safe return to play measure. Evidence suggesting that concussion prolongs reaction time leads to tools being developed to measure reaction time for the assessment of concussion in athletes [1, 2, 3]. Secondly, it may have uses in determining the level of risk an athlete is under for suffering certain reaction related injuries, for example ankle sprain, landing injuries or heavy contact injuries which could have been avoided. Also from a performance point of view, players can be measured and re-measured during training periods to examine the benefit of certain training modules. There are also strong links between ability to react quickly to visual cues and sporting success [4], highlighting the benefit that trainers and coaches can gain from the testing reaction times of players. To date, simple upper limb reaction time measures have been used to measure reaction time in various clinical and non-clinical populations. However, tests that are more functional and which measure the lower limb such as that proposed in this study would be more clinically relevant.

To date, there have been very few studies describing the measurement of lower limb reaction times. There are some recent studies which utilise the Optojump Next (Microgate, Bolzano, Italy) system to measure the reaction time of athletes [5]. The Optojump Next system is based on two strips of receiving and transmitting LEDs. The test set up for the MobiFit Reaction time measure is based on the set up for the Optojump Next system. This involves a visual stimulus on a screen which the participants must react to with the desired movement. A lower body reaction test was presented previously [6] which utilized a force plate to quantify onset of movement.

Current systems which are used to measure lower limb reaction times (Optojump, force plate) are cumbersome and expensive. An affordable and easily transportable system for measuring reaction time in a more functional context than existing systems is required. Due to issues with cost and functionality lower limb reaction times are not commonly measured in practise. The system proposed herein easily and cost-effectively measures lower limb reaction times. This study establishes its validity and agreement with a gold standard laboratory optical motion capture system. Furthermore, the study tests the feasibility of capturing data with this novel device in the field and providing on the spot results. This new system could be used easily and cost-effectively to measure lower limb reaction times and explore the usefulness of such a test further.

K. Taylor (phone: 0035317165326; e-mail: ken.taylor@ucd.ie).
O. Lennon (e-mail: olive.lennon@ucd.ie).
C.Blake (e-mail: c.blake@ucd.ie).
D. Fitzgerald (e-mail: diarmaid.fitzgerald@ucd.ie).
D. Fox (e-mail: domhnaill.fox@ucdconnect.ie).
C. J. Bleakley (e-mail: chris.bleakley@ucd.ie).
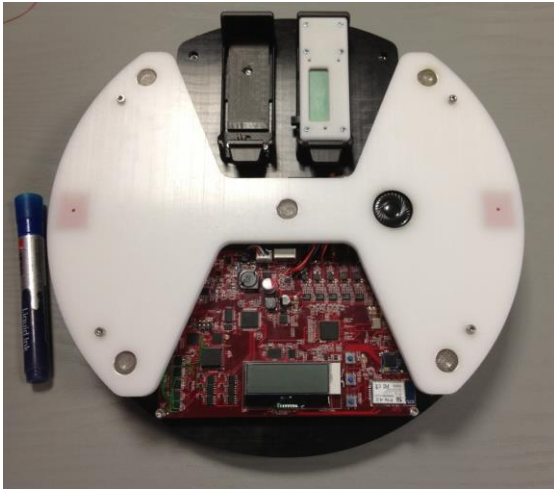All authors with University College Dublin, Belfield, Dublin 4, Ireland

Figure 1. MobiFit basestation and whiteboard marker for scale. 3 of the transmitters (grey circles) are used in this case.

II. SYSTEM DESIGN

A. Motion Capture Technology

Reaction testing was performed using the MobiFit motion capture system to monitor the movement of small wearable sensors relative to a base station which is located on the floor in front of the subject. A script loaded onto the laptop controls the visual stimuli and synchronizes with the motion capture recordings collected by the sensors. The wearable sensors are receivers which pick up ultrasonic signals transmitted from the basestation. Ultrasonic signals allow estimation of range with a high degree of accuracy at relatively low cost [4]. The distance between the transmitter (Fig. 1) (TX) and receiver (Fig. 2) (RX) is determined based on a time-of-flight (TOF) measurement, which is then multiplied by the acoustic propagation velocity. The delay of the peak of the cross-correlation between the TX and RX signals is used as an estimate of the time-of-arrival (TOA) of the signal relative to that of an ultrasonic wired loopback or wireless Radio Frequency synchronization signal. The difference in phase between the two signals then used to refine the range estimation to sub-millimetre accuracy [4]. By means of Frequency Hopped Spread Spectrum modulation, the basestation sends multiple concurrent ultrasonic ranging signals. These are received at the wearable and the range to all transmitters is determined. The 3D position of the wearable is then estimated by means of multi-lateration. The differential of the position with time gives the speed of movement.

