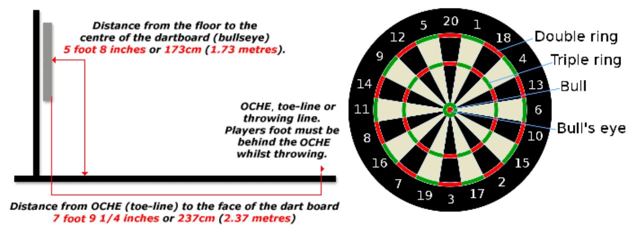
A Multi-Technology approach to identifying the reasons for Lateral Drift in Professional and Recreational Darts

***Abstract*—This work performs an extensive charterisation of precision targeted throwing in professional and recreational darts. The goal is to identify the contributing factors for lateral drift or throwing inaccuracy in the horizontal plane. A multi-technology approach is adopted whereby a custom built body area network of wireless inertial measurement devices monitor tilt, force and timing, an optical 3D motion capture system provides a complete kinematic model of the subject, electromyography sensors monitor muscle activation patterns and a force plate and pressure mat capture tactile pressure and force measurements. The study introduces the concept of constant throwing rhythm and highlights how landing errors in the horizontal plane can be attributable to a number of variations in arm force and speed, centre of gravity and the movements of some of the bodies non throw related extremities.**

***Keywords*—body area network, wireless inertial measurement, professional darts.**



(a) (b)

Fig. 1. (a) Regulation board and player position in darts (b) Darts board scoring system where the large portions of each of the numbered sections scores the points value of that section, the triple ring scores three times and the double ring scores twice the points value of that section. The central circle is divided into a green outer ring worth 25 points and a red inner circle worth 50 points

I. Introduction

There are a number of sports where the participant throws an object from the hand. The dimensions of the projectile in conjunction with the size of the target area constrain the movement pattern of the throw [1]. This inertial blueprint varies dramatically for different sports and has been studied extensively for some time [2]–[4]. More recent technological advances particularly in the wearable inertial sensing space have enabled researchers to revisit these early studies and to perform a more fine grained analysis [5]. In addition new findings have enabled the sports scientist to more fully understand the requirements for precision throwing particularly in professional sports [6], [7].

Darts is a sport where accuracy and repeatability are key elements to performance. The goal of throwing darts is to allow the projectile or dart to end at a certain position on the target. The target or dartboard is located so that it's center or bullseye is 173 cm above floor height as illustrated in Figure 1(a). The oche or the line behind which the throwing player must stand is positioned 237 cm from the face of the dartboard measured horizontally. A regulation dart board shown in Figure 1(b) is 451 mm in diameter and is divided into 20 radial sections scoring from 1 to 20 points. The sections are separated with metal wires and additional circular wires subdivide each section into single, double and triple areas. Players are free to select their posture during throw and generally orient their trunk parallel and their leading foot horizontal to the throwing direction as illustrated in Figure 2. This paper investigates how professional and recreational darts players perform targeted throwing using a combination of custom built and off the shelf technologies. More specifically the study highlights how horizontal errors, where the darts final position ends left or right of its intended location, are introduced to the final outcome or score.

A. Capturing the overarm throw in darts

The study of biomechanical movements during throwing darts is a challenging topic as the position a dart will hit the target (the outcome), is dependant on a combination of numerous factors including position, direction and speed of motion at the moment of release. This is made all the more complex as there are an infinite number of combinations of

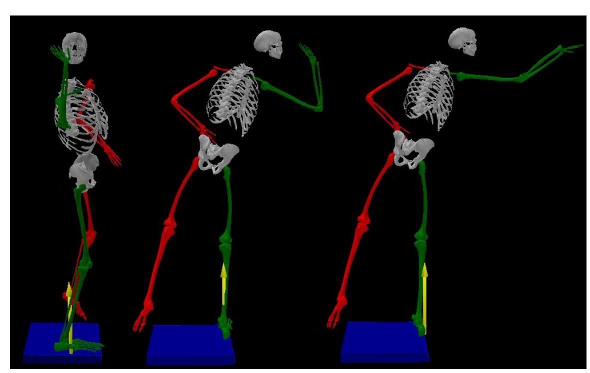


Fig. 2. Kinematic model of player stance during throw. This player is right handed and therefore places his right or leading foot approximately perpendicular to the throwing direction. The following foot is extended backward to stabilize balance

these parameters that will result in the same outcome. In addition these movements span less then 200ms, too brief a duration to adjust movement strategy based on proprioceptive or feedback information. Technique for this sport is therefore optimised using feedforward control in the form of efferent information or pre-planned movement.

