ASTN-Q Conference 2016
Research & Innovation in Sports Technology
The Australian Sports Technologies Network (ASTN) was formed in 2012 with representatives across the nation. The Queensland Sports Technology Cluster, a collective of sports technology researchers was an integral part of this network and hosts the Queensland node of the ASTN. Since this time the organisation has grown nationally to over four hundred institutional members from industry, business and universities alike. With sponsorship from the Australian Sports Commission today all National Sporting Organisations (NSO) and many State Sporting Organisations (SSO) are members as well.

The state of Queensland has a strong international reputation for sport technology innovation through the success of its elite athletes and activities of Queensland research institutions and small and medium enterprises.

The ASTN together with the support of its hosts SABEL Labs, Griffith University School of Engineering research programme on human technologies and the Queensland Academy of Sport Centre of Excellence for Applied Sport Science Research hopes you enjoy today’s activities and looks forward to the continued support in enhancing sport technology strength in Queensland. This special issue of the Journal of Fitness Research, (in itself a melting pot at the intersection of research and the fitness industry), is a snapshot of recent research and innovation activity from our Queensland based members and collaborators presented at the most recent Queensland meeting August 9th 2016.
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3. Computer applications in sports

IMPORTANT DATES:
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July 2017           Notification of abstract acceptances
1 September 2017    Earlybird registration opens
1 December 2017     Full paper submissions deadline
                    Earlybird registrations close
                    Standard registrations commence

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www.isea2018.com.au
Can wearable technology predict pain like pain predicts the weather?

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ABSTRACT
Measuring risk factors of injury with technology may be possible with inertial sensors. The aim was to highlight inertial sensor capabilities, to propose future research interventions. Student’s T tests were completed for statistical comparisons of gyroscope angular rate of change, between deadlifts completed with a neutral spine posture and a flexed spine posture. It was concluded that inertial sensors can monitor anterior-posterior spine technique differences in resistance exercise. Therefore future research is needed to assess the capability of inertial sensor technology to measure parameters of human movement that reflect the risk of sustaining injuries.


INTRODUCTION
Human movement is often overlooked as the major contributor to sustaining injuries. However, workplace injury rates demonstrate one out of three injuries (34%) occur from preventable lifting, pushing, pulling or bending human movement.1 These injuries cause high workers compensation costs and contribute 45% of the total yearly economic cost in Australia (au$61.8 billion).2 Preventing injuries is essential in sporting contexts, specifically in novice athletes who lift differently to experts and have higher risks of sustaining injuries due to less muscle and neural pathway development.3 Aside from expertise, other known risk factors of sustaining injuries include the speed of movement, muscle activity, the angle of joints and position of the body.4 Measuring risk factors of injury with technology is a new field of research and inertial sensors are a disruptive technology that may provide a practical means for this purpose. Therefore the aim of this research was to highlight inertial sensor capabilities for the possibility of measuring injury risk factors, in hope that future research and interventions are implemented. This was achieved by monitoring the anterior-posterior movement of the spine during the concentric phase of a conventional deadlift with inertial sensors.

METHODS
Ethical clearance was granted by the Charles Darwin University Ethics Committee (H14046). Participants performed two sets of conventional deadlifts for five repetitions with no weight (broomstick). One set was performed with a neutral spine and one set was performed with exaggerated spinal flexion. Inertial sensors including tri-axial accelerometers and gyroscopes (SABEL Sense) were attached to participant’s skin at the locations Cervical vertebrae seven (C7), Thoracic vertebra 12 (T12) and Sacral vertebrae one (S1).5 The concentric phase of each lift was determined by manually picking the start point or first upward movement and the end point or lockout. Data was normalised for time by interpolating data to 100 samples (N = 100), and a five Hertz low pass filter...
was applied. Pearson’s correlations and Student’s T tests were completed for statistical comparisons of group means for Y axis angular rate of change. Gyroscope Y axis data was the chosen channel of analysis, due to the movement around this axis occurring in the sagittal plane. The group means of gyroscope rate of change outputs from the conventional deadlift, performed with no weight and safe technique, was compared against deadlift trials with exaggerated flexion of the spine. Group means were plotted for visual comparisons and cross referencing video playback observations.

RESULTS

The null hypothesis that no significant difference between safely executed conventional deadlifts and conventional deadlifts with spinal flexion was tested. The statistical analysis yielded three separate Student’s T tests, one for each relationship between sensor locations. One significant difference (P=0.004) and two strong significant differences (P<0.001) were found between S1, T12 and C7 rate of change between safely executed deadlifts and deadlifts with spinal flexion (Table 1). Therefore the null hypothesis was rejected for all flexion correlations. It was concluded that there are significant measurable differences between safely executed deadlift technique and deadlift technique with spine flexion.

Models of deadlift technique represent the time normalised mean lifting patterns or Y axis angular rate of change for the concentric phase of lifting trials (Figure 1).

Table 1 Student’s T tests

<table>
<thead>
<tr>
<th>Variables</th>
<th>Correlation</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C7 vs. Flexion C7</td>
<td>0.889</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>T12 vs. Flexion T12</td>
<td>0.786</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>S1 vs. Flexion S1</td>
<td>0.893</td>
<td>P=0.004</td>
</tr>
</tbody>
</table>

DISCUSSION

Identifying mistakes in technique is essential for early identification of injury risks and for providing relevant feedback to improve technique for safety, efficiency or performance. To demonstrate the viability of measuring common technique mistakes with inertial sensors, spinal flexion was compared to safely executed deadlifts. There were significant differences between conventional deadlifts and deadlifts with spine flexion for upper (C7), middle (T12) and lower (S1) back (Table 1). Models of technique demonstrated that flexion trials were more normally distributed with higher rate of change peaks than neutral spine deadlifts, and achieved these peaks at earlier time points (Figure 1). This may be due to less knee extension, as spine flexion was the primary mover during flexed trials, possibly resulting in a more continuous spinal rate of change. Therefore, the null hypotheses for no significant difference between correlations was rejected. These results suggest that obvious differences between flexion and neutral spine posture can be measured using inertial sensors. Inertial sensors are capable of accurately monitoring postural changes during resistance exercise. The flexion of the spine during lifting increases the risk of sustaining lower back pain by placing higher compression loads on the spine. These results demonstrate that inertial sensors may be capable of distinguishing between technique differences during resistance exercise, to provide quantitative measures for coaches and health professionals. Accelerometers measure acceleration along an axis and gyroscopes measure angular rate of change about an axis. Therefore aside from flexion and extension, other risk factors of injury that inertial sensors may be able to monitor include joint angles, the speed of body segments, power and force production. Monitoring human
movement risk factors of injury with technology is a relatively new field of research, with many possibilities for research interventions to be designed to validate technology and reduce the high prevalence of injuries.

**CONCLUSION**

Measuring risk factors of injury with technology may have benefits in numerous fields of research such as novice and professional sport, recreational exercise, daily living, occupational environments and health and rehabilitation. Inertial sensors can be housed with numerous devices, linked with phone applications or computer programs to provide feedback systems, creating a variety of development pathways for biomechanical research and possibilities for commercial products with simple interface structures that anyone can use. Inertial sensors may provide a practical means of monitoring parameters of human movement that reflect the risk of sustaining injuries. Research interventions are required to test the capability of inertial sensor technology for this purpose.

**PRACTICAL APPLICATIONS**

- Inertial sensors can be used to monitor a variety of human movement parameters.
- Inertial sensors may be capable of monitoring risk factors of injury.
- Research is needed to assess the capabilities of inertial sensors for this purpose.

**REFERENCES**

Developing an AHRS tool for a wearable sensor to obtain attitude and heading information

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ABSTRACT

Wearable sensors are now widely used in sport and sports science to assess human movement. With sensor fusion, attitude and heading information of the inertial and inertial-magnetic sensor can be obtained. This technique enables measurement of the transition of angles, e.g. lean angle and heading direction of an athlete. This paper describes the development of an attitude heading reference system (AHRS) tool for an inertial-magnetic sensor platform. The tool includes functions to calculate and animate 3 dimensional attitude of the sensor and to acquire angular displacements around sensor local axes.

Keywords: sport monitoring, inertial-magnetic sensor, AHRS

INTRODUCTION

Technology plays now an important role in sport. To assess human movement during sporting activities wearable sensor devices are used frequently. The MEMS inertial-magnetic sensor typically includes tri-axial accelerometers, gyroscopes and magnetometer. A number of sport related researches and practices have been performed using inertial sensors, e.g. gait, running³, jumping⁶, throwing⁹, bat⁷ and oar⁸ measurements. Accelerations and angular velocity can be significant information in the analysis of the movements. However the sensor data is difficult for people to read and interpret because it typically consists of multiple channels of time series data.

Sensor fusion is a technique to combine data from several different types of sensors. Attitude and Heading Reference System (AHRS) is one of the sensor fusion techniques to provide attitude information from an inertial-magnetic sensor²⁵. By adopting AHRS, the attitude of the wearable sensor is obtained quantitatively and is able to be presented visually. In this paper, we integrate AHRS algorithm into our existing inertial sensor platform¹⁴ in order to provide a straightforward and intuitive way to observe and visualise the movements in sport.

