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# The Design, Construction and Assessment of a Sprint Kayaking Balance Training Aid

By

Benderi b. Dasril

A Doctoral Thesis

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# Abstract

The main purpose of this study was to develop and assess an on-land training aid for learning balance in sprint kayaking. The literature has shown the importance of biomechanical analysis and how training aids can provide a beneficial part in the learning process of new skills. An on-water experimental analysis was conducted on experienced paddlers to establish the kinematic characteristics and the centre of rotation position of the kayak-paddler system. From this analysis it was found that the kayak rolling motion is dependent on the paddler's ability and the centre of rotation of the kayak paddler system relative to the seat of the kayak was found to be between 10 cm – 13 cm above the seat. Findings from this analysis were interpreted into technical requirements and integrated into the design of the training aid. Once built the training aid prototype was evaluated by a series of testing and modification to enhance its ability to replicate the on-water kayak. The evaluation data showed that the stationary sprint kayak on-water medial-lateral rolling motion is affected by weight variations and further evaluation demonstrated that the training aid has the ability to replicate the motion for different weights. An experimental assessment on a group of beginners was carried out and the results showed that the training aid was able to facilitate the learning of balance in sprint kayaking. The experimental subjects who used the balance training aid had the same total number of sessions as the control subjects who learned to balance in the actual sprint kayak (experimental, 9 $\pm$ 1 sessions; control, 9 $\pm$ 1 sessions). However, the experimental subjects only spent half of the total number of sessions learning on-water (4 $\pm$ 1 sessions) and the other half on the training aid (5 $\pm$ 1 sessions).

*Key words: sprint kayak, training aid, balance, equipment design.*

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# Publications

## Conference Presentations

Dasril, B., King, M.A. and Yeadon, M.R. 2011. "Centre of rotation for sprint kayak medial-lateral (rolling) balancing motion". *Proceeding of the 26th Biomechanics Interest Group of the British Association of Sport and Exercise Sciences*: 2011, pp 24.

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# Chapter 1

# Introduction

## 1.1 Chapter overview

This chapter presents an overview of balance in sprint kayaking. Also included in this chapter are the statement of purpose and specific research questions. To provide an overview of the structure of this thesis, the organisation of chapters is described.

## 1.2 Background of study

Sprint kayak primary design considerations are acceleration and maximum speed (Szanto & Henderson, 2004). For these reasons sprint kayaks are built relatively long, narrow and lightweight. A long and narrow cross-section of the kayak results in instability but provides greater speed while a short and wide kayak tends to be more stable and slower. The speed and acceleration of the kayak moving over water is a function of the force of the paddling, and the effect of the drag/friction created against the hull of the kayak as it passes through the water. The greater the drag, the more power is required to move the kayak at the same speed. However the International Canoe Federation has established and enforced rules for kayak design to create an equal opportunity and to ensure that the athletes determine the outcome of competition, not the design of the kayak (Szanto & Henderson, 2004).

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In sprint kayaking, appropriate balance and orientation of body segments are extremely important in maintaining an upright position while sitting on a long, narrow and unstable sprint kayak (McKean & Burkett, 2010; Michael et al., 2009; Ralph & Jay, 1980). Balance and postural control allows the paddler to stay upright on a rippled water surface or in a strong head wind. From the beginning of their training, paddlers learn to coordinate segment movements to enable the necessary dynamic changes of the body in order to stabilise the sprint boat while in a stationary position (Vescovi et al., 2011b). In view of this, balance and postural control ability can be considered as an important basic skill which must be acquired by a beginner paddler before any other basic skills are learned. Nevertheless, the balance skill gained will facilitate the learning process of other required skills in sprint kayaking.

In explaining the importance of balance in kayaking, the most significant requirement is to minimise the medial-lateral rolling motion of the kayak about its longitudinal (X) axis and to prevent the risk of the kayak being capsized in the water (Baker, 2012). Furthermore, a split second of off-balance motion during the start of a race can have a significant effect on the kayak initial velocity and efficiency of the starting stroke. However, kayak capsizing during competition does happen, so stabilisation and balance control ability is an issue for skilful as well as unskilled paddlers.

In order to fulfil this balance demand, there are a few training approaches that have been practised by coaches and paddlers. By far the most common practice in balance training is repetition training (Vescovi et al., 2011a). This approach

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requires more training time in the sprint kayak, enabling the paddler to learn to utilise the required balance control mechanisms. The other method of training requires several progressive learning stages (Edwards, 2005). In the beginning, paddlers are introduced to a more stable kayak and only the hands are used as a stabilising mechanism. After the paddler becomes comfortable with the kayak the paddle is introduced. Otherwise, if the athlete is unable to control the balance, the kayak centre of gravity is lowered by adding weight or filling the kayak with water. Both of these conventional methods of training are dependent on the individual's capabilities to integrate the complex interaction of balance control mechanisms. Furthermore, it is time-consuming and the possibility of capsizing can lead to high drop-out rates.

Currently there is no specific commercial balance training aid for sprint kayaking. A few concept balance training aids have been introduced by individuals and coaches, but their functionality is still in question. A stability ball has also been used as have a couple of commercially available balance simulator devices: the Dansprint Balance (Figure 1-1) and Landkayak Dynamic Balance (Figure 1-2). According to the manufacturer, both of these innovations are designed to optimise on-land training by incorporating the actual degree of roll during on water paddling (Dansprint, 2012; Landkayak Dynamic Balance, 2012). Interestingly, the writer has not found a single publication that has investigated these balance devices; and doubts have been raised over their utility as a training aid for balance performance because of a fixed medial-lateral rolling centre of rotation. This feature may not be applicable to all athletes of different sizes and abilities. This particular problem is the motivation for this study: to develop and

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evaluate a balance training aid that can simulate the real medial-lateral angular (rolling) movement of the kayak.

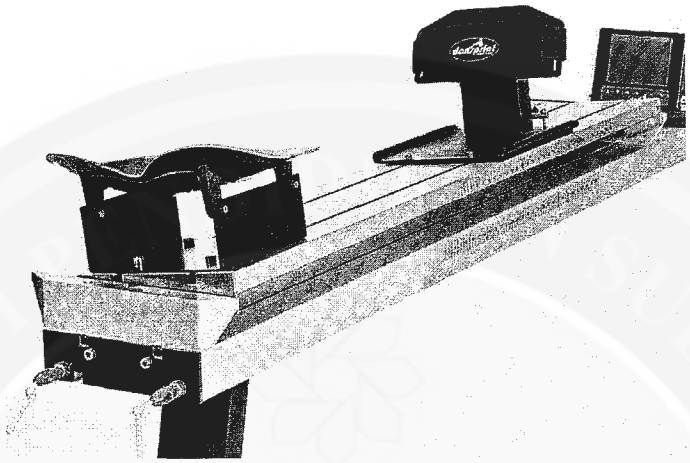


Figure 1-1: Dansprint Balance (adapted from www.dansprint.com).

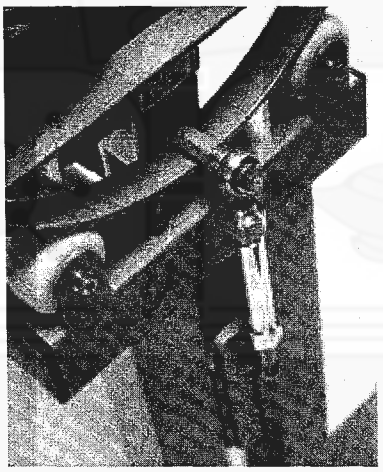


Figure 1-2: Dynamic Balance (adapted from www.landkayak.co.uk).

## 1.3 Statement of purpose

The purpose of this study is to develop and assess an on-land balance training aid for sprint kayaking.

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## 1.4 Research question

**Question 1:-** *What are the characteristics of on-water kayak-paddler motion and where is the centre of rotation of the kayak-paddler system relative to the seat of the kayak?*

In order to design a suitable and reliable sprint kayak balance training aid, the fundamental kinematic characteristic of the kayak and the paddler motion during on-water balancing need to be established. It has been determined that the medial-lateral rolling motion has the greatest effects on the kayak balance and stability (Baker, 2012; Michael et al., 2009). Two dimensional motion analysis is the most appropriate method used to determine the on-water kayak-paddler motion characteristic and the optimal centre of rotation height relative to the seat of the kayak.

**Question 2**:- *Is the on-water kayak rolling motion affected by weight variations?*

The sprint kayak balance training aid should be able to accommodate a wide range of paddler's size and weight. Therefore, further analysis on the kayak medial-lateral rolling motion with additional weight variations is conducted to validate the effects.

**Question 3**:- *Can the sprint kayak balance training aid prototype replicate the medial-lateral rolling motion of the stationary sprint kayak?*

A training aid should simplify the movement task by permitting individual degree of freedom and should successfully fulfil all identified requirements (Yeadon et al., 2012). Moreover, it should replicate the motion of the task in its real environment.

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Therefore, in-depth evaluation of the prototype sprint kayak balance training aid should provide more information on its reliability.

**Question 4**:- *Does the sprint kayak balance training aid facilitate the learning of balance for a beginner paddler?*

An experimental assessment enables the researcher to determine the functionality of the prototype sprint kayak balance training aid. A balance training programme is administered to complete beginners using the training aid and compared with on-water training using the same programme.

## 1.5 Chapter organisation

Chapter 2: Literature review

This chapter will discuss details of relevant reviewed literature. It also contains several topics which are considered important in the development process of sprint kayak balance training aids. The chapter also provide information specifically related to this study.

Chapter 3: On-water analysis of stationary sprint kayak.

The purpose of this chapter is to establish scientific information on stationary sprint kayak on-water motions during balancing. The information gained will be integrated into the design of the balance training aid.

Chapter 4: Sprint kayak balance training aid design and construction.

This chapter discusses in detail the design procedure undertaken during the development of the sprint kayak balance training aid. An experimental evaluation

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is conducted to establish a significant relationship between the kayak balance training aid and on-water sprint kayak oscillation parameters.

Chapter 5: Sprint kayak balance training aid prototype evaluation.

An experimental evaluation is conducted to establish a significant relationship between the kayak balance training aid and on-water sprint kayak oscillation parameters.

Chapter 6: Sprint kayak balance training aid assessment.

An experimental assessment of the kayak balance training aid performance in training balance for beginner paddlers is discussed in detail. A quantitative comparison between data collected from a control group and an experimental group is analysed and discussed.

Chapter 7: General summary and conclusions.

Summary of the findings and results from the previous chapters, and how this can be applied to answer the research questions outlined in the first chapter. Conclusions on the suitability of the kayak balance training aid and how the research could be furthered for future work.

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# Chapter 2

# Literature Review

## 2.1 Chapter overview

In the first section of this chapter the current literature related to the development process of a new product or prototype is reviewed. In the next section the review will introduce the balance training aid used for sprint kayaking. Balance control research, biomechanical research on kayaking and experimental techniques related to this study will also be discussed within this chapter.

## 2.2 Review on development process of new product and prototype

A product development process is defined as a sequence of steps or activities of planning, designing and commercialising a product (Ulrich & Eppinger, 2012). However, product development can also be regarded as comprising three phases; (1) product planning, (2) product design and (3) product realisation (Cross, 2008). The generic model of product development process consists of six phases, as shows in Figure 2-1.

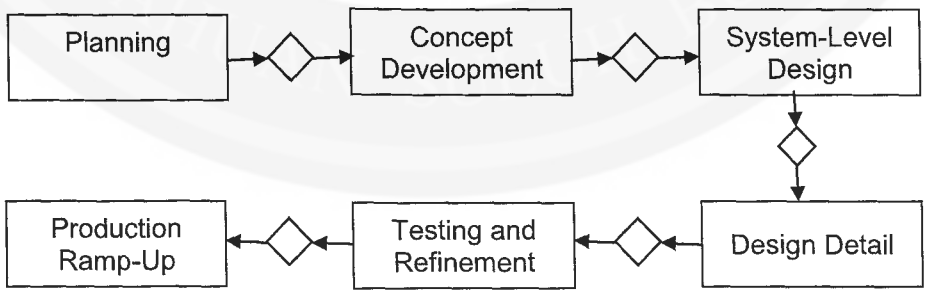



Figure 2-1: The generic product development process (adapted from Ulrich and Eppinger, 2012).

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According to the given definitions and the above model, the design process is a part of the product development process and both need to be closely related to each other to enable an efficient production of a new product or prototype. The key role of design in the overall process of product development is shown in Figure 2-2, adapted from British Standard BS 7000 'Guide to Managing Product Design' (Cross, 2008).

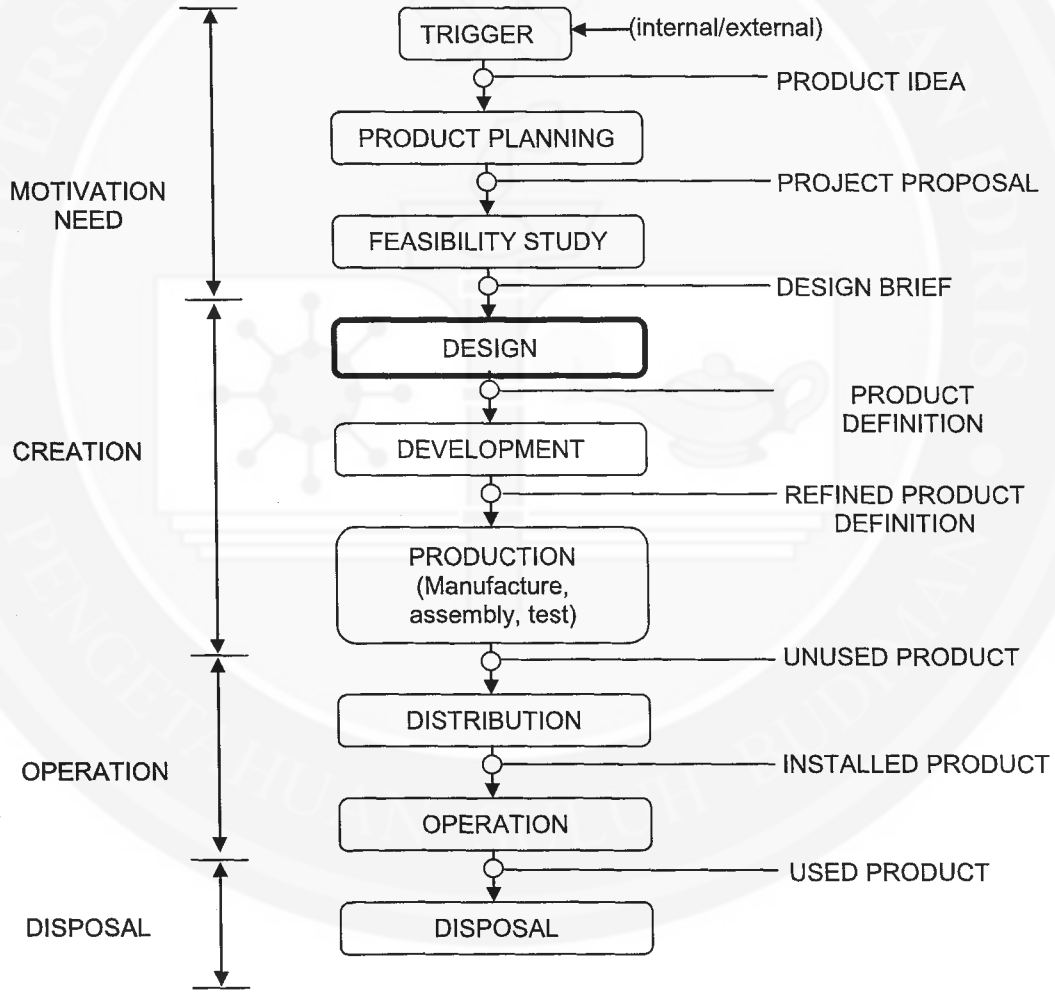



Figure 2-2: Product development process according to BS 7000 (adapted from Cross, 2008).

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### 2.2.1 Design process

The process of designing a product is defined as the transformation of information from the condition of needs, demands, requirements, objectives and constraints into the description of a product (a prototype) which is capable of fulfilling these conditions (Wright, 1998). The design process has been described and explained by various models (Ulrich & Eppinger, 2012; Cross, 2008; Wright, 1998; Pugh, 1991). These models are primarily focused at describing and prescribing the complex process of design activity. A simple descriptive model of the design process consists of only four stages: (1) exploration; (2) generation; (3) evaluation; and (4) communication (Figure 2-3, Cross, 2008).

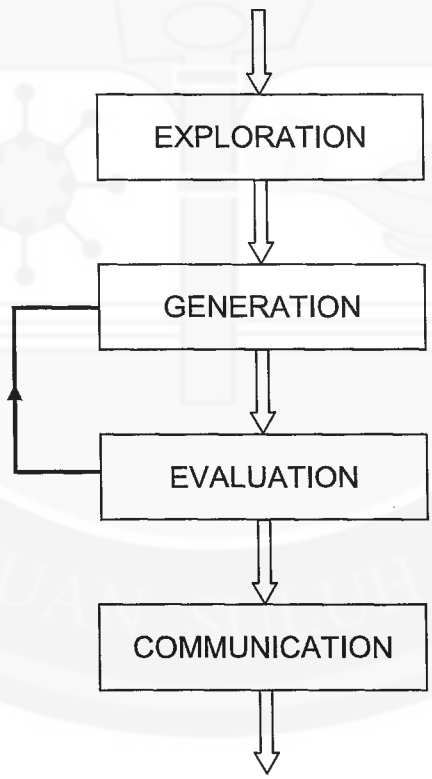



Figure 2-3: A simple four-stage model of design process (adapted from Cross, 2008).

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The initial exploration stage of the model is the most essential component of the design process and product development (Cross, 2008). To increase the chances for an effective and economically successful product, it is important that all significant needs and requirements are identified at the early stages of the process. The needs and requirements of product design are usually stated and communicated through product design specification (Wright, 1998). In general, each need or requirement of a design is stated as a quantified short description with a value and a metric known as a constraint. However, some design needs and requirements are difficult to quantify, and can only be seen as objectives (Ulrich & Eppinger, 2012). A requirement tree can provide a means of 'thought ordering' for an individual designer working alone. It also provides a means of communicating objectives and constraints to other designers (Wright, 1998). Furthermore, it is important to validate the established specifications during the exploration stage in order to ensure that the design process is based on the most relevant needs and most current information as possible.

The next stage of the design process is about solving problems and finding solutions by the generation of ideas and initiation of concepts. The process of generating new ideas and promising solutions is relatively straightforward, but in some situations it may need creativity as well (Cross, 2008). The most common ways to ensure that the ideas and solutions are totally explored in a creative manner are methods such as morphology, brainstorming and analogies (Ulrich & Eppinger, 2012; Cross, 2008; Wright, 1998; Pugh, 1991). At this stage the designer is thinking of many aspects together, such as materials, components, structure, functions and constructions (Cross, 2008).

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In the previous stage, drawing is the key feature in proposing solutions or the design process. Even in the evaluation stage the drawing is important before deciding on a final design for manufacture (Cross, 2008). Careful evaluation of a proposed design drawing is important to identify and assess feasible solutions that balance all applicable requirements. The purpose of having the design process separated from the construction process is that the proposals or drawings for new products can be evaluated and checked before they are put into production (Cross, 2008).

The final stage of the design process is the production of a final description of the product. This description should be communicated in a form that is understandable to those who will make the product. These descriptions will range from a rather general overview of the product, such as plans, elevations and arrangement drawing; to the most specific, such as sections and details on how the product is to be made (Cross, 2008).

Another simple diagrammatic model of the various stages that a product goes through during its design is represented in Figure 2-4. The stages are depicted as a linear sequence of events and the initial part of the process is based on a determination of needs and user requirements (Wright, 1998).

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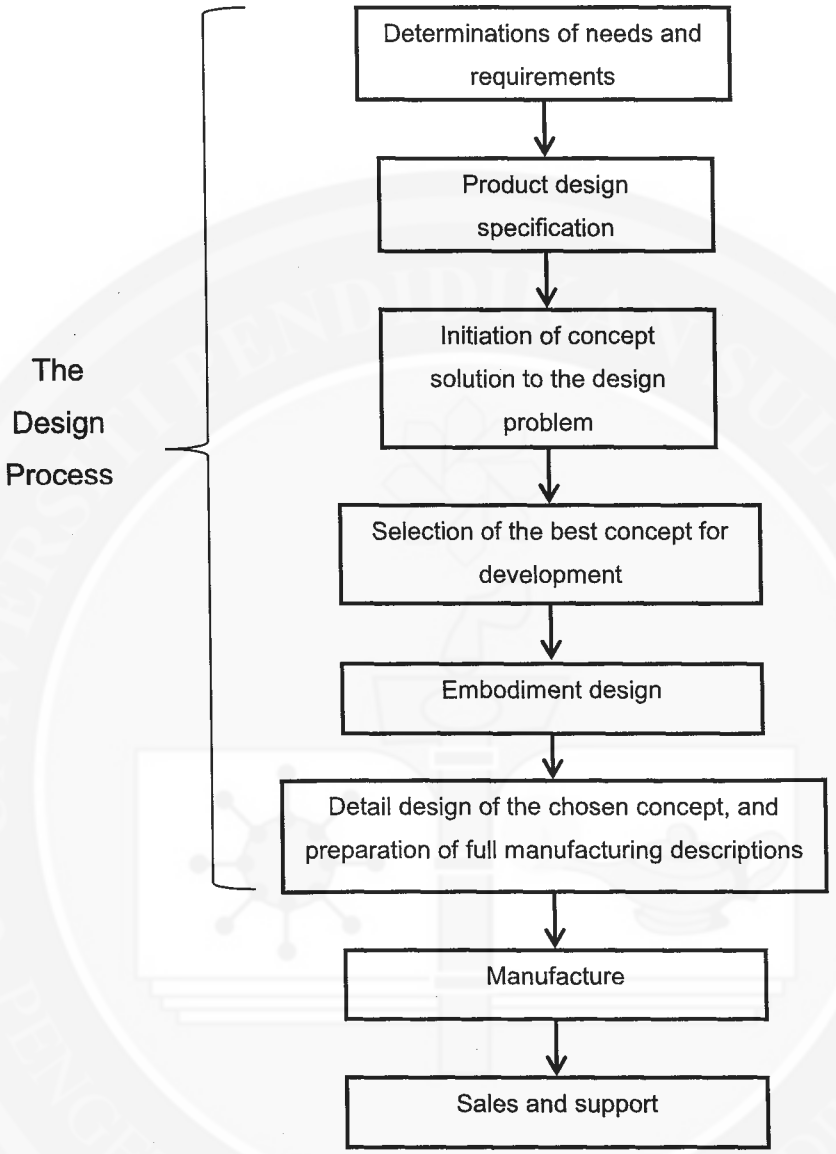



Figure 2-4: The design process as a linear activity (adapted from Wright, 1998).

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### 2.2.2 Design method

Design method can be considered as any identifiable systematic way, working within the context of designing process (Cross, 2008). The introduction of design method is to take advantage of previous experiences on design work in achieving better solutions. By using the design method effective communications and interactions between individuals involved in the design of product can be encouraged (Wright, 1998). Generally, the benefit of using a structured design method in the product development process is to uphold a 'keep-it-simple, keep-control' approach and adapting the methods according to the context within which they are applied (Wright, 1998).

### 2.2.3 Biomechanical considerations in the product design process

Research in sports biomechanics has the ultimate potential to build an understanding of causal mechanisms in terms of the kinematics and kinetics of selected movements (Elliott, 1999). In the successful design of sports equipment, however, it has been proposed that end user feedback implementation (Gros, 1999). This should form a continuous process from the beginning of the project through to manufacturing and testing of the product as well.

The design process of sports equipment should take into account biomechanical principles, understanding of injury mechanisms and human tolerance. Furthermore, the biomechanical characteristics of a product should be largely transparent to the user (McIntosh, 2012). Unfortunately, this has not been the case, leaving users unable to determine if marketing claims for "improvement" in

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equipment design were truly biomechanical innovation or just creative marketing strategies (Knudson, 2007).

A product design strategy for a gymnastic handstand on rings training aid was developed by combining specific expert knowledge, alongside a biomechanical analysis of skill and other developmental needs (Yeadon et al., 2012). The biomechanical approach was also used to compare the mechanics of the handstand by a competitive gymnast on the new developed prototype training aid with that on the ring, floor, and two other existing training aids.

In kayaking biomechanical research, a balance device (Figure 2-5) has been purposely developed to simulate both the sliding and rotational movement, with the combination of a real paddling condition (Wei-Hua et al., 2005). The study concluded that the balance device is an appropriate instrument to assist in the kinematic and kinetic analysis of kayaking stroke mechanics. However, their reports did not provide the overall biomechanical results of the particular function analysis.

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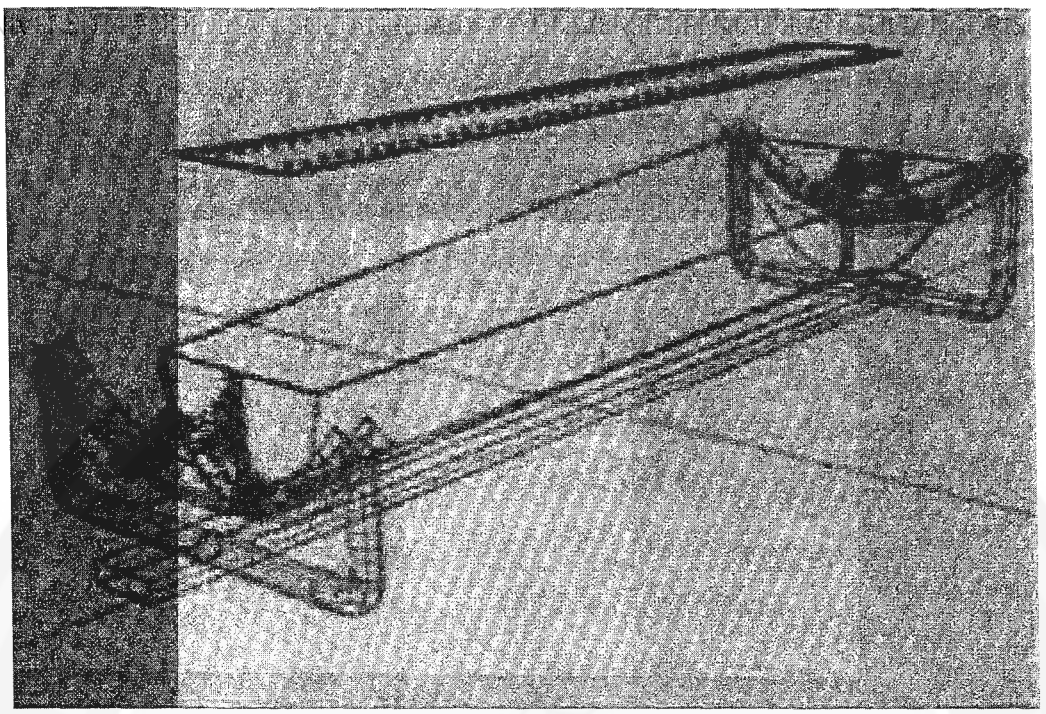


Figure 2-5: Canoe and kayak balance device design chart (Wei-Hua et al., 2005).

Another study introduced a kayaking ergometer (Figure 2-6) with a specially built sliding trolley that can slide forwards and backwards along the static frame of the ergometer (Begon et al., 2009). This ergometer was instrumented with uni-axial piezoelectric sensors to measure contact forces between the athlete and the ergometer (through the foot-brace and the seat). Load cells were connected to the paddle to measure paddle tip forces during paddling and kinematic data was captured using six infrared cameras. This study showed that their on-land kayak training system was suitable in assessing inter-athlete variability such as pelvis rotation combined with measurement of forces applied to the foot-brace and the seat of the kayak.

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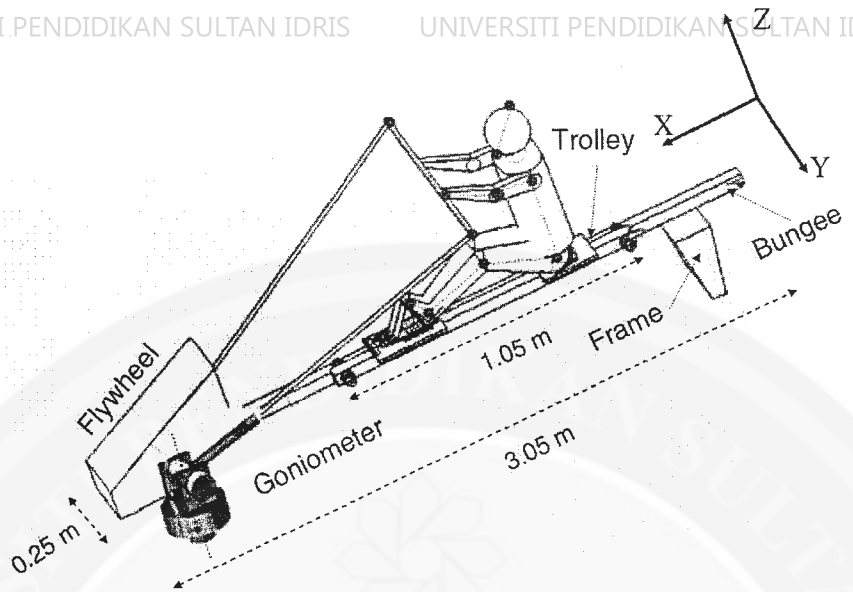



Figure 2-6: Dimensions of kayaking ergometer with the sliding trolley device (adapted from Begon et al., 2009).

## 2.3 Review on balance training aid for sprint kayaking

Balance is the most basic skill required for sprint kayaking. The progression to other essential skills is not possible until a proper balance in the sprint boat is achieved. There was no existing literature discussing a specific balance training aid used in sprint kayaking. Hence, the review is focused on the current practice and experience of the researcher. The common practice of balance training has been discussed earlier in Chapter 1. However, there are several different training aids used to train the balance skill for sprint kayaking. The first to be discussed is the most commonly used piece of equipment to practice balance, the stability ball (Figure 2-7). The ball allows movement in all planes and has a high degree of difficulty.

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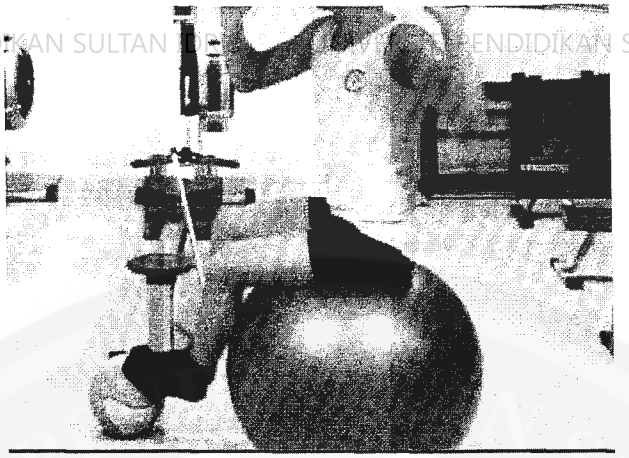


Figure 2-7: Sprint kayak balance training using stability ball.
(Adapted from https://www.youtube.com/watch?v=ko4hKQJ39Fw&list).

The next training aid introduced a single degree of medial-lateral movement and is based on a rocker mechanism (Figure 2-8). Although this training aid had the same rolling movement as a kayak, the centre of rotation was fixed depending on the diameter of the rocker.



Figure 2-8: Sprint kayak balance training using a rocker wood.
(Adapted from https://www.youtube.com/watch?v=9azAGIyTNKY&list).

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## 2.4 Review on balance control

To be able to achieve good balance control in sprint kayaking, the weight centre should remain vertically above the base of support or the seat of the kayak. Balance control in sprint kayaking involves a single plane of movement and can be considered as not overly complicated. However, the unstable water support and the complex interaction of forces acting on the athlete-kayak system may pose a great challenge to postural balance (Stambolieva et al., 2011). There is no such literature existing in explaining the mechanics of balance control in sprint kayaking. For the purpose of this review, activities such as stationary stance and unstable sitting, which have similar control technique, are discussed.

Maintenance of upright stance during different environmental and support conditions is critically dependent on adequate sensory integration and reweighting of information from the visual, vestibular and somatosensory inputs (Horak, 2006; Massion, 1998). Body orientation and movement related to the environment is monitored by the visual system. The vestibular system provides information about the position, linear and angular acceleration of the head. The somatosensory system provides information concerning movement of body segments with reference to each other and relative to the environment (Winter et al., 1990).

In relating the postural control of quiet stance to balance control ability of paddlers a study was conducted by (Stambolieva et al., 2011). The most interesting finding of this study was that the kayak athletes had greater amplitude of postural sway, both in sagittal and frontal planes compared to the untrained

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subjects, while standing on a stable support with eyes open. However, the athletes had lower amplitudes of sway than the untrained subjects in both planes when the support condition was changed from stable to unstable. This evidence suggests that the paddlers are able to maintain their standing balance control strategy regardless of the support features, and can be considered as an adaptation to their sport-specific environment.

Maintaining the sitting posture in kayaking requires continuous compensation for perturbations to the upper body by motion of the kayak and the paddle on water. Based on this description a study was conducted to compare sitting balance control in paraplegic and able-bodied individuals and evaluate the effects of kayak training on sitting balance in a group of paraplegic participants (Anatoli et al., 2004). This study revealed that large differences were present in balance control variables during quiet sitting between the paraplegic and able-bodied group. Evidently, this study has proven that the strategies for balance in kayaking require the function of the legs and the trunk.

Studies on balance control during sitting have been conducted by many researchers (Thrasher et al., 2010; Slota et al., 2008; Preuss et al., 2005; Cholewicki et al., 2000; Zedka et al., 1998; Forssberg & Hirschfeld, 1994b). However, these studies have focused on the function and control of segments in the sagittal plane rather than the frontal plane.

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## 2.5 On-land kayaking biomechanical research review

In biomechanics and physiology research, on-land kayak training devices or ergometers have been widely used, because they can provide unsophisticated, cheap and standardised procedures in a controllable environment (Rodano et al., 2001). On-land kayak training devices have been used in kayaking and canoeing research since the early 70's (van Someren et al., 2000; Pyke et al., 1973). During that period, researchers modified a cycling ergometer for testing and analysing physiological parameters of kayaking athletes (Holt et al., 1980; Pyke et al., 1973). This modified ergometer was able to determine physiological characteristics of the activity with high reliability, but did not simulate the real kinematics of paddling motions. However, their work signified an early contribution to the recent design of a specific on-land kayak training device and they were among the pioneers to highlight the limitation of arm crank ergometry usage in earlier kayaking research.

The evolution of on-land kayak training device research became more specific when a number of researchers (Campagna et al., 1986; Campagna et al., 1982; Dal & Leonardi, 1976) introduced an on-land kayak training device which had similar stroke patterns and physiological parameters to on-water paddling. There were limitations in their findings, where the relationship between the athlete's body and paddle positioning differed to the on-water paddling. In other words, during a complete cycle of on-water paddling the athlete's body moves past the paddle whereas for their on-land kayak training device the paddle was pulled past the athlete's body. Moreover, the trunk motions during on-land kayak training device paddling were not comparable to the trunk extension movement observed

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for the on-water paddling. The reason for this difference was due to the resistance wheel system embedded in the on-land kayak training device, and it tended to influence the on-water paddling mechanics. Further development and research of an on-land kayak training device system was done by a group of researchers from University of Ottawa, Canada (Stothart et al., 1986). They introduced a system which had similar capability to the on-water telemetric system including stroke timing, force rate, peak force, and additionally provided data on work output and power.