B. Reaction Testing

This ability to track the speed of movement of wearable sensors can be used to implement reaction tests when the tracking of their movement is synchronized in time to a visual stimulus. In this case the subject is presented with an initially white screen and is required to raise a foot off the ground when a portion of the screen changes to green. During the test, an ultrasonic sensor attended to a lower limb is used to monitor motion. The time instant at which the sensor reaches a predetermined threshold velocity (Vth) is

Figure 2. CODA (orange) and MobiFit (black/grey) sensors attached to velcro strap for comparison.

automatically detected. The time delay between the visual stimulus and the sensor reaching Vth is recorded as the reaction time. The MobiFit system facilitates use of multiple sensors. In our tests, an additional sensor was placed on the trunk of the subject's body. This sensor was used to track any weight shift prior to raising the required foot, providing an additional means to analyze reaction to the visual stimulus.

III. METHOD

A. Validation Procedure

Since use of the MobiFit motion capture system for the purpose of a lower body reaction test is new, it was necessary to first validate the accuracy of the reaction times which it obtains. This was done by testing a subset of the participants under laboratory conditions and simultaneously acquiring measurements using the CODA motion capture system (Charnwood Dynamics Ltd., Leicestershire, United Kingdom) [7]. CODA is an optical based motion capture system that uses an active marker system to measure 3D movement. The CODA system employs masked linear arrays in multiple CX1 scanner units to capture infrared light signals pulsed sequentially by markers and has an acquisition frequency of up to 800Hz. While the CX1 scanner units show a high degree of resolution (standard deviation in position of a static marker at 3m range 0.05mm X and Z axes, 0.3mm Y axis) [5], their size (800x112x80mm) and set up time limit their use outside of a laboratory setting. Two CX1 scanner units were utilized for the purposes of this experiment. Five subjects were tested using both systems simultaneously giving a total of 40 pairs of data for comparison. MobiFit and CODA sensors were attached side-by-side (Fig. 2) to the anterior knee and navel areas, so that the accuracy of the MobiFit position data could be assessed. The MobiFit system records position data for the 2-5 second window between the initial blank screen and the appearance of the left/right indicator and two seconds after to allow time for the subject to react. Movement above Vth before the indicator appears renders the test invalid and reaction time is not returned. For the purposes of validation, the position data
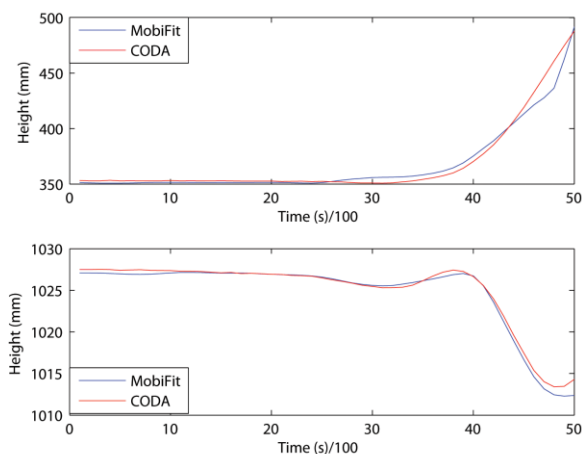
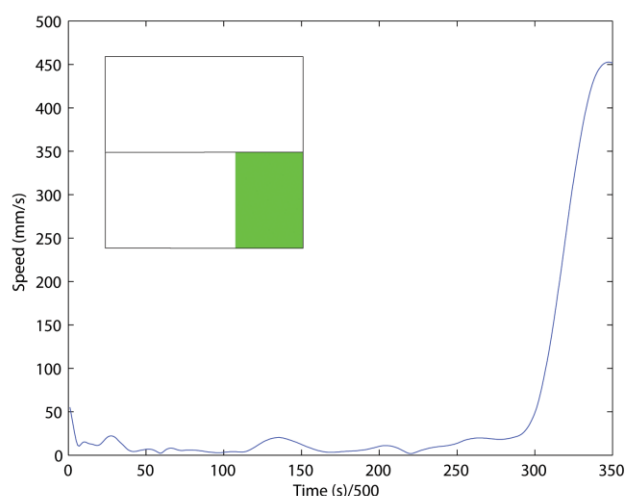Figure 3.   Leg (top) and body (bottom) comparison data.