METHODS

Several AHRS protocols have been proposed in the literature. Madgwick et al. (2011) proposed a novel orientation algorithm which is computationally efficient and as accurate as other Kalman based algorithms. Their algorithm is relatively simple and light compared to other proposed algorithms and considered that it
provides an adequate accuracy for sporting measurements. The algorithm is available as open source (http://x-io.co.uk/), thus we adopt this for our AHRS tool. The algorithm uses a quaternion representation for calculation. The quaternion representation simplifies computation and avoids the problem of Gimbal lock. However, the output by the quaternions is a stream of values which makes it difficult to comprehend the attitude. Therefore, we have developed an animation display tool for the sensor. All the calculations for the animation required the data to be in a quaternion representation to avoid Gimbal lock.

The data generated by the AHRS algorithm is the attitude of the sensor relative to the earth’s frame of reference. This means that the data always shows the angle relative to the horizontal plane (pitch and roll) and magnetic north (heading). This is useful for applications to measure movement achieved along the earth frame, such as the trunk lean angle for runners, since the runners are always standing on the earth. Pitch and roll angles show anterior and lateral flexion of trunk and the heading shows the orientation of the body. However, if the sensor moves in complex way, it can become hard to recognize the sensor’s movement. In these cases, observation of the sensor’s angle from one of a sensor local axis could be useful. Thus a function was developed to obtain the angular transition of the sensor relative to the sensor’s local frame.

Our inertial sensor platform is developed in the MATLAB computing environment (MathWorks, http://www.mathworks.com/), thus AHRS tools are also provided as MATLAB functions. The existing GUI was modified to call the AHRS functions.

RESULTS

The inertial sensor platform has a real time data display tool for accelerometer, gyroscope, and magnetometer. AHRS calculation and animation display function has added to the tool. Figure 1 shows a screen captured image of the time series attitude data as well as the animated display showing the attitude of the sensor shown as a blue box. Attitudes are displayed in degrees in 3 dimensional Euler expressions. The adopted algorithm was light enough allowing it to be used for real time processing.

Figure 1 Real time AHRS display with animation

Figure 2 shows a transition of sensor angles obtained from AHRS tool for a soccer player and its measurement settings. The sensor was attached to the sacrum of the player and zig-zag running was carried out. The turn angle of the zig-zag trial was set to 120 degrees. This heading change (red line) of 120 degrees can clearly be seen as the player turned. The blue and green lines show the lean angles of the trunk which reflects the subject’s movement during the trial, e.g. upper body rises up during deaccelerating phase (blue line), and body roll (green line) which is in synchronisation with the turns.

DISCUSSION AND CONCLUSIONS

The AHRS tool using sensor fusion techniques has been added to our inertial sensor platform. The attitude of the inertial-magnetic sensors can be obtained as angles allowing quantitative analysis of the movement. In many applications, attitudes of the athlete or apparatus could be useful in the understanding of the state of the movement. The advantage of our tool is that the animation presentation and/or observation from the sensor’s local frame will make easier to understand attitude compared to 3 dimensionally separated Euler
angles. It is envisaged that these functions may expand the utilization of wearable inertial sensors in sport measurements.

REFERENCES


Non-traumatic shoulder instability measurements from accelerometer and audio records

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ABSTRACT

Accelerometer sensors used to determine limb movement have significant high frequency noise levels which are often ignored and removed by low pass filtering. This preliminary investigation reports the relationship between audible shoulder events and accelerometer measurements at the shoulder and the wrist during repeated flexion and extension of the arm with a 3 kg weight. Repeated cycles show audio events (clicks) which strongly correlate with high frequency acceleration events at the same arm inclination angle and leads to an explanation of some of the high frequency acceleration events during rhythmic movements such as ballet.

Keywords: accelerometers, audio signal, arm lifting, shoulder instability, high frequency, NTSI.

INTRODUCTION

Small accelerometer sensors have a very low base-line noise level. When fixed to the body, the noise level increases slightly due to human movement even when the human is attempting to remain stationary. In rhythmic movements, higher frequency vibrations are observed as the same part of the rhythmic cycle.

Flexion of the arm above the horizontal plane is a relatively infrequent activity but is often part of an exercise regime which can be measured using a wrist mounted accelerometer. Such movements are often accompanied by audible “clicking” as the complex shoulder joint does not smoothly transition and are described as non-traumatic shoulder instabilities (NTSI) and have been studied using electromyography. While the combination of audio and acceleration sensing has been reported for work activities, there is no previous known research which reports a relationship between the internally generated audio sounds and the effect on the acceleration recordings. This paper reports initial findings based on a single participant who had a left shoulder reconstruction and a “normal” right shoulder.

EXPERIMENTAL METHODS

One male participant was asked to raise a hand-held weight (3 kg) with eight repetitions using both right and left arms one at a time. The arms were flexed from vertical rest to approximately 20° above the horizontal. The participant (66 years) had a left shoulder reconstruction performed in 2012. The movements were recorded using two accelerometers, one mounted in the wrists using
observed in the anteroposterior acceleration profile corresponding with a regular audio burst at the onset of the minimum height (resting). In addition, the anteroposterior wrist acceleration has high frequency noise when the hand is at maximum elevation. The former effect is thought to relate to skeletal instability and the latter effect is thought to relate to muscle activity as the participant endeavours to hold the weight stationary.

The experiment was conducted under Griffith University’s ethics committee project approval (ENG/14/13/HREC).

RESULTS

The raw data is presented in Figures 1 and 2 together with the audio recordings. The vertical acceleration (blue trace) is directly related to the vertical arm position. A comparison between the left shoulder (reconstructed) and the left wrist with the audio signal is shown in Figure 1 (top: left wrist / bottom: left shoulder). The acceleration data was converted to g forces (g being the gravitational acceleration) and synchronised with the audio signal.

From Figure 1 (top), small wrist indents can be

![Figure 1](image1.jpg)  
**Figure 1** Vertical (blue line), mediolateral (green line) and anteroposterior (red line) acceleration, and the audio signal (black line) of a sensor mounted on the left wrist (top) and on the left shoulder (bottom).

The high frequency noise on the vertical acceleration on Figure 2 is relatively low. As the arm

![Figure 2](image2.jpg)  
**Figure 2** Vertical (blue line) and anteroposterior (red line) acceleration, and the audio signal (black line) of a wrist mounted sensor on the right arm during seven arm flexions. Significant negative wrist anteroposterior acceleration is evident when the arm is flexed to the horizontal position (0°).
extends, there is a small audio spike mid-way at a consistent position. As the arm extends to the horizontal position indicated by the vertical acceleration wrist (0°), a negative wrist anteroposterior acceleration prompted by an audio click was observed. This is consistent in 6 from 7 arm lifts (85%).

**DISCUSSION AND CONCLUSIONS**

Two different effects in the acceleration records correlate with the audio signal: one is evident as a step-wise change in acceleration when the arm nearer the resting position following elevation, and the second is evident as a minor deviation in the shoulder acceleration profile. EMG (electromyography) events are the result of muscle electro-activity. The audio clicks from joint movement are the result of skeletal instability. The regular appearances of clicks during repetitive NTSI movements were shown to correlate to several acceleration events noted in either the shoulder or the wrist during flexion and extension of the arm. These preliminary results confirm the relationship between audible shoulder events and accelerometer measurements during arm flexion and extension.

**PRACTICAL APPLICATIONS**

- Interpretation of accelerometer profiles which arise due to shoulder instability (NTSI).
- Potential measurements of non-traumatic biomechanical instabilities using accelerometers.
- Locating structural instabilities in repetitive biomechanical cycles.

**REFERENCES**

Evolution of smart devices and human movement apps: recommendations for use in sports science education and practice

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ABSTRACT
Many smart phones and tablets possess high-speed cameras. An increasing number of human movement professionals (e.g. personal trainers, athletics coaches, strength and conditioning coaches and physiotherapists) are beginning to use human movement analysis apps with their smart phones/tablets to quantitatively assess their clients’ performance and injury risk. However, an understanding of the validity and reliability of these tools is required. This narrative review seeks to list some relevant human movement apps; summarise the validity and reliability of selected apps and to provide recommendations for their use in education and practice.

Keywords: biomechanics; coaching; personal training; physical education; physiotherapy; smart phones; sports and exercise science.

INTRODUCTION
The accurate quantification of human movement is vital in many professions including the coaching, personal training, physical education, physiotherapy as well as sports and exercise science. A considerable portion of human movement analysis is performed qualitatively, with the professional using their own eyes and understanding of the movement to assess overall movement competency; with the aim to identify potential movement issues that may reduce performance and/or increase injury risk.

POTENTIAL BENEFITS OF HUMAN MOVEMENT APPS
Newer devices e.g. iPad Pro and iPhone 6 have high-speed (240 fps) video camera, 3-D accelerometers and gyroscopes that provide a cost-effective method of quantitative performance analysis.1 As a result of these technological innovations, a relative explosion in the number of human movement analysis apps is now occurring. Some of these apps are somewhat generic and have multiple applications e.g. the TiltMeter app which has been used to assess shin angle in the weight bearing lunge test.2 Other apps have been developed for specific tasks including range of motion (e.g. Simple...
Goniometer), bike fitting (e.g. Bike Fast Fit), postural analysis (e.g. Posture Aware), weight training (e.g. IronPath), gait analysis (e.g. RunMatic), sprinting (MySprint) and vertical jumping (e.g. MyJump).

VALIDITY AND RELIABILITY OF HUMAN MOVEMENT APPS

While such data may prove invaluable data to the human movement professional and client, the validity and reliability of these apps needs to be demonstrated if they are to be used in practice and research. A summary of some validation and reliability studies of a cross-section of fitness industry relevant human movement apps is provided in Table 1.