A specifically designed on-land kayak training device equipped with a lateral oscillation effects mobile carriage was used to investigate which kinematic variables influence performance of elite, intermediate and novice paddlers (Rodano et al., 2001). Side-to-side kinematic asymmetries were measured by analysing the simultaneous right and left motions of the selected segments and the on-land kayak training device seat. It was reported that the lateral oscillation was more pronounced in the intermediate group than in the novice group. Additionally, through examining the angular movement of the seat and the pelvis in the frontal plane, paddlers can be characterized as elite (with lower range of motion) and novice (with higher range of motion) respectively. However, no further technical explanation on the mechanics of the side oscillating mobile carriage were provided, but it was claimed that this device was capable of simulating a highly realistic paddling sensation.

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More recently, a study has integrated a motion capture system to determine the paddle trajectory pathway, body motion and forces developed by elite female Olympic kayak athletes while paddling in an on-land kayak training device (Petrone et al., 2006). Two different seats were used and compared: the normal fixed seat and special vertical axis rotating seat. The main finding of this study indicated that the rotating seat generally induced a higher force production on the foot-brace by increasing the knees range of motion. However an asymmetrical paddling trajectory and knee angle between right and left side still existed when using either a fixed seat or a rotating seat.

There have also been efforts made by researcher to test the validity of on-land kayak training devices, by comparison with on-water paddling. Begon et al. (2008) proposed a 3D kinematic technique to compare the paddling motion on an outfitted back and forth sliding trolley on-land kayak training device with on-water paddling in an indoor paddling tank. The comparison was only based on movement timing and joint kinematics of the upper body segments (the lower body segments were hidden inside the kayak cockpit). The main finding of this study with regards to joint kinematics was the difference in shoulder frontal planes trajectories, because of the non-existence of medial-lateral rotation component in ergometer paddling. This result showed how important it is to have a more reliable effect of medial-lateral rolling in improving the relevance of kinematic studies.

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## 2.6 Technique of investigation

The following section reviews the available techniques of investigation for pursuing this research study.

### 2.6.1 Motion analysis system

Imaging or motion-caption systems are the most popular techniques used to record the motion of a markers affixed to an object or a human subject (Robertson et al., 2004). These recorded motions are then digitised either manually or automatically to acquire the markers' coordinates, followed by mathematical data processing to obtain kinematic variables that characterise movements. The most common imaging or motion-caption system used in biomechanics to obtain time histories of various body markers during athletics performance has been video recording (digital video camera or high speed video camera) and automatic motion capture system (Vicon$^{TM}$). The following subsections describe the motion analysis system used in each experimental section conducted within this research.

#### *2.6.1.1 Video recording motion analysis*

Video recording is a sampling process: the movement is captured for a period of time and the number of pictures taken per second is called the 'sampling rate' or 'sampling frequency' (Bartlett, 2007). This will correspond to the frame rate or field rate during the recording stage of movement analysis. Therefore, the essential components and equipment needed for the video sampling process are: the image capturing device; recording and storage device; playback or viewing

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system; coordinate digitiser; and finally the processing software to quantify selected parameters of the movement (Payton, 2008). Commonly, the components and equipment listed above can be used either with two-dimensional or three-dimensional motion analysis techniques. However, both techniques have certain advantages and disadvantages which must be taken into consideration when making decisions on which technique is to be used.

Two-dimensional techniques use one camera to capture movements that are essentially planar in nature, where the plane of motion is perpendicular to the optical axis of the camera (Grimshaw et al., 2007). The technique of recording and analysis is simple, conceptually easier to relate to and requires less equipment. Furthermore, there is less digitising time and fewer methodological problems (Bartlett, 2007). A sufficient sampling rate or frame rate should be used depending on the signal frequency of the movement of interest. The Nyquist sampling theorem requires that the sampling frequency is at least twice the maximum frequency in the signal (not frequency of interest) to avoid aliasing. For example: 25 Hz is adequate for swimming; 50 Hz adequate for tennis serve (not ball impact); 100 Hz is needed for fast movement such as golf swing (Bartlett, 2007). Aliasing is a phenomenon seen in films when wheels of a moving vehicles appear to revolve backwards (Bartlett, 2007) Two-dimensional analysis can produce reasonable results for essentially planar movements but movements outside the plane are ignored and this may result in inaccurate findings (Yeadon & Challis, 1994).

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To provide an accurate and meaningful video footage the camera used in video motion analysis must be positioned, zoomed and focused properly. Furthermore the field of view or capture volume must also be calibrated. This is achieved by placing an object of known length in the same plane as the movement to be analysed and then digitising its ends or marked locations. In two dimensional video analyses the total number of pixels measured between the two ends or marked location could be related to the object's length to provide a calibration coefficient. The calibration is performed in both horizontal and vertical directions as the resolutions are not always similar in both axes.

Three-dimensional video analysis has more complex experimental procedures, but it can reveal the participant's true movements (Grimshaw et al., 2007). Nonetheless, it allows parameters to be calculated accurately, without viewing distortions and enables the reconstruction of simulated views of the performance (e.g. stick figures). Consequently, it requires more expensive equipment and increased computational complexity (e.g. synchronisation and reconstruction). The most common reconstruction technique used in three dimensional vide motion analysis is the Direct Linear Transformation (DLT) technique (Abdel-Aziz & Karara, 1971)

Generally, procedures used for two-dimensional or three-dimensional video analysis are different in nature, therefore there are largely dealt with separately (Grimshaw et al., 2007). However, in this research only the two dimensional video recording motion analysis was used.

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*2.6.1.2 Automatic motion analysis system (Vicon)*

The main limitation of video analysis is the vast amount of manual coordinate digitisation (Bartlett, 2007). However to overcome this drawback, a motion analysis system that can automatically track the location of markers attached to the body was developed. The Vicon system consists of hardware (cameras etc.) and software applications for the complete control and analysis of real-time and offline motion captures (Peter et al., 2002). A typical Vicon motion capture space comprises of a capture volume area surrounded by a number of high resolution cameras (Figure 2-9). Each camera has a strobe unit ring that emits flashes of near infrared light, illuminating retro-reflective markers attached at well-defined locations on the subject. The reflected light from the marker is captured by the camera lens and strikes a light sensitive plate in the camera which creates a video signal. The signals are collected by the system data station and passed to a computer on which the Vicon software suite is installed. The software known as the Nexus processes the raw video data. Two-dimensional data from each camera is combined with calibrated data to reconstruct the equivalent digital motion in three-dimensions. This reconstructed data is passed to other Vicon or third party applications (Microsoft Excel or Matlab) for further analysis and manipulation (Peter et al., 2002).

The calibration process for the Vicon Nexus system is important to determine the accuracy of the reconstruction process. The calibration consists of a dynamic and static component. The dynamic calibration tracks the movement of calibration wand (3-marker or 5-marker) and produced a camera residual which measures the accuracy of the system as a function of the individual accuracies in each

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camera. Residual of each camera is the root means squares value of the distance between two infrared light rays and expressed in pixels. The first light ray is from the centre of the strobe ring to the centroid of the marker while the second is the reflection of the light ray from the marker to the camera lens. The overall mean residual is then calculated as the mean of all camera residuals. For an accurate reconstruction of a capture volume, Vicon recommends that camera calibration residuals need to have a maximum error of 2.0 mm or less. The static calibration sets the origin and axis orientation for the capture volume by locating either a static L-frame or T-frame consisting of multiple markers at known distances apart.

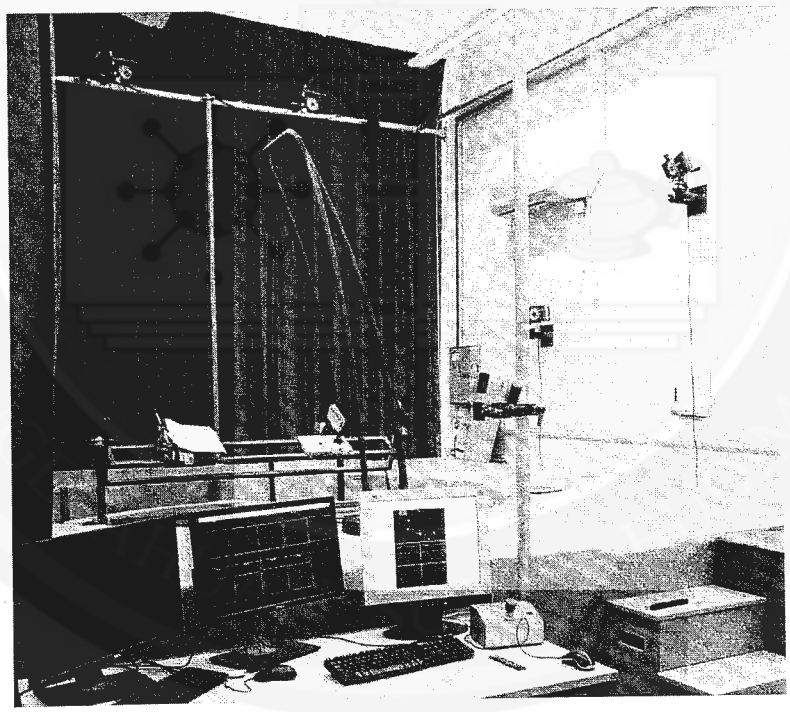


Figure 2-9: A view of the Vicon system experimental set-up.

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### 2.6.2 Smoothing and filtering technique for motion data

There are various smoothing and filtering methods used to eliminate the high frequency errors or noise introduced in motion data sets (Bartlett, 2007). These numerical methods involve mathematical functions to represent the motion data and can be categories into three main techniques which are digital low-pass filters, Fourier series truncation and spline fitting (smoothing). Noise removal for three-dimensional studies is normally performed after data reconstruction, and should also be performed before calculating any kinematic variables. Data smoothing technique used in this research is a low-pass Butterworth digital filter with a cut-off frequency determined using the residual analysis (Winter, 2009).

### 2.6.3 Residual analysis

The residual analysis is used in the field of biomechanics to determine the optimal cut-off frequency for a signal band without distorting the desired signals too much (Winter, 2009). The method consists of low-pass filtering the signal with different cut-off frequencies and calculating the residuals, i.e. what is left over when the filtered signal is subtracted from the raw signal. The residual should be rather small as long as the filter is only reducing the noise. However, residuals become larger when the filter starts to reduce the desired signal. By administering this analysis for several cut-off frequencies, and plotting the resulting residuals, the overall picture of effect is shown. This plot can then serve as the basis for determining a reasonable cut-off frequency (Winter, 2009). However, many researchers tend to use previously published values by assuming the similarity and appropriateness of the studies.

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### 2.6.4 Simulated annealing optimisation algorithm

As a part of combinatorial optimisation, simulated annealing origins are in thermodynamics. It models the physical process of heating a material and then slowly lowering the temperature (annealing) to decrease defects, thus minimising the system energy. Similarly the simulated annealing algorithm attempts to minimise some analogue of energy in the annealing process to find the optimum global minimum (Goffe et al., 1994). This method performs well in the presence of a very large number of variables (Corana et al., 1987). The simulated annealing algorithm is based on random evaluations of the cost function, in such a way that transitions out of a local minimum are possible. Although finding the global minimum is not assured, it still can figure out if the assessed function has a lot of near-optimal values. Specifically, it has the ability to distinguish between gross and detailed behaviour of the function. Operationally, it begins within an area in the function where the existing global minimum should be, and following the gross behaviour irrespective of small local minima found along the way. Then it develops finer detail before finding a good, near optimal local, or possibly global, minimum. This process is illustrated in Figure 2-9.

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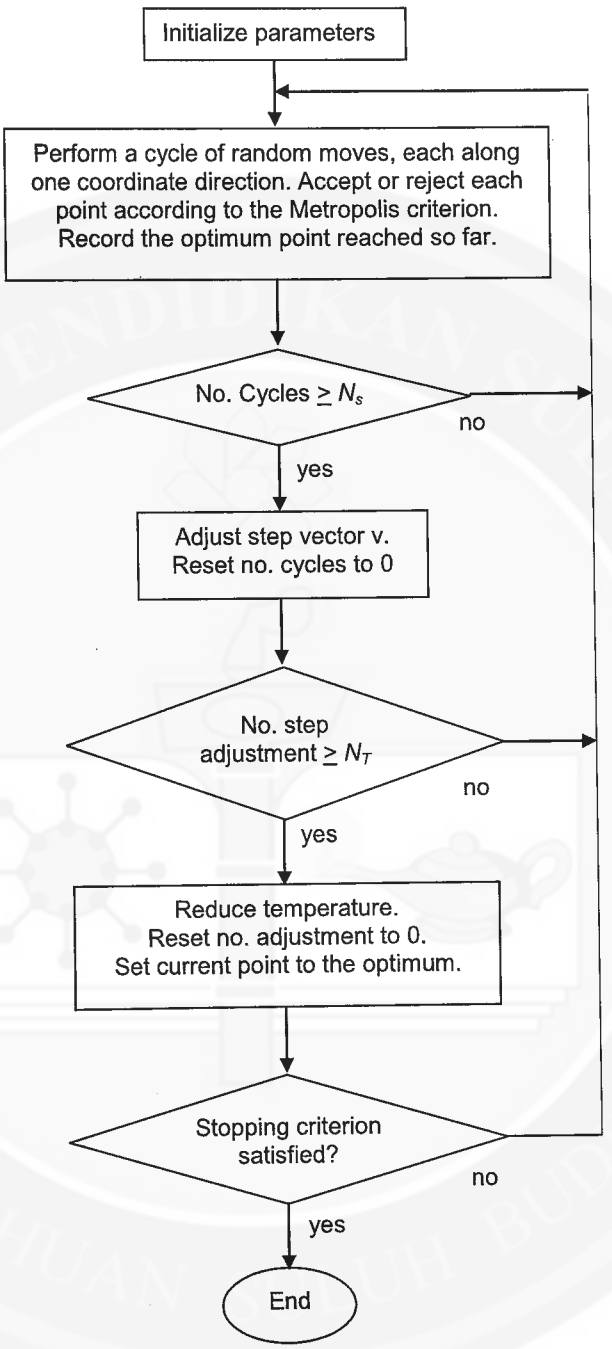



Figure 2-10: Simulated Annealing optimization algorithm (adapted from Corona et al., 1987).

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Simulated annealing has been used to investigate the contribution of knee motion in improving the termination of total body centre of mass forward movement (Iqbal & Pai, 2000). This study demonstrated the potential of numerical analysis particularly using the simulated annealing algorithm, in analysing and synthesising a complex multi-segmental postural and voluntary balance control motion. In order to develop individual human models and to derive the resultant lower limb joint moments the simulated annealing optimisation routine is used together with inverse dynamics formulation to study the reactive stability control following unexpected slip during gait (Yang & Pai, 2010).

It was also alternatively possible to use simulated annealing to achieve faster optimisation techniques for estimating centre of rotation of marker positions for two body segments motions (Ehrig et al., 2006). In their study, they analysed and compared eleven methods for the determination of spherical joint centres from marker position data. Furthermore, a new technique for robotic inverse kinematics has used simulated annealing by implementing a multi-objective cost function to find intermediate angles for the transitional points of a trajectory (Dutra et al., 2008).

## 2.7 Chapter summary

The literature has highlighted the general design process that will aid in the success of the design and development project. The review has outlined the importance of biomechanical analysis in order to obtain knowledge on motion characteristic of required skill. Specific area of research and various equipment's or methodologies that might utilised for the study have been discussed.

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# Chapter 3

# On-Water Analysis of Stationary Sprint Kayak

## 3.1 Chapter overview

This chapter will quantify stationary sprint kayak on-water balancing motion. This information will be utilised as a foundation to design a kayak balance training aid which can simulate the actual on-water medial-lateral rolling motion. The first section of this chapter explains the mathematical process of finding the centre of rotation for the on-water kayak-paddler system. The second section discusses the quantitative relationship between the kayak motion and the paddler's segment motion during the on-water balancing tasks.

## 3.2 Introduction

A sprint racing kayak is a relatively slender hollow shell, trenchant at both ends, and propelled by human power over water by means of paddles (Michael et al., 2009). Balancing the stationary sprint kayak is a very challenging task for a beginner but relatively straight forward for experienced athletes.

In hydromechanics terminology the static non-moving boat floats because the downward force of gravity is evenly matched by the upward force of buoyancy (Pulman, 2002). The force of gravity is represented as the total weight of the kayak-paddler system which acts at a single point, known as the centre of gravity. On the other hand, the buoyancy forces of the water act upwards at the centre of

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buoyancy which is the centroid of the volume of water displaced by the object (Knudson, 2007). Furthermore, the centre of rotation is also known as the metacentre, which is defined as the intersection of two successive lines of action of the buoyancy force through a very small angle of roll (Jacques & Janis, 2010). Figure 3-1 shows the interaction of centre of gravity, centre of buoyancy and centre of rotation (metacentre) in determining its function on stability of a floating boat. When the centre of gravity is at the same position as centre of rotation (metacentre) the boat is stable and the balance is neutral. Similarly, when the centre of gravity is lower than centre of rotation (metacentre) the boat is also stable. However, when the centre of gravity is above the centre of rotation (metacentre) it will generate a turning moment for any small displacement from equilibrium and makes the boat relatively unstable (www.atm.ox.ac.uk).

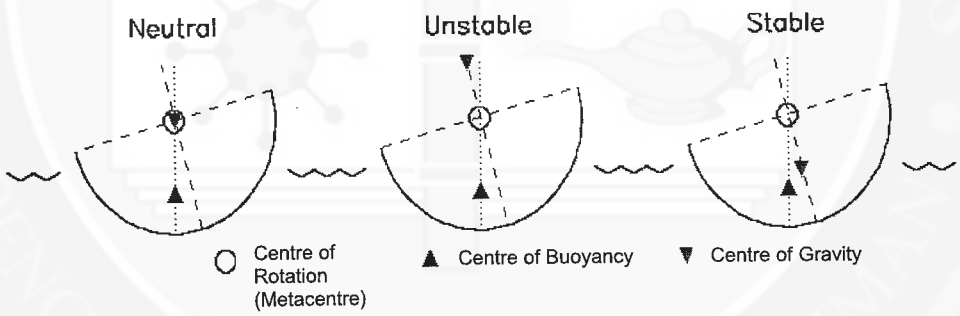



Figure 3-1: Interaction between centre of gravity, centre of buoyancy and centre of rotation (adapted from http://www.atm.ox.ac.uk/rowing/physics.html).

Little is known about the exact mechanisms that explain the movement control and balancing motion of a stationary sprint racing kayak. Moreover, there is also limited literature on determining the metacentre or centre of rotation of the kayak, although it is vital for stability and balance performance. However, there are numerous studies in developing a quantitative approach to find the centre of

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rotation (metacentre) in relation to ship stability (Bugalski, 2011). This approach can also be applied to kayaking since the sprint racing kayak can be considered as a semi-displacement ship according to classic ship theory (Jacques & Janis, 2010). Consequently, the results of their study showed that the centre of rotation (metacentre) yielded the same distinct point regardless of its definition and was applicable for any shape of the floating body not only during an equilibrium condition but also for any roll angle.

Kinematic analysis of segment interactions has provided researchers with an improved knowledge and understanding on human balance control in a seated position (Preuss & Popovic, 2010; Cholewicki et al., 2000; Forssberg & Hirschfeld, 1994a). Pelvis and hip kinematics have been found to be predominant in triggering postural responses during sitting on a moveable platform (Forssberg and Hirschfeld, 1994). This may suggest that pelvic and hip strategies would be used to control balance in an unstable sitting position. Multi-segmental kinematic analysis has provided improved insight into the complex task dependent motion of the human body during unstable sitting position (Preuss & Popovic, 2010; Cholewicki et al., 2000; Forssberg & Hirschfeld, 1994a).

The first aim of this study was to determine the centre of rotation of a sprint kayak medial-lateral rolling motion using video motion analysis and the simulated annealing algorithm (Goffe et al., 1994) for participants with a range of kayaking ability. The second aim of this study was to quantify kinematic data on kayak frontal plane motion during three different on-water balancing tasks; and to investigate strategies used by paddlers to balance a stationary sprint kayak in

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three different balancing tasks. This study is useful as it will provide *novel* information and knowledge that could be used as a foundation for designing a kayak balance training aid which can simulate on-water medial-lateral rolling motion.

## 3.3 Methods

### 3.3.1 Subjects and data collection

Eight competitive male paddlers ranging from national to university level volunteered for this study. Four of the subjects were national Great Britain junior development athletes, with a minimum of 12 hours of training per week (elite athletes). The other four subjects were university athletes, with a minimum of 6 training hours per week (non-elite athletes). Characteristics of the subjects are presented in Table 3-1. Before any data was collected, the testing procedures were explained to each subject in accordance with Loughborough University Ethical guidelines; an informed consent form and a health screen questionnaire were signed. Meanwhile, for under age participants, coach or parental permissions were obtained and coaches were present during data collection sessions. All of the above forms are provided in Appendix 3-1.

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Table 3-1: Subject's characteristic

| Subject | Age (year) | Paddling Experience | Weight (kg) | Height (m) | Sitting height (m) |
|---|---|---|---|---|---|
| **1** (non-elite) | 19 | 12 | 75.1 | 1.76 | 0.86 |
| **2** (non-elite) | 18 | 5 | 73.5 | 1.86 | 0.93 |
| **3** (non-elite) | 21 | 16 | 81.2 | 1.85 | 0.94 |
| **4** (non-elite) | 19 | 7 | 81.6 | 1.92 | 0.97 |
| **5** (elite) | 17 | 6 | 90.9 | 1.93 | 0.98 |
| **6** (elite) | 17 | 8 | 69.7 | 1.69 | 0.93 |
| **7** (elite) | 17 | 10 | 75.6 | 1.82 | 0.96 |
| **8** (elite) | 16 | 6 | 69.8 | 1.75 | 0.92 |
| **Mean** | 18 | 9 | 77 | 1.80 | 0.94 |
| **SD** | 2 | 4 | 7 | 0.08 | 0.04 |

Eight retro-reflective 20 mm markers were placed on the subjects to define the pelvis, trunk, shoulder and head segments, respectively (Figure 3-2). Two more markers were attached on the left and right deck of the kayak to monitor the kayak motion. The two markers were also used to define a horizontal scale (Figure 3-3). Additional markers were attached to the bottom and the top end of a vertically projected rod (40 cm in length) mounted on the middle of the kayak deck for vertical scaling (Figure 3-3). Subjects were given sufficient time to get used to the kayak and testing environment. Subjects were instructed to perform three frontal plane stationary balancing tasks: Task A - holding the paddle at shoulder height and voluntarily rolling the stationary kayak with a controlled motion while maintaining balance; Task B –holding the paddle at shoulder height while maintaining stationary balance; Task C – subjects with arms folded across the chest (without paddle) while maintaining stationary balance. Marker placement and experiment task conditions are illustrated in Figure 3-2.

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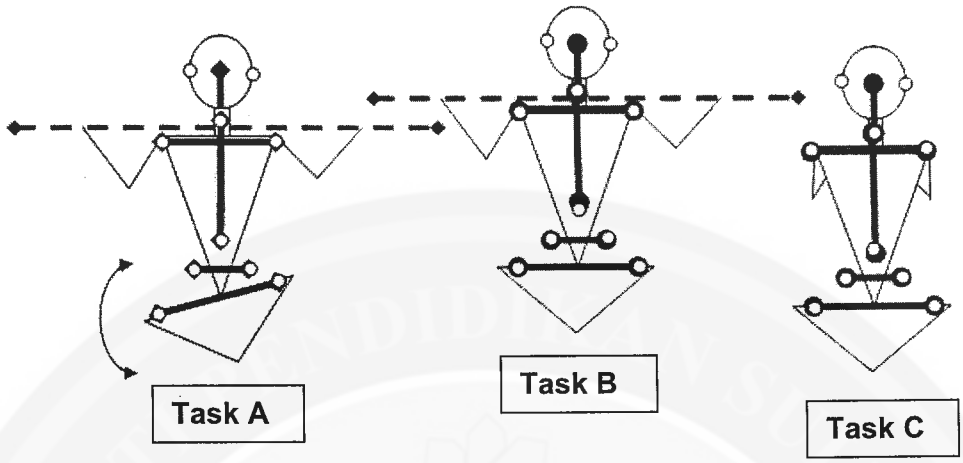



Figure 3-2: Experimental task conditions and retro-reflective markers placement. Curved solid arrow on Task A represents the voluntary lateral rolling movement of the kayak. A dashed line on Task A and Task B represents the paddle and its position. The solid lines depict the head, shoulder, trunk, pelvis and kayak segments. Meanwhile, the white circle represents the marker position.

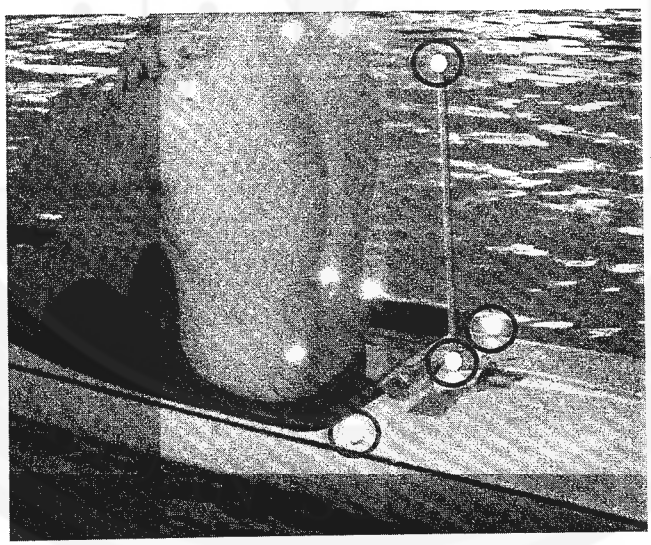


Figure 3-3: Horizontal and vertical scaling markers.

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Data collection took place in the Loughborough University swimming pool. A standard 50 Hz digital camera (Panasonic NV-GS), with a shutter speed of 1/300 s was used to acquire video data of each trial. To capture frontal plane medial-lateral motion, a camera was placed to the posterior of the subject. The camera was angled perpendicular to the plane of balancing motion. The performance area was marked with two white marker buoys positioned laterally two metres apart. A specially built start block device was anchored in the middle of the performance area, about 2 metre in front of the two white marker buoys. This device acted as a guide and ensured that the kayak and the paddler were positioned in the middle of the required field of view. The data collection area set-up is shown in Figure 3-4.

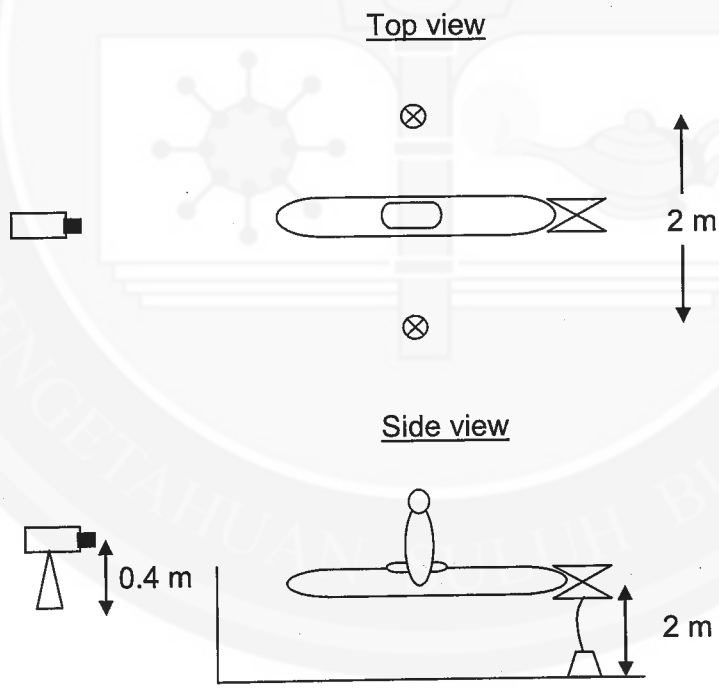



Figure 3-4: The data collection area set-up.

### 3.3.2 Data acquisition and processing

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AviDigitiser software (RF Spectrum Modelling Ltd, 2008) was used for digitising. The software uses a 'sub-pixel' cursor which allows marker centre points to be digitised to within 0.1 pixels, allowing the user to be potentially ten times more precise. Interpolation is used to produce a smoother zoomed image while enhancing the visibility of the desired point. To ensure consistency (reliability) of the digitising process the same operator digitised all video recording files. For a measure of digitising precision the researcher digitised some trials twice and the root mean square difference of less than 2 mm was found.

The digitised data were smoothed using a low-pass Butterworth digital filter with a cut-off frequency of 5 Hz selected using a residual analysis (Winter, 2009). Digitised pixel coordinates were then converted into real-life horizontal and vertical positions of the markers in metres (Grimshaw et al., 2007). All positional data were carefully evaluated and as expected drift (slow continuous lateral movement of the kayak) was observed in the medial-lateral direction. Drift was analysed by fitting a polynomial straight line equation ($y = mx + c$) to the calculated average between two halves of data which created the segment. For the purpose of this study the drift was only removed for medial-lateral (Z) axis coordinates data by subtracting the calculated drift from the positional data of each segment. An example of data with drift and with drift removed is shown in Figure 3-5.

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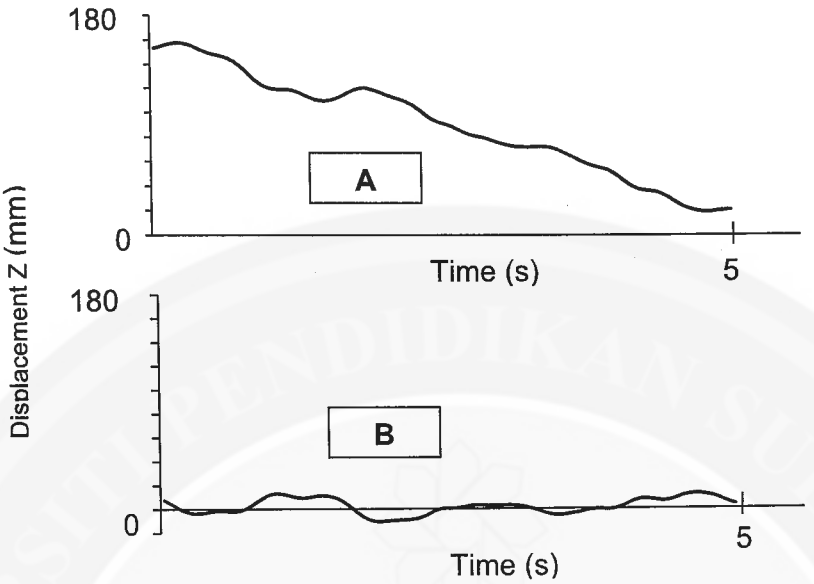



Figure 3-5: Difference between horizontal (Z-coordinate) data with drift (**A**) and data with drift removed (**B**) taken from left kayak marker of one subject in voluntary kayak rolling task (Task A).

## 3.4 Centre of rotation of sprint kayak medial-lateral rolling motion

### 3.4.1 Data analysis

Task A and Task B were used.to determine the centre of rotation of the kayak using the two markers representing the kayak segment. The midpoint of the two digitised markers on the kayak was calculated and used to correct lateral drift during each trial. A circle was fitted to the corrected data and the mean radius and standard deviation calculated. Two parameters defining the location of the centre of the circle were varied using the Simulated Annealing optimisation algorithm (Goffe, et. al., 1994) to minimise the standard deviation of the radius. All calculations were performed using Matlab® software (The MathWorks Inc., Cambridge, UK). The average vertical and horizontal coordinates of the kayak seat centre were calculated by subtracting the measured distance of the seat from the average midpoint of the two markers on the kayak.

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The calculated data was further analysis using *PASW* Statistics version 18.0 for windows (SPSS: IBM Inc., Chicago, Illinois). Data sets were checked for normality using a Shapiro-Wilk test and homogeneity of variance was verified using Levene's test. Pearson correlation was used to statistically indicate the relationship between subject weight, height and sitting height with the centre of rotation vertical position. The correlation coefficient (*Pearson r*) value was used as a measure for effect size (Field, 2009). In assessing whether the centre of rotation vertical position was affected by the amplitude of rolling oscillation condition (Task A vs. Task B) Paired samples *t*-tests were used. The distance of the kayak centre of rotation from the seat centre between the elite and non-elite groups were compared using Independent sample *t*-tests. Finally, effect-sizes were calculated to provide substantive measures of importance in practical terms (Field, 2009). The level of effect size $r = 0.1$, $r = 0.3$ and $r = 0.5$ represents small, medium and large effect-sizes respectively (Cohen, 1988).

### 3.4.2 Results

The results for vertical centre of rotation position relative to the seat of the kayak, calculated radius and standard deviation of radius are presented in Table 3-2. Shapiro-Wilk test revealed that none of the data was statistically significant ($W_{(8)} \geq 0.84$, $P > 0.05$), so the data were normally distributed. Similarly, the variance between elite and non-elite subjects for both balance tasks were homogenous ($F(1,6) = 0.35$, $P = 0.56$). Table 3-2 shows the mean centre of rotation of the kayak-paddler system for Task A (10.7 ± 0.7 cm) above the centre of the seat of the kayak for the eight subjects analysed, meanwhile for Task B (12.7 ± 0.7 cm)

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the location was significantly higher $t$ (6) = -5.46, $p < 0.05$. Furthermore, the difference was supported by a very large effect sizes ($r$ = 0.9). There was no significant difference between elite and non-elite mean centre of rotation location in Task A. However, in Task B the elite subjects (13.2 ± 0.3) have significantly higher ($t$ (7) = -2.37, $p < 0.05$) centre of rotation then the non-elite subjects (12.3 ± 0.7).

Table 3-2: Centre of rotation position (cm) relative to the seat of the kayak for Task A and Task B (mean ± SD)

| **Subject** | | **Task A** | | **Task B** | |
|---|---|---|---|---|---|
| **(N)** | | CoR position | radius | CoR position | radius |
| Non-elite | (4) | 10.6 ± 0.6 | 21.2 ± 0.7 | 12.3 ± 0.7** | 20.5 ± 0.7 |
| Elite | (4) | 10.7 ± 0.8 | 21.3 ± 0.6 | 13.2 ± 0.3** | 20.1 ± 0.5 |
| Overall | (8) | 10.7 ± 0.7*** | 21.2 ± 0.6 | 12.7 ± 0.7*** | 20.3 ± 0.6 |

** Significant at level $p < 0.05$; *** Significant at level $p < 0.01$

In determining the relationship and the effect of subject characteristic (weight, height and sitting height) on the positioning of centre of rotation of the kayak-paddler system Pearson correlation coefficient was used. Table 3-3 shows, that the subject characteristics were not significantly correlated with the centre of rotation position, indicated by $p$ value > 0.05 in both tasks. However, the level of effect sizes for weight on Task A ($r$ = 0.3) was positively medium, but negatively small effect sizes on Task B. Effect sizes for height was small for both Task A ($r$ = 0.2) and Task B ($r$ = -0.2). Large effect sizes ($r$ = 0.6) were indicated for the relationship between sitting height and centre of rotation position in Task B, but negatively small in Task B ($r$ = -0.2).