There have been a number of attempts to use technology as a means of identifying the factors limiting throw accuracy in darts. In [8] a flexible metal cloth was fitted around the tips of the fingers and connected via a resistance to a battery to measure the time of release. This was coupled with an Optotrak movement registration system to capture the kinematics of the arm and shoulder during throw. A Vicon optical system was employed in [7] to monitor movements and the time of release was determined by replacing the dart with a reflective marker so that the flight trajectory could be captured. The later work concluded that the time of release was the primary factor ($> 95\%$) influencing inaccuracy. This finding contradicts the former study which indicates that hand speed variation was the limiting factor.

This highlights that the problem is inherently difficult to solve, owing mainly to the number of variables present in the system. However it is worth noting a number of the limitations in the methodologies employed to date namely:

- Studies to date monitor the throwing limb only and as a result are unable to determine if the overall body movement of the subject contributes to errors.
- In general error in the vertical plane alone is considered ignoring inaccuracy in the horizontal plane. It is assumed that hand speed, position and direction alone contribute to horizontal error, a key performance limiting factor in professional darts (where it is referred to as lateral drift).
- While millimeter error precision is often reported calculations of error do not consider air resistance or rotations while the projectile is in flight [7], [8]. These factors influence outcome particularly in studies where the dart is replaced with a reflective marker, which will exhibit very different aerodynamical properties to that of a dart [7]. In addition complex mathematical extrapolation is required to calculate the actual time the dart is released. Assumptions made during extrapolation can introduce additional errors.
- The subjects who were studied were required to aim specifically for the center of the target. This makes data analysis a little more straightforward, however in competitive darts approximately 80% of the throws are aimed at the triple 20 section of the target. Limiting the analysis to one section of the board can therefore have a smoothing effect on the results when comparing the skill levels of competitive and recreational players.

B. A Darts Centric Study

This study is less general in the sense that it examines a single hypotheses specific to performance in the sport of darts. We hypothesize that lateral drift or throwing inaccuracy in the horizontal plane is not alone as a result of the position, speed and trajectory of the hand at the moment of release but is also contributed to by other movement variations. In this regard the following questions are posed:

1) Do variations of the following factors during throw contribute to horizontal error or lateral drift?
   a) The speed at which the throwing arm moves.
   b) The players centre of gravity (CoG)
   c) Force exerted at the wrist by the lower limb extremities particularly the stabilising following leg (see figure 2).
2) Does muscle fatigue play a role in the introduction of lateral drift?

The goal of this work is to investigate each of these questions in turn placing the focus on the overall scoring performance and consistency of the subjects while analysing occurrences of lateral drift. In addition observations made during experimentation formed a basis for an answer to the following question which is often posed in professional darts: While individual throws are considered as discrete complex movements is the establishment of a constant throwing rhythm a real quantifiable possibility?

II. Experimental Methodology

The experimental methodology employed in this study uses a number of technologies to monitor the biomechanical movement behaviour of a darts player and relates this behaviour to outcome error. This multi-technology approach enables validation where redundancy exists within the set-up. This in turn ensures the study is not reliant on complex mathematical models from which to draw conclusions. In addition the study allows the benchmarking of wearable body area networking (BAN) technologies with state of the art 'gold standard' optical solutions [9].