As can be seen in Table 1, some apps have been demonstrated to have sufficient validity and reliability for measuring variables including segment angles, joint range of motion and jump height. While this list is not exhaustive, this suggests that a number of apps may provide feasible quantitative analysis options for the analysis of human movement. However, human movement students and professionals need to be aware of the potential pitfalls of these apps. We therefore recommend that prior to using any human movement app, the peer-reviewed literature is consulted so to determine its validity and reliability; and that an attempt is made to understand the process in which the outcome measures are generated. We also recommend conducting some in-house reliability testing of the app so to gain an understanding of the likely error of measurement that may be observed with repeated measures. By following this advice, human movement students will be provided with greater real-world educational opportunities that will improve their graduate employability; while human movement professionals may be able to further improve the performance and reduce the injury risk of their clients.

REFERENCES


Table 1: Validity and/or reliability of selected iOS human movement apps.

<table>
<thead>
<tr>
<th>Study</th>
<th>App</th>
<th>Validity</th>
<th>Intra-tester reliability</th>
<th>Inter-tester reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balsalobre-Fernandez et al.¹</td>
<td>My Jump</td>
<td>Against force plate R² = 0.99; ICC = 0.997 (CI = 0.996-0.998); BAB = 1.3 ± 0.5 cm</td>
<td>α = 0.99, CV = 3.4-3.6%</td>
<td>ICC = 0.999 (CL = 0.998-0.999); MD = 0.1 ± 0.4 cm</td>
</tr>
<tr>
<td>Jones et al.¹</td>
<td>Simple Goniometer</td>
<td>Against Universal Goniometer r ≥ 0.96; ICC &gt; 0.93; BAB = +0.5°</td>
<td>Not reported</td>
<td>Not reported</td>
</tr>
<tr>
<td>Williams et al.²</td>
<td>Tiltmeter</td>
<td>Against digital inclinometer ICC = 0.83; MD = -0.15° (CI: -0.74° to 0.45°)</td>
<td>Straight ICC = 0.81 (CI 0.66-0.96 Bent ICC = 0.85 (CI 0.74-0.97)</td>
<td>Straight ICC = 0.80 (CI 0.57-0.92) Bent ICC = 0.96 (CI 0.90-0.98)</td>
</tr>
</tbody>
</table>

BAM = Bland Altman bias; CI = 95% confidence interval; MD = mean difference; SEM = standard error of the mean.
Platform technologies and Visual analytics for inertial sensors

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ABSTRACT

A software package for control and visualisation of an inertial sensor system was developed. This was achieved using the software environment MATLAB. Through a number of iterative development stages, the system grew into a flexible, user-friendly platform. Future developments are expanding the system into the cloud.

Keywords: Inertial sensors, MATLAB, Human monitoring, 9DOF, visualisation

INTRODUCTION

Inertial sensors are highly regarded in sports science and have found much utility in sports science applications.¹ The authors over time have developed a number of prototypes² to gather data. A review of their activities led to the development of a standard sensor platform (SABEL Sense)¹,² and a decision to use and develop common tools and data standards in MATLAB. While SABEL Sense is primarily a 9 Degrees of Freedom (9DOF) inertial sensor platform, it has considerable flexibility for additional sensors and customisation and has seen a much wider utility in engineering research. To ensure data is collected in a common framework a customised structure (ATHDATA)³, MATLAB toolbox (ADAT)³ and accompanying data analysis GUI was developed and more recently have evolved into a cloud-based solution. This ensures data and analysis techniques can be shared among members.

The developed solutions are robust, user-friendly and highly customisable. MATLAB was central in developing a system where individual requirements for simplified visual interfaces, graded access to data detail, heavy customisation and integration of other data sources was key. The benefits of MATLAB’s flexibility work alongside the iterative development stages to improve the development process.

METHODS

The software used with the SABEL Sense system is required to perform two primary purposes. The first is sensor control, handling the interface between the user and the sensor system. Second is data analysis, allowing the user to visualise the sensor data with synchronised video.

The interface to the sensors provided by the control centre delivers a user-friendly and flexible experience. The sensor interface displays device status, consisting of battery life, logging state, and previous session information. Control of the system can also be achieved, allowing for sensor configuration changes, data download, and network control. A built in semi-automated calibration⁴
method delivers an easy to use system calibration tutorial. To ensure the system is robust and remains customisable it has the ability to notify and install both software and firmware updates.

To aid in analysis a tool to visualise the sensor data with synchronised video was developed. It has the ability to process files in the standard laboratory structure (ATHDATA)\(^3\). Multiple files can be selected and loaded with up to three being displayed at once. This allows multiple devices to be synchronised and analysed. To ensure the flexibility of the tool support for several standard video formats (mp4, mov, avi) is provided. The user experience is enhanced by the auto calculation of data sample rate and video frame rate to provide synchronisation of video and sensor data.

**RESULTS**

Arrival at the current stage of the system has required a number of incremental updates. Most notable are refinements of the control centre interface (Figure 1). This evolution of the system has come from improving the user experience, optimising based on technology updates and user feedback. The system began as a text based command line interface (Figure 1a). This legacy system was not user-friendly and prompted the move to a MATLAB-based graphical user interface (Figure 1b). The move to a GUI allowed for improvements in the user experience while using MATLAB at the core provided a highly customisable solution. The most recent iteration (Figure 1c) focused on the refinement of the system interface.

The data analysis GUI used to visualise the sensor data with synchronised video (Figure 2). This tool is also MATLAB-based and has undergone a number of backend processing (data management, video system) upgrades during its deployment. The flexibility of the MATLAB environment provided the ability to increase the number of supported video containers (mp4, mov, avi) and video codecs (MJPg, MPEG2, H.264), allowing the tool to adapt to new technology. Using the MATLAB Compiler Runtime the software can...
be compiled into a standard executable. This aids in the deployment and upgrade process by allowing automation of a number of installation steps.

**DISCUSSION**

The software for the SABEL Sense system has been developed to provide a user-friendly and quickly customisable toolset. This was achieved by using MATLAB and a modular development approach. Each primary subsystem is kept independent to allow for quick modification and upgradability. The software allows a user to quickly capture data from several synchronised sensors. The complex inertial movements can then be visualised with synchronised video. This assists the user in understanding the movements by providing context for the data capture.

**CONCLUSIONS**

Future development will service user demands based on user engagement and technology advancements. The iterative development process will continue to refine and improve the user experience. Development is currently underway to integrate the system with a recently developed cloud-based data storage system.

**PRACTICAL APPLICATION**

- Video synchronisation to inertial sensor data for enhanced data analytics across sporting and rehabilitation contexts.
- Collection of synchronised swimming data from several devices with biomechanical analysis of the swimming strokes.
- Instrumentation of trail bike for data collection and analysis of jump flight times.

**REFERENCES**

Quantifying Consistency of Technique in Swimming

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ABSTRACT

Swimming consists of a repetitive action which can be visualised using overlay and phase portrait techniques to determine the consistency of the swimming action. However, this does not lead to a quantifiable value for the consistency. This paper uses curve fitting techniques on the body roll data measured by inertial sensor gyroscopes to quantify the consistency of action of two swimmers. It was found visually that the consistency between the two swimmers were different and the curve fitting technique also showed a difference indicating that the technique can be useful in quantifying the consistency of the action.

Keywords: visualisation, swimming, inertial sensors

INTRODUCTION

Inertial sensors have been applied with success to many sports [1-3]. These sensors typically generate large datasets especially for long periods of capture time. Visualisation is a useful tool in extracting information from these long duration or large datasets [4]. Many sporting activities contain repetitive motion which can benefit from the use of visualisation techniques [5]. Particular visualisation techniques such as the overlay method [5], and phase space portrait methods [5] (both delay and derivative types) are very useful to see changes in the repetitive activity over multiple repetitions. These visualisations are graphical in nature and thereby allow changes to be readily identified by inspection but do not quantify these changes. What would be useful is a method to use the visualisations to quantify the consistency of a repetitive action. This paper uses curve fitting techniques on the body roll data measured by inertial sensor gyroscopes to quantify the consistency of action of two swimmers.

METHODOLOGY AND RESULTS

The body roll was determined from the gyroscopic data of an inertial sensor unit placed at the 7th Cervical Vertebra (C7) of the spine. Body roll data was collected from two swimmers according to the method outlined in [5]. (ENG/02/13/HREC). Swimmer 1 is a former Olympian and Swimmer 2 competed at state and national age championships. The data collected consisted of 7 swimming strokes with individual
strokes being separated before being visualised. The visualisation of this data is shown in figure 1. The top graphs use the overlay method, the middle graphs use the phase portrait delay method, and the bottom graphs use the phase portrait derivative method. Curve fitting was used as the method to quantify each graph. The type of curve fitting used depended upon the shape of the graph and was applied to each individual stroke. A sinusoidal fit of the form Asin(Bx+C) was used for the Overlay graphs and an elliptical fit was used for the Phase portraits. The extracted fitting parameters from the ellipse consisted of the ratio of the major axis to minor axis and the distance from the centre of the ellipse to the origin.

The fitting parameters were extracted from each individual stroke in a given graph. The variability of these parameters were determined by calculating the mean, standard deviation, and a percentage value representing the spread of the parameter. This was repeated for every graph in Figure 1 with the results given in Table 1.