Figure 4.   Speed of right leg movement during a test. Recording starts when the screen changes from white (top of inset) to the right leg indicator (bottom of inset). The reaction time is given by the first sample above the threshold velocity of 100mm/s.

immediately surrounding the onset of movement following a left/right indication is of most interest. Hence for each reaction test a half second recording of vertical position data centered around the moment each sensor began to move was analyzed (Fig. 3). A typical reaction time was assumed to be in the region of 0.3s, and the MobiFit system obtains data for between 4-7s of movement before discarding irrelevant sections. Data centering about the onset of movement ensures that the content is 50% stationary and 50% moving sensor data, whereas including the entire reaction test would contain a much higher percentage of stationary data, especially for slower reaction times.

B. Field Testing Procedure

Field testing of participants was performed with two Gaelic football teams during strength & conditioning sessions in the team gym. Ethical approval for testing was granted by UCD HREC A (LS-13-31-Lennon, LS-13-38-Fox-Blake). Since a large amount of space is not required to perform the test, a 0.5x1m area is suitable. Generally any location where the subjects can stand in front of a laptop is sufficient. Prior to testing participants were required to read a participant information leaflet and sign a consent form, and the procedure was explained. They were then informed that each test would begin when the screen turned white, and after a random delay of 2-5 seconds either the left or right side of the screen would change to green (Fig. 4), indicating which foot the subject should raise. The process was repeated for a total of 8 reaction times for each subject. The start screen and left/right indicators were shown to the participant and an example reaction movement was demonstrated. No trial runs were permitted. After the testing was completed the trainer was provided with a set of results detailing the overall mean reaction time for each player, and the mean reaction time for both the left and right side seperately. Retesting of the players can then be performed upon completion of their preseason training to assess progress.

IV. RESULTS

A. Validation

Criterion validity against the gold standard laboratory measure CODA was established using Pearson's correlation coefficient. MobiFit lower limb position data when correlated with CODA data indicated a large strength of linear relationship as outlined by Cohen (1988) with $r = 0.979$, $p < 0.001$. A similarly strong relationship was observed with MobiFit and CODA trunk position data with $r = 0.977$, $p < 0.001$. Intraclass correlation coefficients (ICC, 2way mixed model) and Bland Altman plots for multiple measurements per subject established the agreement between variables in each testing method. ICC values for lower limb and trunk measurements demonstrated excellent agreement with ICCs of 0.979 ($p < 0.001$) and 0.977 ($p < 0.001$) respectively. Bland Altman plots for multiple measurements per subject are provided in figures 5 and 6.and demonstrate excellent compliance within the 1.69sd limits of agreement. Figure 3 graphically displays the vertical displacement of MobiFit and CODA sensors over time.
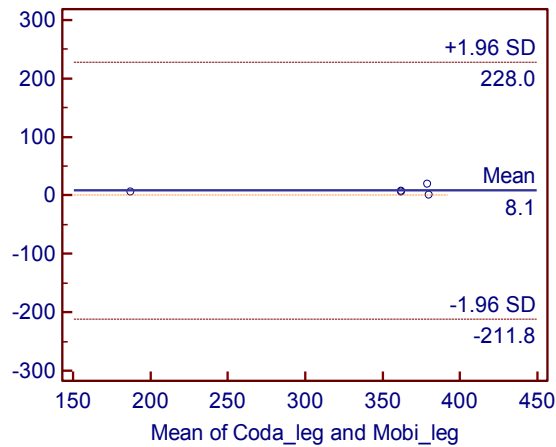
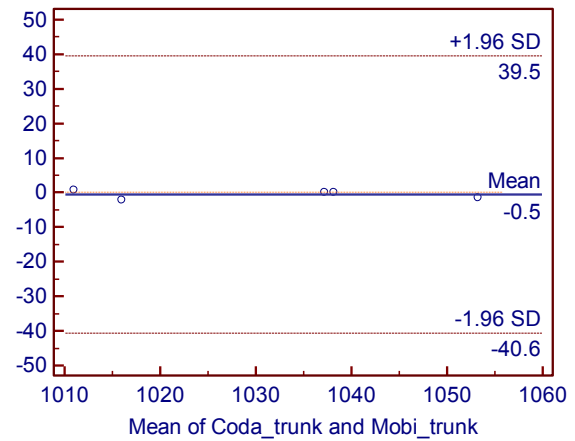Figure 5.   Bland Altman plot for multiple measures per subject for lower limb data