A. Hardware Description

As mentioned previously a number of technologies are used in tandem in this study as illustrated in Figure 3. These include a custom built BAN of wireless inertial measurements units

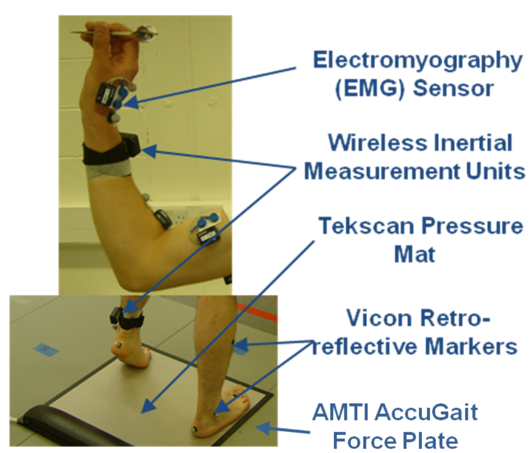
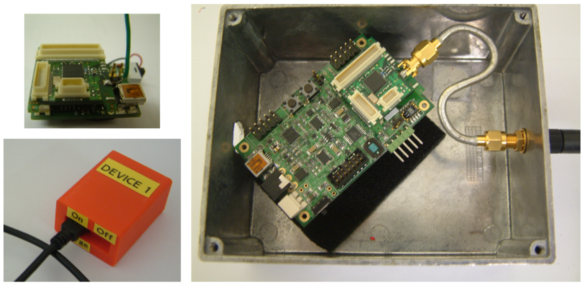


Fig. 3. Experimental setup



(a) (b)

Fig. 4. (a) Modular Wireless Inertial Measurement Unit (WIMU): Upper unpackaged, Lower packaged and charging, (b) Base station unit with data processing and communications module

(WIMUs) to capture tilt, force and timings, an optical 3D motion capture system to provide a complete kinematic model of the subject, electromyography (EMG) sensors to monitor muscle activation patterns and a force plate and pressure mat to capture tactile pressure and force measurements.

1) Wireless Inertial Measurement Units: In the first instance a BAN of WIMUs were designed and manufactured. The WIMU is comprised of two separate modular components. The data processing and communications module consists of the Atmega1281 microcontroller (Atmel Corp.) and the EM2420 (Ember Corp.) 802.15.4 compliant transceiver. The inertial module has onboard circuitry for battery recharging and signal conditioning. It includes the ADXL330 (Analog Devices, Inc) low power, complete 3-axis accelerometer. This component was selected as it can capture dynamic movement as well as static acceleration of gravity in tilt-sensing applications. The WIMU is programmed using the TinyOS embedded operating system. Sampling frequency for this study was set to 200Hz. Care was given when selecting communications channel so as to avoid interference from the Wifi enabled EMG sensors. The WIMU forwards time stamped data to the base station unit shown in Figure 4 which in turn sends data via USB to a laptop PC for analysis.

2) Vicon 3D Motion Capture System: An eight, high speed, infrared camera 3D motion analysis system (VICON Ltd, UK) was used to capture movement of the dart player at 100 Hz. A set of retro-reflective markers was attached to the subject over predetermined bony landmarks of the trunk, upper and lower extremities. The joint kinematics during a series of throws were calculated using Vicon Plug-in-Gait model coupled with a set of the subject's measurements. The kinematic model generated by the system is illustrated in Figure 2.

3) Zerowire EMG System: The electrical activity produced by skeletal muscles of the trunk and upper limb during throw was evaluated at 4kHz using Zerowire EMG electrodes (Aurion, Italy). The electrodes comprise of a small compact unit for EMG detection, 16 bit analog to digital conversion, signal processing and transmission of data to an access point via Wifi wireless communication. The access point is directly connected with a PC thus allowing real-time representation of all the active channels. A devoted algorithm assures the offset on all channels employed.

4) AMTI AccuGait Force Plate: The AMTI AccuGait forceplate (AMTI, US) was used to measure the ground reaction force along the X, Y, Z axis as depicted in Figure 3.

5) Tekscan Pressure Mapping Sensor: Finally the changes in the plantar pressure distribution were investigated using a Tekscan high resolution pressure mapping sensor (Tekscan, US).

B. Experimental Scenario

Data from two right handed players were used in the analysis for this work. One professional player ranked within the top 75 in the Professional Darts Corporation (PDC) world rankings was fully instrumented with each of the technologies outlined above. An additional recreational player was instrumented with WIMU technology for comparison where required. Both players provided written and informed consent prior to data collection. For the professional player the following biometric parameters were recorded for each throw:

- Maximum, minimum and average hand speed was captured using the motion capture system.
- Maximum, minimum, average and variation in force exerted was recorded at the left (following) ankle and right wrist using the WIMU BAN.
- In addition the precise timing between throws was monitored employing the WIMU system.
- Muscle activation patterns were recorded using 8 EMG sensors attached to the player's torso and right upper limb according to SENIAM recommendations [10]. The electrical potentials generated by Upper and Lower Trapezius, Anterior and Posterior Deltoid, Biceps Brachii, Triceps Brahii, Brachioradialis and Flexor Pollicis Brevis muscle groups were included in the trial.
- The ground reaction force, balance and pressure distribution were captured using the force plate and pressure mat.