**DISCUSSION AND CONCLUSIONS**

It can be seen from Figure 1 that the consistency of Swimmer 1 is better than the consistency of Swimmer 2. Swimmer 2’s graphs are more spread compared to Swimmer 1 and the centre locations from the ellipse fit (red dots) are also more spread. The ratio of the standard deviation to the mean expressed as a percentage indicates the relative spread of each parameter and will be referred to as the relative spread.

<table>
<thead>
<tr>
<th>Visualisation Technique</th>
<th>Swimmer 1</th>
<th></th>
<th></th>
<th>Swimmer 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>stdev</td>
<td>(stdev/mean)%</td>
<td>mean</td>
<td>stdev</td>
<td>(stdev/mean)%</td>
</tr>
<tr>
<td>Overlay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>9.064</td>
<td>0.147</td>
<td>1.624</td>
<td>10.495</td>
<td>0.432</td>
<td>4.1193</td>
</tr>
<tr>
<td>B</td>
<td>0.035</td>
<td>0.001</td>
<td>2.906</td>
<td>0.032</td>
<td>0.001</td>
<td>3.9378</td>
</tr>
<tr>
<td>C</td>
<td>0.684</td>
<td>0.051</td>
<td>7.476</td>
<td>0.765</td>
<td>0.055</td>
<td>7.3039</td>
</tr>
<tr>
<td>Delay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Major/Minor</td>
<td>11.3328</td>
<td>0.3562</td>
<td>3.1435</td>
<td>13.6731</td>
<td>1.0876</td>
<td>7.9541</td>
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<tr>
<td>Distance</td>
<td>0.6158</td>
<td>0.1407</td>
<td>22.8523</td>
<td>0.9063</td>
<td>0.6860</td>
<td>75.6930</td>
</tr>
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<td>Derivative</td>
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<td></td>
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<tr>
<td>Major/Minor</td>
<td>28.4472</td>
<td>0.8894</td>
<td>3.1263</td>
<td>34.3493</td>
<td>2.7417</td>
<td>7.9819</td>
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<tr>
<td>Distance</td>
<td>0.4356</td>
<td>0.1010</td>
<td>23.1815</td>
<td>0.6422</td>
<td>0.4868</td>
<td>75.7995</td>
</tr>
</tbody>
</table>

Figure 1 Visualisation of body roll for 2 swimmers from a sensor placed on the body at the 7th Cervical Vertebra (C7). The red dots show the centre as determined by an ellipse fit.
The relative spread of parameters A and B in the Overlay graph is larger for Swimmer 2 than Swimmer 1 indicating that Swimmer 1 has the more consistent technique. This matches what is shown in Figure 1. It should be noted that parameter C is about the same for Swimmer 1 and 2.

The relative spread of the major/minor axis in the delay phase portrait is 2.5 times larger for Swimmer 2 compared to Swimmer 1 and the relative spread of the distance of the centre from the origin is 3.3 times larger for Swimmer 2 compared to Swimmer 1. This indicates that Swimmer 1 has a more consistent technique which matches the graphs from figure 1.

The relative spread of the major/minor axis in the derivative phase portrait is 2.5 times larger for Swimmer 2 compared to Swimmer 1 and the relative spread of the distance of the centre from the origin is 3.3 times larger for Swimmer 2 compared to Swimmer 1. This indicates that Swimmer 1 has a more consistent technique which matches the graphs from figure 1. It should be noted that the y axis on the derivative phase portrait graphs is approximately 30 times greater in magnitude than the x axis hence the major/minor ratio is around 30 as seen in Table 1.

All the fitting parameters in table 1 are derived from the graphs in figure 1 and show larger or close to equal values in the relative spread for Swimmer 2 compared to Swimmer 1 which indicates that Swimmer 1 is more consistent than Swimmer 2. This matches the graphs which show Swimmer 2 has a larger spread than Swimmer 1. Overall the technique of fitting curves to the visualisation graphs looks like a promising method to quantify the consistency in the swimming action.

REFERENCES


CONFERENCE PAPER

An assessment of mediolateral knee and ankle acceleration as an indicator of fatigue

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ABSTRACT

Lower limb injuries in football (soccer) are caused by a lack of muscle strength and fatigue. The mediolateral acceleration of the knee and ankle was measured during a simple running exercise using 25 elite football players over a full playing season (26 weeks). Each run was compared using acceleration skewness comparing base line and fatigue. Most (79%) participants exhibited significant changes (0.002 < p < 0.044) in left-ankle acceleration skew, and 55% (0.0003 < p < 0.045) in right-ankle acceleration skew. Recording ankle and knee accelerometer data and analysing for skewness offers a potential detection method for fatigue assessment.

Keywords: accelerometer, joint stability, knee, ankle, football

INTRODUCTION

Injuries occur in all sports but this is particularly common in sports involving running, quick direction changes, jumps etc, typically found in ball based team sports. Professional and amateur football associations are concerned about the effects on player wellbeing, player performance and match time minutes.¹

The definition of fatigue poses difficulties during match play because of the individuality of each athlete. A correlation between ankle sway velocity and the level of fatigue has been reported² and also knee joint position and fatigue.³ The monitoring of fatigue becomes extremely important as the ankle and knee are two of the most affected areas¹ according to the percentage of injuries in football.

Prolonged physical activity results in metabolic muscle fatigue and weakened proprioception. These impairments increase the risk of musculoskeletal injuries⁴.

A combination of voluntary and reflex control of muscles in knees and feet are used to maintain stability during walking. Whilst proceeding in the direction of motion, the knee and foot muscles are also coordinated to minimise the horizontal and vertical displacement of the body’s centre of mass. When muscles become fatigued they have impaired ability to generate force. This is believed to induce an adaptation in the level of muscle activity. Indeed, it is known that knee and ankle flexion increases after runners become fatigued.⁵⁻⁹

Several studies report measurements of fatigue during running.⁵⁻⁹ Kinematic variables were
compared at the beginning and end of the running on a treadmill. Plantarflexion, ankle inversion and eversion were observed to increase with running time. In addition fatigue may cause muscle imbalances and alteration of joint stability and the maximum angular velocities of knee flexion and ankle flexion increased after ankle fatigue. Runners tested before and after a fatigue protocol showed an acute decrease in muscle strength capacity of the knee extensors and flexors which occurs about the knee and ankle before and after foot impact. The foot motion of runners equipped with shoe-based inertial measurement units was analysed. The range of foot motion in the sagittal plane increased in the final phases of 10 km long running races.

This paper describes an investigation of a fatigue detection method for sports involving running. While heart rate is a common variable describing the fitness quite precisely, the analysis of data recorded during a simple exercise with accelerometers fixed to the athlete’s knees and ankles may provide a method for detecting fatigue to assist managing the risk of injuries. The results were obtained with the assistance of a professional football (soccer) team.

MATERIAL AND METHODS

25 professional football players participated in this study (Ethics approval 2015/865). The athletes were monitored over 26 weeks of the competitive season 15/16. The physical dimensions of each player such as age, weight and height were recorded. During the season the fitness and conditioning manager provided information about current and previous injuries and activities including strengthening and conditioning regimes.

The players were asked to run through a coordination ladder of 10 meters length three times at a default speed of 50% of their maximum speed. Every run was taken in the same direction, so the players had to walk around the ladder back to the start where they occupied a static stance before starting again. This coordination task was also performed following a very intensive field training session.

The data was recorded with Sabel® wireless inertial sensors. One of these sensors was fixed to the lateral side of each knee, and to the lateral side of the ankle respectively, using strapping tape. The sensors measured the acceleration amplitude in three directions – mediolateral, anteroposterior and craniocaudal. The mediolateral axis was of main interest.

The data was split in single runs. Secondly, the skewness of the mediolateral acceleration during each run was calculated. Paired T tests were performed in many variations between ankles and knees as well as baseline and fatigue conditions.

RESULTS

Table 1 – Percentage changes in mediolateral skewness for knees and ankles before and after fatigue for all players.

<table>
<thead>
<tr>
<th>Base-fatigue change</th>
<th>Left ankle</th>
<th>Right ankle</th>
<th>Left knee</th>
<th>Right knee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentages %</td>
<td>79.2</td>
<td>54.5</td>
<td>75</td>
<td>75</td>
</tr>
</tbody>
</table>

A significant change in the skewness between base line and fatigue, ankle and knee, was common through the recorded data (Figure 1). The right ankle of 55% of all participating athletes changed skewness between base line and fatigue significantly. A significant change in left and right knee skewness between baseline and fatigue occurred in 75% (0.0001 < p < 0.047/ 0.001 < p < 0.049) of the data. Particularly significant was the change of left ankle’s skewness where 79% (0.002 < p < 0.044) of the participant’s left ankle changed between base line and fatigue significantly (Table 1).
DISCUSSION

This work was designed to assess the influence on fatigue on the knee and ankle mediolateral acceleration during running. It is shown that the individuality of every player makes it always difficult to define fatigue adequately. There are several other mental and physiological causes/reasons which may affect fatigue but these factors were ignored in this study. The mediolateral ankle acceleration could be used as a reliable and assistant support for the real time detection of fatigue in training or even in a game according to the high percentage of players that suit the method of skewness observation.