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Table 3-3: Relationship between subject centre of rotation position with subject characteristic (weight, height and sitting height)

| | Centre of rotation position *(Pearson r)* | |
|---|---|---|
| | Task A | Task B |
| Weight | $r$ = 0.34 ($p$. = 0.41) | $r$ = -0.05 ($p$. = 0.92) |
| Height | $r$ = 0.18 ($p$. = 0.67) | $r$ = -0.18 ($p$. = 0.67) |
| Sitting Height | $r$ = -0.18 ($p$. = 0.66) | $r$ = 0.55 ($p$. = 0.15) |

An Independent samples *t*-test ($t_{(6)}$ = 0.2, p ≥ 0.05) showed that there was no significant difference in the location of the centre of rotation between the elite group (10.7 ± 0.8 cm) and non-elite group (10.6 ± 0.6 cm) for Task A; and, it did represent a small effect size ($r$ = 0.1*)*. On the other hand for Task B, the difference was statistically significant ($t_{(6)}$ = 2.4, p ≤ 0.05) with the elite group having a much higher centre of rotation than the non-elite group (13.2 ± 0.3 cm vs. 12.3 ± 0.7 cm, respectively); this was also supported by large effect size ($r$ = 0.7, Table 3-4). Effect sizes in the sample were used to estimate the likely size of the effect in the population (Field, 2009). Even though a difference was non-significant, a large effect size showed that a small difference would be deemed statistically significant if a large enough sample were used.

Table 3-4: Differences in the centre of rotation position between elite and non-elite subjects in Task A and Task B

| | | **N** | **Mean ± SD** | ***t*** | **Sig. (2-tailed)** | **Effect-size** |
|---|---|---|---|---|---|---|
| Task A | Elite | 4 | 10.7 ± 0.8 | 0.24 | 0.82 | 0.1 |
| | Non-elite | 4 | 10.6 ± 0.6 | | | |
| Task B | Elite | 4 | 13.2 ± 0.3 | 2.4 | 0.05** | 0.7 |
| | Non-elite | 4 | 12.3 ± 0.7 | | | |

**. Significant at level p < 0.05

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### 3.4.3 Discussion

This study gives a simple straightforward technique for finding the centre of rotation for a lateral rolling kayak motion. The mean centre of rotation of the kayak and paddler relative to the top of the seat for the eight subjects was between 10 cm to 13 cm above the height of the seat; this was in good agreement with guidelines provided by kayak manufacturers. A higher centre of rotation position from the seat denotes that its position is nearer to the centre of mass for the whole kayak-paddler system. As indicated in this study, the more obvious the rolling motion the more it demonstrated an unstable condition. For instance, the static balance control task (Task B) which had less rolling motion displayed a higher centre of rotation (12.2 $\pm$ 0.7 cm) compared to the more chaotic continuous side to side rolling Task A (10.6 $\pm$ 0.6 cm). Although the centre of rotation did not appear to be influenced by the paddler's technique, there was a tendency for the elite subjects to have a slightly higher vertical centre of rotation location (more stability and control) than the non-elite subjects

An alternative technique using video analysis was developed to locate the centre of rotation for a sprint kayak and paddler. This method could be used to replace a traditional hydrostatic marine technique previously used by most kayak manufacturers. The technique presented in this study demonstrated that it is possible to use Simulated Annealing in order to produce a reliable optimum solution for finding the centre of rotation for a kayak balancing motion. The results of this study were sufficient enough to be used as the foundation for designing a

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sprint kayak balance training aid; however further research is required to confirm whether the prediction is the same in a greater variety of kayak athletes.

## 3.5 Quantifying kinematics of stationary sprint kayak balancing

### 3.5.1 Data analysis

To describe the subject's balance strategies in the frontal plane, several translation and rotation kinematic measurements were used. The horizontal and vertical linear displacements of the segments centre were also identified as the sway and heave translation motion characteristic of the kayak-paddler system. The standard deviation (SD) of the displacement was used as a measure of segment stability for balancing motions. Kayak, pelvis and shoulder angular orientation were determined by calculating the angle between medial-lateral (Z) axis and the line connecting the two markers that represented those segments. On the other hand, the head and trunk angular orientation were determined by calculating the angle between vertical (Y) axis and the line connecting the two markers that represented those segments (Figure 3-6 A and B). Near to zero angles was indicated by equilibrium alignment of segments with the both axis, respectively. The angle was positive for $y>0$, $z>0$ and negative for $y<0$, $z<0$ respectively. Pearson correlation was used in each task performed to statistically indicate the relationship between kayak motion and the orientation of body segments in maintaining balance and equilibrium.

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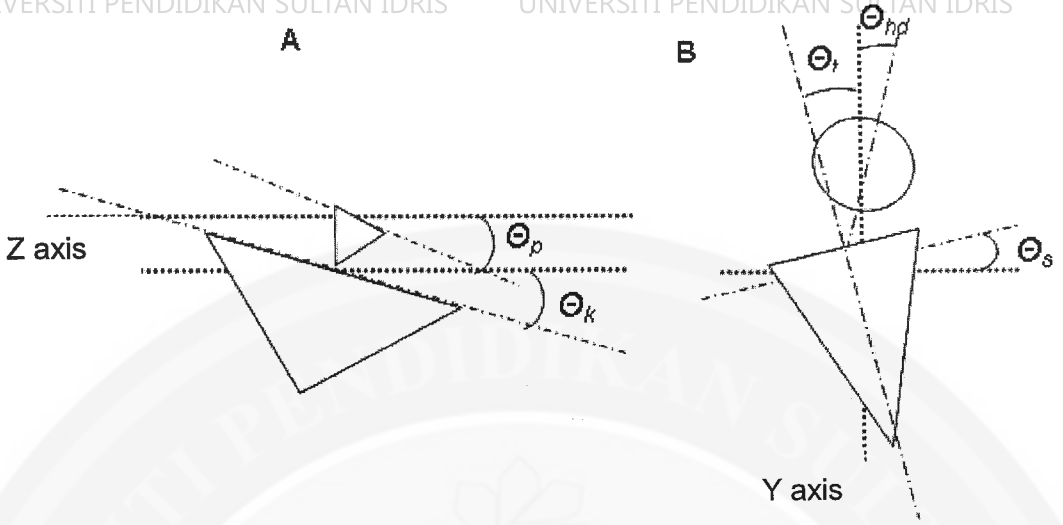



Figure 3-6: Angular orientation determination: **A.** kayak ($\theta_k$) and pelvis ($\theta_p$); and **B.** head ($\theta_{hd}$), shoulder ($\theta_s$) and trunk ($\theta_t$).

### 3.5.2 Results

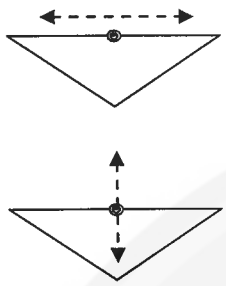
*3.5.2.1 Kayak linear and angular motion characteristics.*

Table 3-5, shows the mean kayak medial-lateral displacement (sway) was largest in Task A (45 ± 8 mm) compared to Task B (24 ± 12 mm) and Task C (17 ± 7 mm). This was due to voluntary initiation of kayak medial-lateral rolling by the subject. The highest sway range of 57 mm was produced by subject S6 and the lowest range of 35 mm was produced by subject S5, respectively (Figure 3-7). Kayak vertical displacement (heave) motion in this test (mean stability magnitude 4 ± 1 mm) was significantly small compared to medial-lateral motion (mean stability magnitude 13 ± 2 mm). The highest vertical displacement range of 25 mm was produced by subject S7 and the lowest of 12 mm was produced by subject S5. As expected, the heave movement was minimal and mainly caused by the difference between kayak centre (calculated at the midpoint of two markers on the kayak deck) distance and the whole kayak-paddler system centre of rotation.

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Table 3-5: Medial-lateral and vertical displacement range and magnitude (SD) of the kayak centre



| | Range | SD |
|---|---|---|
| Task A | 45 ± 8 mm | 13 ± 2 mm |
| Task B | 24 ± 12 mm | 6 ± 4 mm |
| Task C | 17 ± 7 mm | 4 ± 2 mm |
| Task A | 20 ± 6 mm | 5 ± 1 mm |
| Task B | 11 ± 2 mm | 3 ± 1 mm |
| Task C | 15 ± 6 mm | 4 ± 2 mm |

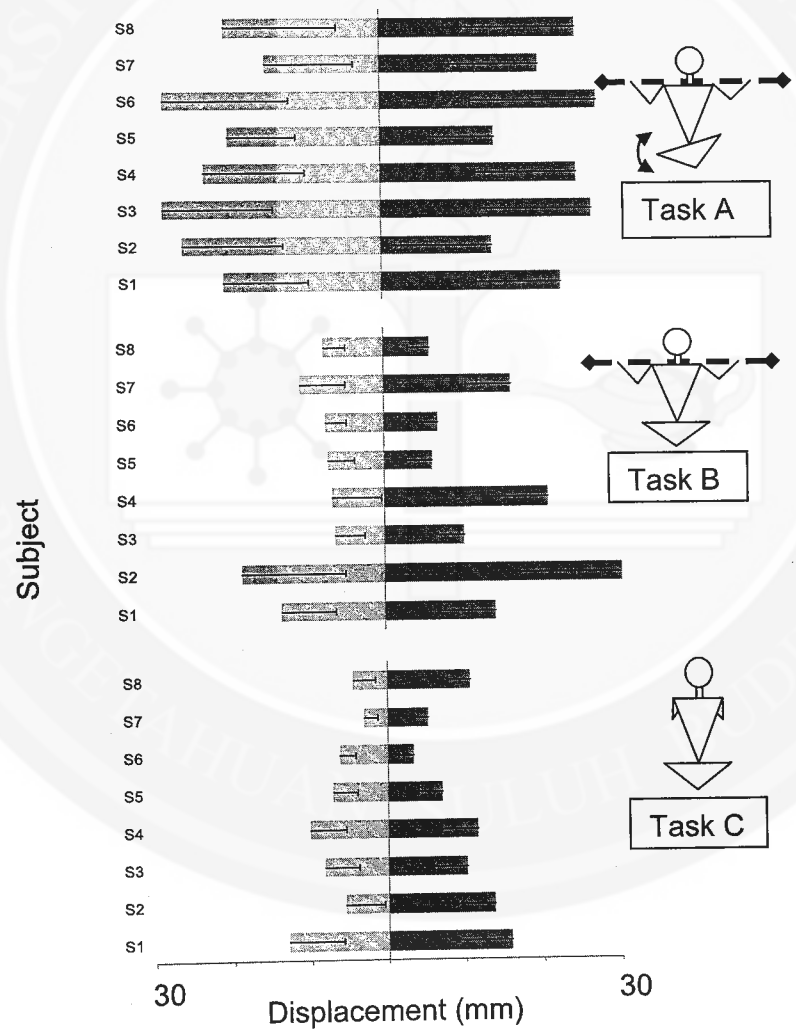



Figure 3-7: Kayak sway (horizontal displacement) range for all subjects in three task conditions.

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Table 3-6 shows the mean right and left roll angle produced by subjects in three test conditions. With voluntary initiation of kayak rolling motion, medial-lateral roll angle for anticlockwise rotation was 25° ± 5° and -24° ± 4° for clockwise rotation. The highest medial-lateral roll angle range produces was 65° by subject S8 Figure 3-8. Meanwhile, subject S1 produce the lowest medial-lateral roll angle range of 41°. As illustrated in Figure 3-8, subject S3 and S6 was able to maintain a symmetrical angle between right and left dynamic rolling motion (Task A), with 28° anticlockwise and -25° clockwise respectively. On the other hand, the rest of the subjects showed more variability between anticlockwise and clockwise roll angle, with differences ranging from 2° to 6°.

The static nature of balance control in Task B and Task C produced much lower roll motion compared to the dynamic condition in Task A. Between both conditions Task B produced lesser roll motion than Task C, with mean magnitudes of 3° ± 3° and 4°± 3° mm respectively. However, high standard deviation or magnitude indicated that most subjects were unable to maintain left and right symmetry (Table 3-6 and Figure 3-8).

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Table 3-6: Kayak roll angle and magnitude (SD)

| | Anticlockwise angle | Clockwise angle | SD |
|---|---|---|---|
| Task A | 25° ± 5° | -24° ± 4° | 15° ± 3° |
| Task B | 7° ± 8° | -6° ± 7° | 3° ± 3° |
| Task C | 8° ± 7° | -7° ± 8° | 4° ± 3° |

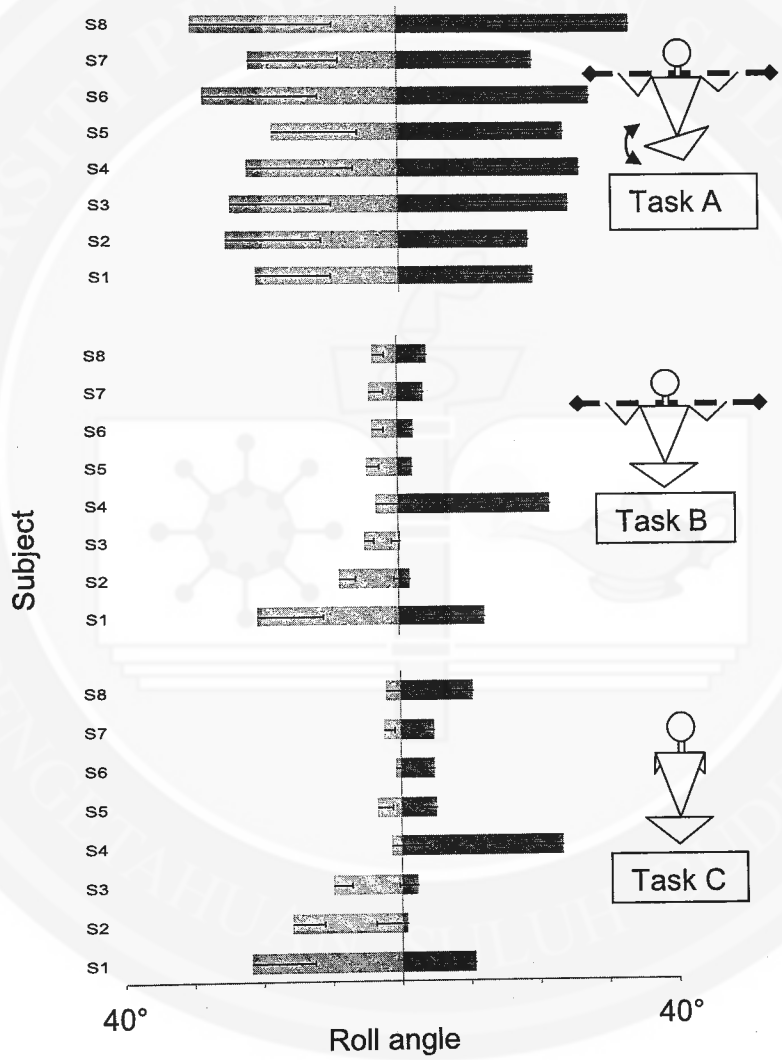



Figure 3-8 : Kayak medial-lateral roll angle range for all subjects in three experimental conditions

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*3.5.2.2 Relationship between segments and kayak orientation.*

It has been suggested that lateral-medial body motion in the frontal plane should be described by a multilink model with more segments involved in controlling balance (Pozzo et al., 1995). In order to investigate the control strategies used by paddlers in three stationary balancing tasks, the orientation of pelvis, trunk, shoulder and head segments were compared relative to the kayak orientation (Table 3-7, Figure 3-9 and Figure 3-10). As expected, the kayak rolling motion was primarily controlled by continuous loading and unloading movement of the pelvis. The high correlation coefficient value (Pearson $r > 0.50$) and positive correlation indicated that the movement was proportional with the direction of the kayak movement in all task conditions (Table 3-7). This relationship was more obvious in voluntary initiation of kayak lateral rolling by the subject in Task A ($r = 0.9$). This result also suggested that the pelvis segment medial-lateral rolling motion was the predominant response in triggering and controlling the angular orientation of a stationary racing kayak (Figure 3-9 and Figure 3-10).

Within all three task conditions, the trunk segment had the least angular movement compared to other segments (Table 3-7, Figure 3-9 and Figure 3-10). Furthermore, in order to compensate for the highly dynamic voluntary movement of the kayak in Task A, the trunk segment orientated itself with a small magnitude (SD) in an opposite direction of the kayak, indicated by high negative correlation ($r = -.73$, shows in Table 3-7). The trunk angle was within minimum range ratio (0.2 to 0.3) relative to the kayak angle in all task condition (Table 3-7). The roll angle trace illustrated in Figure 3-9 and Figure 3-10 indicated that the trunk

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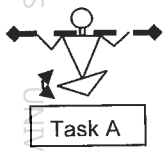
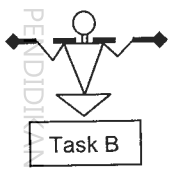
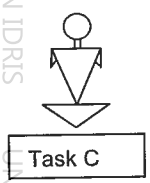
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stiffness strategy was used by subjects to limit excessive movement of the whole body centre of mass relative to kayak centre of rotation.

The shoulders and the head were also actively oriented in an opposite direction of the voluntary kayak movement in Task A to compensate the high magnitude (SD) of kayak movement (Figure 3-9 and 3-10). However, the result showed that these segments had a proportional direction of movement relative to kayak in anticipatory static balancing control (Task B and C). As the trunk kept vertically oriented to maintain equilibrium and centre of pressure, any other excessive oscillation and sudden movement of the system will initiate head or shoulder strategies (Rietdyk et al., 1999).

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Table 3-7: Kayak and segments angle range and magnitude (SD) relationship for three experimental task conditions

| | | Counter-clockwise angle | Clockwise angle | Range | Magnitude (SD) | (vs. kayak) | |
|---|---|---|---|---|---|---|---|
| Kayak | | 25° | -24° | 49 ± 8° | 15 ± 3° | Angle range ratio | Pearson *r* |
|  Task A | Pelvis | 10° | -12° | 22 ± 9° | 6 ± 3° | 0.5 | 0.88 |
| | Trunk | 6° | -5° | 12 ± 4° | 3 ± 1° | 0.2 | -0.71 |
| | Shoulder | 11° | -9° | 20 ± 12° | 5 ± 3° | 0.4 | -0.08 |
| | Head | 9° | -19° | 20 ± 10° | 5 ± 23° | 0.4 | 0.10 |
| Kayak | | 7° | -6° | 12 ± 10° | 3 ± 3° | | |
|  Task B | Pelvis | 2° | -5° | 7 ± 4° | 2 ± 1° | 0.6 | 0.64 |
| | Trunk | 2° | -2° | 4 ± 2° | 1 ± 1° | 0.3 | 0.41 |
| | Shoulder | 6° | -3° | 9 ± 4° | 2 ± 1° | 0.7 | 0.74 |
| | Head | 7° | -7° | 14 ± 7° | 3 ± 2° | 1.1 | 0.55 |
| Kayak | | 8° | -7° | 15 ± 9° | 4 ± 3° | | |
|  Task C | Pelvis | 2° | -5° | 8 ± 4° | 2 ± 1° | 0.5 | 0.77 |
| | Trunk | 2° | -2° | 4 ± 1° | 1 ± 0° | 0.3 | 0.40 |
| | Shoulder | 4° | -6° | 10 ± 6° | 2 ± 2° | 0.7 | 0.65 |
| | Head | 5° | -8° | 13 ± 8° | 3 ± 2° | 0.9 | 0.39 |

(Correlation coefficient Pearson *r* value: - more than 0.50 and positive - indicates proportional direction of movement; less than 0.50 - corresponds to uncoupling movement; negative - opposite direction of movement (Pozzo et al., 1995)



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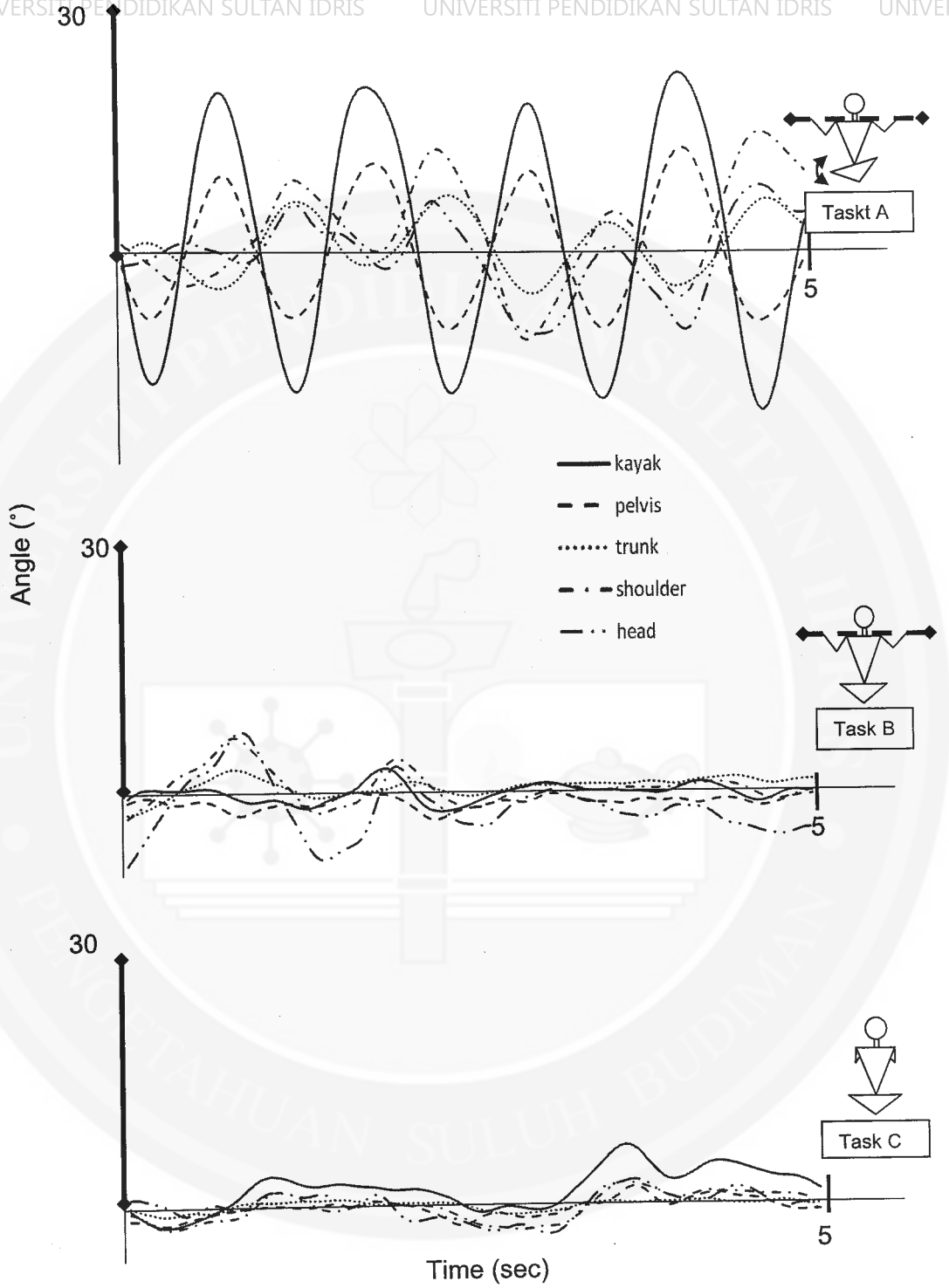



Figure 3-9: Relationship between segments (pelvic, trunk, shoulder and head) and kayak roll angle trace on three experimental conditions, plotted for duration of 5 s for one typical elite subject.

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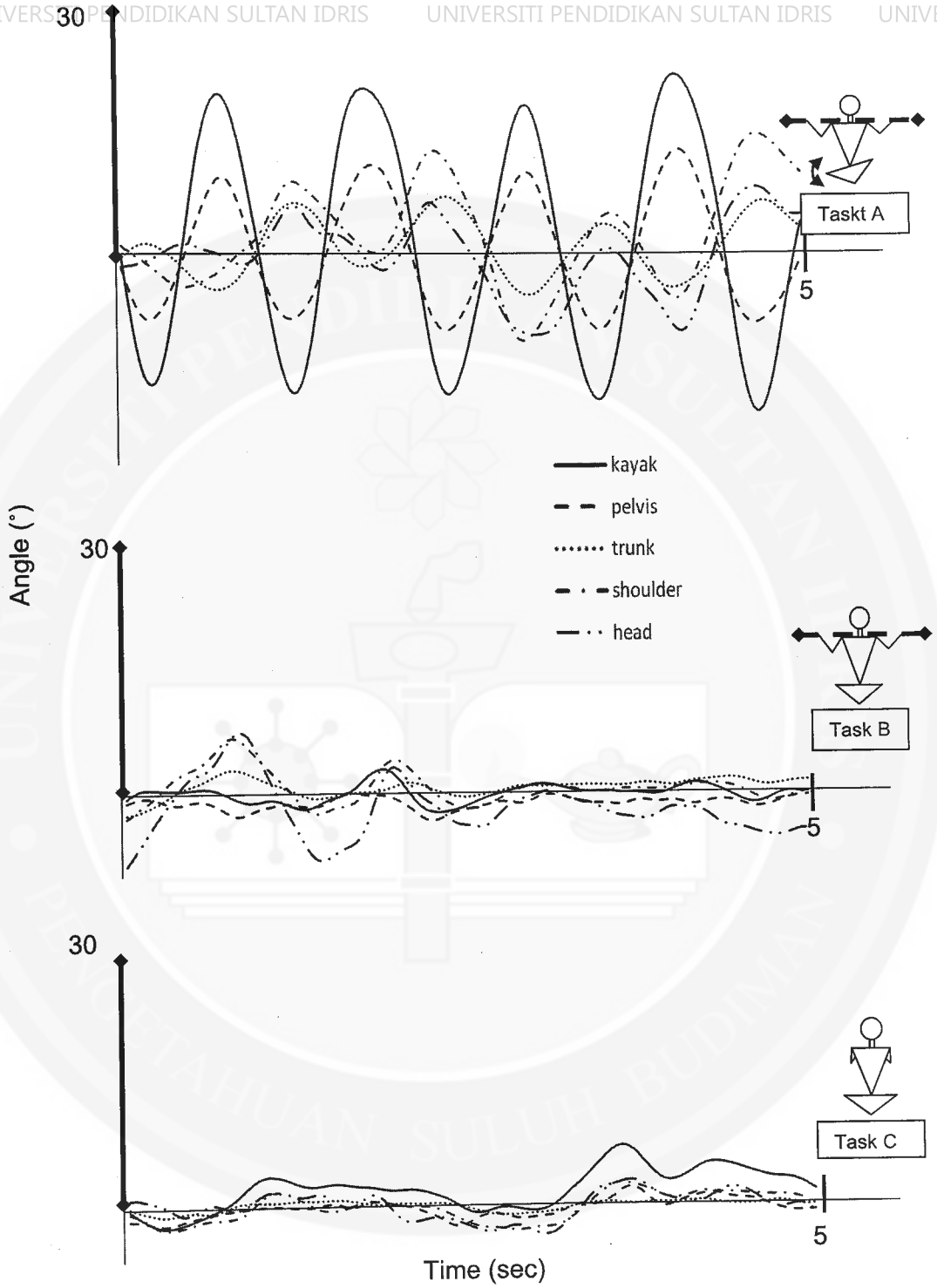



Figure 3-9: Relationship between segments (pelvic, trunk, shoulder and head) and kayak roll angle trace on three experimental conditions, plotted for duration of 5 s for one typical elite subject.

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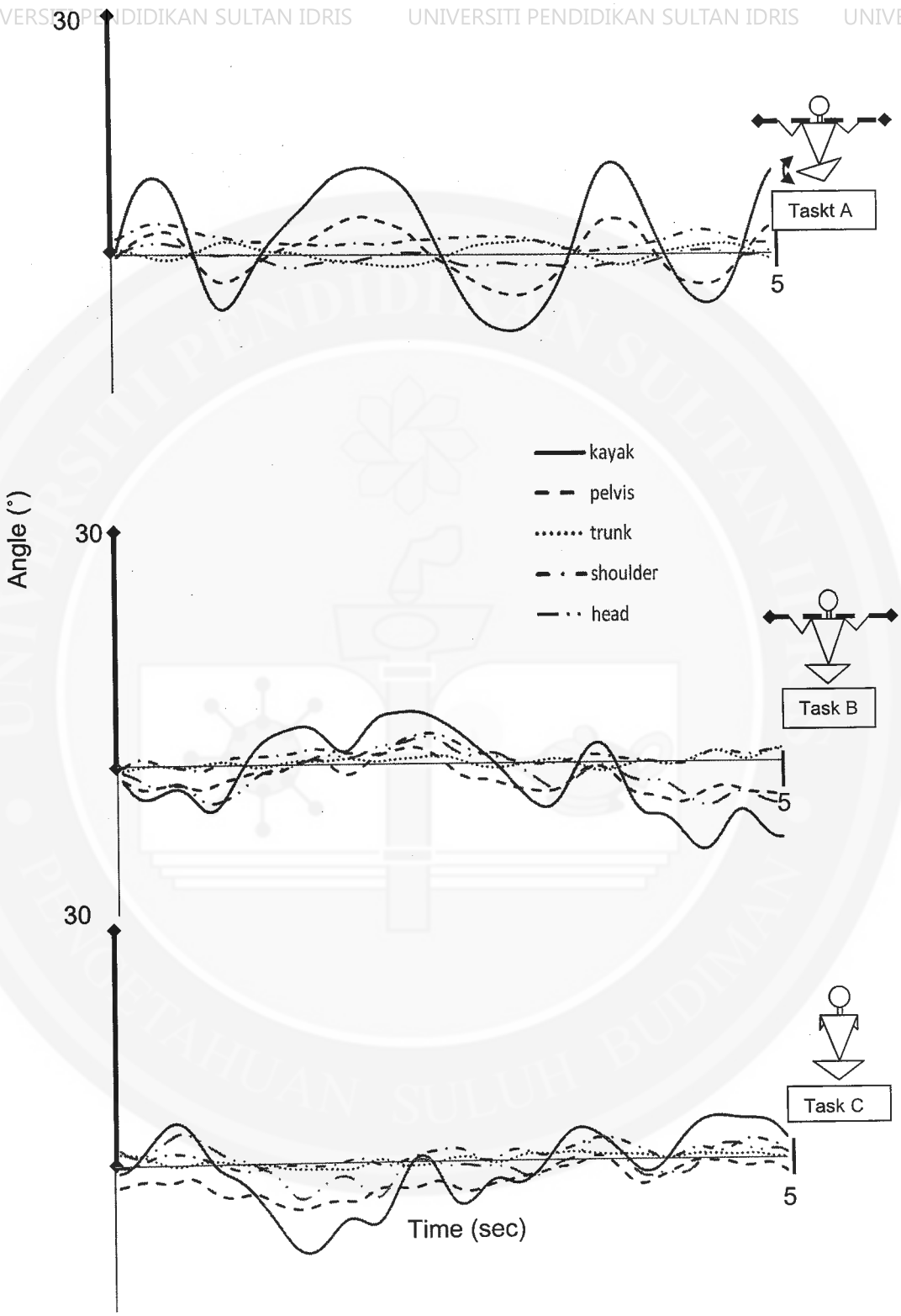



Figure 3-10: Relationship between segments (pelvic, trunk, shoulder and head) and kayak roll angle for three experimental conditions, plotted for duration of 5 s for one typical non-elite subject.

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### 3.5.3 Discussion

*3.5.3.1 Kayak motion characteristics*

This study was conducted to establish the kinematic characteristics of stationary sprint kayak in three different balancing conditions. The results demonstrated that the horizontal (sway) and the vertical (heave) motion of the kayak were within acceptable ranges for each experimental task condition (see Table 3-5). Referring to the results of this study the kayak medial-lateral rolling centre of rotation was located between 10 cm to 13 cm from the lowest point of seat. So, the calculated distance of average kayak marker centre was approximately 2 cm to 4 cm above the kayak rotation centre. This characteristic may become the major contributor to sway and heave oscillations magnitude (SD) of kayak centre. As clearly shown in the first experimental condition (Test A), higher translation magnitudes (SD) were generated as a consequence of the voluntary rolling motion combined with continuous anticipatory postural adjustment by subjects.

Another main characteristic was the asymmetrical translational and rotational motion of the kayak, with most subjects being unable to produce balanced counter-clockwise and clockwise lateral oscillations (see Figure 3-7 and Figure 3-8). This asymmetric balance characteristic would also affect the drift state of the kayak showed in Figure 3-5, as well as being able to be used to distinguish between elite (good stability) and non-elite (lack of stability) kayakers. For example, in more demanding experimental conditions such as in task C, the non-elite subjects (n=4) initiate high kayak oscillations and sway ranges compared to elite subjects (n=4). Furthermore, this unbalanced characteristic was supported by initiation of higher asymmetrical kayak roll angles by those non-elite subjects

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(see Figure 3-8). Due to poor balance control non-elite subjects failed to initiate enough counterbalance action to stabilise the kayak, resulting in the kayak remaining tilted to one side for a period of time. However, the highest maximum kayak roll angle of 30° was proactively produced by an elite subject in a control voluntary rolling condition (Task A), and this angle was almost symmetrical on either side for whole duration of the task (see Figure 3-8).

*3.5.3.2 Segments and kayak motion relationship*

As discussed earlier in the previous study, the gravitational forces of the whole kayak-paddler system act at some distance above the system centre of rotation and the buoyancy forces act from underneath. Furthermore, this condition produced unbalanced moments, which if unopposed may cause the kayak to roll excessively or capsize. The results showed in Task A indicate how each segment was utilised to make appropriate adjustment magnitudes to control the anticipatory and unbalanced motion produced. In addition, the results in both static (stationary) balance experimental conditions (Task B and Task C) showed that limitations in segment involvement will increase the magnitude of balance control (see Figure 3-9 and 3-10).

From the results it was suggested that the pelvis was the main actuator in initiating the kayak oscillation motion. This was shown by a constant and proportional pelvis angular motion direction relative to the kayak movement. Generally, in order to voluntarily generate lateral rolling of the kayak, subjects need to constantly shift their centre of pressure from one side of the seat to the other while maintaining stability or equilibrium. This was achieved either by

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alternately pushing the foot-brace with one leg each time or continuously shifting both knees side to side by internal and external rotation of the hip joints. For this study the pelvis segment was used to represent this lower extremity motion. The association between pelvis and hip movement has also been reported in previous studies (Blackburn et al., 2003; Rietdyk et al., 1999; Winter et al., 1993). However, analysis of the pelvis alone may not provide enough information regarding the roles of the lower extremities in controlling balance and stability of sprint kayaking.

For complex equilibrium tasks mass centre movements should be minimised. Therefore upper body movement, especially trunk displacement, must be limited and must remain inclined relative to the vertical (Pozzo et al., 1995). The results of the present study demonstrated that the trunk was constantly inclined, indicated by low translational and rotational magnitudes along with a proportional movement relationship with kayak motion especially in Tasks B and C. In addition, the trunk angle magnitudes were at minimum value with negative correlation, although additional voluntary oscillation of the kayak was involved in Task A (see Table 3-7). This result may compromise the possibility of using the trunk strategies for stabilisation. However, there is a possibility that this strategy may only be useful in controllable balance tasks where the trunk is not utilised as an actuator for additional stabilisation.