For the recreational player fewer parameters were recorded as a result of being instrumented with fewer sensors namely:

- Maximum, minimum, average and variation in force exerted is recorded at the left (following) ankle and right wrist using the WIMU BAN.
- In addition the precise timing between throws is monitored employing the WIMU system.

1) Scoring Performance and representing Lateral Drift: During a competitive game the player throws three darts per visit to the board with the goal of reducing a fixed score, commonly 501, to zero and with the final dart landing in either the bullseye or a double segment. In the context of a game there are therefore two aspects of a players performance that will influence the outcome. Firstly the player must be capable of scoring highly early in the game so that they are first to attempt a final throw at a double segment. Secondly the player must be proficient at what is known as 'finishing' or accurately hitting the final double segment.

To examine proficiency in both of these skills each player firstly performed 150 throws attempting in the process to score as highly as possible. Score and the projectile's final position on the target were recorded manually. The players were allowed to select their target in real-time and throughout this part of the trial the primary target ($> 96\%$ attempts) was the triple 20 section of the inner ring (see figure 1). This was followed by 75 attempts by both players to target the outer or double ring. Again score and the projectile's final position on the target were recorded manually.

Lateral drift is represented by means of a binary system where 0 indicates that error in the horizontal plane is not present and 1 highlights when lateral drift has occurred. This negates the requirement for complex and error prone mathematical approximations of the error as mentioned in section I-A. This binary vector is statistically compared with a number of recorded parameters to determine their role in introducing horizontal error. A correlation coefficient was arrived at for each variable according to the following

$$\rho_{LDV,X} = \frac{E[(LDV - \mu_{LDV})(X - \mu_X)]}{sigma_{LDV}\sigma_X} \quad (1)$$

where ρ is the correlation coefficient, LDV is the Lateral Drift Vector, X is the contributing variable vector, E is the mean operator, μ is the mean and σ is the standard deviation.

III. Results and Discussion

Following completion of the trial the following results were recorded and observations made. The scores and degree of lateral drift was recorded and a binary array was constructed for each player. The vector illustrated in Figure 5 highlights immediately that the recreational player averaged a lower score and was far more prone to error and subsequently horizontal inaccuracy as would be expected.

A. *The role of Force, Speed and Centre of Gravity on Lateral Drift*

The forces measured at the throwing wrist for the professional subject over the course of 15 throws are illustrated in Figure 6. Table I compares the statistical information for the entire trial for both the professional and recreational players. Information is divided into two sections examining each subjects attempts at the triple and double segments of the target. The maximum, minimum, average, standard deviation from the mean value and correlation with the Lateral Drift Vector are included. While the influence force exerted at the wrist on lateral drift is small there is sufficient information, based on standard deviations and correlation coefficients, to surmise that larger variations in force can result in an increased likelyhood of horizontal error.

Table II contains similar information for an additional WIMU placed on each of the player's following leg (see Figure 2). The information gathered in this part of the study when correlated with pressure mat readings (for the professional player) found that both players were prone to removing their following leg during throw thusly contributing in a small way to the introduction of error.

Table III displays throwing hand speed information for the professional player gathered using the 3D optical motion