CONCLUSION

Every player showed a significant change in skewness in either a knee or an ankle joint independent of previous injuries when they are fatigued compared to baseline. Especially the skewness of the mediolateral acceleration of the athlete’s ankle was remarkable and can be considered as a reliable indicator of fatigue. From the 25 players, 79% exhibited a significant change in mediolateral acceleration skewness of the left ankle with fatigue. The dominant leg as well as lower limb injuries did not affect the results. Because only 3 players showed a slight relation between the ankle-knee skewness, this result was not considered to be useful. In routine measurements the accelerometers could be positioned in the player’s socks with minimal risk of impact injury.

The results of this study can be used for:
• The rapid assessment of player fatigue during training
• The fitness level of players can be monitoring during the season
• Warning indications for potential injury onset can be developments of each player individually.

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Assessing Ankle Instability During a Relevé Using Accelerometers

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ABSTRACT

Ankle injuries are a common occurrence in classical ballet. Identifying weakness could reduce the possibility of future injury. Two female dancers in an undergraduate dance programme stood in first position with their arms in second position and performed a sequence of relevés. A single accelerometer was attached to the ankle to determine instability during the study. The results indicate that during the holding phase of the relevé the two participants had different patterns, with Participant 2 showing a continuous spike throughout the 5 relevés. This indicates a weakness in the ankles and therefore suggesting that the coaches should implement an ankle strengthening programme.

Keywords: accelerometer, ankle instability, classical ballet, relevé

INTRODUCTION.

Classical ballet dancers perform exaggerated and difficult movements, and are required to perform these movements with effortless fluidity and precision. This takes significant hours of training from an early age to develop muscle control. The movements are so varied and demanding that they commonly cause health issues.\textsuperscript{1} Ankle injuries have been shown to be a common injury that occur within both professional ballet companies\textsuperscript{2,3} and students\textsuperscript{4} with an increased level of reoccurrence of injury in the future.\textsuperscript{5} Research has also shown that as children age, the occurrence of injury increases. Therefore it is important to have simple methods that can identify possible weakness in the hope of preventing ankle injuries.

Accelerometers are sensitive to static acceleration in the Z axis allowing measurements to be taken that can be accredited to a change angle with regard to gravity. Accelerometers have been implemented in research to assess postural sway\textsuperscript{6,7} and pronation of the ankle.\textsuperscript{8} The aim of this study was to identify instability in the ankle during the holding position of a relevé. This is important as knowing this may help prevent future injury and may be a way of assessing whether or not an individual is ready to progress to using point shoes.

EXPERIMENTAL METHODS

Two female participants (19-20 years of age) from a university dance programme volunteered to participate in this study. The participants were verbally instructed on the protocol and where made aware that this study would, in no way, affect their grades. Ethical approval was obtained from the Institution's Ethics Committee (ENG/14/13/HREC). The participants’ height and weight were taken and they completed a background survey reporting their age, current level of training, classical ballet experience in years and current training load.

The participants wore ballet class attire along with flat
ballet shoes. The study took place in a dance studio with mirrors blacked out. Prior to testing, the dancers had warmed up. The participants were asked to perform a series of 5 relevés to verbal counts from a qualified dance instructor. The participants commenced in first position, (a lateral rotation from the hips with heels together) with their arms placed in second position (arms are held out to the sides, angled slightly down and forwards, with the palms facing forward) as shown in Figure 1a. The trial consisted of five relevés that were held on demi-pointe for four counts. A relevé involves a demi-plié, a flexing of the knees whilst the ankles dorsiflex (Figure 1b). The step is completed with the extension of the knees and a planter flexion of the ankle. The weight is placed over the forefoot (Figure 1c).

The ankle acceleration was recorded at 100 samples per second using an inertial sensor (SABEL Sense®) consisting of a tri-axial accelerometer (size 55mm x 30mm x 13mm, weight 23g) wirelessly activated through the use of SABEL Sense software. The sensor was attached to the two participants whilst standing in the anatomical position and secured to the left ankle above the lateral malleolus using Velcro fabric bands. A standard speed video recorder (25 f/s) was used to record the session.

The acceleration data was uploaded to computer and calibrated using SABEL Sense software allowing the data to be expressed in terms of gravitational acceleration (g=9.8ms⁻²). The anterioposterior acceleration of the ankle accelerometer was converted to angle (degrees from the horizontal) and plotted using MATLAB.

RESULTS

A pattern emerged identifying the instability of the ankle during the sequence of the relevé. The difference between the two participants was clearly demonstrated during the holding position of the relevé (Figure 2). During the hold of the relevé, participant 1 manages to return close to the baseline measurement during the elevated stationary phase. However participant 2 continued to oscillate during the held position phase never reaching a stable ankle joint. Participant 2’s results also demonstrated an acceleration spike (evident as an angle spike) thought to be the result of the participant unlocking the ankle joint to allow the return to first position from the relevé.

DISCUSSION

It is important that stability can be attained during a relevé as the progression of this step in female dancers is to be able to perform this same step on pointe. During pointe work, the orientation of the talus and talocrural joint alters⁹, therefore any weakness could result in the foot pronating or supinating, which may lead to increased instability and the possibility of injury.

A limitation of this study was the fact that only one ankle accelerometer was used. Using 2 accelerometers would have allowed comparison between both ankles and would have allowed acceleration patterns to be compared. A more detailed background of ankle injuries would have been beneficial to draw greater conclusions.
The purpose of this study was to identify instability of the ankle during the held position of a relevé. The results show the two female dancers reported differences in ankle joint stability. The results suggest that using accelerometers baseline measurements could assist dance teachers to identify weakness in the ankles, allowing strength training programmes to be introduced to ensure that the dancer has sufficient strength to maintain a stable position during the held phase of the relevé.

PRACTICAL IMPLICATIONS

- Acceleration measurements can indicate ankle instability during relevé.
- Ankle instability is a major indicator of on-coming injury
- Ankle strengthening exercises should be used to reduce instability so the probability of injury is reduced.

REFERENCES

Wearable Wireless Sensor for Real-Time Angle Measurements

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ABSTRACT

Wearable sensors provide an easy solution for capture and processing athlete movements while eliminating the need for wired connections. This paper reports a new approach for limb rotation and angle measurements through the use of a 2.45 GHz wireless accelerometer sensor, by measuring the tilt angle as function of gravitational acceleration. The acceleration values were normalized and mapped to calculate angle measurements with prediction accuracy of 5°. This type of measurements can play a significant role in the process of athlete rehabilitation, such as, restoring the full range of movement for ankle sprain injuries.

Keywords: BSN, wearable sensors, accelerometers, tilt-angle, real-time, sports monitoring.

INTRODUCTION

Body sensor networks are an innovative technology to gather information for many human applications, ranging from health and sport monitoring, real-time feedback, positioning and tracking, to emergency responses. An example of real-time sport monitoring network was demonstrated by the use of an acceleration sensor at the grip for measuring the angular motion of an arm swing in golf. Another study showed an investigation of the joint flexion angles using a knee goniometer application (KGA) developed on a smart phone, the knee range measurements reliability were validated using the standard universal goniometer (UG). The sensing accuracy, long lifetime, and network latency are essential characteristics of such networks and unreliable wireless links and node (connection point) failures reduce the network reliability. Additionally, the node physical design and dimensions add to the user-friendliness feature of the network by overcoming body natural movement hindrance and support nodes placement.

This paper follows previous work on identifying human gestures (body movements) for multiple locations around the human body (foot, leg, and arm), to trigger information broadcast for specific actions.

EXPERIMENTAL METHODS

The orientation of an inertial acceleration sensor is referenced to the direction of gravity. This paper used an acceleration sensor developed at Griffith University, to calculate tilt angle for athlete stationary positions. The sensor was modified to include the wireless transceiver ability. In the test, an analogue tilt meter and the modified wireless accelerometer were attached to a participant arm and moved together with respect to the ground. The node was configured to measure the acceleration data at a 100 Hz sampling rate, and wirelessly transmit the samples off-body for real time display. The acceleration values were recorded at 72 stationary positions from -90° to 90° with step size of 5° in both y & z directions (y & z planes are parallel to the...
ground at 0°). The experiment was conducted under Griffith University’s ethics committee project approval (ENG/20/13/HREC).

RESULTS

At each stationary position, the resultant acceleration values were normalized to (g) units for all three axes and mapped against the recorded analogue angles resulted from tilting as shown in figure 1. The result showed that, leaning the sensor in y direction changes the acceleration readings in the y-axis from a negative value of -1 (g) at -90°, to 0 (g) at 0°, and back to 1 (g) at 90°; same results were obtained for z-axis acceleration in z direction. This corresponds to the physical movements of the sensor components in the y-axis or z-axis while remaining still in the other axis.

DISCUSSION

From these values an indication of the direction of the sensor (limb) was obtained for stationary positions. A four quartiles circle which shows the singularity of the acceleration values was drawn in figure 2. For instance, if both y and z values were positive then the sensor is located in the first quartile, similarly negative values indicate a sensor location in the third quartile. Furthermore, the acceleration values in the x-axis change almost identically to the variation in either y or z directions and can provide a clear indication of the tilted angle. Given the digital resolution of the acceleration values and the sinusoidal dependence of the angle on acceleration, the maximum angular error was 5° providing the human body is motionless. When the limbs are moving, then the dynamic acceleration greatly increases the angular uncertainty.
CONCLUSIONS

This study presented a reliable measurement sensory tool for joint angles based on the recorded acceleration values with a small error of measurement. Athlete and sports monitoring represent an important aspect of body sensor network applications. A method for capturing the tilt angle from sensor orientation was presented, and a comparison between the analogue and acceleration measurements were made. The angles for stationary measurements can be used to identify degree values, with a 5° estimation accuracy.