From the results it was demonstrated that the shoulder and head have a higher angular mean magnitude compared to the trunk. This characteristic was also found to be associated with large and sudden oscillation of the kayak-paddler

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system coupled with higher trunk lateral translations. Therefore, head and shoulder stabilisation strategies would be used by subjects to counteract the additional oscillations of the system. In the voluntary kayak lateral rolling condition (Task A) the shoulder movement had a negative relationship with kayak motion which indicates that shoulders oscillate in the opposite direction to compensate the excessive kayak motion. In addition, the head tended to stay vertically oriented providing a reference for postural control in this task.

### 3.5.4 Conclusion

Balance control strategies may vary depending on the individual's goals and environmental context. It must also be considered that balance control and maintenance of balance in sprint kayaking is reliant on the assessment and control of various body parts, and should not be treated as automatic reflex responses only. As a limitation of this study, the focus was solely on the involvement of upper body, with the lower body represented only by the pelvis segment. Furthermore, for a complex equilibrium maintaining task such as sprint kayaking, it would be more beneficial to analyse the biomechanical quantities of the system as a whole (kinematics, kinetics and muscle activation) in order to obtain the most objective and accurate control strategies. Balance control can be considered to be an essential skill to be learned and practiced. When learning and practice is varied in environmental and task contexts, more flexible and generative skills will be developed. Thus, like any other skills sprint kayak balance control can be developed and improved with practice and with the aid of a reliable balance training aid.

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# Chapter 4

# Sprint Kayak Balance Training Aid Design, Development and Evaluation

## 4.1 Chapter overview

In this chapter the design process undertaken during the development of the sprint kayak balance training aid will be discussed in detail. The requirements and specific areas of the design which were essential to the outcome of the training aid will also be reflected on. Diagrams and materials descriptions will be detailed in order to justify the final construction stage of the training aid prototype.

## 4.2 Design process

The design process for a training aid is significantly distinct from the design process of other products. This is because it requires considerations of the physical and mechanical factors of the learning process of the task which an athlete is trying to accomplish. Taking these factors into consideration along with information from literature, survey, observation and experimental analysis, a design process diagrammatic model for the sprint kayak balance training aid has been developed and represented in Figure 4-1. This model is based on input from literature that is detailed in Chapter 2 (Cross, 2008; Wright, 1998; Pugh, 1991). This design process model is followed throughout the progression of this chapter.

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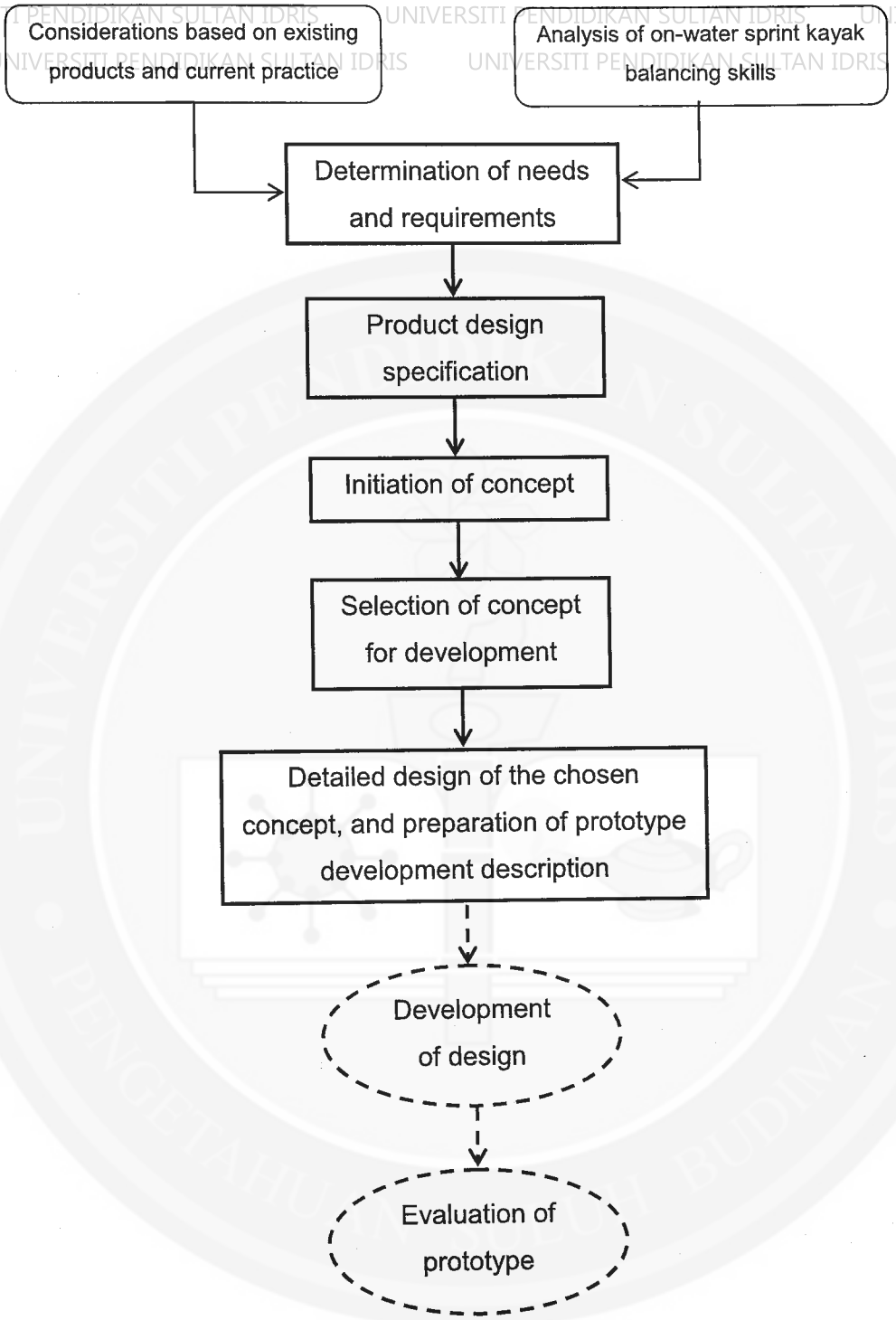



Figure 4-1: Design and development process for sprint kayak balance training aid.

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### 4.2.1 Determination of needs and requirements

According to French's model the design process begins with a statement of 'needs' determinations (Cross, 2008). This statement represents the first stage in the design activity, which is to analyse the problems and identify the crucial components of the design. In order to explain the 'needs' of a sprint kayak balance training aid prototype design, a mapped description of this initial stage is represented by a design plan (Figure 4-2). The design plan is developed by examining all information obtained from literature (Chapter 2) and from data collected through on-water testing detailed in Chapter 3.

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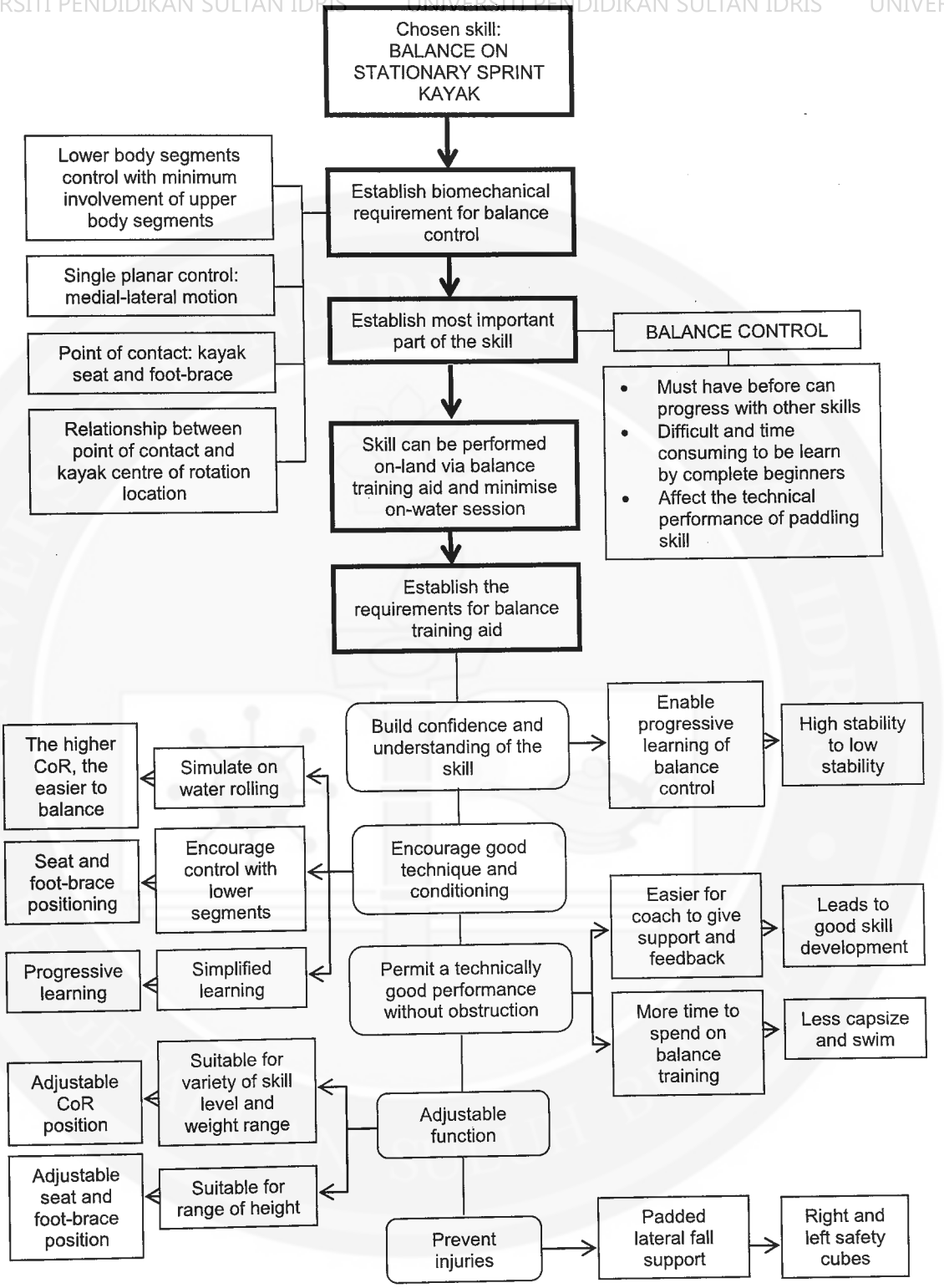



Figure 4-2: Design plan for sprint kayak balance training aid.

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By analysing all of the information from the design plan, the needs can be organised into a requirement tree. Requirement trees are a method used by designers to encourage a structured investigation into the objectives, constraints and the needs of a design project. They can provide a means of 'thought ordering' for an individual designer working alone (Wright, 1998). The detailed requirement tree for the sprint kayak balance training aid is showed in Figure 4-3, Figure 4-4, Figure 4-5, and Figure 4-6.

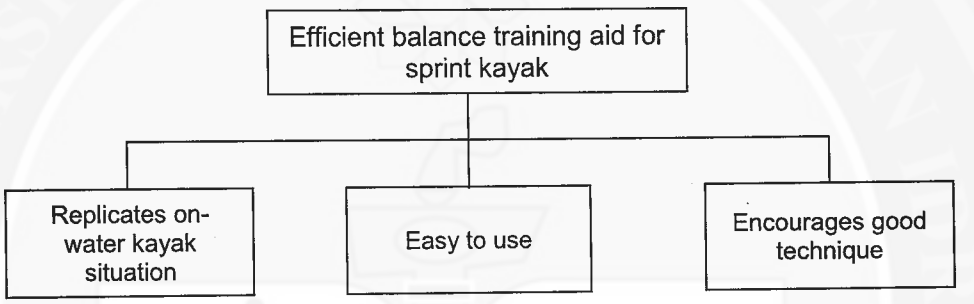



Figure 4-3: Top level of requirement tree.

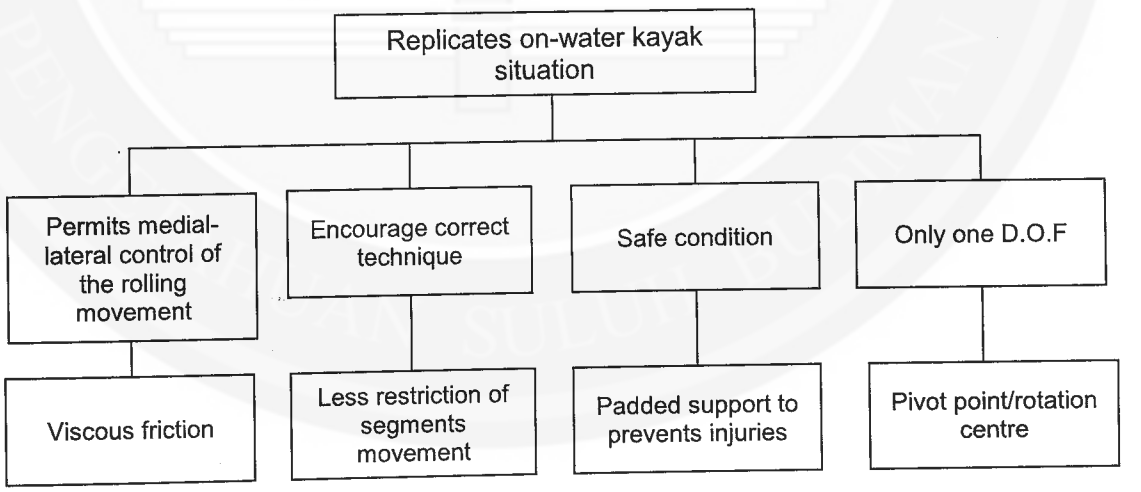



Figure 4-4: Sub-level 1.1 of the requirement tree.

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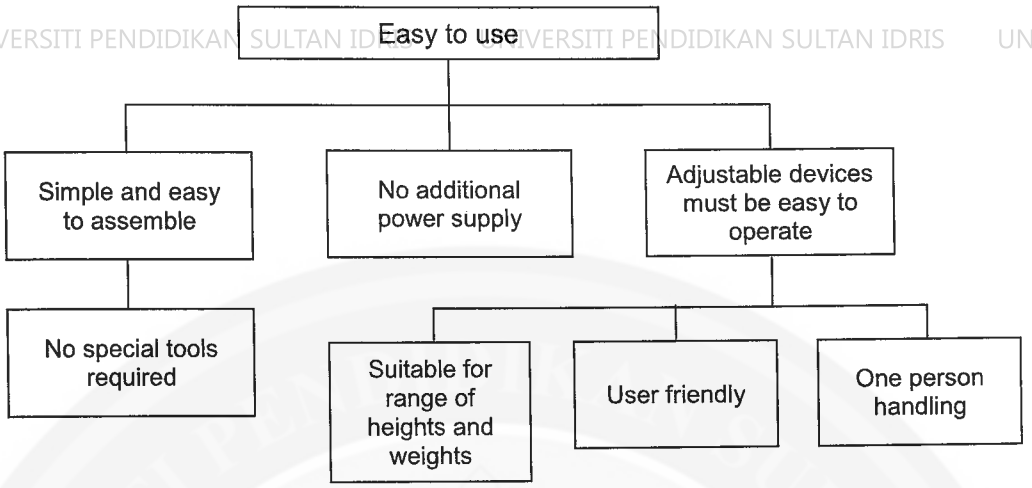



Figure 4-5: Sub-level 1.2 of the requirement tree.

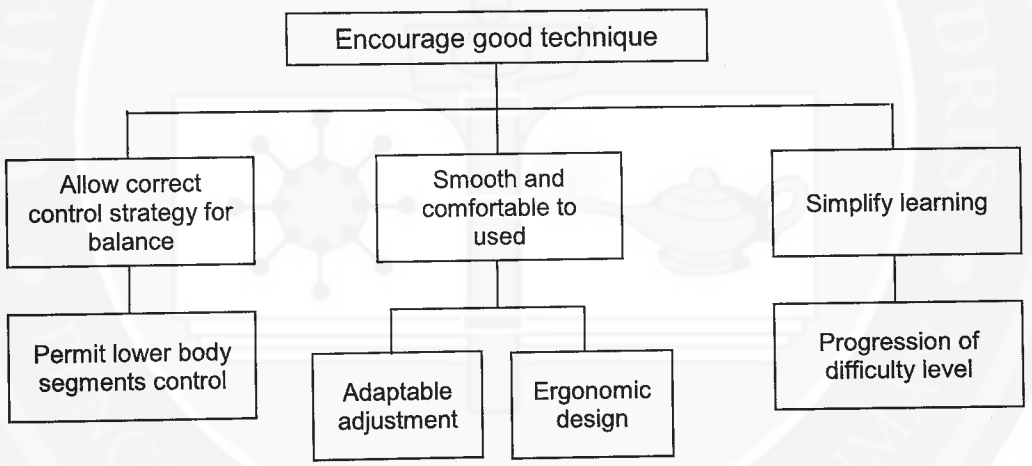



Figure 4-6: Sub-level 1.3 of the requirement tree.

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### 4.2.2 Product design specification

The establishment of product design specification is an important element in the design process as it contains all the information necessary to successfully produce solutions to the design problem (Wright, 1998). The product design specification or a formal listing of objectives and constraints is established with the help of requirement trees. The constituent element proposed by (Pugh, 1991) has been considered in preparing the product design specification for the sprint kayak balance training aid showed in Table 4-1.

Table 4-1: Product design specification for the sprint kayak balance training aid

| | |
|---|---|
| Function: | Allow a medial-lateral rolling element and to be used to train balancing skill. |
| User requirements: | i. Able to simulate the actual properties of on-water instability and rolling motion in sprint kayaking.<br>ii. Flexible lateral range of motion for balance maintenance, allowing natural mechanics of control to take place without obstruction.<br>iii. Adjustable to accommodate range of ability and physical characteristics.<br>iv. Easy to handle and encourage confidence.<br>v. Safe and able to prevent any foreseeable injury. |
| Design specifications: | *Performance*<br>i. Able to provide variation in level of lateral stability.<br>ii. Provide lateral tilt until maximum of 50 degrees on both sides.<br>iii. Suitable for range of ability from complete beginner to elite athlete.<br>*Environment*<br>i. Mainly will be used indoors, inside standard gymnasium or room.<br>ii. The product may also be used in a sheltered outdoor environment.<br>iii. No additional power supply needed.<br>*Maintenance* |

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i. To be maintenance free except for light lubrication once a month.
ii. No special tools needed for maintenance.

*Construction process*

i. Process should be simple and cost effective.
ii. Minimal specialist construction.
iii. Should take minimal time to produce.

*Size*

i. Width not to exceed more than the width of a normal sprint kayak seat.
ii. Length not to exceed 200 cm.
iii. Height not to exceed 60 cm.

*Weight*

i. Not more than two men required in handling the device.

*Materials*

i. Material that can withstand the weight of the device and the paddlers.
ii. Able to withstand the force of rigorous paddlers.

*Ergonomics*

i. Any adjustable device must be located at a suitable position.
ii. Minimum effort is required to alter equipment setting.
iii. The device should not deform excessively or permanently during full loading.
iv. The foot-brace and seat need to be adjustable to accommodate different leg lengths.
v. Overall the device should offer comfort and safety to user.

*Safety*

i. Padded support device in case of fall (Safety block).
ii. Any element under stress should be enclosed so they do not cause harm to user.
iii. Nothing can get caught in the moving element of the device.

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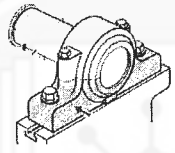
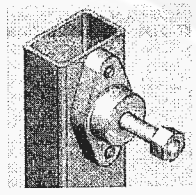
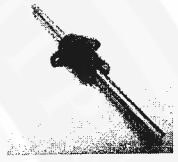
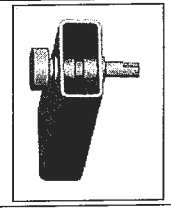
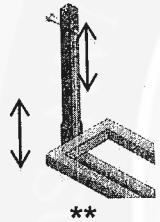
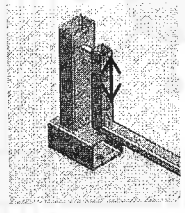
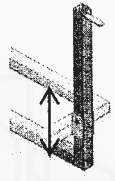
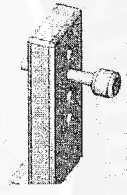
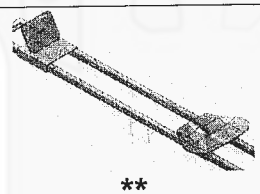
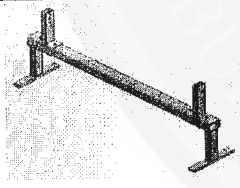
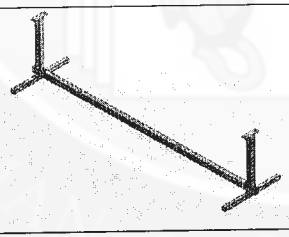
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### 4.2.3 Initiation and selection of concept

As previously discussed, several design specifications have been established and listed. So, the next phase of the design process was to generate possible creative solutions to these functional requirements and specifications. The most common approach used by designers to exploit this phenomenon, and encourage identification of various combinations of elements or components is the morphological chart method (Cross, 2008; Wright, 1998). The adjustment of movement: (1) rotational motion at the pivot or rotation point; (2) adjustment of the seat to rotation centre height and (3) adjustment of the seat to foot-brace distance; were the main features essential for the sprint kayak balance training aid design. Therefore, a morphological chart (Table 4-2) is developed to enable the consideration of possible design solutions.

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Table 4-2: Morphological chart for sprint kayak balance training aid design

| Sub-functions \ Solutions | | Morphological Chart (not to scale) | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| A | Pivot point for rotation centre |  |  ** |  |  |  |
| B | Rotation centre height adjustment |  ** |  |  |  | |
| C | Seat and foot-brace distance adjustment |  |  |  ** | | |
| D | Main frame and base support |  |  ** | | | |

**Feasible sub solutions combinations chosen for sprint kayak balance training aid design: A2 – B1 – C3 – D1

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With considerations of requirements outlined in the product design specifications and solution provided by the use of morphological chart a concept design for the prototype first adjustment has been chosen and illustrated in Figure 4-7. The design used pillow block bearings (A2) for the pivot point or rotation centre as they were the simplest solution. The bearings were very rigid and have a base that could simply be attached to a solid flat steel bar.

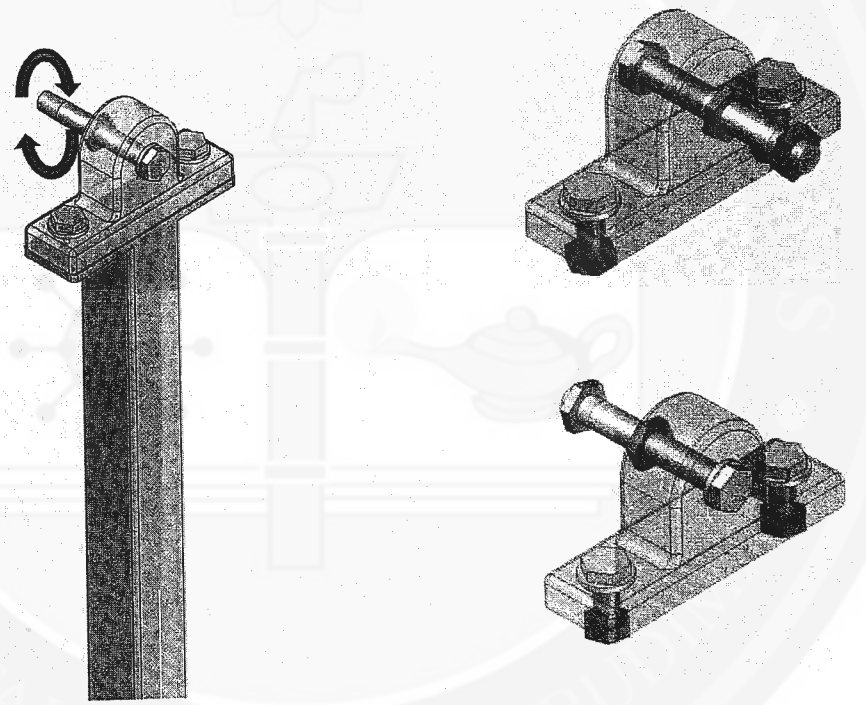


Figure 4-7: Initial concept of the pivot point or rotation centre (not to scale).

The second adjustment was the vertical height between seat and rotation centre of the design. As shown in Figure 4-8, the feasible combination chosen was the adjustable swing arm with adjustable platform (B1) to provide optimum adjustment of possible height range. From the data analysis detailed in Chapter

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3, it was decided that the range of 10 to 12 cm with at least 0.15 cm increment should be included. Furthermore, this adjustment was found to be the most important feature of the balance training aid capability. This adjustment introduced the degree of instability to the prototype user and importantly simulated the on-water kayak medial-lateral rolling motion.

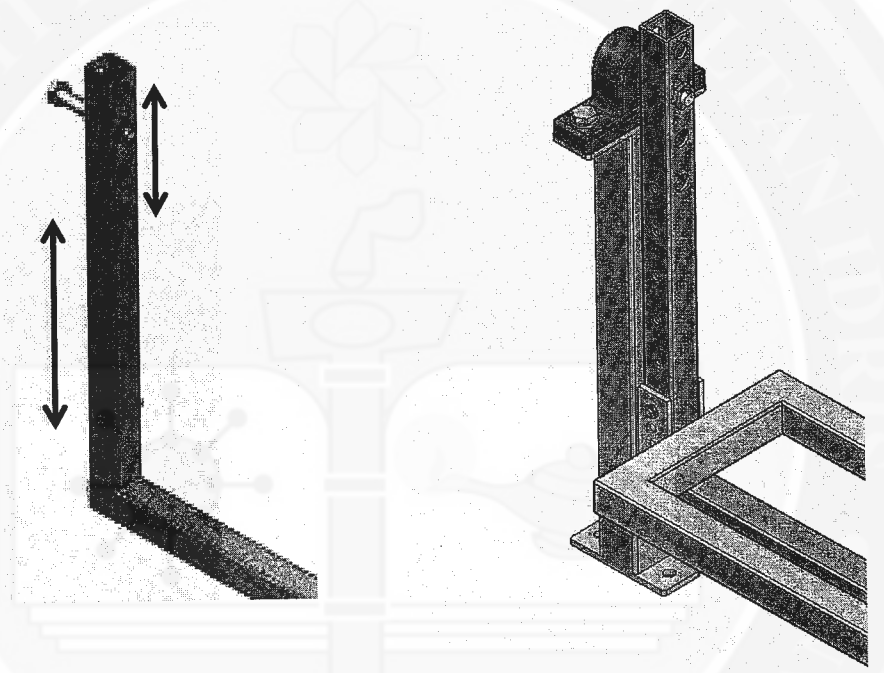


Figure 4-8: Initial concept of centre of rotation height adjustment (not to scale).

Another adjustment essential for the prototype design was the seat to foot-brace distance. The adjustment should provide level of increment suitable for range of athletes with different heights. The possible solution for this concept is shown in Figure 4-9. The combination (C3) was chosen because both seat and the foot-brace can be moved to get the desired distance.

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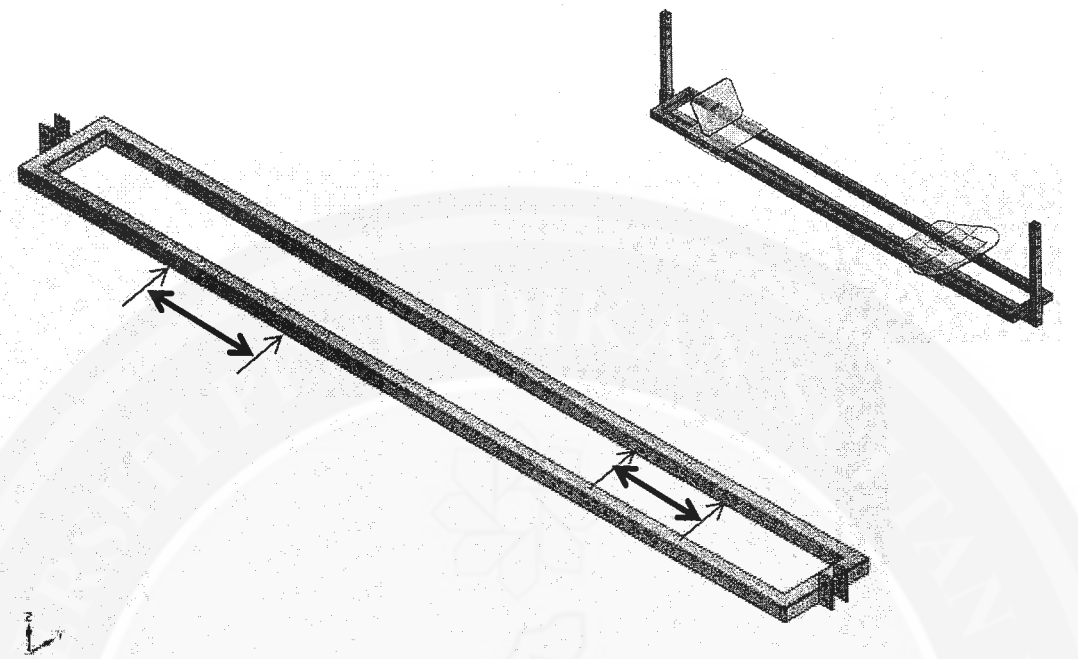


Figure 4-9: Initial concept of seat to foot-braces distance adjustment (not to scale).

Finally, a rigid main frame to support the entire balance training aid and the weight of the user was chosen (Figure 4-10). It was not difficult to make a decision on which main support frame is the most suitable, because the frame should be compatible with the other components chosen earlier. Before any decision could be made regarding the final design of the training aid prototype, it was crucial that any required calculations to ascertain component, parts and materials were obtained from the supplier or manufacturer.

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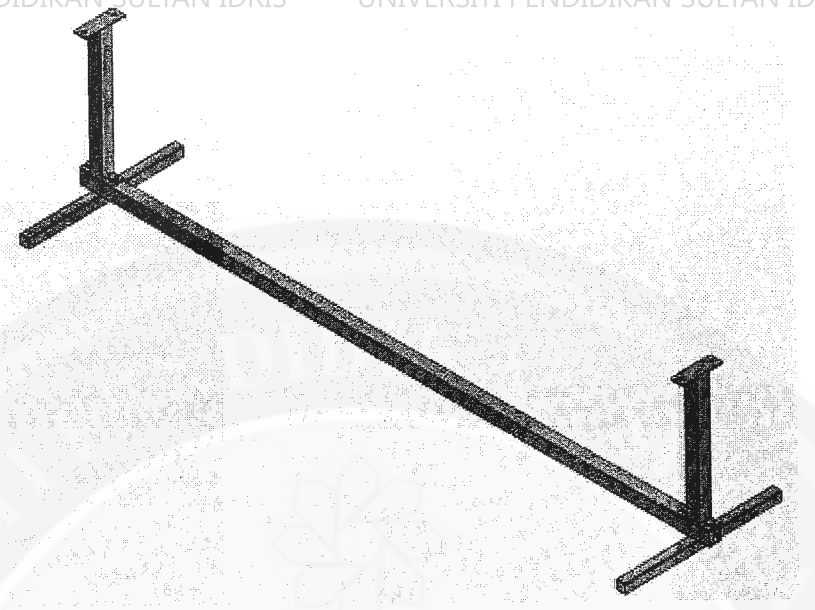


Figure 4-10: Initial concept of main support frame (not to scale).

4.2.4 Final prototype design and dimension

After a preliminary concept design had been completed and accepted, detailed drawing and parts dimension must be completed. The final design of the sprint kayak balance training aid was modelled in Solid Edge Software (www.plm.automation.siemens.com). All consecutive dimensions were analysed, and the prototype design was produced as a three-dimensional solid model (Figure 4-11, Figure 4-12, Figure 4-13 and Figure 4-14).

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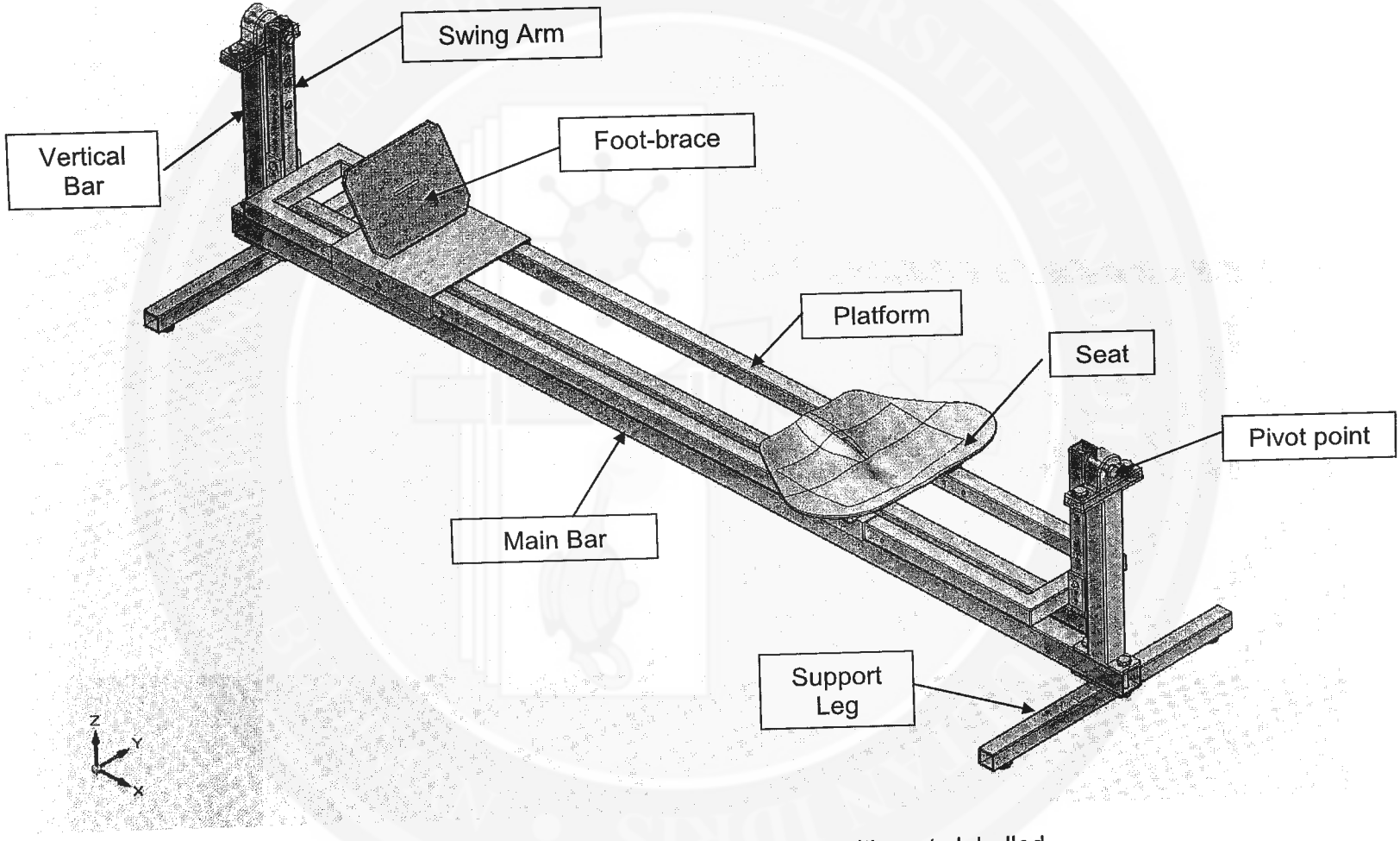



Figure 4-11: Final prototype design concept with parts labelled.