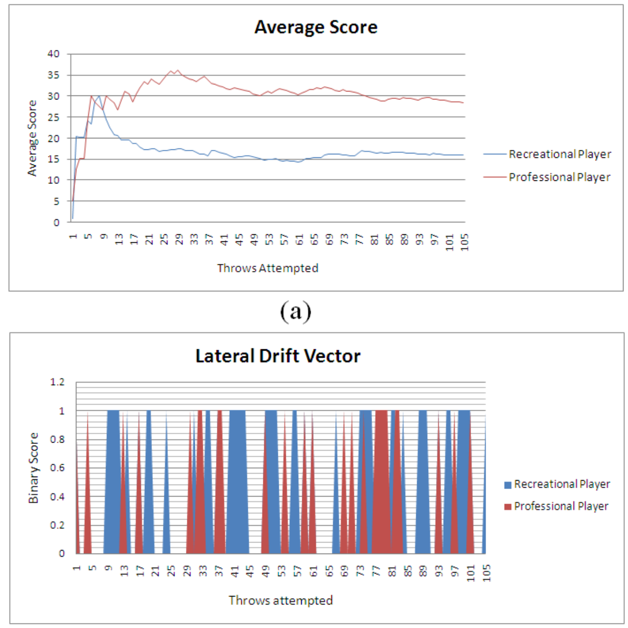


Fig. 5. (a) Average score achieved by the recreational and professional players, (b) Lateral drift vector

TABLE I
Comparison between Professional and Recreational player force (g) exerted at the wrist recorded using a BAN of WIMUs

Stat.	Pro. Triple	Pro. Double	Rec. Triple	Rec. Double
Max.Force	-2.8516	-2.8906	-2.7034	-2.7416
Min. Force	-2.4001	-2.4351	-2.0109	-1.9431
Avg. Force	-2.6613	-2.6450	-2.426	-2.383
Std. Dev.	0.1402	0.1551	0.8714	0.6301
Corr. Coef.	0.0812	0.1046	0.1248	0.1403

capture system. The maximum and minimum speeds coincide with previous published results [7]. A strong correlation was found between maximum hand speed and error which is in agreement with conclusions drawn in [8]. However here the results are applied to the lateral drift problem. Figure 7 illustrates the relationship between lateral drift and variations in ground reaction force in the Y plane (perpendicular to the throwing direction). This data was recorded by the force plate and validated using the pressure mat. As is evident

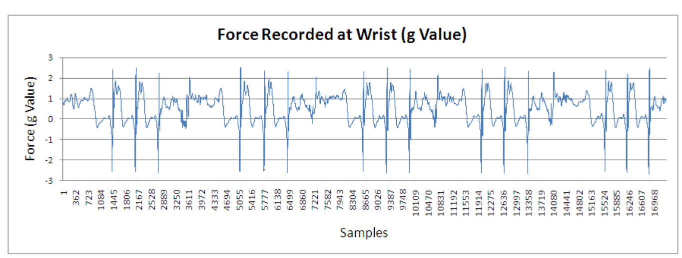


Fig. 6. Force recorded by WIMU on the wrist of the professional player for 15 successive throws.

TABLE II
COMPARISON BETWEEN PROFESSIONAL AND RECREATIONAL PLAYER FORCE (G) EXERTED AT THE FOLLOWING LEG RECORDED USING A BAN OF WIMUS

Stat.	Pro. Treble	Pro. Double	Rec. Treble	Rec. Double
Max.Force	-0.5491	-0.5018	-0.8444	-0.7412
Min. Force	-0.1174	-0.2255	-0.333	-0.2182
Avg. Force	-0.3305	-0.3808	-0.5494	-0.5573
Std. Dev.	0.0803	0.0666	0.1002	0.1174
Corr. Coef	0.1078	0.0989	0.1224	0.1164

TABLE III
PROFESSIONAL PLAYER MAXIMUM SPEED (M/SEC) DURING THROW RECORDED USING THE OPTICAL 3D MOTION CAPTURE SYSTEM

Stat.	Pro. Treble	Pro. Double
Max.Speed	4.743	4.665
Min. Speed	4.2287	4.0173
Avg. Speed	4.5216	4.3881
Std. Dev.	0.1537	0.231
Corr. Coef.	0.6826	0.5902

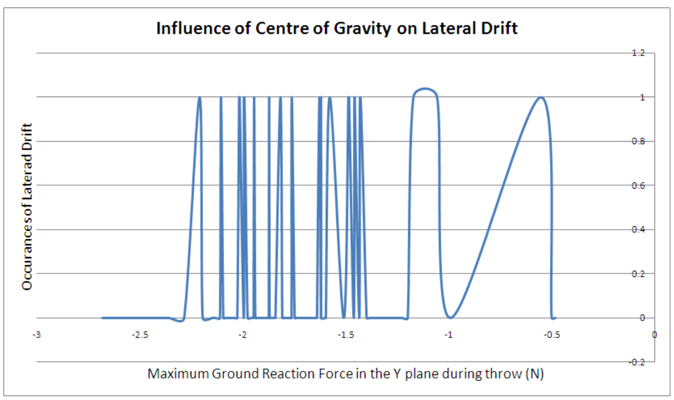


Fig. 7. Increasing lateral drift .