PRACTICAL APPLICATIONS

• The system could be used by novice practitioners and athletes to measure and monitor their own progress in flexibility pre and post injury.
• More complicated algorithms can be used to determine angular velocity and movement direction.

REFERENCES


ABSTRACT
Wearable technologies impact on human performance monitoring. Technology designed for human monitoring was used as a proof of concept study to determine the effectiveness of monitoring physical activity of two different sized dogs. The device found significant step count differences with the smaller dog having greater step count. This was confirmed from step counts taken from an associated video recording. Therefore the study showed that a wearable device could measure step counts of dogs. Meaning that users can monitor their own physical activity or that of their pet with the same device.

Keywords: Canine; Fitbit; Gait; Physical activity; Wearable technology.

INTRODUCTION
Technology is widely used in human movement for performance analysis and rehabilitation monitoring. To some degree technology has been successfully used for kinematic and kinetic analysis of dogs. While data has been collected using canine specific activity trackers e.g. FitBark, there appears to be little published research on the application of wearable technology on these animals. Additionally, it is unknown whether this data has factored in differences between breeds.

Wearable technologies (wearables) have gained popularity to monitor human movement, from individual self monitoring through to high end research applications. According to professional services firm, PWC, 20% of people use wearables, of this, 45% use fitness bands. No published research was found in a review of the literature that reported a fitness band device to assess canine movement. Extrapolating PWC and pet ownership data, approximately 400,000 people who own dogs also own fitness bands, giving these owners the ability to use a familiar device, and avoid the cost of buying a specific device for their pet.

Wearable technology data could be used by veterinary clinicians and owners to monitor orthopaedic conditions or post-operation rehabilitation, by assessing increased movement as an indication of improvement. Additionally, decreased movement is detrimental to injury recovery and musculoskeletal health, therefore wearables may provide a measure of motivation that could assist in rehabilitation. Moreover to injury, canine obesity is prevalent in Australia and overseas. Use of activity monitors may motivate owners to increase their dog’s activity, in the same way devices have successfully done so in humans. Their use also presents an
opportunity for research. Since specific recommended levels of canine activity have not been found in the literature, these devices have the potential to capture large amounts of data, establishing such information.

A concern of gait analysis in dogs are differences in temporospatial and kinetic data between different dog breeds, potentially due to differences in size. Fitness bands used for assessment of dogs would be required to allow for size and shape differences that may influence gait. Furthermore, differences may be seen in data due to changes in gait and not from breed/size. This information may influence the clinician’s conclusion from data. For example, inactivity as a result of dog size must be distinguished from inactivity due to pain. Therefore the aim of this report was to investigate the capability of a fitness band to detect between dogs with anthropological differences in step count. Furthermore, a secondary aim was to determine whether animal size impacted on data output.

**RESULTS**

The FitBit detected approximately 20% of the steps in both smaller and larger dog. The FitBit detected a mean value of 71 steps in the smaller dog and 53 steps in the larger dog (Standard Deviation 1 and 3 respectively) (Figure 2). Student’s T-tests showed a significant difference between smaller and larger dog (p=0.005). This was verified by the video (p=0.003).

**DISCUSSION**

The FitBit detected 20% of steps in both breeds. It was speculated this inaccuracy was due to limited event detection of gait phases as a result of collar attachment. Future research may be required to determine the ideal sensor position to better measure step rates, e.g. on the leg, or close to the centre of mass. The research will also need to address new challenges such as change of gait due to device positioning. However, since the error was consistent in both dogs, owners could use this knowledge to calculate a specific step count manually. This would expand the potential of the FitBit to unsupervised monitoring. Many dogs spend time alone.
Unsupervised monitoring would allow for assessment for the need to take the dog for a walk, based on its activity while their owners were away. Data collected showed that smaller dogs have a different (higher) step count to larger dogs. Wearable technology specifically designed for dogs has been used to collect data, providing information such as breed differences in activity levels, and changes in activity with osteoarthritis. No published information was found for recommended levels of activity, step count or distance for dogs. This may be due to wide ranging dog sizes and morphologies, making it impractical to establish an average. The current study indicated there are significant differences between dogs. It is unknown if research accommodated for the known differences. For example, many active listed dogs are smaller breeds, however, active larger breeds could be misrepresented due to their naturally lower step count. There is a need to establish a normal range for different sized dogs. This would provide a reference point enabling clinicians and owners to use data received more effectively. The potential for wearable technology to provide such data should be noted.

**CONCLUSION.**

A device designed for human exercise monitoring may be capable of monitoring activity in different sized dogs if error patterns are accommodated. This provides an opportunity for dog owners to measure their animal’s movement with a device they may already own. Additionally, dogs of different size display significant differences in step count. These differences should be considered when drawing conclusions of a dog’s health.

**PRACTICAL APPLICATIONS**

- Monitoring of canine activity in absence of humans
- Veterinary monitoring of activity during rehabilitation
- Possible motivator for human exercise
- Baseline for in-depth monitoring research

**REFERENCES**

ABSTRACT

Inertial sensor data cannot be used to directly display kinematic motion parameters. In this research, we therefore developed a processing pipeline for the provision of visual motion feedback from inertial sensor data. Following the computation steps of the presented system pipeline, it is possible to determine full-body motion kinematics that can then be animated as moving figures. Data analysis showed that the accuracy of the estimated body kinematics is within few degrees of deviation from the actual data, enabling a use of the system in future applications such as mobile training tools.

Keywords: motion analysis, inertial sensors, motion data processing, body kinematics, data visualisation

INTRODUCTION

Although various augmented motion feedback devices were introduced for sport training within the last years, video data remains the most conventional medium for the display of motion information. However, not all motion tasks allow for the acquisition of meaningful video footage. Especially in outdoor sports with a wide range of motion activity or water sports it can be difficult to obtain quality video data. For those scenarios, we developed a visual motion feedback system on the base of inertial sensor measurements. Studies showed that the human brain is able to intuitively understand motion patterns from even abstract data representations like point clouds and stick figures. This internal biological motion perception shall be used for visual feedback provision here, transforming the inertial sensor data into animated data plots of relative body joint positions.

METHODS

Motion data of four junior ski jumpers were collected using nine-axial waterproof inertial measurement units (Logical Product. SS-WS1215/SS-WS1216, Fukuoka, Japan). Nine sensors were placed on pelvis and both left and right thigh, shank, ski and upper arm of the participating athletes (Figure 1). This sensor placement enabled the acquisition of all body segments relevant for ski jumping. After data collection, the inertial sensor data was processed, and sensor mounted segment orientations and related joint positions estimated for all data captures. In concrete, the following sequence of computation steps was passed: (1) determination of initial sensor orientations with an algorithm based on trigonometric relations in the field measurement vectors, (2) compensation of magnetic disturbances to correctly align every sensor to the global reference frame using pre-measured reference vectors of every sensor in the present magnetic field, (3) estimation of sensor
sample. The temporal progression of those visualisations could then be rendered as animated video data, creating a full body motion visualisation of the complete ski jump - from the sitting position at the top of the jump hill through to the landing and outrun (Figure 2).

Comparison of the estimated segment orientations to the control data of the high-speed video camera data showed a data accuracy within 5 degree of deviation for all data captures. Furthermore, pitch values from the orientation estimates at the ski equalled the hill construction properties (e.g. the slope of the in-run and outrun) of less than 3-5 degree difference during all annotated motion phases. The estimated body kinematics from the simulation data were of similar data accuracy, with deviations between 1 to 10 degrees to the optical motion capture data.

**DISCUSSION AND CONCLUSIONS**

Detailed examinations of the simulation data showed that inaccurate orientation estimates were mainly caused by sensor noise and varying settings of the chosen processing filter. With suitable filter values, it was possible to adapt the fundamental sensor orientation estimation from step (4) to the present motion task, bringing the permanent deviation to a sufficiently small amount. The final data visualisations did not indicate any errors or miscalculations. Consisting of an accurate and
reliable processing pipeline, the presented mobile capture system could therefore be considered as a reasonable tool for the provision of additional motion information. Under certain sports such as ski jumping, snowboarding or free water swimming, it is deemed to be particularly useful, presenting motion information to the athlete that might not have been obtained otherwise.

PRACTICAL APPLICATION

The system and data processing pipeline can be used as presented to determine and visualise meaningful body kinematics from a collection of inertial sensor data (Figure 2). It can furthermore be freely adapted with respect to the number and placement of the sensors used, enabling its application under sport-specific training scenarios. Adding two additional sensors at both forearms, it becomes for example possible to visualise and separately monitor elbow and wrist positions. We consequently believe the present system to be a very useful support for future mobile training and motor skill acquisition tools.

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Figure 2 Screenshots of the animated figure visualisation at the jump phases in-run, flight and preparation of the landing
An interactive tool for conditioning inertial sensor data for sports applications

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ABSTRACT
Measurements with inertial sensors have been used in many sports applications through the last decades. The data extracted from the sensors are used by coaches, players and sports scientists to monitor athletes’ performance; this often requires graphical user interfaces for viewing and processing of data. An interactive user interface is presented in this paper for the basic analysis of sensor data (accelerometer). The tool allows for the analysis and understanding of basic data processing including different types of filtering and threshold-based activity classifiers. To demonstrate the effectiveness of the tool, an application for human gait analysis is presented.