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From the finding in Chapter 3, it has been established that mean centre of rotation (pivot point) distance relative to the point of contact (lowest point of the seat) is between 10 cm to 12 cm for a competitive male paddler. With the established value and taking into account the maximum height of the kayak (from the lowest point of the hull to the highest point of the deck which is 28 cm (Ong et al., 2005). It was decided that the acceptable distance between the pivot points relative to the lowest point of the seat for a complete beginner should be two times larger than the competitive paddler. So, for more stability it was decided that the maximum distance of the pivot points is 30 cm above the seat (Figure 4-12). To provide a stability challenge to the elite paddlers, it was decided that the distance could also be less than 10 cm. Therefore, to accommodate various levels of user the pivot point distance as set at 5 cm below the seat for less stability to 30 cm above the seat for more stability. Two sets of holes at the ends of the platform and on the swing arms allowed 1.5 cm incremental adjustments to be made to suit the stability level (Figure 4-12).

It was also decided that the acceptable distance between the seat and the foot-brace would be from a minimum of 60 cm to a maximum of 120 cm (Ong et al., 2005; Fry & Morton, 1991). The distance would be sufficient enough to accommodate a range of user's heights (Figure 4-12). Finally it was decided that the overall dimensions of the kayak balance training aid would be 200 cm in length; 50 cm in width; and 55 cm in height (Figure 4-13 and Figure 4-14).

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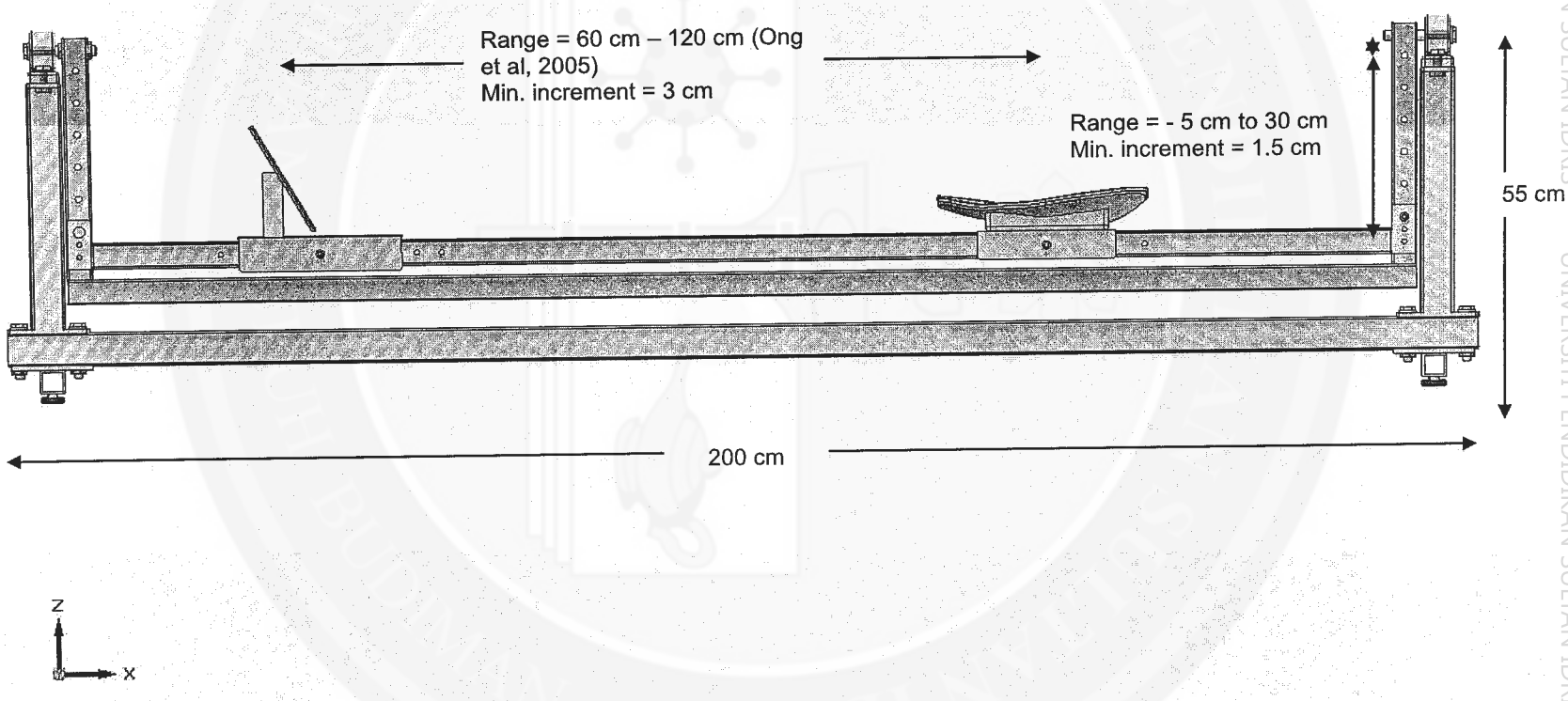



Figure 4-12: Final prototype design concept lateral view with dimensions.



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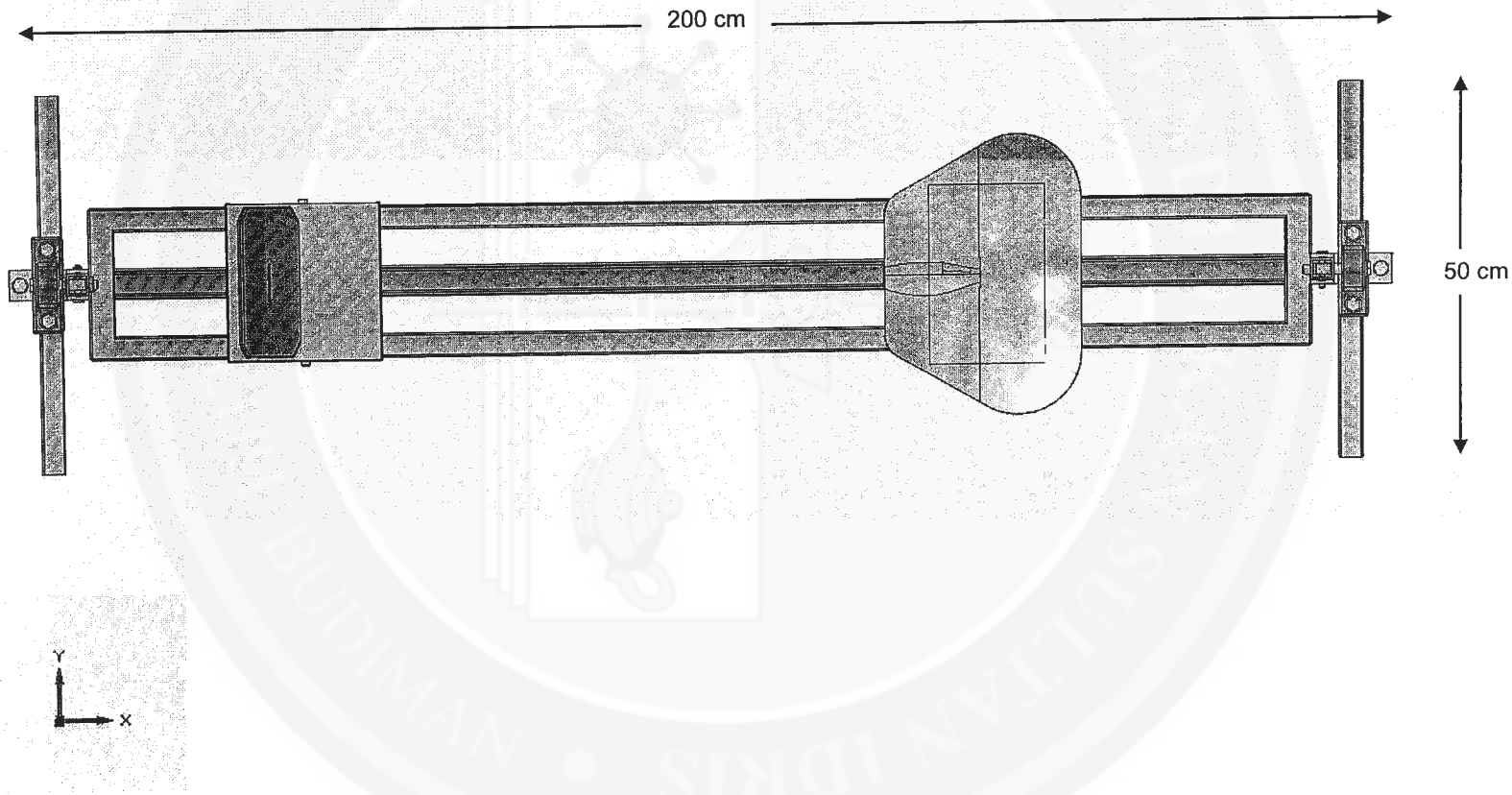



Figure 4-13: Final prototype design concept superior view with dimensions.



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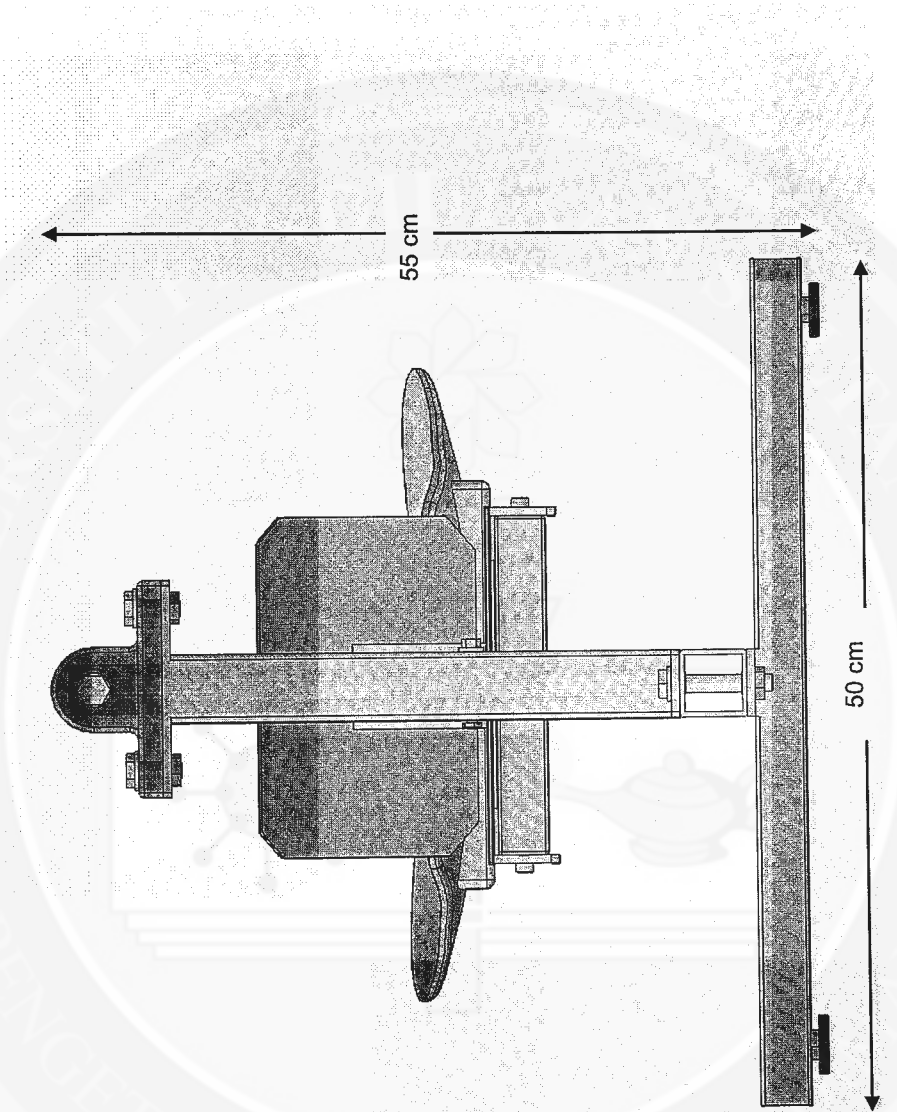



Figure 4-14: Final prototype design concept posterior view with dimensions.

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## 4.3 Prototype construction

A large part of the kayak balance training aid prototype development criteria was ease of manufacturability and low cost production. In order to accomplish this, it was decided that the construction of the training aid would use parts and materials which are readily available in the market, not custom made parts or materials. For construction purposes, the final design concept of the balance training aids was broken down into three main components: the frame; the seat and foot-brace; and the pivot point (rotation) mechanism.

The frame provides supports to all other components and was divided into three parts: the main frame, the swing arm and the platform. For the frame, a combination of mild steel box and mild steel flat bar was selected. Steel box was chosen because of its availability and because it is lighter than solid steel while being strong enough. The outside dimensions were chosen from standard stock to be 4 x 4 cm for the main frame and 3 x 3 cm for the swing arm and the platform. The wall thickness of all steel boxes was chosen to be 0.3 cm. Based on the stress analysis provided by the manufacturer, these materials would produce a sufficient safety factor. For the flat bar the thickness was chosen to be 0.5 cm.

The seat and foot-brace component provides a foundation for the two points of contact between the device and the user. The material for the base of the component was chosen to be mild steel flat bar (0.3 cm thick). The seat and foot-brace chosen were standard sprint kayak parts which are available in the market. The pivot or rotation mechanism mimics the medial-lateral rolling experienced by the paddler while trying to balance the on-water sprint kayak. This component is

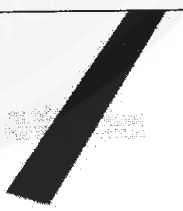
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the most essential for the balance training aid. A housed pillow block bearing was chosen as the pivot mechanism.

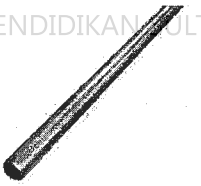
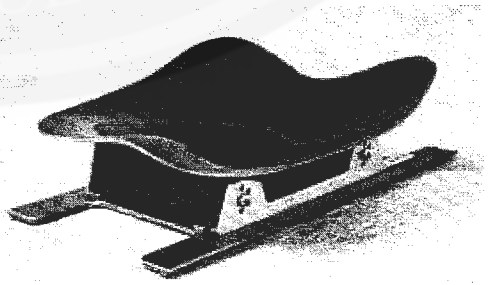
The construction process detailed parts and materials descriptions are presented in Table 4-3, with component specification detailed in Figure 4-15 to Figure 4-21. Finally for safety precaution, a safety blocks were designed and purposely build by specialised manufacture. Specifications for the training block are presented in Appendix 4-1.

Table 4-3: Parts and materials descriptions for balance training aid

| Item | Descriptions |
|---|---|
| 1. | Mild Steel box<br>4 x 4 x 0.3 (cm)<br>http://www.metals4u.co.uk  |
| 2. | Mild Steel box<br>3 x 3 x 0.3 (cm)<br>http://www.metals4u.co.uk  |
| 3. | Mild Steel flat bar<br>4 x 0.5 (cm)<br>4 x 0.3 (cm)<br>http://www.metals4u.co.uk  |

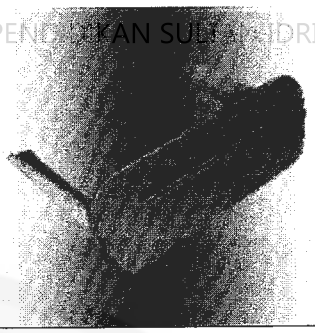
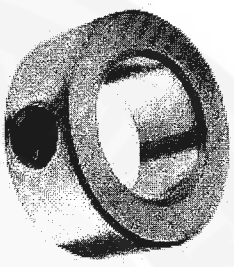
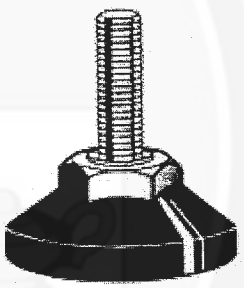
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| 4. | Mild steel round bar<br>6 (cm)<br>http://www.metals4u.co.uk<br> |
| 5. | Normal Duty 2 Bolt Hole Pillow Block (budget brand)<br>1.2 cm Shaft<br>Length: 12.7 cm<br>Width: 3.8 cm Weight: 500g<br>Height: 6.2 cm<br>Bolt Hole Centres: 9. 6 cm<br>Base To Centre Height: 3.2 cm<br>Bolt size: M10<br>www.bearing-king.co.uk<br> |
| 6. | Hex Head Bolts Screws + Nuts<br>M6 x 4.5 cm<br>M6 x 2 cm<br>M10 x 2.5 cm<br>M10 x 5 cm<br>M12 x 9 cm<br>http://www.screwfasteners.co.uk<br> |
| 7. | Low back sliding seat<br>www.kirtonkayaks.co.uk<br> |

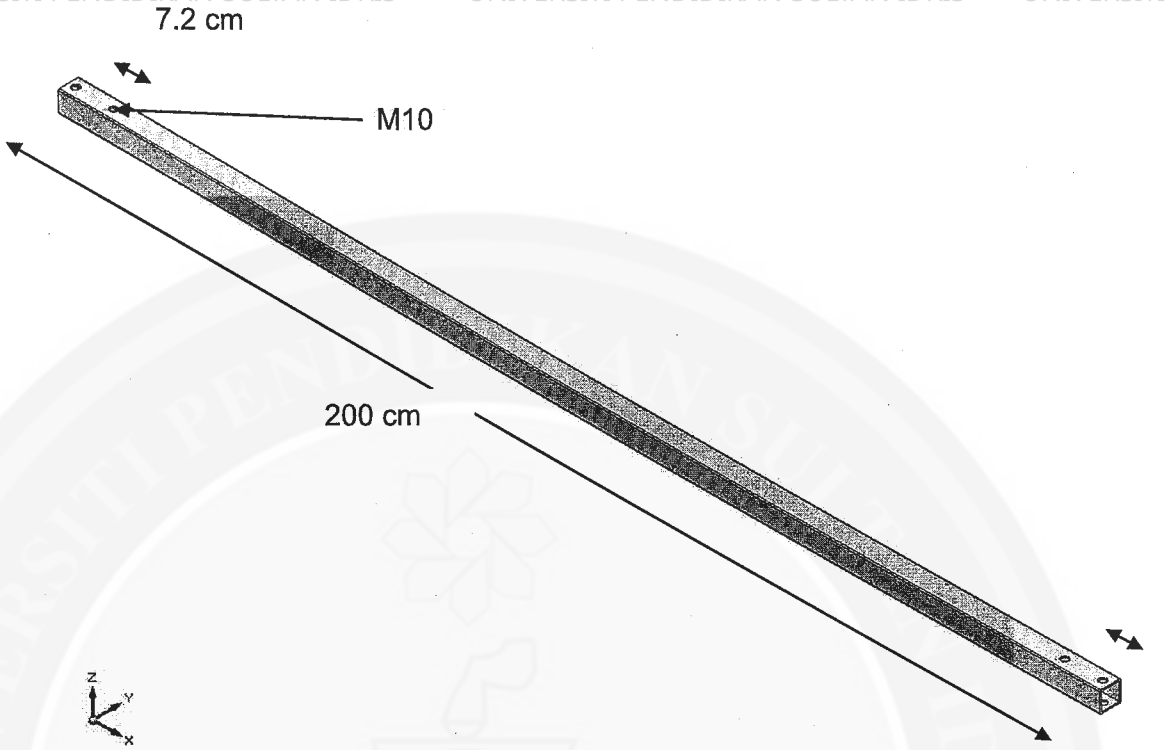
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| | |
|---|---|
| 8. | One piece footrest K1<br><br>www.kirtonkayaks.co.uk  |
| 9. | 1.2 cm Shaft Collar (CABU12Z)<br>Width : 1.2 cm<br>Outside Dia: 2.2 cm<br>Inside Dia: 1.2 cm<br>www.bearingboys.co.uk  |
| 10. | Rigid Adjustable Feet<br>Base Dia = 3 cm<br>Thread size = M10 x 4 cm<br>Static loading = 150 kg<br><br>(model – 5210-1)<br>http://www.rosshandling.co.uk/rigid-feet.asp  |

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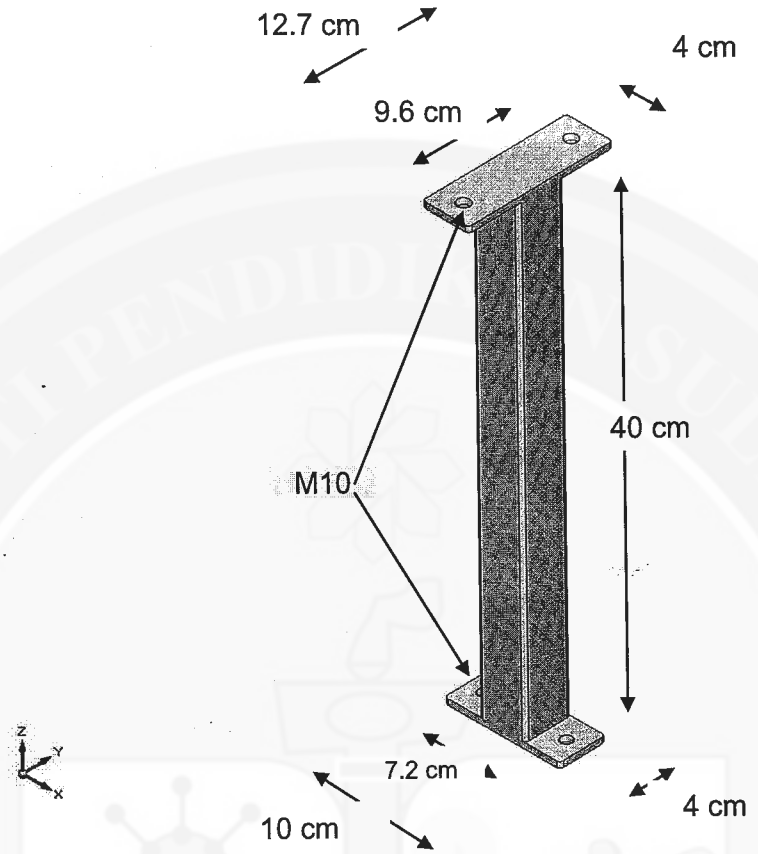



| Item | Description |
|---|---|
| Length | 200 cm |
| Materials | Mild Steel box (4 x 4 x 0.3 (cm) |
| Hole size | M10 |
| Quantity | 1 unit |

Figure 4-155: Component specifications for balance training aid main bar.

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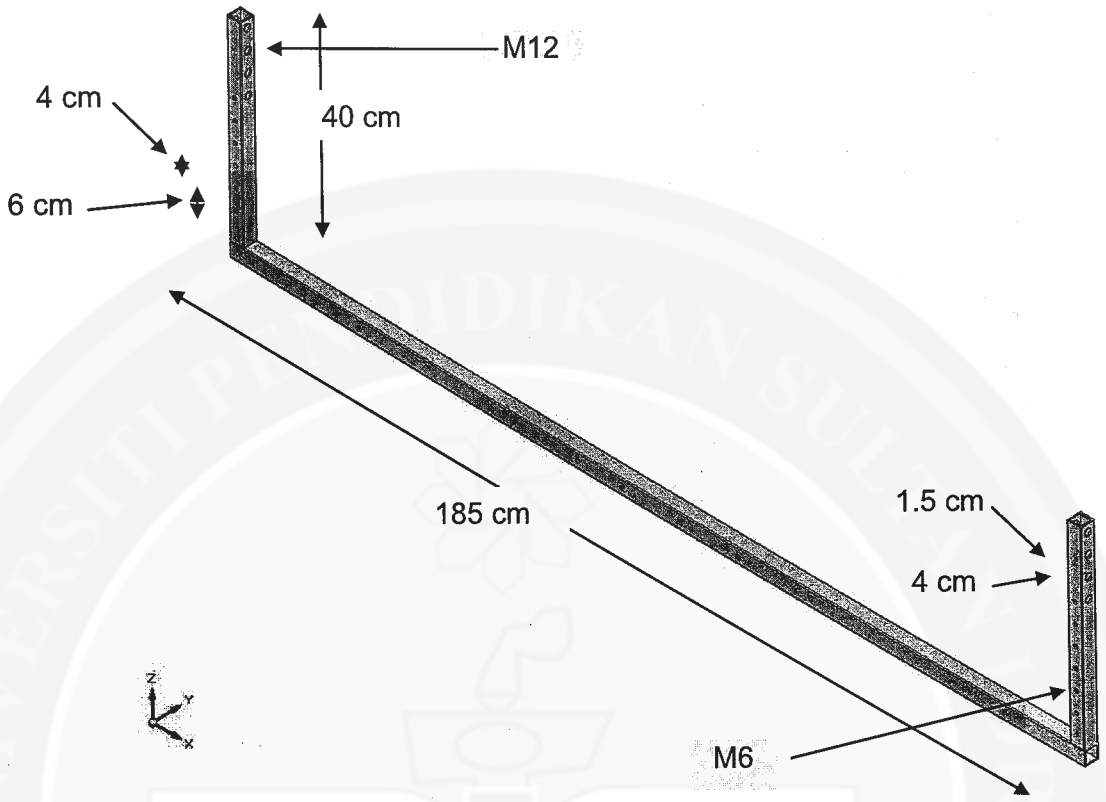



| Item | Description | Notes |
|---|---|---|
| Length | 41 cm | Overall length |
| Materials | Mild Steel box - 4 x 4 x 0.3 (cm) | Welded joints |
| | Mild Steel flat bar 4 x 0.5 (cm) | |
| Hole size | M10 | |
| Quantity | 2 unit | |

Figure 4-166: Component specifications for balance training aid support arm.

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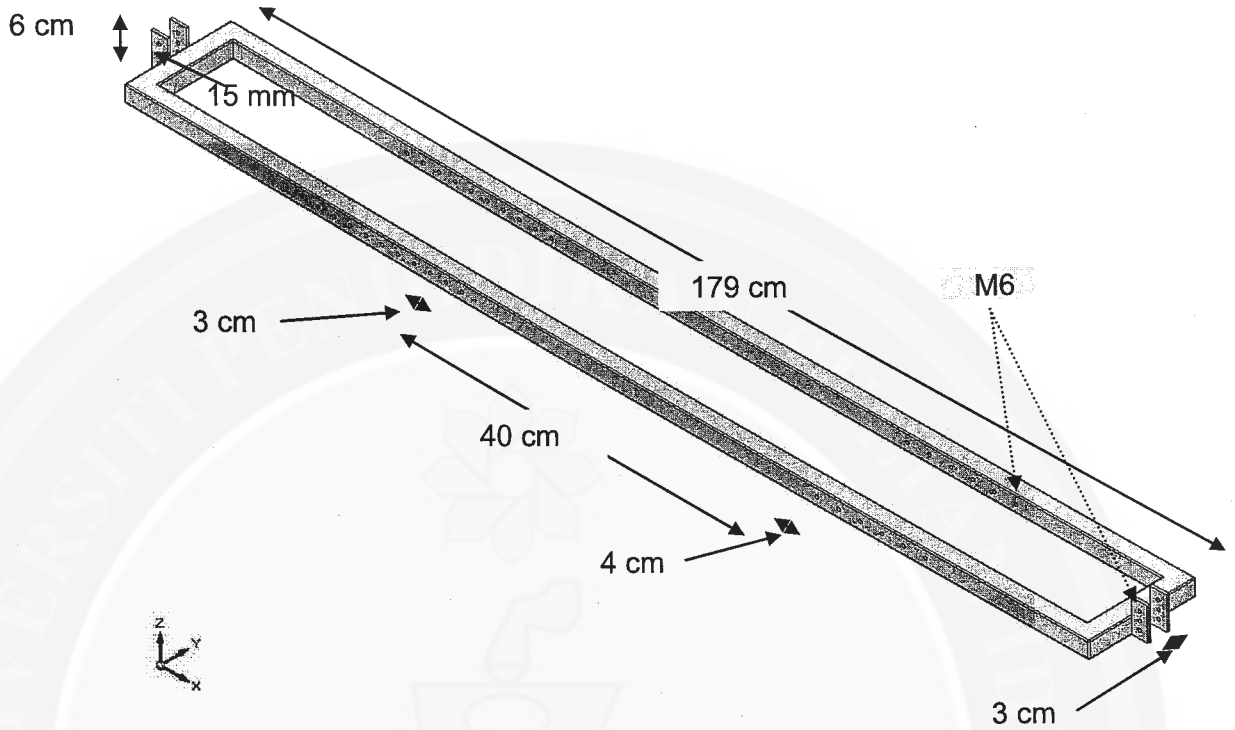



| Item | Description | Notes |
|---|---|---|
| Length | 185 cm | Overall |
| Height | 43 cm | Overall |
| Materials | Mild Steel box - 3 x 3 x 0.3 (cm) | Welded joints |
| Hole size | M12 & M6 | |
| Quantity | 1 unit | |

Figure 4-177: Component specifications for balance training aid swing arm.

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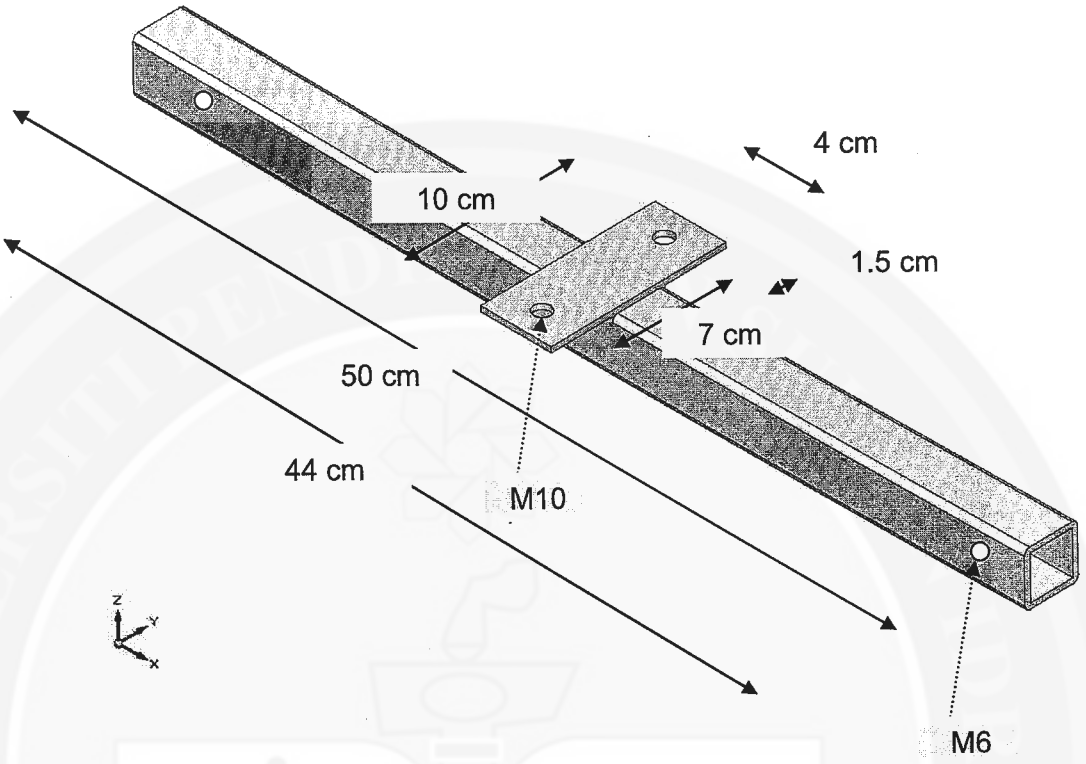



| Item | Description | Notes |
|---|---|---|
| Length | 187 cm | Overall |
| Width | 6 cm | Overall |
| Materials | Mild Steel box - 3 x 3 x 0.3 (cm) | Welded joints |
| | Mild Steel flat bar - 4 x 0.5 (cm) | |
| Hole size | M6 | |
| Quantity | 1 unit | |

Figure 4-188: Component specifications for balance training aid platform.

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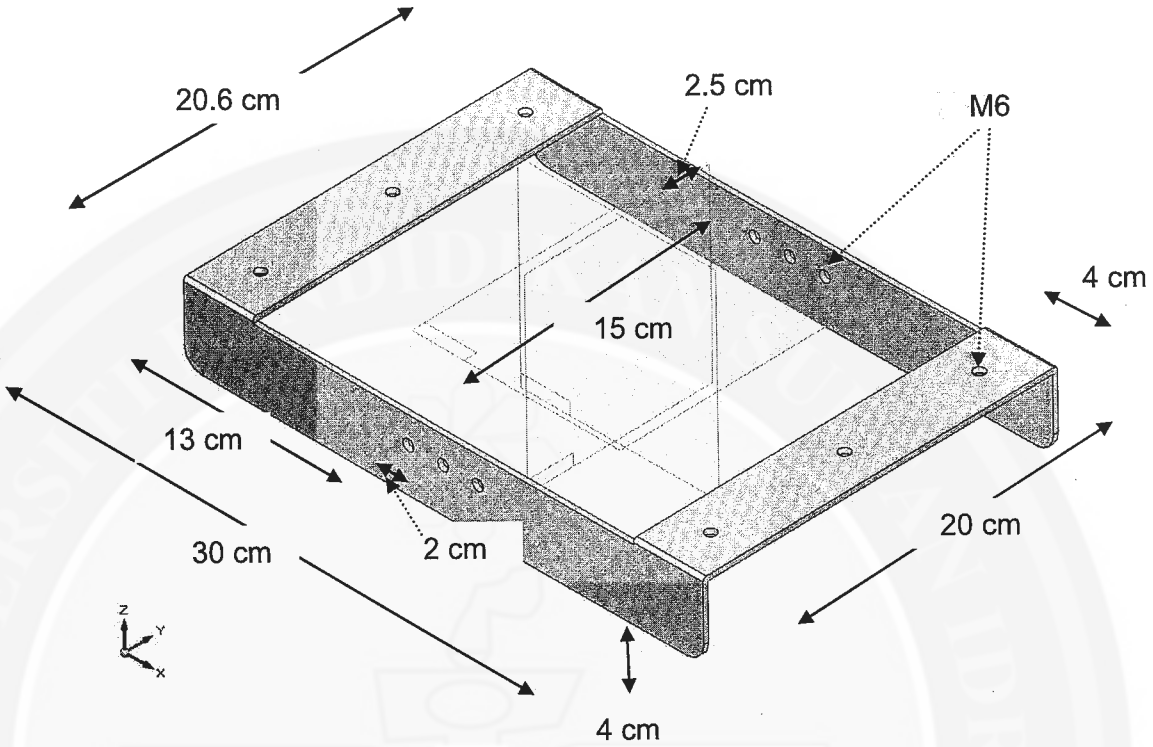



| Item | Description | Notes |
|---|---|---|
| Length | 50 cm | Overall |
| Height | 35 cm | Overall |
| Materials | Mild Steel box - 3 x 3 x 0.3 (cm) | Welded joints |
| | Mild Steel flat bar - 4 x 0.5 (cm) | |
| Hole size | M10 & M6 | |
| Quantity | 2 unit | |

Figure 4-199: Component specifications for balance training aid support leg.