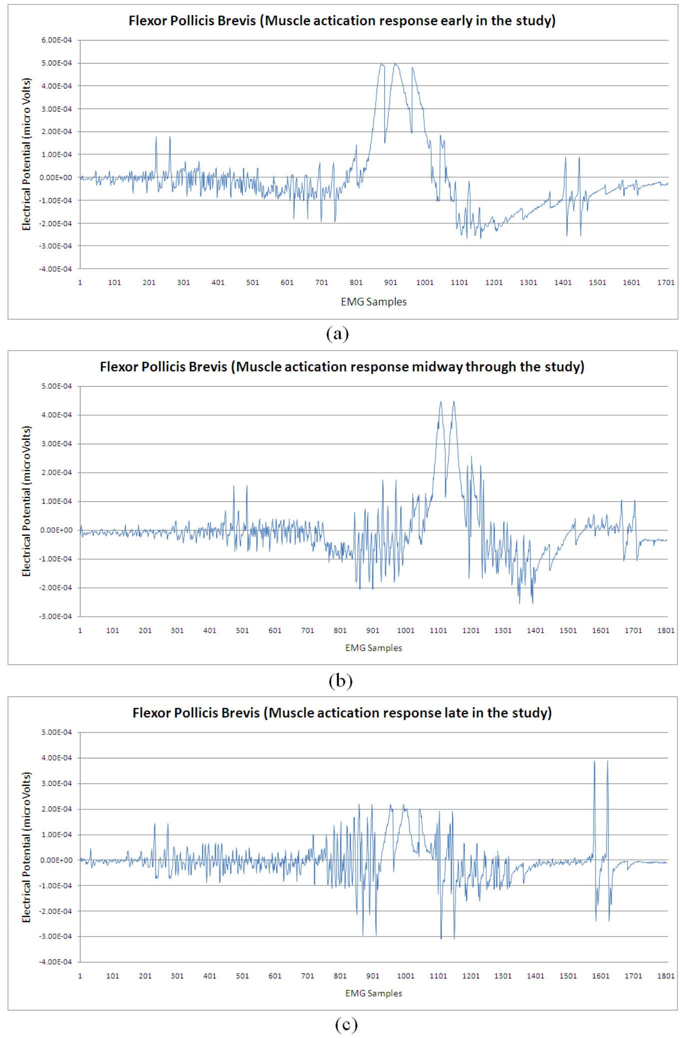


Fig. 8. Muscle activation pattern for the Flexor Pollicis Brevis Muscle (a) Early in the Study, (b) Midways through the study, (c) At the end of the study

by the distribution of occurrences of lateral drift the greater the variation in the players centre of gravity during throw the more frequently horizontal errors occur. This contradicts previous findings which state that hand speed, orientation and direction alone influence lateral drift [8]. While the correlation is relatively small ($\rho = 0.1864$) it is sufficient to suggest that the throwing limb is sometimes incapable of compensating for low frequency centre of gravity variations.

B. Effects of Fatigue on Performance

Fatigue as would be expected plays a role in performance. EMG sensors are employed in this study to illustrate how fatigue contributes to inaccuracy. The Upper and Lower Trapezius, Anterior and Posterior Deltoid, Biceps Brachii, Triceps Brahii, Brachioradialis and Flexor Pollicis Brevis muscles were instrumented and EMG was recorded throughout the study. Figure 8(a) illustrates the EMG signal from early in the study for the Flexor Pollicis Brevis muscle which controls release action during throw. Figures 8(b) and (c) illustrate the muscle activation patterns for the same muscle midway and at the end of the recorded session. There is a clear reduction in overall exertion throughout the study by the Flexor Pollicis Brevis muscle. This trend is shown in Figure 9 along with data recorded by the additional 7 EMG sensors. The Upper and Lower Trapezius, Anterior and Posterior Deltoid, Biceps Brachii, Triceps Brahii and Brachioradialis exhibit little fatigue during the study. The Biceps Brachii is in fact observed to increase in workload intensity to compensate for the fatigue experienced by the Flexor Pollicis Brevis. The correlation between this drop off in muscle activation pattern and lateral drift was found to be too small to indicate that fatigue contributed to horizontal error specifically. However upon closer examination there was found to be a strong correlation ($\rho = 0.6892$) between average score and the inherent fatigue of the Flexor Pollicis Brevis. This is thought to be as a result of the growing influence the Biceps Brachii has on outcome as the more precise timing of the Flexor Pollicis Brevis tires.