Keywords: accelerometers, inertial sensors, graphical user interface, FFT, filtering, noise.

INTRODUCTION
Inertial sensors are nowadays widely used for monitoring sports applications. Data collection using sensors can be considered an easy task, but extracting information out of the data can be an arduous work. Skilled professionals are normally required to carry out the analysis and assess the information provided from the data. The viewing and manipulation of data collected from such sensors requires, in certain circumstances, the use of graphical user interfaces to monitor, among other things, athlete workload, injury recovery, over- and under-training.

Several interfaces and visualization techniques have been developed in recent years. Some examples include the monitoring of upper arm and forearm rotations of cricket bowlers, a monitoring system for the biomechanical analysis of swimming strokes, video indexing using inertial sensors for stroke detection in tennis and automatic detection of overs and deliveries in cricket.

An interactive user interface for the analysis of data collected from inertial sensors is presented in this paper. As the accelerometer data are normally corrupted with noise, the tool’s aim is to provide the user with basic capabilities (e.g. data filtering, peak detection) to remove unwanted responses that may affect the actual measurements. The tool can be used in different research fields, as well as in educational applications where fundamental understanding of data analysis and factors such as noise and data reduction is required.

DESIGN AND DEVELOPMENT
A snapshot of the user interface is shown in Figure 1. The tool was created using Matlab (The Mathworks, Inc.) environment and the main screen includes six different tabs. After loading the raw data extracted from the sensor, the user is required to select the area to be analysed by using the Matlab.
the peak’s threshold (%) using the sliding bar (Fig. 2).

APPLICATION: HUMAN GAIT ANALYSIS

Acceleration data extracted from an ankle mounted sensor during walking and running were analysed using the graphical interface. The sensor’s sampling rate was set to 250 Hz. The raw data were filtered using the low pass filter with a cut-off frequency of 5 Hz (Fig. 1). The peak finder was then applied to the RMS filtered data (Fig. 2). The minimum peak width was maintained to half of the sampling rate, so that the peaks at toe-off and heel-touch could be easily distinguished. Some peaks in Fig. 2 correspond to heel-touch and some to toe-off, however, a step is completed during toe-off so the heel-touch peaks can be discarded. This is done using the peak threshold (horizontal bar) which is manually increased until the accurate number of steps is determined. The threshold is measured from the maximum peak and in this case corresponds to 68% which results in a count of 10 steps. Five trials were performed and the results showed more than 95% accuracy in the system. The results were compared with those obtained manually by counting complete steps during
CONCLUSIONS

The interactive user interface for inertial data analysis described in this paper provides a simple way to analyse and understand body movement patterns using basic processing techniques. Application of the tool to human gait analysis has been shown to produce results highly consistent with those determined manually.

REFERENCES


Figure 2. Peak detection and peak threshold of RMS filtered acceleration data.
A single subject study was completed to compare a wearable inertial sensor with first person and third person video footage, to measure the number of head turns of a participant while he explored his surroundings. Results showed that the inertial sensor was more sensitive and accurate than both types of video footage for measuring head turns. Further development of the inertial sensor for measurement of exploration behaviour is recommended, which may provide a simple tool for researchers and practitioners to measure exploration behaviours of athletes in situ.

Keywords: Gaze; Inertial Measurement Unit; Decision Making; Perception; Visual Search

INTRODUCTION

In order for athletes to make appropriate decisions, they must perceive their surroundings in order to prospectively (ahead of time) control their movement to act in the appropriate way \(^1\). Skilled perception in dynamic and complex competitive team contexts, such as football, is critical for high-level performance. Positions, movements, and intentions of teammates and opponents need to be perceived to make effective and accurate decisions for action. This coupling of perception and action is an integral part of prospective control of movement and effective decision making in team sport, as one cannot function without the other \(^1\). In order to perceive ones surroundings, an athlete must manoeuvre their body in a way that allows exploration of information relevant for decision-making. Exploration may include movement of the eyes, head, and/or body. Without exploration through movement of the eye-head-body system, athletes are unable to visually perceive their surroundings, which ultimately limits their ability to control their actions, and make effective decisions.

Visual exploration is typically assessed through the measurement of eye movements by means of eye-movement registration techniques. However, eye-movement research has a number of methodological shortcomings \(^2\) which limit the conclusions that can be made for applied, in-game situations. Typically, studies have been performed in laboratory-based settings. These tasks determine where subjects search for information, as information is displayed only in front of the participant. During live play, athletes are typically completely surrounded by potentially relevant information, and they are able to determine themselves where to explore for information. Therefore, it is questionable whether much of the
current research can be generalised to actual visual search and exploration behaviours as employed in a natural setting. Due to the above methodological trends and reliance on eye-tracking technology, research investigating the head movements that support exploration is slim.

A very small amount of research has utilised head turns as a measure of visual exploration, with a higher rate of head turns representing an increase in exploration behaviour \(^{(3)}\). In these studies exploration was measured using notational analysis in which an analyst watches recorded video footage of games while recording the number of head turns completed. This research provides an initial understanding of in-game exploration behaviour, however notational analysis is typically time consuming and prone to errors \(^{(4)}\). Technological advances present a unique alternative to the current methods of data collection. Wearable inertial sensors may provide a reliable, easy to use method to measure the head movements of athletes in situ. The aim of the current research was therefore, to compare inertial sensor data with video footage (captured from first person and third person perspectives) for the measurement of exploration behaviour. It was expected that an inertial sensor would measure head turns of athletes more accurately than notational analysis of both first person and third person video footage.

**METHODS**

Ethical approval was attained from the Human Research Ethics Committee of Australian Catholic University. A single participant (male, 25 y/o) was involved in data collection, which occurred during one data collection session. The participant was situated on a sports field, surrounded by four research assistants. He was asked to verbally identify the number of fingers presented by the research assistants whilst being free to choose where and when to shift his gaze between the research assistants. After the number of fingers were identified, the research assistants would randomly change the number of fingers presented. This process was repeated for 20 seconds. Three devices were used to collect data; an inertial sensor (IS) (SABEL Sense, SABEL Labs, Brisbane, Australia) attached to the back of the participants head with adhesive tape, a mobile eye tracking device (Mobile Eye, Applied Sciences Laboratories, Bedford, MA) which provided first person video (FPV) footage, and a tripod mounted video camera (Canon Legria HV40, Canon Inc., Tokyo, Japan) which provided third person video (TPV) footage (Figure 1).

Notational analysis was completed for each data source, with the total number of head turns completed as the outcome measure. Each video data source was analysed independently by three researchers familiar with the study. Each video-source, each researcher was asked to count the number of head turns completed by the participant. The IS data was visually analysed by one researcher to obtain the total number of head turns completed. The IS provided a graphical data feed of head movement over time. As the IS was very sensitive to movement, a head turn was defined as an obvious peak or trough in the data.
RESULTS

Analysis revealed the IS was able to detect 25 head turns. The TPV detected the least number of head turns (M = 18.67, SD = 2.31), while the FPV showed one less head turn than the IS unit (M = 24, SD = 0) (Figure 2).

DISCUSSION

With the aim of comparing inertial sensors to video footage for the measurement of exploration behaviour, head turns were counted through three different measurement techniques. Of the three methods used, the TPV condition provided the least sensitive measure of head turns, and the IS provided the most sensitive measure.

There was a large amount of variability between researchers in the TPV condition, showing that this method is prone to errors in data collection. A possible reason for this variability may come from the difficulty in obtaining quality video footage which clearly shows the orientation of the participants head. This is a known issue with notational analysis, and illustrates the need for alternative data collection methods for this type of behaviour. In addition, notational analysis is typically time consuming (4), limiting the practicality of its use in research and applied settings.

The difference between the FPV and the IS was one head turn. Reviewing the FPV and IS data together clearly shows a major benefit of the use of IS units for the measurement of exploration. In the video footage, the participant appears to do a single head turn from right to left. However, as the participant turns from right to left, there is a slight pause which was not detected by the researchers. This pause causes two peaks in the IS data plot (Figure 1), and suggests the participant momentarily paused in order to perceive additional information, indicating two head movements. The IS was sensitive enough to pick up the pause, showing a major benefit in the use of IS units compared to current notational analysis methods.

CONCLUSIONS

The inertial sensor provides a more sensitive, accurate and user friendly method for detecting head movements associated with exploration in sport than has previously been utilised. Further development is recommended to fully validate and implement these units to assist with research investigating exploration behaviour in sport.

PRACTICAL APPLICATION

Monitoring the amount of exploration behaviour being utilised by athletes in training.
Using inertial sensors to encourage and develop exploration behaviour in training contexts.
Comparing the exploration behaviour of athletes within a team, enabling more informed training practices.

REFERENCES

Targeting Rio: Enhancing the Daily Training Environment in Archery Using Technology

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ABSTRACT

Skilled archers have demonstrated a greater ability to control their postural sway immediately before the arrow is released. This study examined the effect of training conditions on in-situ postural sway of elite archers. Three elite male archers shot 12 arrows at a regulation target while standing on a Tekscan Sports Balance Analyser. Data was collected in two conditions; standing on the ground; and standing on a raised platform. Postural sway was significantly higher in the anteroposterior direction when on the platform. The results highlight the need for athletes to replicate their competition environments in their daily training environments.