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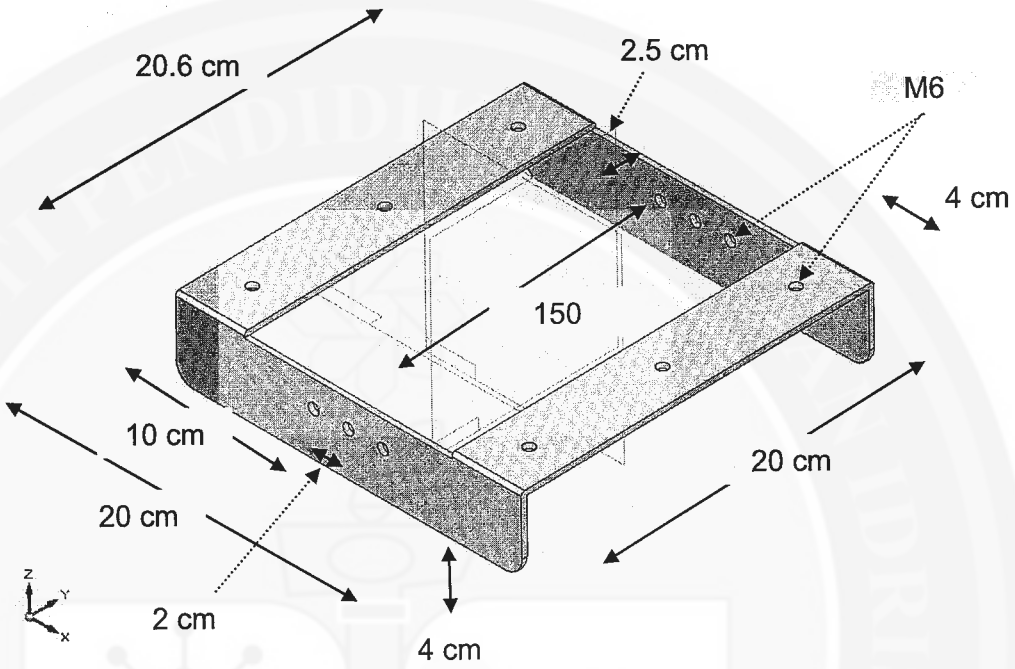



| Item | Description | Notes |
|---|---|---|
| Length | 30 cm | Overall |
| Width | 20.6 cm | Overall |
| Materials | Mild Steel flat bar - 4 x 0.3 (cm) | Welded joints |
| Hole size | M6 | |
| Quantity | 1 unit | |

Figure 4-20: Component specifications for balance training aid seat base.

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| Item | Description | Notes |
|---|---|---|
| Length | 20 cm | Overall |
| Width | 20.6 cm | Overall |
| Materials | Mild Steel flat bar - 4 x 0.3 (cm) | Welded joints |
| Hole size | M6 | |
| Quantity | 1 unit | |

Figure 4-21: Component specifications for balance training aid foot-brace base.

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## 4.4 Chapter summary

This balance training aid was carefully designed to accommodate the training needs of individuals to be able to balance a sprint kayak. It was designed to fulfil all established requirements and necessity identified from experimental data collected on experienced sprint paddlers. It was decided that the design was satisfactory for construction, and once built the prototype will be physically evaluated and assessed. The evaluation process will be detailed and discussed in the following chapter.

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# Chapter 5

# Sprint Kayak Balance Training Aid Prototype Evaluation

## 5.1 Introduction

To ensure that the prototype sprint kayak balance training aid functioned as intended, two different evaluations were carried out. The first of these evaluations was the medial-lateral rolling motion analysis in order to establish similarity between the on-water sprint kayak and the balance training aid. Further evaluation then took place to test the safety of the training aid.

## 5.2 On-water kayak medial-lateral rolling motion analysis

To enable an evaluation of the sprint kayak balance training aid medial-lateral rolling motion, the on-water sprint kayak medial-lateral rolling motion characteristics needed to be established first. In order to fulfil this need, medial-lateral rolling data of an on-water sprint kayak with several additional weight variations were collected. The first objective of this test was to determine the centre of rotation for the on-water kayak rolling motion with additional weight. Secondly, to compare the on-water kayak and the balance training aid medial-lateral rolling characteristics (frequency and amplitude). Finally, with this analysis the research question: "Is the on-water kayak rolling motion affected by weight variations?" will be addressed. An Initial decision was made to perform preliminary on-water testing without additional and with additional weight ranging

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from 10 kg to 50 kg. The data collection procedure and the result of this preliminary testing are presented in Appendix 5-1. Based on the results of the preliminary testing another medial-lateral rolling test was conducted in order to produce more reliable data. This time it was decided that the additional weight increment needed to resemble the real subject weight distribution, ranging from 30 kg to 80 kg. The data collection procedure of this testing was similar to the preliminary testing.

### 5.2.1 Data collection

For the ease of the on-water data collection, the data collection took place in a purposely built training pool with dimensions that could accommodate a sprint kayak (Figure 5-1). The equipment used for data collection was a high speed camera (Phantom) with frame rate set at 50 Hz; a standard K1 sprint kayak; weight plates; and a spirit level. Two retro-reflective 20 mm diameter markers were attached on the left and right rear cockpit[1] of the kayak (40 cm apart between each) and were used to define the kayak motion. Meanwhile, two other markers were attached at the bottom and the top end of a vertically projected rod (40 cm in length) in the middle of the kayak. These pairs of markers (Figure 5-1) were used to give the horizontal and vertical scaling, respectively. Up to eight TECHNOGYM®'s 10 kg weight plates were used as additional weight. The weight plates measured 30 cm in diameter and 4 cm in thickness. A special platform was built and placed inside the sprint kayak cockpit to replace the seat of the kayak and to hold the weight plates in place (Figure 5-1). The platform was

[1] Refers to the large hole on the deck of the kayak where the paddler steps into and sits; and is made to accommodate different size paddlers.

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securely fixed to the internal hull of the kayak and the measured height of the platform top surface was similar to the lowest point of the kayak seat.

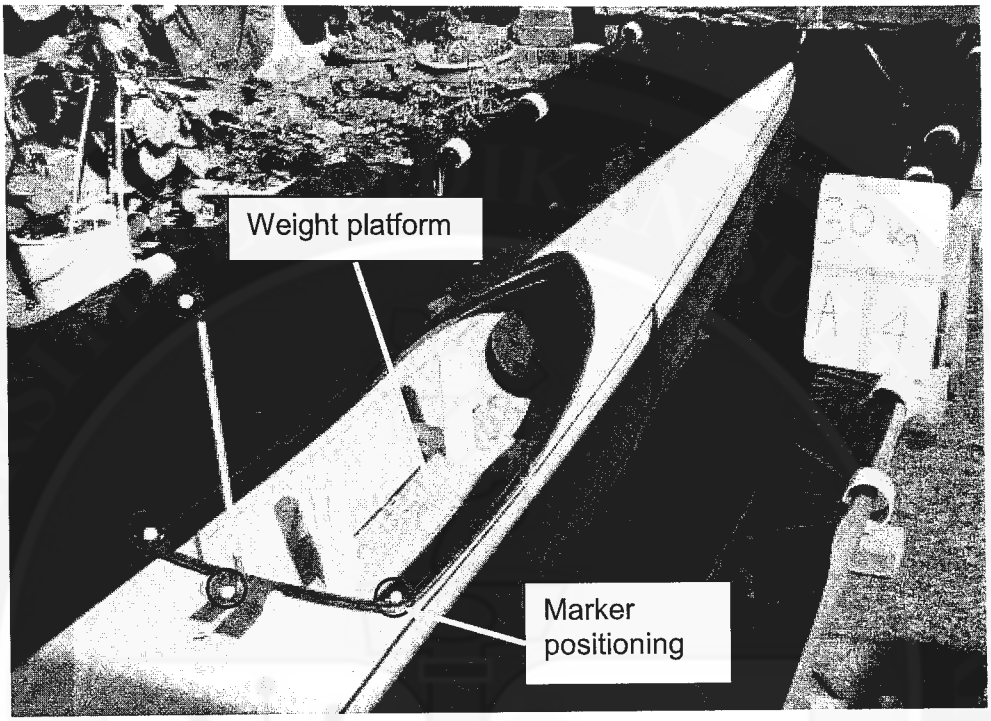



Figure 5-1: Training pool for on-water kayak medial-lateral rolling testing and retro-reflective markers locations.

Before commencing with the data collection trial, a weight stacked test on the platform was carried out. The weight platform was built to accommodate only two stacks of weight plates. It was found that the kayak would only remain stable and gradually oscillate up to maximum of two stacks of three plates (30 kg each stack), equivalent to 12 cm of plate's height. So, it was decided that three weight plates (30 kg) were securely positioned at the rear and in front of the platform and set as the initial weight increment (Figure 5-2). The first data collected was the initial 30 kg additional weight with a measured centre of mass height of 3 cm from the top surface of the platform (Table 5-2). To initiate the rolling motion, the kayak

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was tilted to the right at a 20° angle and was then released to oscillate on its own. To avoid any medial-lateral drift the bow and the stern of the kayak were carefully secured to the side of the pool. The same procedure was followed in order to obtain data from variations of additional weight as shown in Table 5-1. Additional weight more than 80 kg was not possible to be arranged inside the kayak. It would also make the kayak unstable due to the centre of mass being higher than the centre of rotation. Figure 5-3, shows the additional weight plates positioning and set up for the on-water kayak oscillation test.

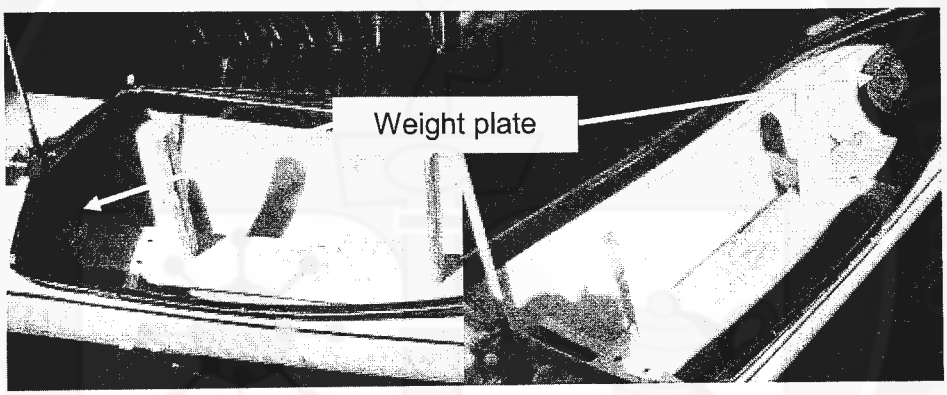



Figure 5-2: Weight plate positioning of the initial 30 kg (3 plates) additional weight.

Table 5-1: Variations of additional weight for rolling analysis

| Additional weight (kg) | Additional weight centre of mass height (cm) | Initial release angle (°) |
|---|---|---|
| 30 | 3 | 20 |
| 40 | 4 | 20 |
| 50 | 5 | 20 |
| 60 | 6 | 20 |
| 70 | 7 | 20 |
| 80 | 8 | 20 |

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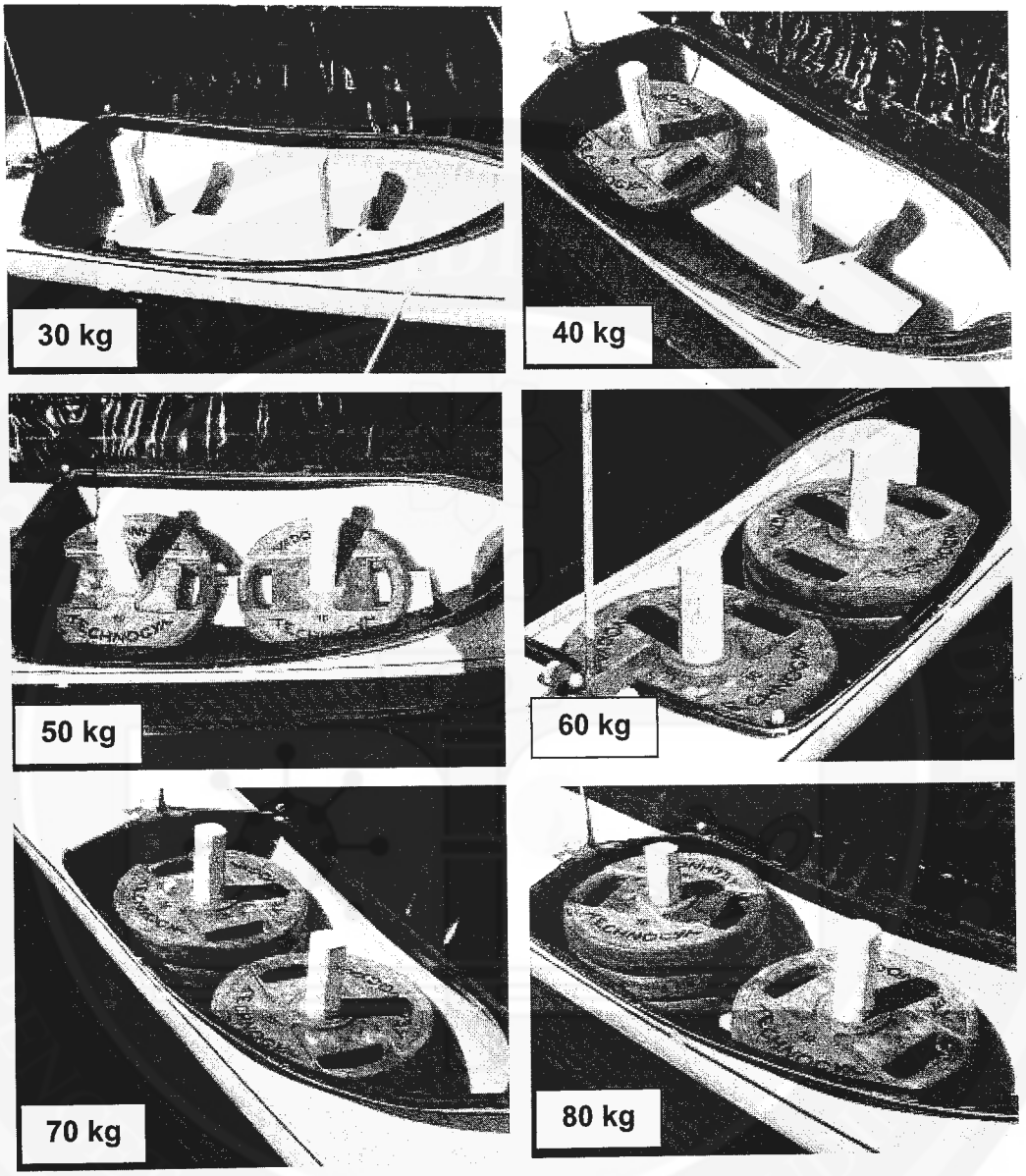



Figure 5-3: Additional weight positioning for the on-water medial-lateral rolling analysis.

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### 5.2.2 Data analysis

The video footage of the two markers on the kayak was digitised using the AviDigitiser software (RF Spectrum Modelling Ltd, 2008) producing a 2-dimensional model of the kayak segment. From the model, kayak medial-lateral rolling angles were determined by calculating the angle between the kayak segment and the horizontal line along the medial-lateral (Z) axis. A positive angle was recorded for rotation above the reference axis ($y>0$, $z>0$) and a negative angle for rotation below the reference axis ($y<0$, $z<0$), respectively. The digitised data was smoothed using a low-pass Butterworth filter set at a 5 Hz cut off frequency (determined by residual analysis) to smooth the data (Winter, 2009). Digitised pixel coordinates were converted into real-life y and z position in metres. The method previously described in Chapter 3 was used to determine the centre of rotation of the kayak.

### 5.2.3 Results

The medial-lateral rolling angle information of the on-water kayak was the most important data needed for the evaluation of the sprint kayak balance training aid. Figure 5-4 shows a representative data trace of the on-water kayak medial-lateral rolling motion for a variety of additional weights from 30 kg to 80 kg, respectively. It seemed like that the calculated medial-lateral rolling frequency and the amplitude of oscillation was reduced after every additional weight. In each trial, the amplitude of oscillation decreased exponentially after each complete oscillation. However, with high loading the reaction wave effect from the containing walls was greater. The centre of rotation location and medial-lateral

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rolling frequency of the on-water kayak for various additional weights is shown in Table 5-2.

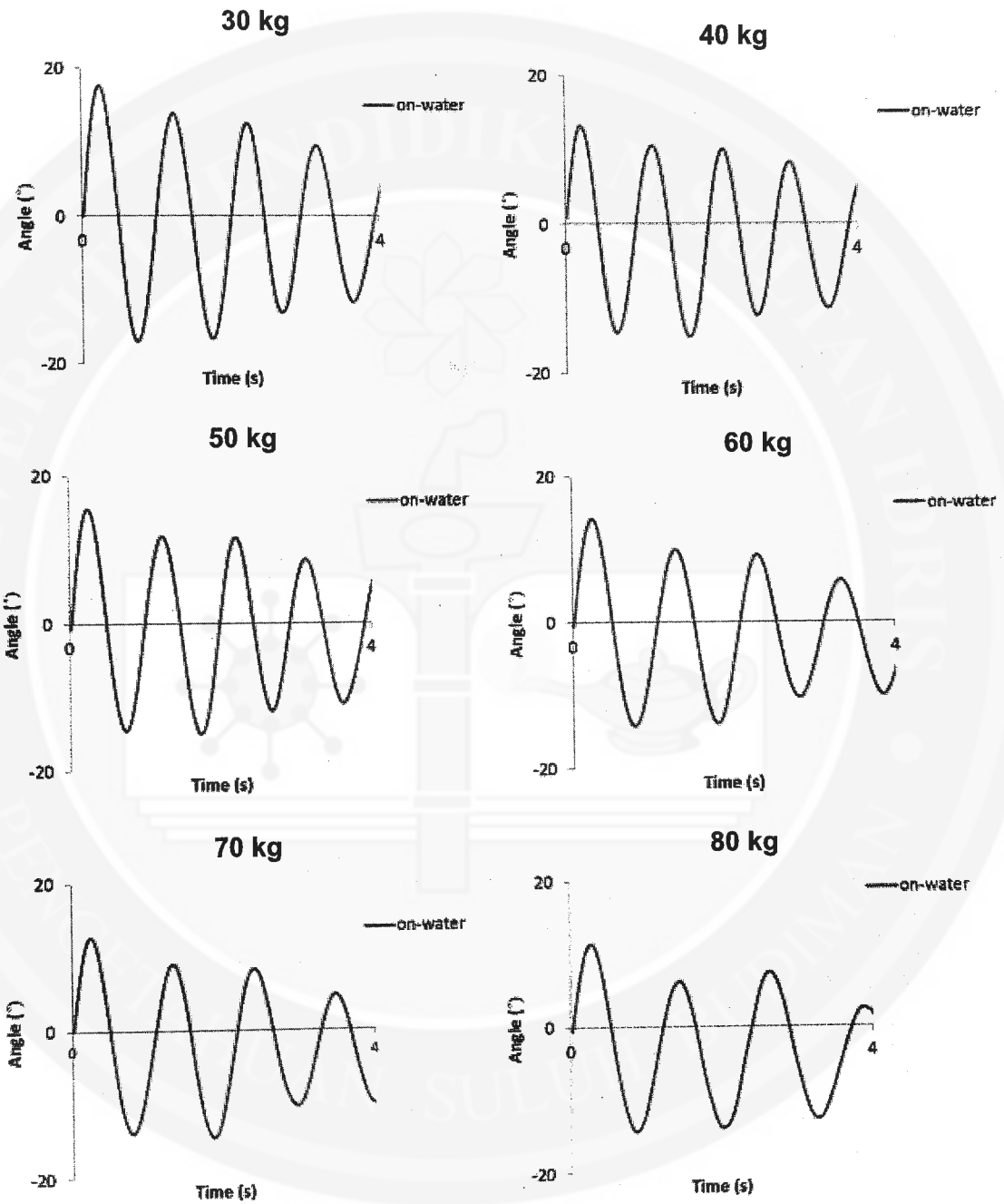



Figure 5-4: Medial-lateral rolling time history of on-water kayak for various additional weights.

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Table 5-2: On-water kayak centre of rotation position and rolling frequency for various additional weights

| Weight (kg) | 30 | 40 | 50 | 60 | 70 | 80 |
|---|---|---|---|---|---|---|
| Centre of rotation position (cm) | **8** | **8** | **9** | **10** | **10** | **11** |
| Rolling frequency (Hz) | **1.02** | **1.03** | **1.02** | **0.97** | **0.93** | **0.81** |

### 5.2.4 Discussion

From this on-water evaluation an important piece of information has been revealed. The research question "Is the on-water kayak rolling motion affected by weight variations?" could also be answered by this information. Increased weight does affect the medial-lateral rolling motion and the centre of rotation position of the on-water kayak. The results show that the kayak medial-lateral rolling frequency gradually decreased after every additional weight. On the other hand, the peak rolling amplitude for every additional weight decayed exponentially as a function of time. This occurred due to the viscous friction acting on the wetted hull surface of the kayak. Furthermore, the calculated centre of rotation was also increased with every additional weight. Figure 5-5, shows the extension of the previous linear regression result on the relationship between kayak centre of rotation and additional weight. A significant positive relationship, with correlation coefficient value $r$ = 0.98 and regression equation y = 0.6429 (x) + 58.476. The data set (predictor variable) will be used as a guide for subsequent level setting of the balance training aid centre of rotation.

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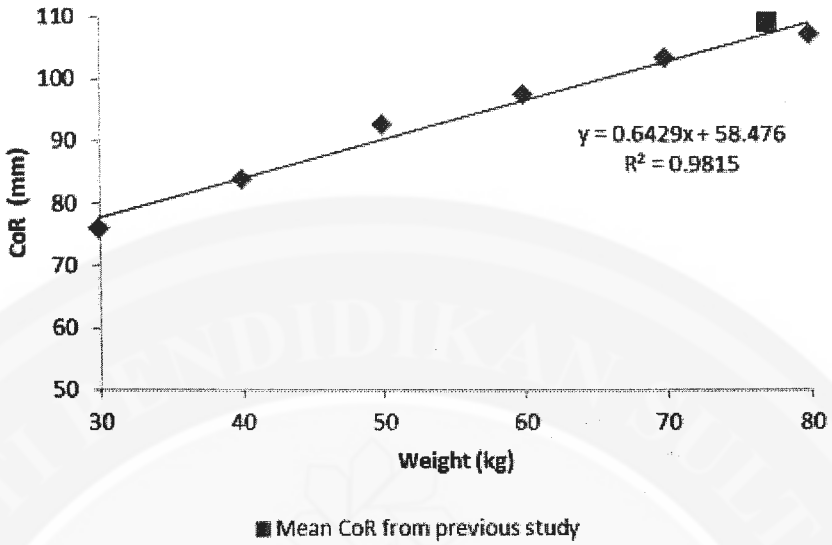



Figure 5-5: Relationship between weight increment and centre of rotation for on-water kayak medial-lateral rolling motion.

## 5.3 Balance training aid medial-lateral rolling motion comparison

After the establishment of the on-water sprint kayak medial-lateral rolling angle characteristics, a similar motion data collection and analysis was conducted for the kayak balance training aid prototype. A comparison was made to investigate the differences in medial lateral rolling frequency and amplitude.

### 5.3.1 Data collection

The data collection took place in the Robin Hooper Biomechanics Research Laboratory at Loughborough University. A Vicon Nexus motion capture system (Vicon Motion System Ltd, 2009) was used to collect motion data of the balance training aid with a variety of additional weights (refer previous section Table 5-1). Nine Vicon MX cameras, sampling at a frequency of 50 Hz, were used to track the motion of two markers attached to the kayak balance training aid (Figure 5-6).

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These two markers were placed at a similar height and position as the kayak markers on the previous on-water testing and were used to determine the medial-lateral rolling motion of the training aid. The cameras in this laboratory were already permanently positioned and focused to give an appropriate capture volume for the data collection (Figure 5-7). Before any data was collected, static and dynamic calibrations were performed until the required calibration residual maximum error of 2.0 mm or less were achieved for each camera.

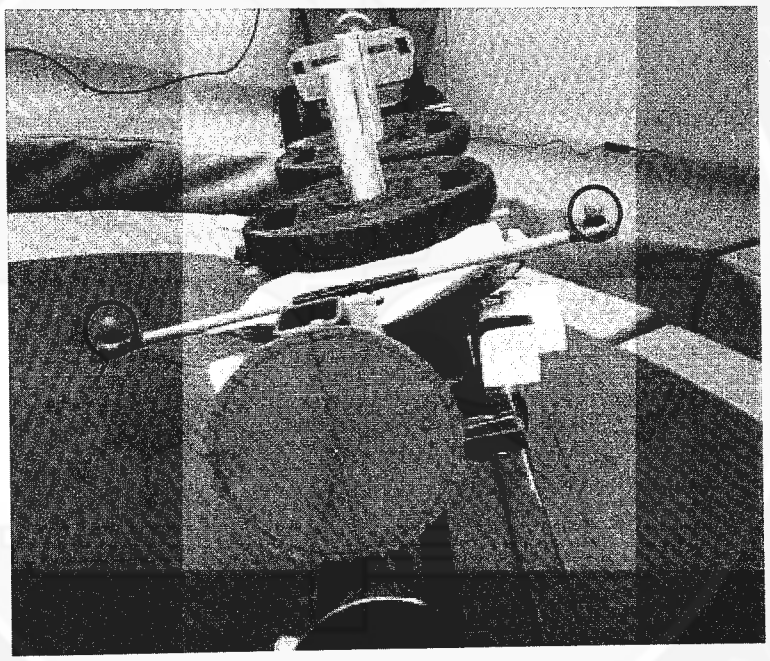


Figure 5-6: Vicon markers placement on the kayak balance training aid.

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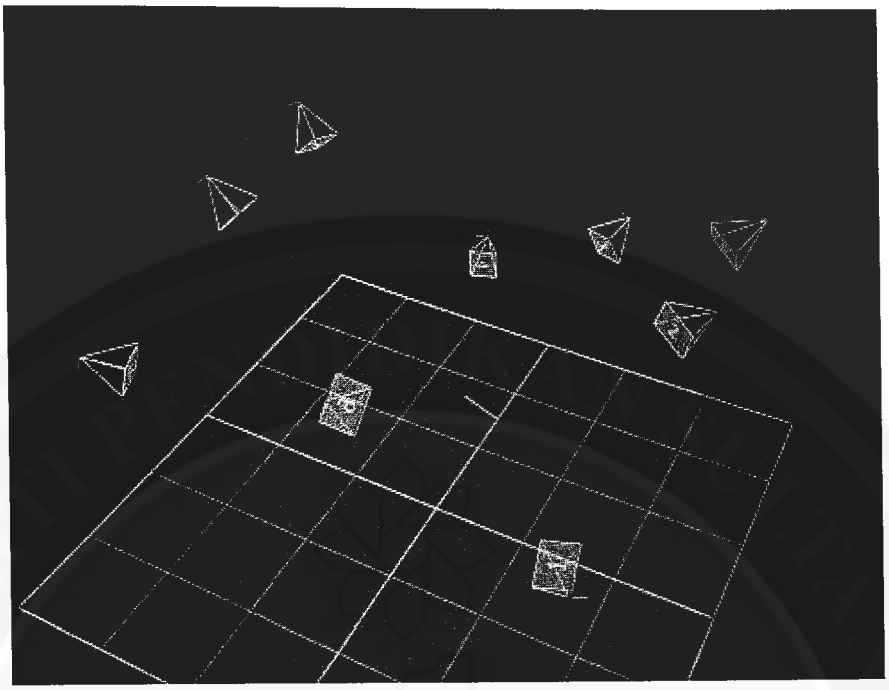


Figure 5-7: Nine Vicon MX cameras position in the laboratory.

The kayak balance training aid prototype was placed in the middle of the capture volume. A similar data collection procedure used on the previous on-water testing was administered for the balance training aid. The weight plates' platform used for the on-water data collection was also attached to the training aid to hold the weight plates in place (Figure 5-8). For each additional weight, the centre of rotation/pivot point was set to the specific height determined from the results of the previous on-water analysis (refer to previous Table 5-1 and Table 5-2). A single trial for each additional weight was chosen for data analysis.

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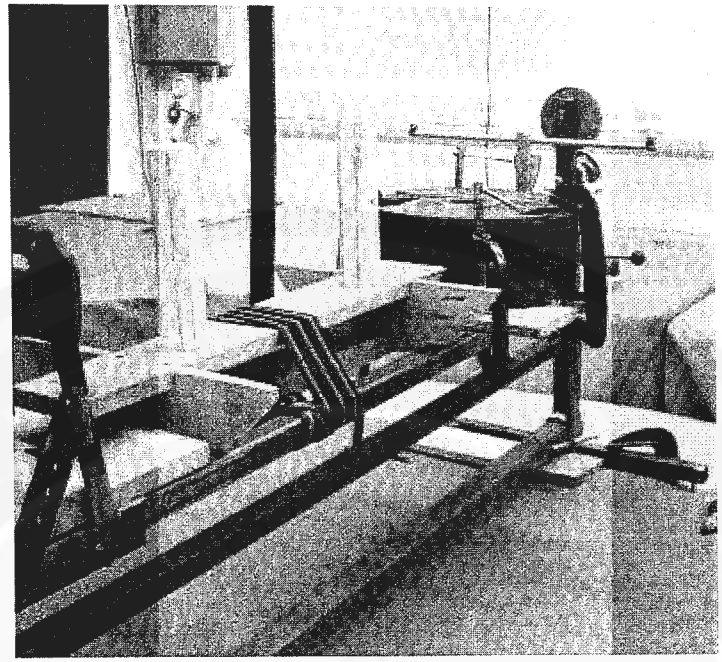


Figure 5-8: Weight plates platform/holder.

### 5.3.2 Data analysis

The reconstructed Vicon markers data were exported as an ASCII file and processed using Microsoft Excel. For the purpose of this analysis, only frontal plane (y and z) coordinates were used. The data was then smoothed and the angle data obtained, using the same method as described in Section 5.2.2.

### 5.3.3 Results

Figure 5-9, illustrates the medial lateral rolling frequency of the on-water kayak and the balance training aid with additional weight of 30 kg to 80 kg. As discussed in the previous section (5.2.4), the on-water kayak medial-lateral rolling frequency decreased after each additional weight. However this did not happen for the balance training aid (Figure 5-9).

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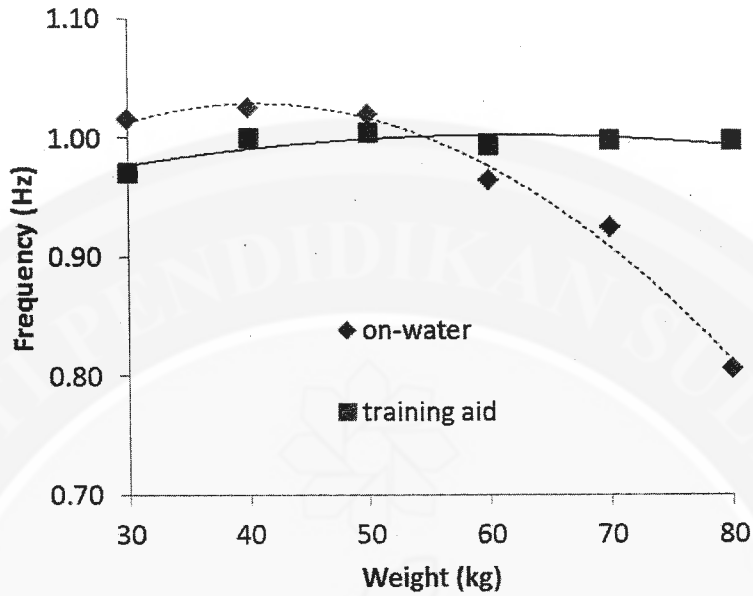



Figure 5-9: Medial-lateral rolling frequency differences between on-water kayak and balance training aid prototype.

Figure 5-10 - Figure 5-15, show the difference between the medial-lateral rolling amplitude of the on-water kayak and the balance training aid. The peak amplitude decay of the kayak balance training aid was linear with a function of time. From 30 kg to 60 kg additional weight, the amplitude decay was not too obvious. However, when 70 kg and 80 kg were added to the kayak the decrease was much clearer.

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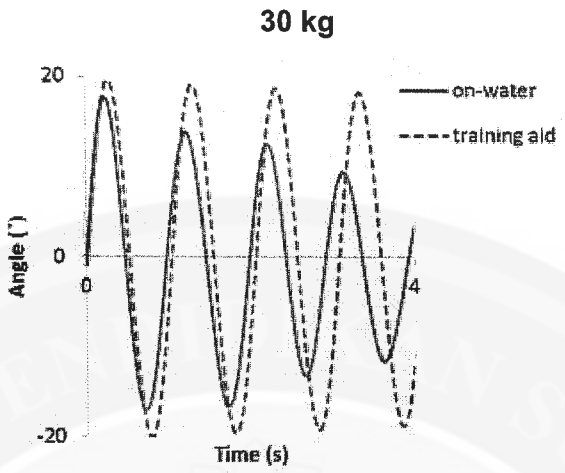



Figure 5-10: Medial-lateral rolling amplitude comparison between on-water kayak and balance training aid with 30 kg additional weight.

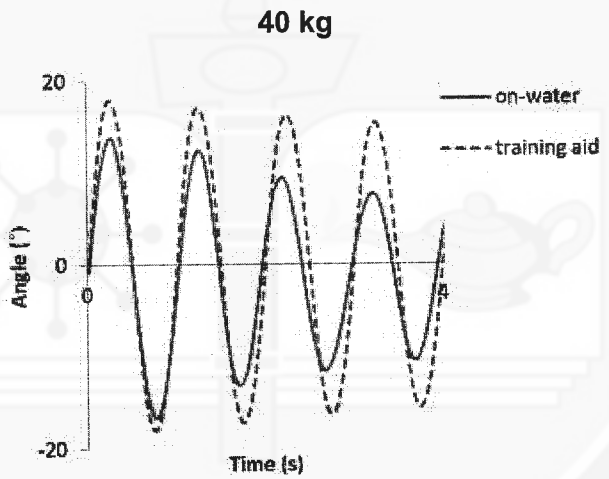



Figure 5-11: Medial-lateral rolling amplitude comparison between on-water kayak and balance training aid with 40 kg additional weight.

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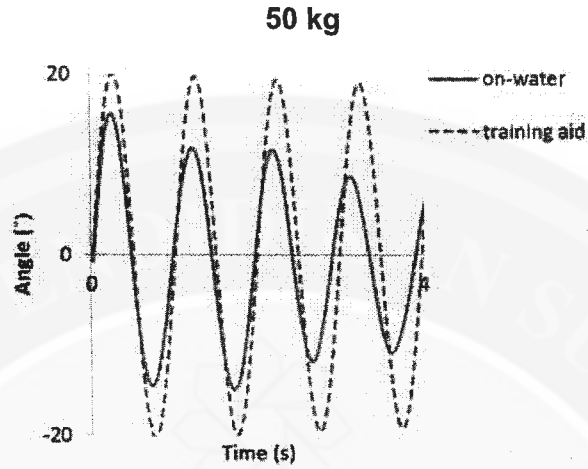



Figure 5-12: Medial-lateral rolling amplitude comparison between on-water kayak and balance training aid with 50 kg additional weight.