Figure 6.   Bland Altman plots for multiple measures per subject for trunk dat

B. Feasibility

Having validated the accuracy of the MobiFit system for this assessment, the practicality of the test was then examined. Typical gym training sessions last in the region of 60-90 minutes and take place in locations which are often noisy and cramped. The MobiFit motion capture system is robust to noise from loud music and any noise caused by machines or free weights being used nearby, both were present during field testing and although the Rx sensors picked up this noise, processing of the recordings was unaffected due to the signals being of higher frequency content and easily distinguishable from background noise. Participants were all Gaelic football players with no prior experience with the test apparatus (n = 35; age: 23.89 ± 5.07 years; height 1.82 ± 0.05 m; mass: 82.34 ± 9.95 Kg). Total time to gather demographics and perform 8 reaction tests was approximately 5 minutes per person. Under tighter time constraints or with a larger squad, testing could be completed more promptly by collecting demographic information in advance, as 50% of this time was spent filling out the provided form. The trunk sensor was intended to capture weight shift prior to raising the leg, however on occasion participants did not balance themselves prior to raising a leg, leading to the leg sensor being triggered first. In all cases the lower of the two values were recorded for overall reaction time. Mean reaction time across all participants was found to be 0.229 ± 0.061 seconds. Only leg sensor results were considered for the left/right comparison, with the mean difference between left and right side for each participant being 0.089 ± 0.074 seconds. 69% of participants had faster reaction times for their dominant leg.

V.   CONCLUSION

We present here a new method for testing lower body reaction times which allows assessment of a gross motor task and also has the advantage of being portable. Validation against a gold standard motion analysis system shows acceptable test accuracy and field testing in a sporting population shows the utility of the system in the training setting. Future studies should investigate test retest reliability.

REFERENCES

[1]   J. T. Eckner, J. S. Kutcher, J. K. Richardson, "Between-Seasons Test-Retest Reliability of Clinically Measured Reaction Time in National Collegiate Athletic Association Division 1 Athletes," in *Journal of Athletic Training,* 2011: 46(4): 409-414.

[2]   M. P. McClincy, M. R. Lovell, J. Pardini, M. W. Collins, M. K. Spore, "Recovery from sports concussion in high school and collegiate athletes," *Brain Injury,* 2006: 20(1): 33-39

[3]   C. W. Majerske, J. P. Mihalik, D. Ren, M. W. Collins, C. C. Reddy, M. R. Lovell, A. K. Wagner, "Concussion in Sports: Postconcussive Activity Levels, Symptoms, and Neurocognitive Performance," *Journal of Athletic Training,* 2008:43(3): 265-274

[4]   J. J. Adam, R. B. Wilberg, "Individual differences in visual information processing rate and the prediction of performance differences in team sports: A preliminary investigation," *Journal of Sports Sciences* 10, 261-273.

[5]   T. Spiteri, J. L. Cochrane, S. Nimphius, "The evaluation of a new lower-body reaction time test," *The Journal of Strength & Conditioning Research*, 2013 27(1), 174-180.

[6]   M. M. Saad, C. J. Bleakley, S. Dobson, "Robust High-Accuracy Ultrasonic Range Measurement System," *IEEE Transactions on Instrumentation and Measurement.* Vol. 60, No. 10, Oct 2011.

[7]   http://www.codamotion.com