Keywords: Technology, Archery, Postural Sway, Centre of Pressure

INTRODUCTION

Archery is a sport that requires athletes to control their posture to ensure precise positioning of their limbs (and as an extension, the bow) for successful performances. \(^1\) Highly skilled archers have demonstrated a greater ability to control their postural sway, just prior to arrow release. \(^2\) Through measurement of their centre of pressure, this greater control has been linked to an improvement in shooting accuracy in elite archers. \(^3\)

With advances in technology, solutions are now available that permit measurement and recording of postural sway in the performance environment without imposing any restrictions on the athletes. Technology that allows for analysis in situ ensures that the performance characteristics being investigated are the same as or as close to those that occur in competition. \(^4\) It is crucial for skill acquisition that training for elite athletes replicates the performance environments in which they perform.

The aim of this project was to measure the postural control of Australia’s high performance archers using a mobile pressure sensor in-situ at training and to assess the effect of training conditions on postural sway.

METHODS

Three elite male archers with an average age of 23.3 ± 2.89 volunteered for this study. This study was completed as part of an applied sport project that falls under athlete scholarship agreements. These agreements cover athlete consent and involvement in applied sport servicing and research. Data collection took place in-situ. Participants were
required to shoot 12 arrows at an official target located at a distance of 70 m (Olympic distance) while standing on a Tekscan Sports Balance Analyzer (TekScan Incorporated). Centre of pressure (CoP) was recorded in two conditions: (1) standing on the ground as per a typical training session and (2) standing on a customised raised platform to replicate the competition environment expected in the Rio 2016 Olympics.

Centre of pressure data was analysed utilising the Tekscan Software Development Kit (SDK) to record and display centre of pressure. Postural sway was analysed in two directions: (1) anteroposterior (AP) and (2) mediolateral (ML). Total postural sway in each direction was measured by analysing the total excursion of the CoP during the shot. A series of independent samples t-tests were conducted to determine if postural sway differed between the two conditions.

**RESULTS**

The results on this study are displayed in Table 1. Condition 2 resulted in a significant increase in postural sway in both directions for the left foot (ML \(p = 0.027\); AP \(p = 0.001\)) but not the right foot. The results also demonstrated a significantly higher postural sway for the AP direction for the overall centre of pressure (\(p = 0.017\)).

**DISCUSSION**

The purpose of the current study was to assess the postural control of elite archers under two different conditions, in-situ. The Tekscan device and software allowed for accurate measurement of postural sway in the natural competition environment. The overall sway (not individual feet) measurements reported in this study are supported by similar values being reported in previous research \(^2\).

However one key inclusion in the current study was the differentiation of centre of pressure for each foot individually. As such we were able to demonstrate when shooting from a raised platform postural sway increased in the AP direction, but was unchanged in the ML directions. This could be a result of the platform increasing the difficulty of the archers detecting body sway by changing their proprioception on the ground. As the archers also stand quite close to the edge of the platform, it is possible that the drop in height had a subconscious effect on their postural control.

Previous literature has highlighted that arrow precision would be compromised by sway movements in the AP direction as this occurs parallel to the target face, ultimately shifting the arrow left and right of the target. \(^5\)

**CONCLUSION**

This study found that elite archers demonstrated greater postural sway in the anteroposterior direction but not the mediolateral direction while shooting from a raised platform that replicated competition. These results confirm the need to measure performance characteristics in-situ and replicate the competition environment in training to allow athletes to understand the constraints placed on them.
**PRACTICAL APPLICATIONS**

- Measurement of postural sway in-situ and potential biofeedback training
- Analysis of how postural sway changes with differing tasks or constraints
- Ability to link performance outcomes (accuracy) to postural control

**REFERENCES**

Active Drag Device for Resistance Training in the Pool

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ABSTRACT
Swimming resistance gear is aimed at conditioning competitive swimmers. As part of a training program, competitive swimmers are typically cycled through training strokes with elements of additional resistance to build strength, resilience and simulate fatigue. The challenge is to provide variable resistance levels within a single session, dependent on specific needs and training objectives. In this paper varied concepts were created that make use of remote wireless control systems and were compared in a criteria weighted Pugh Matrix. The winning concept, a tethered cone device, scored highly for its simplicity and cost. Although the product is initially aimed at elite athletes, it is likely that the design will have utility in recreational swimming and rehabilitation.

Keywords: drag, swimming, resistance training

Funding: This research is supported by a Seed grant from Griffith University, School of Engineering.

INTRODUCTION
Swimming resistance gear is aimed at conditioning competitive swimmers. As part of a training programme, competitive swimmers are typically cycled through training strokes with elements of additional resistance to build strength, resilience and simulate fatigue. In general the resistance gear can be broken into 3 categories:

1. Devices that connect the swimmer to the pool side; for example an elastic band.
2. Devices that attach to the swimmer and trail behind; for example a parachute or cone.
3. Devices that are worn to simply increase the swimmers overall drag; for example a drag suit, or hand paddles.

Studies have demonstrated that swimmers who receive high resistance training in the water have improved force, velocity and power outputs culminating in significant improvements in race times, especially in 50 – 200m sprints. However, despite some drag devices having resistances that can be adjusted before a training session, controlling the intensity of the exercise in the aquatic environment continues to be challenging. This has limited the application of drag devices for all users. The challenge is to not only maintain, but also reduce or increase resistance levels within a single session, dependent on specific needs and training objectives. This is important because fatigue often results in a loss of technique. If an athlete trains poorly, this may instil poor habits i.e. a situation to avoid. Therefore an ‘active’ drag device that can be controlled by the trainer at the pool side where resistance can be varied to reduce risk of bad habit formation.

Griffith University are undertaking a research and
development project to design, analyse, build and test a wireless operated active drag device. The project has several stages beginning with a conceptual design study to propose a viable design. The viable design will firstly be analysed using Computational Fluid Dynamics (CFD) to determine the drag characteristics followed by flume tank calibration. The final stage will be to test the device for swimmer comfort and performance.

**ACTIVE DRAG CONCEPTS**

Five varied concepts were developed by a team that included professional engineers, industrial designers, sports technologists and a swimming coach. The five concepts were:

1. **Inflatable cap** – a device worn on the head that can be inflated with water through a vascular system.
2. **Tethered propeller device** – a caged propeller concept that creates a thrust in the opposite direction to the swimmer. The level of drag can either be increased by increasing the speed of the propeller or by simply rotating the blades to change the angle of the oncoming flow. Reversing the thrust would turn it into an assist device.
3. **Overhead cable** – In this concept the swimmer is simply tethered to an overhead cable. The drag on the swimmer can be adjusted by clamping brushes on to the cable thus increasing the friction.
4. **Torpedo drone** – drone technology has matured in the past five years. In this concept an underwater drone is tethered to the swimmer and provides an opposing thrust. Similar to the Tethered propeller concept, the device could also be used as an assist device simply by having the drone moving in the same direction as the swimmer.
5. **Tethered cone** – this concept borrows from tethered passive devices that currently exist in the market. The significant difference is the ability of the drag device to change the level of drag on the swimmer without the swimmer having to stop. All these concepts can make use of remote wireless control systems. This will enable a coach to adjust the drag on the swimmer actively from the side of the pool or have autonomous control based on sensory feedback from the swimmer.

To compare the concepts a Pugh Matrix was developed by the team. This common decision making technique compares candidates against agreed weighted criteria. In order to decide which design concept to develop the candidate designs were scored out of 10 on their ability to meet the following criteria:

- **Price**: The lower the unit selling price, the greater the opportunities will be for penetration into the sports equipment market. Analysis shows that squad swimmers are prepared to spend up to $1000 for a swimsuit for performance improvement.
- **Unit cost**: The cost of manufacturing will depend on the ease of manufacturing, material costs and the component costs.
- **Transportability**: One person should be able to carry and install the device. No special fixtures should be needed at the pool for installation.
- **Stroke Mechanics**: The device should not interfere with the swimmer’s stroke action.
- **User comfort**: The device must be comfortable for the swimmer throughout a swimming set.
- **Turning**: The device must not impede the swimmer during tumble turns.
- **Controllability**: The level of resistance needs to be controlled from the pool side. Controllability is assessed by the range of imposed resistance, the number of resistance intervals and the reaction time.
- **Reliability**: The device must not break, tangle or be caught whilst in use and have a usage time of 20 minutes. The device must also be fully waterproof.
- **Aesthetics**: It is assumed that the more aesthetically pleasing the device is the more popular it will become in the market.
- **Safety**: The safety is concerned with the users and the environment around them. The device must not harm the user or the surrounding swimmers. Furthermore, safety precautions must be in place for devices involving electronic components.
Three criteria, nominated as critical to achieving the specified outcomes, were consequently awarded a weighting of 1.5x by the team.

**PRACTICAL APPLICATIONS**

Although the product is initially aimed at elite athletes, it is likely that a design with the intended features and price estimation of AU$250 will have commercial value as a training device in the wider recreational swimming market. In the USA alone there are an estimated 4,500,000 amateur swimmers. Aquatic rehabilitation has also been demonstrated to significantly improve muscle performance and endurance in people with low fitness, for early rehabilitation of injured athletes, for the elderly and suffers of arthritis and knee disorders. Active drag devices could play an important role in progressive hydrotherapy programs to apply controlled resistances safely for rehabilitation purposes.

**REFERENCES**


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