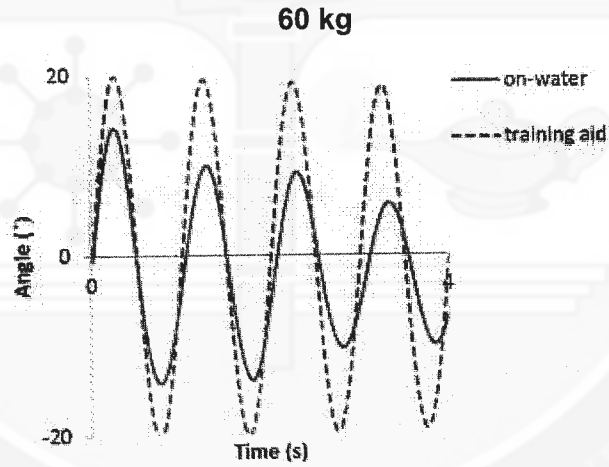



Figure 5-13: Medial-lateral rolling amplitude comparison between on-water kayak and balance training aid with 60 kg additional weight.

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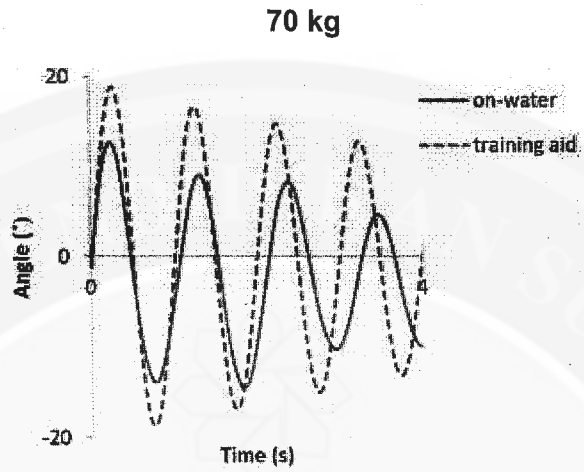



Figure 5-15: Medial-lateral rolling amplitude comparison between on-water kayak and balance training aid with 70 kg additional weight.

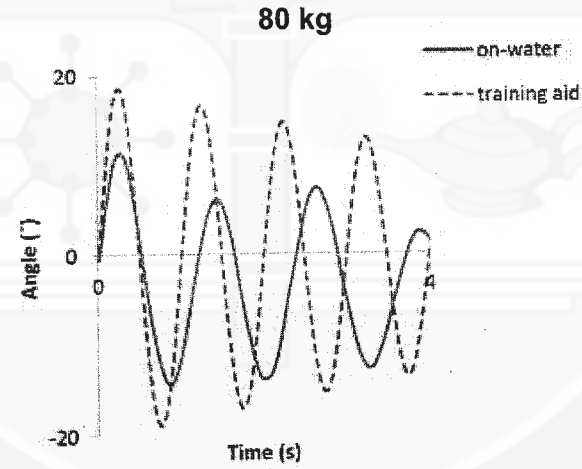



Figure 5-16: Medial-lateral rolling amplitude comparison between on-water kayak and balance training aid with 80 kg additional weight.

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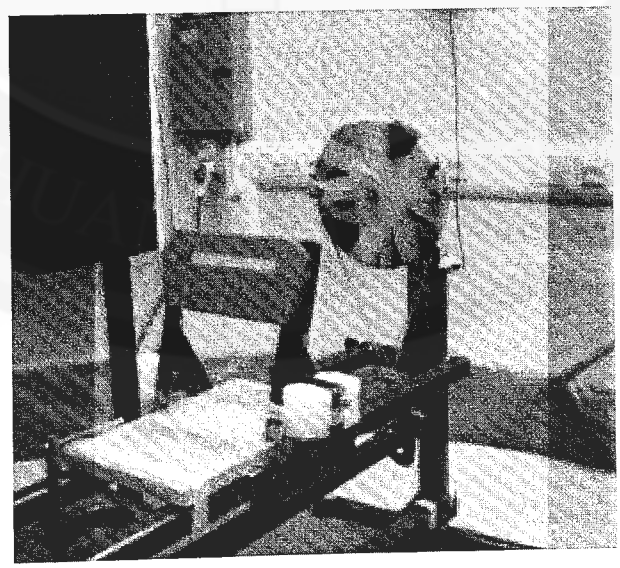
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### 5.3.4 Discussion

A very positive result was obtained from this comparison analysis, and it clearly suggested that the balance training aid needed further modification in order to replicate the on-water kayak rolling motion characteristics. A friction and damping device was needed to control the peak amplitude and the rolling frequency.

## 5.4 Modification and evaluation of sprint kayak balance training aid

To produce similar oscillation characteristics to on-water kayaking, several damping system options were tested on the balance training. The first damping option tested was the elastic flywheel system (see Figure 5-16). This system comprised a 5 kg flywheel attached 8 cm above the training aid centre of rotation. Elastic rubber was used to resist the rotation of the flywheel due to training aid's oscillation. Figure 5-17, shows the comparison between on-water kayak oscillation angles with the balance training aid oscillation angle using the elastic flywheel damping system.



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Figure 5-16: Elastic flywheel system.

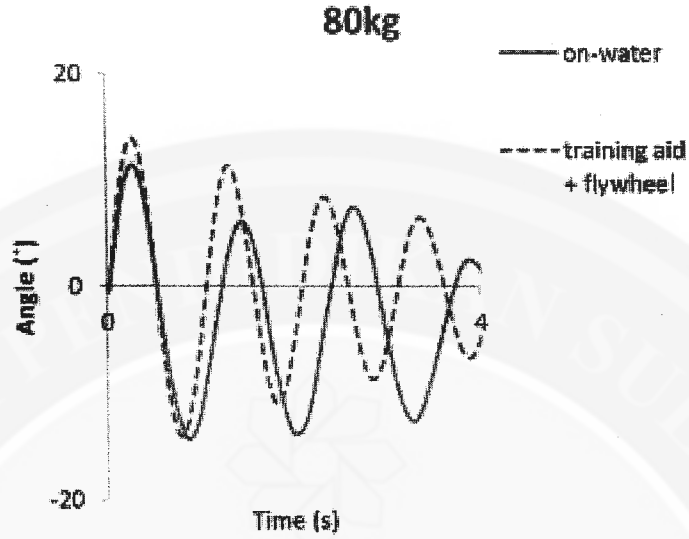
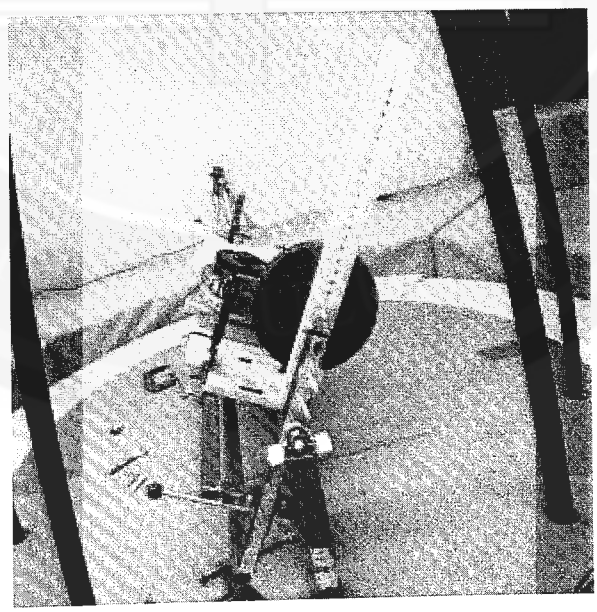



Figure 5-17: Comparison of the balance training aid using the elastic flywheel damping system.

The second option tested was the counter weight system (see Figure 5-18). This system used weight plate variation and positioning. The counter weight is changed to accommodate the different weight added to the training aid. Figure 5-19, shows the comparison between on-water kayak oscillation angles with the balance training aid oscillation angle using the counter weight system.



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Figure 5-18: Counter weight system.

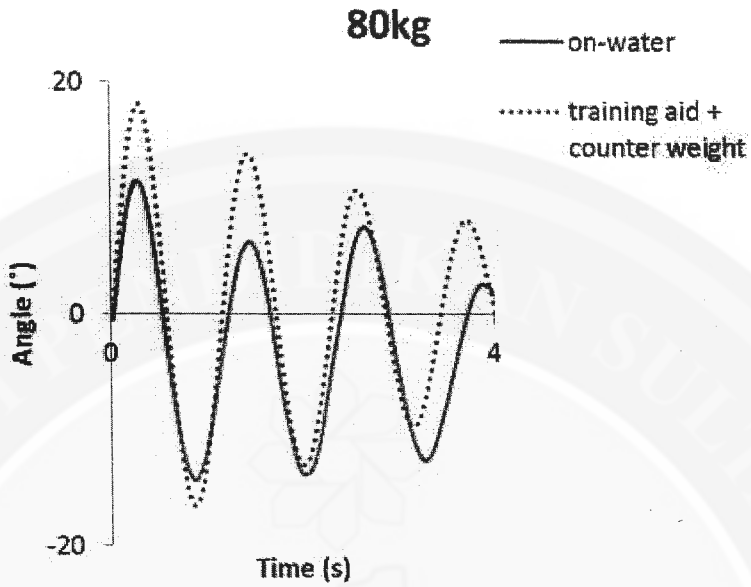
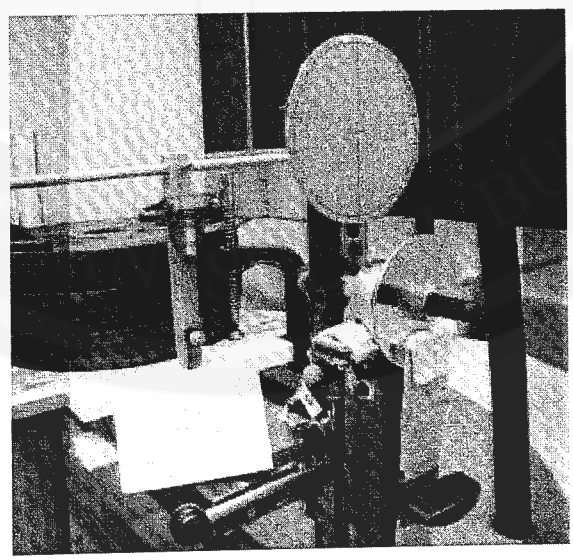



Figure 5-19: Comparison of the balance training aid using the elastic counter weight system.

The third option was the friction disk system (see Figure 5-20). The rigid friction bar could be adjusted to get the amount of damping for each weight condition. Figure 5-21, shows the comparison between on-water kayak oscillation angles with the balance training aid oscillation angle using the friction disk system.



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Figure 5-20: Friction disk system.

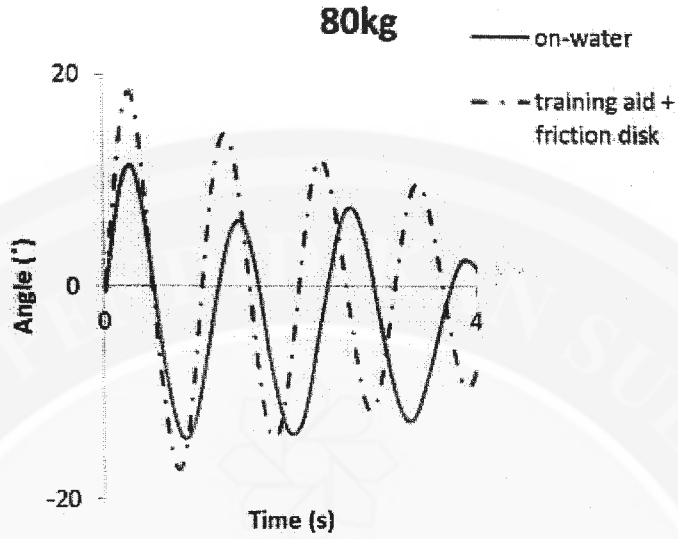
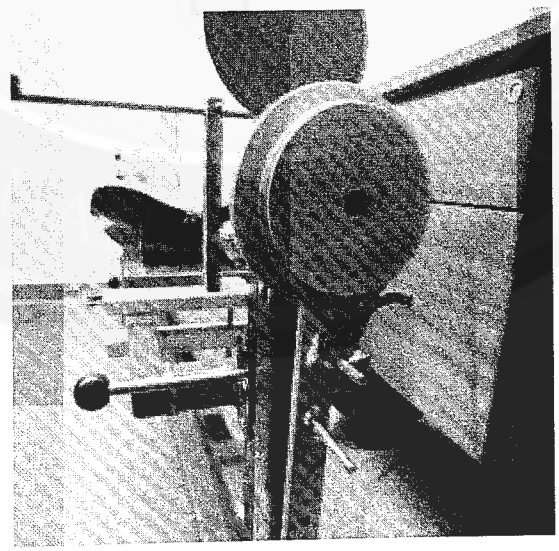



Figure 5-21: Comparison of the balance training aid using the elastic friction disk system.

The final option was the friction wheel system (see Figure 5-22). The wheel on the system rotated simultaneously with the balance training aid platform. The rope cord which runs around the wheel of the system produced the damping friction. The damping friction is changed either by increasing or decreasing the tension of the rope cord against the wheel by placing weight on the weight holder. Figure 5-23, shows the comparison between on-water kayak oscillation angles with the balance training aid oscillation angle using wheel-rope system.



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Figure 5-22: Friction wheel-rope system.

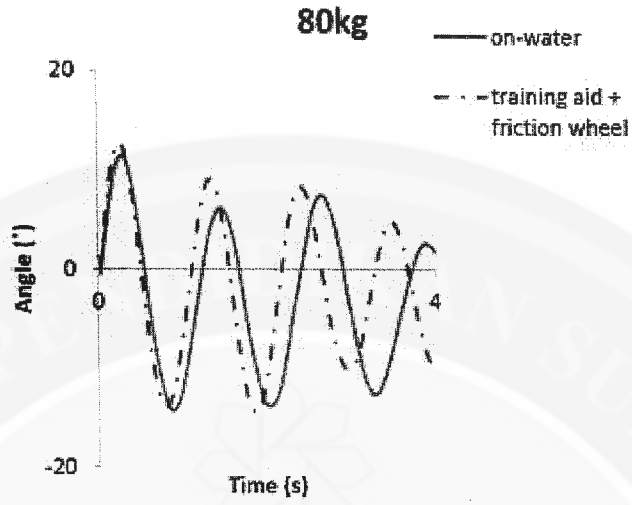



Figure 5-23: Comparison of the balance training aid using the elastic friction wheel-rope system.

The evaluation results of the modifications has found that he best solution used was a friction wheel-rope system with instantaneous damping load applied by means of a suspended weight (see Figure 5-24). This solution is combined with a counterweight system with weight added at a certain distance above the centre of rotation position (see Figure 5-25). Data collection and data analysis methods for the evaluation of modification were similar to those of the previous section.

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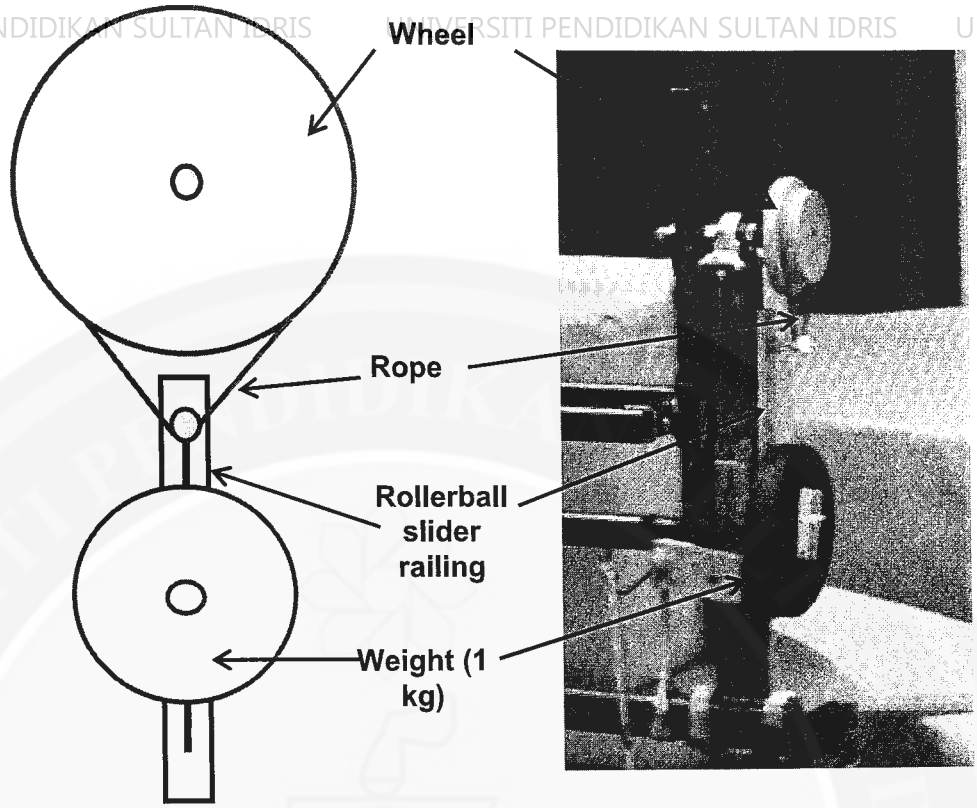



Figure 5-17: Layout of friction wheel-rope damper system with suspended loading mechanism.

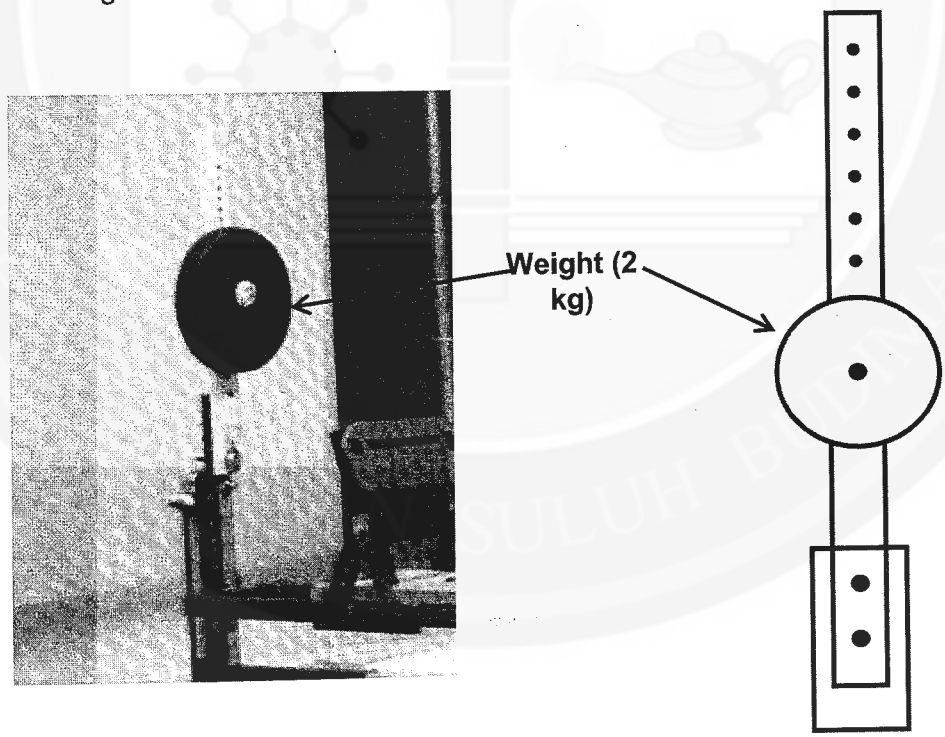



Figure 5-18: Layout of adjustable counterweight system.

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### 5.4.1 Results

Figure 5-26 to Figure 5-31, shows the comparison of medial-lateral rolling angle between the modified balance training-aid with the on-water kayak for additional weight increments from 30 kg to 80 kg. For an additional weight of 30 kg to 50 kg the friction wheel-rope system with suspended weight of 1 kg was used to achieve similarity of the frequency and amplitude characteristics (Figure 5-26, Figure 5-27 and Figure 5-28). A similar setting was also needed for the other additional weights up to 80 kg. However, a counter weight system with counter weight of 2 kg was needed for the additional weight increment of 60 kg (positioned 10 cm above centre of rotation), 70 kg (positioned 16 cm above centre of rotation) and 80 kg (positioned 20 cm above centre of rotation). The modification setting for the balance training aid to be able to replicate the medial-lateral rolling motion of the on-water kayak is presented in Table 5-3.

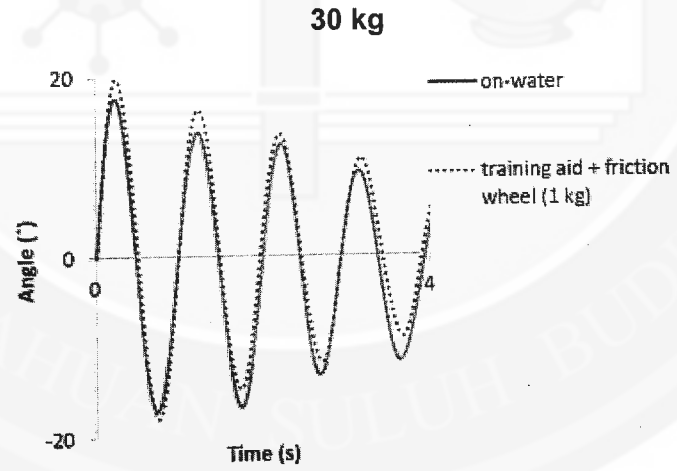



Figure 5-19: A comparison of medial-lateral rolling between on-water kayak and the training aid with friction wheel (1 kg damper weight) for 30 kg additional weight.

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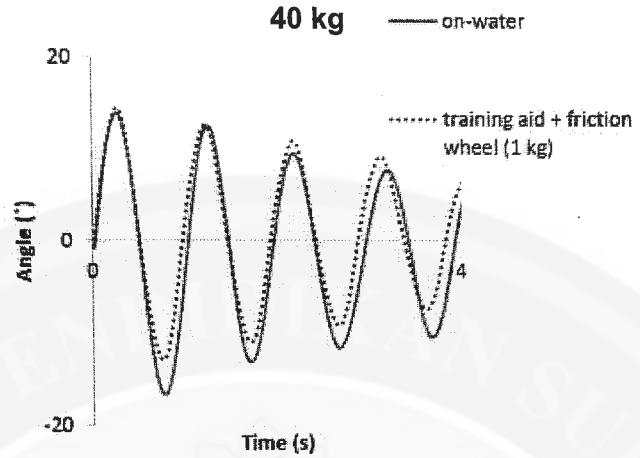



Figure 5-27: A comparison of medial-lateral rolling between on-water kayak and the training aid with friction wheel (1 kg damper weight) for 40 kg additional weight.

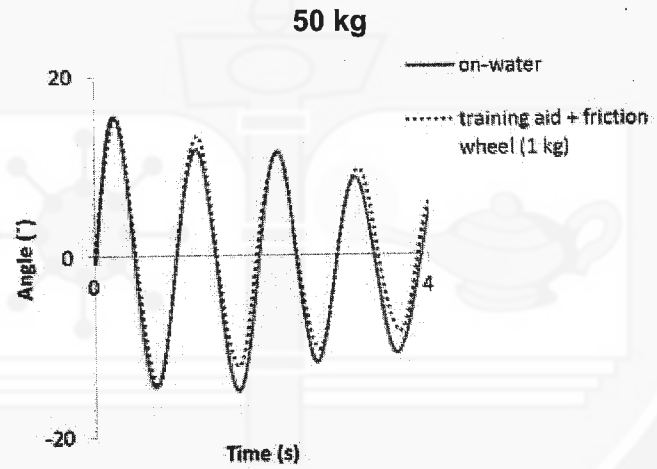



Figure 5-208: A comparison of medial-lateral rolling between on-water kayak and the training aid with friction wheel (1 kg damper weight) for 50 kg additional weight.

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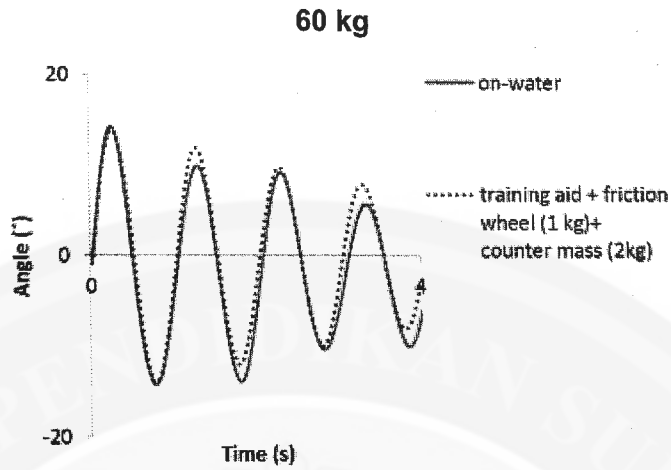



Figure 5-219: A comparison of medial-lateral rolling between on-water kayak and the training aid with friction wheel (1 kg damper weight) + 2 kg counter weight (10 cm above centre of rotation) for 60 kg additional weight.

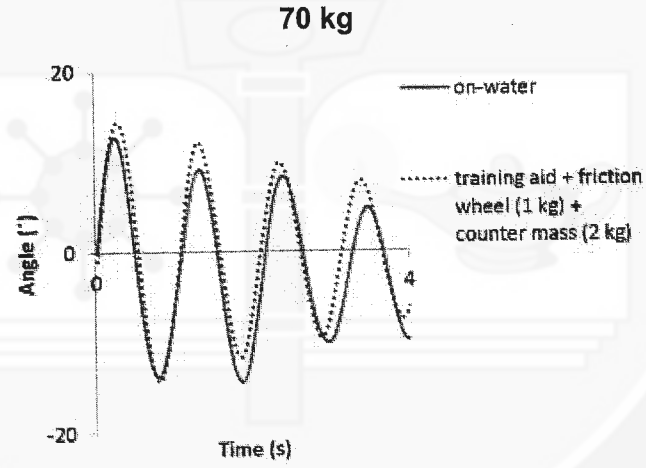



Figure 5-30: A comparison of medial-lateral rolling between on-water kayak and the training aid with friction wheel (1 kg damper weight) + 2 kg counter weight (16 cm above centre of rotation) for 70 kg additional weight.

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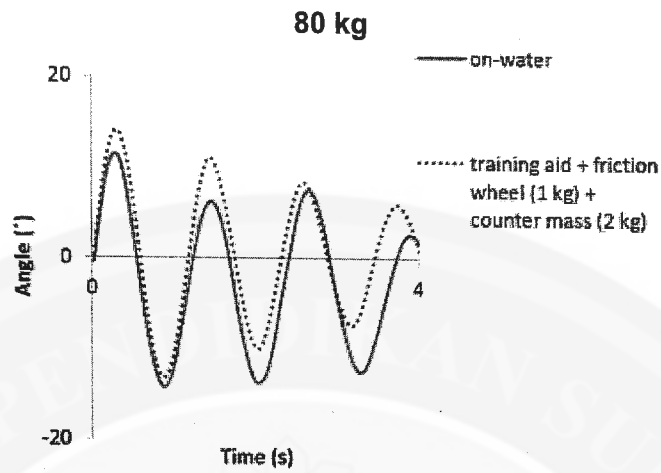



Figure 5-3122: A comparison of medial-lateral rolling between on-water kayak and the training aid with friction wheel (1 kg damper weight) + 2 kg counter weight (20 cm above centre of rotation) for 80 kg additional weight.

Table 5-3: The modification setting for the balance training aid

| Additional weight (kg) | CoR setting (cm) | Damper weight (kg) | Counter weight position above CoR (cm) |
|---|---|---|---|
| 30 | 8 | 1 | Not required |
| 40 | 8 | 1 | Not required |
| 50 | 9 | 1 | Not required |
| 60 | 10 | 1 | 10 |
| 70 | 10 | 1 | 16 |
| 80 | 11 | 1 | 20 |

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### 5.4.2 Discussion

The modified sprint kayak balance training aid had given good agreement to the on-water condition in terms of medial-lateral rolling angle frequency and amplitude. The training aid can now be used by a range of paddlers of different ability and sizes to learn to balance. From the evaluation data analysed within this chapter it is acceptable that this training aid has the ability to replicate the rolling motion of a static sprint kayak.

## 5.5 Safety testing

It was important to assess the safety of the kayak balance training aid before any paddlers or subjects were allowed to use it. The main safety testing carried out comprised a physical test outlined for training equipment standards guidelines. While, another test was related to the specific use of the training aid to ensure the safety of the user.

### 5.5.1 Standard physical safety testing

This test requires several different observational assessments to be made on the training aid.

*Surface finish*

As most parts of the training aid were made from solid metal tube, it was decided that any remaining edges or welded joinery were rounded off.

*Moving parts and point*

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There were typically two pivot point bearings involved in the construction of the training aid. Since all the components had concealed and tight fits, there was no danger of entrapment.

*Adjustment devices*

All adjustable locks needed to be secure with a safety pin. Therefore no accidental release of locks could occur during use.

*Strength and stability*

Horizontal and vertical forces were intentionally applied to the training aid and no tipping or sliding occurred.

### 5.5.2 Ergonomic testing

An experienced paddler from the previous on-water experimental (Chapter 3) was asked to perform the same on-water balancing tasks on the training aid. This would establish the physical ease of use for the training aid, and evaluate how the training aid responded during actual use. Firstly, the paddler was asked to perform a falling exercise, and the foam padded safety block was able to support the fall. There were no components of the training aid which caused concern for the safety of the paddler.

### 5.5.3 Coach and paddler feedback

After satisfying result of the safety testing the sprint kayak balance training aid prototype was brought to a British Canoe Union Coaching Conference and was presented in a workshop. At the workshop the participants were given the

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opportunity to test the training aid and discussions were held in order to gain feedback on the training aid. These discussions provided some very positive and useful feedback. One of the most useful comments was that the training aid would simplify the sprint kayak balance learning process. The adjustable setting of the centre of rotation position could accommodate different levels of paddler.

The training aid felt very similar to the on-water kayak rolling, and gave a psychological advantage to the paddlers since they do not get wet when they lost balance or falling.

## 5.6 Chapter summary

This chapter has described two different evaluations process, and has then discussed the results obtained each evaluations. The balance training aid prototype was evaluated by comparison against the on-water kayak medial-lateral rolling motion characteristics. The evaluation data collected during this research demonstrates that the balance training aid can replicate the rolling motion of stationary on-water sprint kayak. A series of safety testing were also conducted before any subjects were allowed to be on it.

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# Chapter 6

# Sprint Kayak Balance Training Aid Assessment

## 6.1 Introduction

After several evaluations and testing, it has been demonstrated that the sprint kayak balance training aid was able to replicate the medial-lateral rolling motion of a stationary on-water sprint kayak. Finally, the functionality of the training aid can be assessed. In order to assess the functionality and performance of the training aid an experimental assessment was administered. The training aid was used to train a group of complete beginners and comparison was made with a group which train on-water. The aim of this assessment was to investigate whether the balance training aid can facilitate the learning of balance for a complete beginner in a sprint kayak.

## 6.2 Method

It was important to ensure that the subjects were able to complete the whole training session. Therefore, it was beneficial to conduct a pilot test to make certain that the methods and protocol were successful in producing the intended results. The similar methodology discussed in this section was also performed during the pilot study, detailed in Appendix 6-1.

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### 6.2.1 Subjects

All subjects recruited for this study had never participated in or experienced any type of sprint kayaking training before. Twenty male subjects were randomly assigned to a control group or to an experimental. All subjects were healthy, injury free and provided written informed consent prior to their involvement in this study, which was approved by the Loughborough University ethical advisory committee (Appendix 6-2). The overall mean age of the subjects was 24 ± 5 years. The mean height of all subjects was 174 ± 7 cm, while the mean sitting height was 89 ± 4 cm. The mean weight of all subjects was 73 ± 12 kg. Both groups (experimental and control) completed the study with all ten subjects (n = 10), respectively. Complete descriptive statistics for subject demographics in both groups can be seen in Table 6-1, below.

Table 6-1: Descriptive statistics of subject demographic for experimental and control group

| | Group | |
|---|---|---|
| Subjects | Control (mean ± SD) | Experimental (mean ± SD) |
| N | 10 | 10 |
| Age (years) | 24 ± 5 | 24 ± 5 |
| Height (cm) | 171 ± 5 | 177 ± 8 |
| Sitting Height (cm) | 88 ± 3 | 89 ± 4 |
| Weight (kg) | 70 ± 11 | 73 ± 12 |

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### 6.2.2 Procedure

The experimental study was divided into three stages of assessment: Conceptual framework of the experimental methodology applied for this balance training study is detailed in Figure 6-1.

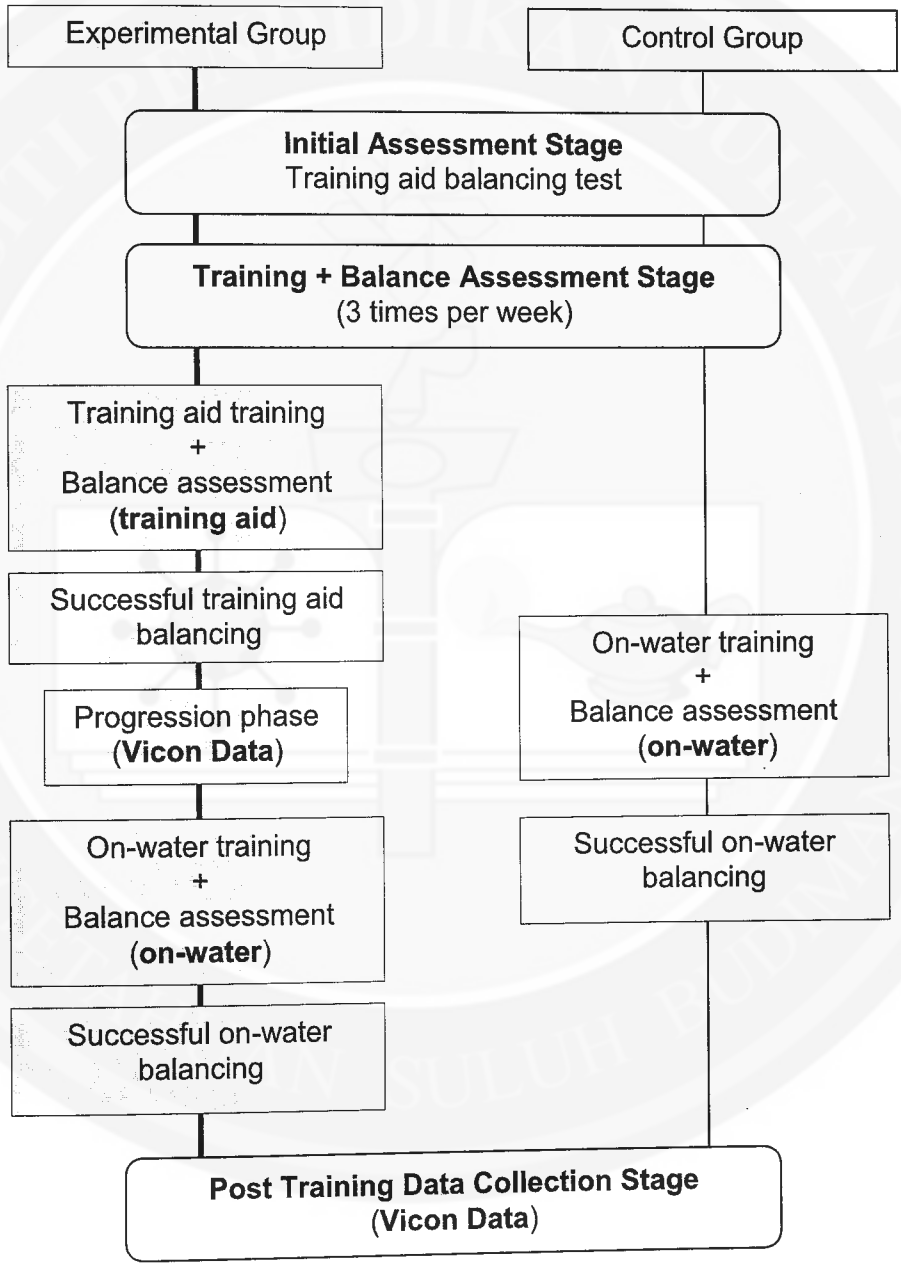



Figure 6-1: Conceptual framework of the experimental training study

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6.2.2.1 Initial assessment stage

Subjects were introduced to the testing environment and explanation was given on the training and testing protocol. Furthermore, a proper sitting posture and the correct hand/leg positioning in a sprint kayak was demonstrated. Measurement of weight, height and sitting height were taken during this stage. After the demographic measurements, the balance training aid centre of rotation and seat to foot-brace could be set-up for each subject. The set-up was based on the data analysis in Chapter 4. The balance training aid set-up for all subjects is further detailed in Appendix 6-3. The initial assessment was administered to ensure that all subjects were genuinely unable to balance on a sprint kayak balance training aid before they proceeded to the next stage. Subjects were asked to maintain their balance for as long as they could and their effort was timed and recorded. The assessment was administered at the Robin Hooper Biomechanics Lab, Loughborough University. The mean time recorded by all the subjects for the initial balance assessment was 2 $\pm$ 1 sec.