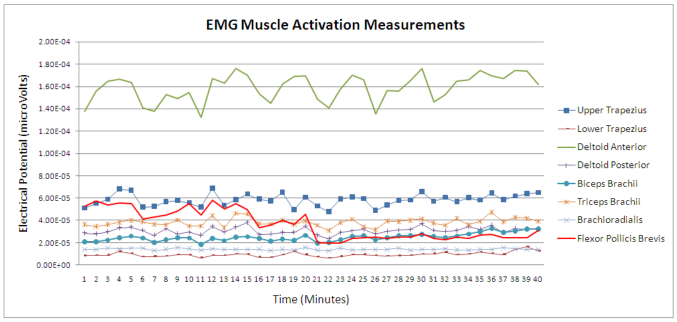


Fig. 9. EMG recordings over the duration of the study

C. Constant Throwing Rhythm

As mentioned previously individual overarm throws are considered as discrete complex movements. However given the complexity of the movements involved it is surely beneficial to the player to establish what could be called a 'constant throwing rhythm'. For instance in this study it has already been established that less variation in maximum force at the wrist during throw will result in fewer errors (see table I). In fact when fatigue is evident in a muscle group central to the throwing action and in order to attempt to keep the force applied constant other muscles will attempt to compensate (see Figure 9).The same is true of variations in maximum hand speed and indeed release time [7], [8]. A technically proficient player will therefore likely choose to limit the number of varying parameters so as to reduce the probably that error will increase in the form of inaccuracy. To support this argument Figure 10 illustrates the time taken between throws for both subjects in this study. In the case of the recreational player the time fluctuates throughout the trial indicating no real technique is applied. The professional player on the other hand maintains almost a constant time between throws highlighting that a constant throwing rhythm is inherent to the technically proficient darts player.

IV. Conclusion

In this study an extensive charterisation of precision targeted throwing in professional and recreational darts was carried out. The goal was to identify the contributing factors for lateral drift or landing error in the horizontal plane. A multi-technology approach was adopted whereby a custom built body area network of wireless inertial measurement devices monitor tilt, force and timing, an optical 3D motion capture system provides a complete kinematic model of the subject, electromyography sensors monitor muscle activation patterns and a force plate and pressure mat capture tactile pressure and force measurements. The experimental scenario demonstrated how landing errors in the horizontal plane are contributed to by a number of variations in arm force and speed, centre of gravity and the movements of some of the bodies non throw related extremities. The work highlighted how fatigue can be monitored and can lead to an overall decrease in scoring performance. In addition the concept of constant throwing rhythm in darts was introduced where a technically proficient player will seek to limit the number of varying parameters so as to reduce the probably of errors.

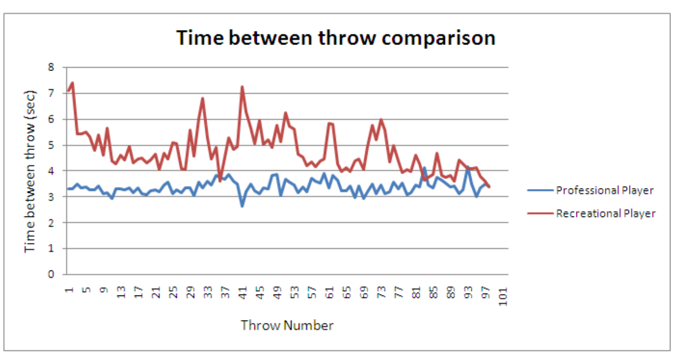


Fig. 10. Timing between throws comparison for professional and recreational darts players.

Acknowledgment

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