6.2.2.2 Training + balance assessment stage

To conduct the on-water kayak training session in a swimming pool was logistically impossible. Also it was not possible to get all subjects to attend one training session together. So, it was decided that the on-water training and balance assessment sessions would be administered in a custom-build training pool (Figure 6-2).

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Figure 6-2: On-water training and assessment pool (Width – 1.5 m: Length – 6.0 m; Depth – 0.30 m).

The training and balance assessment sessions for the training aid were conducted at Robin Hooper Biomechanics Lab (Figure 6-3 and Figure 6-4). The training protocol was similar for both experimental and control groups. Subjects in both groups completed three training sessions per week. Each session lasted for 20 to 30 min, consisted of: (1) self-supported warm-up lateral rolling exercises – 5 to 10 min; (2) self-discovery learning and balance adaptation –10 min; and (3) post training balance assessment – 5 to 10 min. For the warm-up rolling exercises, subjects were asked to perform an alternate left and right maximum lateral tilt and continuous side to side rolling. The on-water subjects were asked to hold the pool side (Figure 6-2) for support; meanwhile the training aid subjects held the safety/support block (Figure 6-3).

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Figure 6-3: Safety/support block for balance training aid.

During the self-discovery balance learning, the subjects were asked to gradually prepare themselves for the post training balance assessment without any intervention and feedback from the tester. However, a constant reminder about the correct posture and limb positioning was given to the subjects during the training session.

At the end of each training session, right after the self-discovery training, subjects were assessed for their balance ability or balance improvement. Subjects were asked to maintain balance with both hands on their waist for a maximum target time of 30 sec (Figure 6-4). Hands on the waist position was chosen for this study and not the positions used in Chapter 1 for safety reasons: it would be easier for beginners to move their hands for support if they lost their balance. The assessment without a paddle was chosen to avoid unnecessary usage of the paddle to control balance at the early stage of training. Furthermore, as discussed in the previous experimental study (Chapter 3) limitations in segment

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involvement will increase the difficulty of balance control. In every session three balance assessment trials were conducted for each subject and their time recorded. The time was stopped when the subjects were unable to maintain balance (capsize or use hands to gain support) or when the maximum target time was achieved.



Figure 6-4: Balance assessment position – hands on the waist.

For the control group, the subjects were considered successful in the balance assessment when they had accomplished the maximum target time (30 sec) in all three trials without failing in two consecutive training sessions. Each subject's total number of training session was recorded and they could proceed to the post training assessment.

For the experimental group, subject was considered successful in the balance training aid balance assessment when they had accomplished the maximum

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target time (30 sec) in all three trials without failing in two consecutive training sessions. Each successful subject then carried out a progression data collection using the Vicon motion analysis system. The experimental group progression data collection protocol was similar to post training Vicon data collection, and will be detailed later in the post training assessment section. Each successful subject was then asked to start their on-water training in the next scheduled training session. Again, at the end of each on-water training session experimental subjects went through the balance assessment. The subject was considered successful when they accomplished the maximum target time (30 sec) in all three trials without fails in two consecutive days of on-water training sessions. The subject's total number of training sessions was recorded, and they proceeded with the post training data collection stage.

6.2.2.3 Post training data collection stage

Subjects from both control and experimental groups completed a final post training data collection within two days of their last successful balance assessment. As mentioned earlier in the previous section, the post itrainig data collection protocol was identical to the data collection protocol which took place earlier during the progression phase of the experimental subjects. Movement data of the subject maintaining balance for a maximum of 30 sec on the balance training aid was obtained using the Vicon motion capture system. The Vicon motion data was used to support the main finding of the experimental training assessment.

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6.2.2.4 Vicon data collection and analysis

The Vicon system used consisted of nine MX cameras, Vicon Nexus 1.6.1 system, and was integrated within a CAREN (Computer Assisted Rehabilitation Environment) systems situated in Robin Hooper Biomechanical Laboratory (Figure 6-5). The Vicon system was set-up to collect data at 100 Hz and twenty Vicon markers were used in a single trial – eighteen on the subject and two on the balance training aid (Figure 6-6). The marker's description and positioning details can be seen in Table 6.2. Two markers located on the training aid were used to analyse the actual medial-lateral rolling motion of the training aid. Meanwhile, the markers attached to the subject were used to determine the kinematics of head, trunk, pelvis and both leg segments during balance maintenance. The subject was asked to perform three trials of maximum 30 sec balance maintenance, similar training balance assessment. Only one trial (the least medial-lateral rolling motion of the balance training aid) was chosen for data analysis. The reconstructed Vicon marker positions were exported and processed using Microsoft Excel. For the purpose of this analysis, only two-dimensional coordinates were used. The data were smoothed using a low-pass Butterworth filter with cut off frequency set at 6 Hz which was determined by residual analysis.

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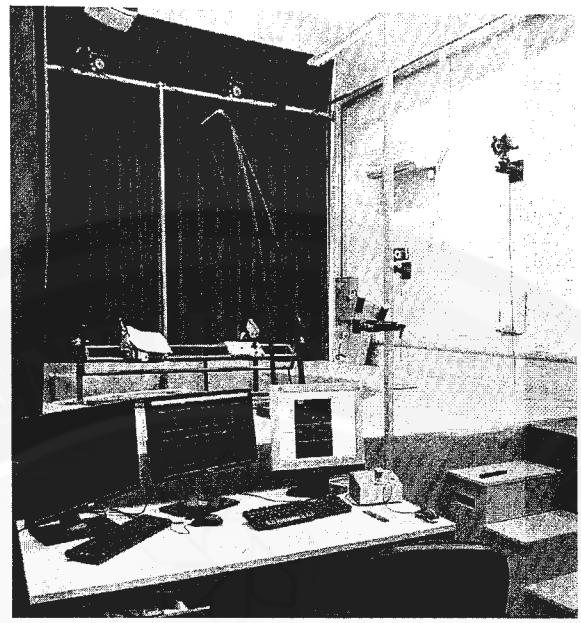


Figure 6-5: Vicon system set-up integrated within CAREN laboratory.

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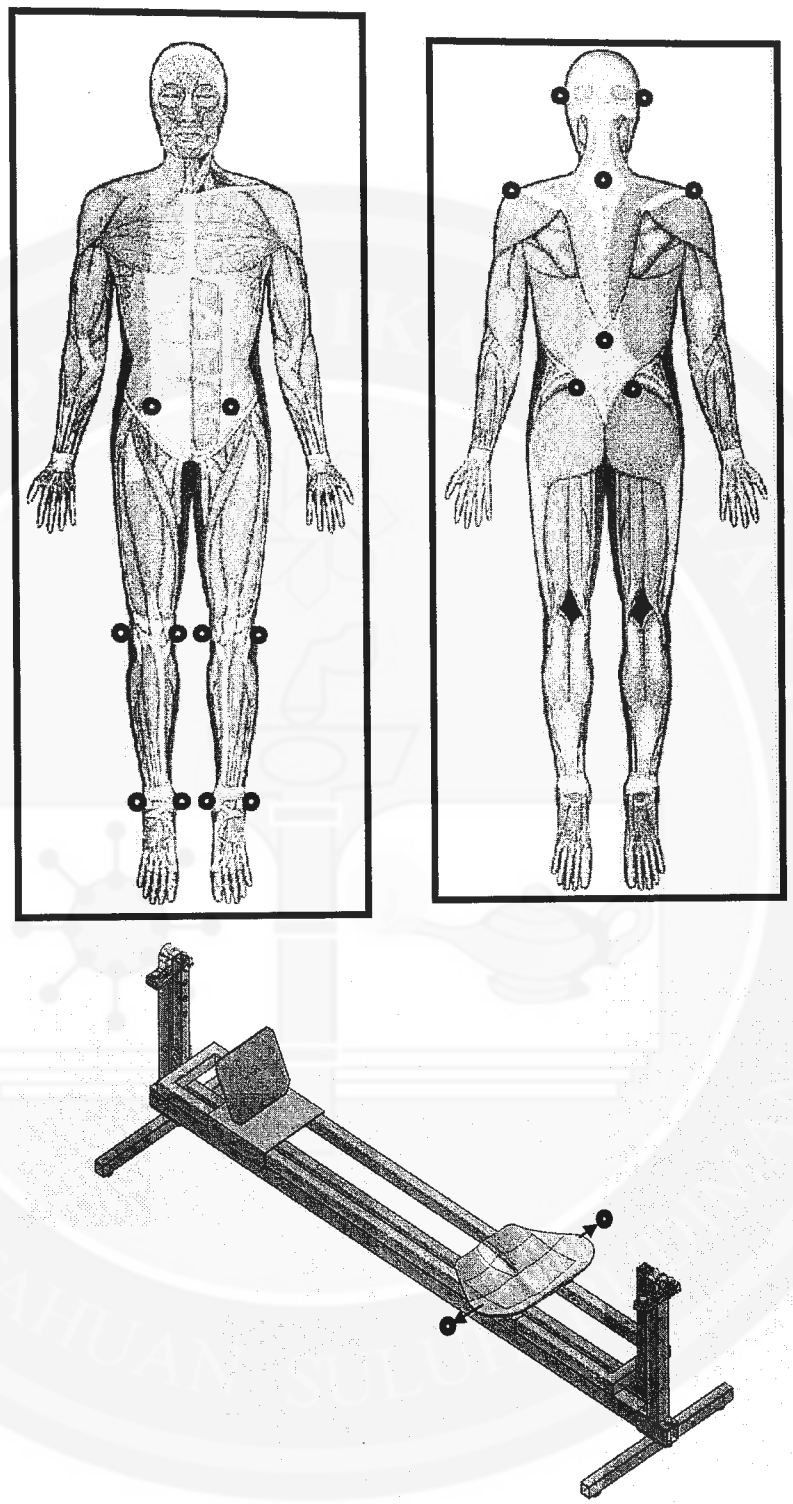


Figure 6-6: Marker placement on the subject and on the balance training aid.

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Table 6-2: Marker description and placement for progression and post training Vicon data collection

| Marker | | Description | Position |
|---|---|---|---|
| Head | | | |
| 1 | RHD | Right head | Approximately above the ear |
| 2 | LHD | Left head | |
| Trunk | | | |
| 3 | C7 | 7th Cervical vertebra | Long spinous process of cervical, particularly prominent when the subject bends their head forwards. |
| 4 | L1 | 1st Lumbar vertebra. | Can be located by initially finding L5, which lies between the two PSIS. From here count up to spinous process of L1 |
| Shoulder | | | |
| | **Marker** | **Description** | **Position** |
| 5 | RSHOT | Right top of shoulder | On top of acromion process |
| 6 | LSHOT | Left top of shoulder | |
| Pelvis | | | |
| 7 | RASI | Right ASIS | Bony protrusion of the right/left anterior superior iliac spine. If markers are invisible due to sitting position, move both markers laterally by an equal amount (recorded) |
| 8 | LASI | Left ASIS | |
| 9 | RPSI | Right PSIS | Dimple created by the right/left posterior superior iliac spine |
| 10 | LPSI | Left PSIS | |
| Legs | | | |
| 11 | RKNEL | Right lateral knee | Lateral epicondyle of the right/left knee |
| 12 | LKNEL | Left lateral knee | |
| 13 | RKNEM | Right medial knee | Medial epicondyle of the right/left knee |
| 14 | LKNEM | Left medial knee | |
| 15 | RANKL | Right lateral ankle | Lateral malleolus side of the right/left ankle |
| 16 | LANKL | Left lateral ankle | |
| 17 | RANKM | Right medial ankle | Medial malleolus side of the right/left ankle |
| 18 | LANKM | Left medial ankle | |
| Kayak Training aid | | | |
| 19 | RST | Right seat contact | Level with seat lowest point |
| 20 | LST | Left seat contact | |

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The main assessment was carried out right after the completion of the pilot test. Schedules were established during the initial assessment phase for subjects to meet with the researcher three times a week for approximately 30 min per session to perform their balance training and assessment. Due to subject's availability and limitations of equipment, the main assessment and data collection was divided into two phases. The first phase was completed within five weeks, with five subjects from each control and experimental group completing their training and assessment. The second phase was also completed within the next five week period, and all ten subjects (5 control and 5 experimental) successfully finished their training and assessment. The primary researcher administered and supervised all training and assessment sessions.

### 6.2.3 Data analysis and statistics

The training session number and balance assessment time for each subject were recorded. Upon completion of all subjects' assessment, the overall session numbers were recorded and determined as one of the dependent variables. Meanwhile, the Vicon data were processed in Excel, and the marker coordinates were calculated into frontal plane angles in degrees. From the calculated angles the following segment orientation dependent variables were determined: Kayak balance training aid medial-lateral roll range; trunk angular displacement range; pelvis angular displacement range; right hip abduction/adduction angle range; left hip abduction/adduction angle range; head angular displacement range; and shoulder angular displacement range. All dependent variables were assessed using an Independent samples *t*–test to determine differences between group (control and experimental). Paired samples *t*–test was then used to determine

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within group (experimental) differences between training sessions (on balance training aid progression and on-water post intervention). To give a further objective inferences meaning to the results, effect sizes were also calculated (Field, 2009). Measures of effect sizes proposed by Cohen (1988): $r$ = 0.1 (small effect); $r$ = 0.3 (medium effect); $r$ = 0.5 (large effect) were used. Statistical analysis was completed using SPSS version 20, and the significance level was set at P<0.05. All data were tested for normality and homogeneity; and significantly confirmed that all data were normally distributed (Shapiro-Wilk: $p$ > 0.05) and the variances were significantly homogenous (Levene's Test: $p$ > 0.05).

## 6.3 Results

*6.3.1 Assessment of overall and on-water session differences between groups*

Table 6-3, shows the Independent *t*-test variables difference between control and experimental group for post training and post intervention data collection. The overall training sessions mean between control group (9 ± 2) and experimental group (9 ± 2) were not significantly different $t$ (18) = -0.29, $p$ > 0.05); and represented by a small effect sizes ($r$ = 0.1). However, the on-water training sessions mean between control group (9 ± 2) and experimental group (4 ± 1) were significantly different $t$ (18) = 8.16, $p$ < 0.01; and represented by a large effect size ($r$ = 0.9). The analysis of segment orientation revealed that the mean differences between groups training aid medial-lateral rolling angle (29 ± 9; control vs. 21 ± 5; experimental) was significant ($t$ (18) = 2.64, $p$ < 0.05) and represented by a large effect size ($r$ = 0.5). There was no significant difference between groups in other Vicon segment orientation data ($p$ > 0.05). However, the trunk and pelvis segment orientation has represented by medium effect sizes of $r$

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= 0.3 and $r$ = 0.4, respectively. Meanwhile, hips, head and shoulder segment did represented by a small effect sizes ($r$ < 0.2).

Table 6-3: Overall and on-water session differences between groups

| Variables | Control Group | Experimental Group | Sig. (2-tailed) | Effect sizes |
|---|---|---|---|---|
| | Mean ± SD | Mean ± SD | | |
| **Overall training sessions** | 9 ± 2 | 9 ± 1 | $p$ = 0.78 | $r$ = 0.1 |
| **On-water training sessions only** | 9 ± 2*** | 4 ± 1*** | **$p$ = 0.01** | **$r$ = 0.9** |
| **Segment orientation** (post intervention) | Mean ± SD (°) | Mean ± SD (°) | | |
| Training aid medial-lateral roll angle | 29 ± 9** | 21 ± 5** | **$p$ = 0.02** | $r$ = 0.5 |
| Trunk angle | 7 ± 3 | 5 ± 2 | *$p$ = 0.16* | $r$ = 0.3 |
| Pelvis angle | 16 ± 8 | 11 ± 4 | *$p$ = 0.08* | $r$ = 0.4 |
| Right hip abd/add angle | 43 ± 32 | 46 ± 21 | *$p$ = 0.84* | $r$ = 0.1 |
| Left hip abd/add angle | 41 ± 33 | 42 ± 20 | *$p$ = 0.91* | $r$ = 0.1 |
| Head angle | 14 ± 8 | 12 ± 12 | *$p$ = 0.61* | $r$ = 0.1 |
| Shoulder angle | 11 ± 5 | 10 ± 7 | *$p$ = 0.92* | $r$ = 0.1 |

*** Significant at level $p$ < 0.01; ** Significant at level $p$ < 0.05

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*6.3.2 Assessment of control group on-water vs. experimental group on-training aid training session difference*

Table 6-4, shows the mean differences between control group on-water session and experimental group on training aid sessions only. The segment orientation differences were between control group post training Vicon data and experimental group progression Vicon data. The session number mean was significantly different between groups ($t$ (18) = 5.38; $p < 0.01$); and represented by a large effect size ($r = 0.8$). The right hip abduction/adduction angle was the only segment orientation which has a significant ($t$ (18) = -2.35; $p < 0.05$) difference between control group (43 ± 32) and experimental group (69 ± 17); with large effect size ($r = 0.5$). All other segment orientations were represented by medium effect sizes ($r = 0.3$ and $r = 0.4$), except head segment with a small effect size ($r = 0.1$).

Table 6-4: Control group (on-water) vs. Experimental group (training aid) differences

| Variables | Control Group | Experimental Group | Sig. (2-tailed) | Effect sizes |
|---|---|---|---|---|
| | Mean ± SD | Mean ± SD | | |
| **On-water vs. training aid** | 9 ± 2*** | 5 ± 1*** | **$p = 0.01$** | **$r = 0.8$** |
| **Segment orientation** | Post intervention Mean ± SD (°) | Progression Mean ± SD (°) | | |
| Training aid medial-lateral roll angle | 29 ± 9 | 23 ± 5 | $p = 0.08$ | $r = 0.4$ |
| Trunk angle | 7 ± 3 | 5 ± 1 | $p = 0.06$ | $r = 0.4$ |
| Pelvis angle | 16 ± 8 | 12 ± 4 | $p = 0.17$ | $r = 0.3$ |

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| | | | | |
|---|---|---|---|---|
| Right hip abd/add angle | 43 ± 32** | 69 ± 17** | **$p = 0.03$** | **$r = 0.5$** |
| Left hip abd/add angle | 41 ± 33 | 62 ± 15 | $p = 0.09$ | $r = 0.4$ |
| Head angle | 14 ± 8 | 12 ± 11 | $p = 0.60$ | $r = 0.1$ |
| Shoulder angle | 11 ± 5 | 8 ± 4 | $p = 0.23$ | $r = 0.3$ |

*** Significant at level $p < 0.01$; ** Significant at level $p < 0.05$

*6.3.3 Assessment of experimental within group differences (training aid vs. on-water training session)*

The differences between experimental group on-water and training aid sessions and assessment are presented in Table 6-5. On average, the subjects in the experimental group experienced significantly fewer on-water sessions (4 ± 1) compare to training aid sessions (5 ± 1), ($t$ (9) = -2.62, $p < 0.05$); with large effect size $r$ = 0.6. For the segment orientation assessment, both right and left hip abduction/adduction angles were significantly different ($p < 0.05$) between the subject training and assessment sessions. Subjects have a higher hip abduction/adduction angle after the training aid sessions (right, 69 ± 17; left, 62 ± 15) compared to after the on-water sessions (right, 46 ± 21; left, 42 ± 20); with large effect sizes $r > 0.8$. However, there was no significant difference for subjects other segment orientations.

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Table 6-5: Within group differences between on-water and training aid for experimental group

| Variables | On-water | Training aid | Sig. (2-tailed) | Effect sizes |
|---|---|---|---|---|
| | Mean ± SD | Mean ± SD | | |
| **Training sessions** | 4 ± 1** | 5 ± 1** | ***p* = 0.03** | *r* = 0.6 |
| **Segment orientation** | Post intervention Mean ± SD (°) | Progression Mean ± SD (°) | | |
| Training aid medial-lateral roll angle | 21 ± 5 | 23 ± 5 | *p* = 0.22 | *r* = 0.4 |
| Trunk angle | 5 ± 2 | 5 ± 1 | *p* = 0.76 | *r* = 0.1 |
| Pelvis angle | 11 ± 4 | 12 ± 4 | *p* = 0.39 | *r* = 0.3 |
| Right hip abd/add angle | 46 ± 21*** | 69 ± 17*** | ***p* = 0.01** | ***r* = 0.9** |
| Left hip abd/add angle | 42 ± 20*** | 62 ± 15*** | ***p* = 0.01** | ***r* = 0.8** |
| Head angle | 12 ± 12 | 12 ± 11 | *p* = 0.95 | *r* = 0.1 |
| Shoulder angle | 10 ± 7 | 8 ± 4 | *p* = 0.24 | *r* = 0.4 |

*** Significant at level $p < 0.01$; ** Significant at level $p < 0.05$

## 6.4 Discussion

The present study compared the training sessions number between the control group (on-water training only) and the experimental group (training aid + on-water training). Furthermore, planar segments orientation data was presented to validate the findings. There were no differences in the total number of training sessions between groups; however the medial-lateral rolling angle was greater in the control group (29 ± 9) compare to the experimental groups (21 ± 5). Although

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both groups experienced the same number of total training sessions, the control group seems to have difficulty in controlling the balance and maintaining the horizontal orientation of the training aid. Figure 6-7, below shows the medial-lateral rolling angle of a subject chosen from each group who represent the greatest rolling angle. It was assumed that this occurred because the control group subjects had to adapt to the new training aid assessment environment. Two of the subjects in the control group changed their balance strategies by moving the thighs outward/inward (hips abduction/adduction) within the angle of more than 90 degrees. Figure 6-78, shows an angle data trace of one of the subject in the control group who had the most hip abduction/adduction angle.

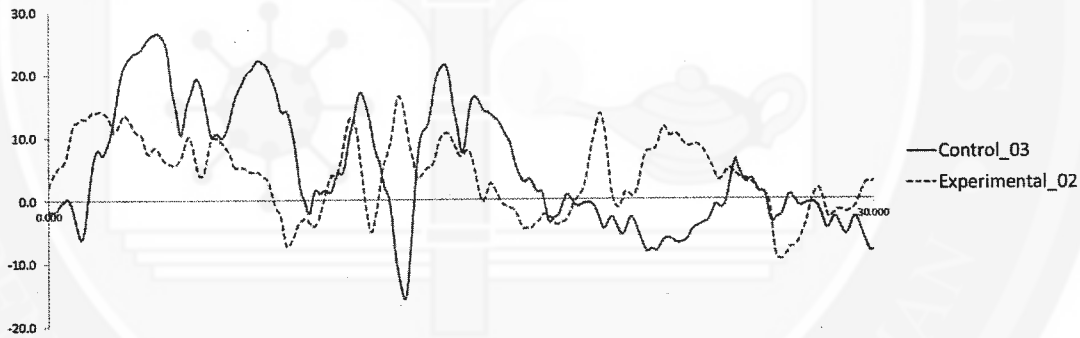



Figure 6-7: Balance training aid medial-lateral rolling angle trace for a control subject-03 and an experimental subject-02, for duration of 30 sec target time.

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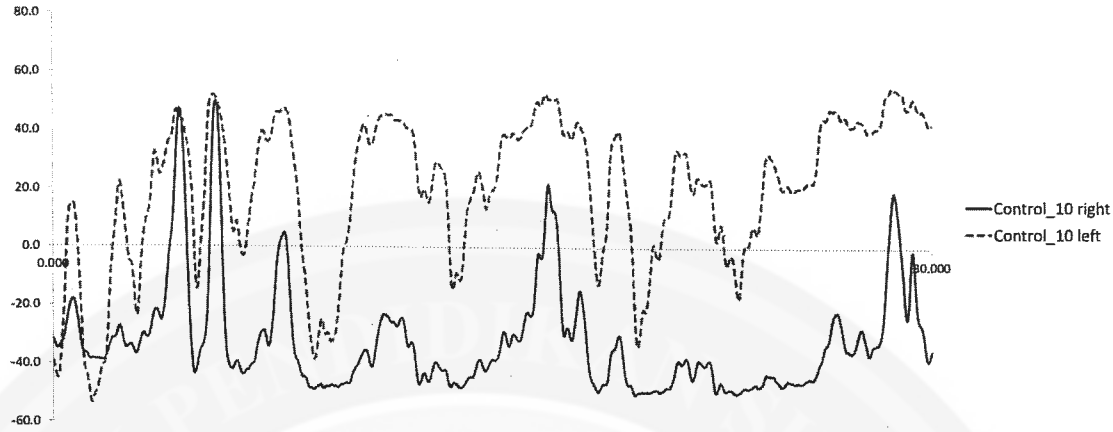



Figure 6-8: Hip abduction/adduction angular data trace of one subject in the control group.

When comparing just the on-water training sessions for both groups, the differences were very significant (Table 6-3). The experimental subjects required less on-water sessions (4 sessions) compared to the control group (9 sessions). This finding shows that the balance training does facilitate the learning of balance for a complete beginner, by reducing the number of on-water training sessions. This shows that the training aid has benefit prior to on water training. The balance training aid allows more time to practice and learn balance per training session rather than emptying the kayak or swimming.

The number of sessions (training aid) for the experimental group before progressing to on-water training was also significantly lower compared to the on-water session of the control group. The progression Vicon data (segment orientation) of the experimental group was also compared to the post training Vicon data segment orientation) of the control group. Even though instructions had been given to the subjects on the correct sitting and knee positioning, the results (Table 6-4) indicates that experimental subjects had significantly greater

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hip abduction/adduction angle compared to the control subjects. It was assumed that the experimental subjects had no restrictions in their hip movement while sitting on the training aid, compared to the control subjects who were restricted by the kayak cockpit. However, the other segments orientation shows no significant differences between groups.

To further investigate the influence of segment orientation in controlling balance, a comparison was made between the training aid sessions and the on-water sessions of the experimental group (Table 6-5). The experimental subjects had to spend significantly more time on the training aid before progressing with on-water training. As suspected, only the thigh segment orientation showed significant differences between group progression data and post intervention data. The difference was represented by a large hip abduction/adduction angle during the progression assessment compared to a smaller angle range during the post intervention assessment. This finding shows that the subjects have to change their strategies during the on-water training by restricting the hips abduction/adduction movement.

In conclusion, the findings of the present study have practical implications on the enhancement of the kayak balance training aid performance. Although the training aid was found to have the ability to make the sprint kayak balance learning process much easier, it also has slight disadvantages in terms of leg movement restriction. On the other hand, this training aid did recruit the same type of segment orientation to maintain balance as was observed by comparison

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with control subjects. This balance training aid was designed to permit a range of ability and sizes of individual to learn the stationary sprint kayak balance.

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# Chapter 7

# General Summary and Conclusions

## 7.1 Introduction

This chapter outlines the overall purpose and summarises the main findings of this research. Research questions posed in Chapter 1 are presented and addressed with reference to main findings obtained in Chapters 3 – Chapter 6. The methods used within the study are also summarised and limitations and potential improvements are identified. The justification of the kayak balance training aid designed and how it can be adapted to actual training use will also be addressed.

## 7.2 Summary of purposes and findings

As was discussed in Chapter 1 and 2, there has been little research into the balance aspect of sprint kayaking and the reason for this was still in question. However, this insufficiency was the main actuator for this study with the main intention being to provide an alternative solution for creating interest in balance aspect of sprint kayaking. The main purpose of this study was to design, develop, evaluate and assess a balance training aid which would provide realistic and functional support when learning to balance a sprint kayak. A series of research questions were posed at the beginning of this study and the results of work completed (Chapter 3 – 6) are discussed below in relation to these principal questions:

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**Question 1** – *What are the characteristics of on-water kayak-paddler motion and where is the centre of rotation of the kayak-paddler system relative to the seat of the kayak?*

An experimental investigation of on-water stationary sprint kayak balance was undertaken to identify the kinematic characteristics which influence the balancing performance of experienced paddlers. Findings from this investigation were interpreted into technical characteristics, and integrated into the designs of the training aid. From the study carried out in Chapter 3, the medial-lateral linear and angular motion of the stationary on-water sprint kayak was measured to ensure that sufficient translation and rotation space was available within the training aid design. It was found that the kayak rolling motion dependent on the paddler ability. The segment motion characteristics were categorised according to their relationship with the kayak motion. The pelvis orientation was found to be the predominant response in triggering the kayak motion. However, the involvement of the pelvis in controlling the balance is still in question until an extensive investigation of the whole lower limb involvement is carried out.

This experimental study has produced an alternative technique using video analysis for locating the centre of rotation for a stationary sprint kayak-paddler system. This method could be used to replace the traditional hydrostatic technique (Jacques & Janis, 2010). It was found that the mean centre of rotation of kayak-paddler system relative to the top of the kayak seat was between 10 cm (high rolling motion) to 13 cm (less rolling motion) above the seat. To ensure that

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the training aid designed closely replicated the same on-water kayak conditions, multiple degrees of centre of rotation setting had to be available.

**Question 2** – *Is the on-water kayak rolling motion affected by weight variations?*

The first on-water experimental study (Chapter 3) was not able to establish any relationship of weight variations on the sprint kayak rolling motion. Due to this, a series of on-water experimental testing was carried out with various additional weight increments from 0 kg – 80 kg (Chapter 5). The result of this study verified that increased weight does affect the frequency and amplitude of on-water kayak medial-lateral rolling motion. Furthermore, the height of the centre of rotation relative to the kayak seat also linearly increased for every weight increment. The data retrieved from this study was used as a benchmark for the balance training aid performance evaluation.

**Question 3** – *Can the sprint kayak balance training aid prototype replicate the medial-lateral rolling motion of the stationary sprint kayak?*

To ensure that the sprint kayak balance training aid prototype performed as intended, the medial-lateral rolling characteristics (frequency and amplitude) of the training aid were compared to the characteristics of the on-water kayak with a variety of additional weight (Chapter 5). Initial evaluation suggested that the training aid needed a damping device in order to restrain and control the frequency and amplitude of the rolling motion. Several modifications (additional attachments) were made and tested to determine the optimal similarity in medial-

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lateral rolling characteristics. Finally, a combination of a friction wheel-rope system and counter-weight attachment was found to be the best solution producing close agreement with the acted kayak motion (Figure 5-15 and Figure 5-17). The modified sprint kayak balance training aid has been shown to have the ability to replicate the on-water sprint kayak rolling motion.

**Question 4** – *Does the sprint kayak balance training aid facilitate the learning of balance for a beginner paddler?*

From the research and development performed earlier, the principal requirements of a balance training aid for sprint kayaking were not only closely replicate the on-water kayak rolling motion, but also make the learning process easier for the complete beginner. Furthermore, the training aid needed to be fully adjustable to accommodate range of users for the purpose of skill development and learning. In order to manifest these functions, an experimental assessment together with biomechanical assessment was carried out to groups of individuals who had never experienced sprint kayak training before (Chapter 6). The experimental subjects who used the balance training aid for balance training had the same total number of sessions as the control subjects who learned to balance in the actual sprint kayak (experimental, 9 $\pm$ 1 sessions; control, 9 $\pm$ 1 sessions). However, the experimental subjects only spent half of the total sessions learning on the training aid (5 $\pm$ 1 sessions) and the other half learning to balance on-water (4 $\pm$ 1 sessions). Through the Vicon angular motion post intervention assessment, the medial-lateral rolling data showed that the experimental subjects produced much better control compared to the control subjects. However, analysis of segment

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orientation data showed that both groups of subjects produce similar trunk, pelvis, head and shoulder angular motion ranges. The difference was only significant for the hip abduction/ adduction angular motion range, due to restriction of kayak cockpit not replicated on the training aid.

In conclusion, through experimental assessment and biomechanical assessment it has been demonstrated that the balance training aid prototype does facilitate the learning of balance in sprint kayaking. Moreover, the training aid has simplified the learning process whilst retaining the correct techniques.

## 7.3 Limitations

This study has the following limitations. The limitation of small subject sizes in the experimental studies was minimised by ensuring normal distribution and homogeneity of data sets. The process of manual digitising involves human error which can lead to inconsistency of reconstruction for kinematic data. However repeated digitisation established precision to be better than 2 mm. Only kinematic data was used to support the design requirement and functionality of the training aid as opposed to also using force and EMG data. The establishment of the on-water kayak rolling motion characteristics for the evaluation process was only carried out in a confined pool environment. However, since the training aid was shown to be successful this was not a major limitation.

The training aid allowed leg abduction whereas a kayak provides a more constrained environment. It would be an improvement if the trainer could constrain the leg movement appropriately. The task of balancing a kayak in water is made more difficult by external perturbations such as wind or waves, the

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balance trainer did not incorporate any such external factors which may of made balancing somewhat easier. Furthermore the training aid was only applicable to static balance (as in the start of a race). In kayaking the kayaker has to both balance and propel the kayak through the water. This balancing occurs with the paddle in the water on the left, the paddle out of the water, and the paddle in the water on the right. Thus the balancing task when paddling is more complex and somewhat different to the balancing task studied in this thesis.

## 7.4 Recommendations for future research and development

The training aid has been shown to assist the learning balance in a sprint kayak. It would be possible to adapt the design and mechanism to improve other kayak training machines or the kayak ergometers that currently available in the market. In order to achieve this, the training aid needs to be compared experimentally to the other existing sprint kayak training devices. The current research has answered all questions posed in Chapter 1 and has produced a reliable balance training aid. However one main area still requires further investigation. This concern the complete biomechanical assessment of balance and postural control involved in sprint kayaking. Thus, further experimental and theoretical research investigating this particular area may possibly enhance the current training aid. Although the training aid performances were satisfactory, the friction damping mechanism could undergo more investigation for the possibility of improvement. The friction wheel and rope system could be made from more specialised material such as a hardened steel wheel instead of wood and nylon webbing instead of cotton rope to increase resistance durability.

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## 7.5 General Conclusions

The main purpose of this research was to design, develop and assess a sprint kayak balance training aid. The need for such a training aid is to encourage more people to get involved in learning new skills, especially in sprint kayaking. There is little sprint kayak training aid equipment that is commercially available and those that do exist are either expensive or have not been evaluated through research. The approach taken for the design of sprint kayak balance training aid was to simulate the fundamental rolling motion, as well as the frictional force produced through interaction of the kayak hull with water. The training aid was experimentally assessed and has been biomechanical shown to be able to replicate the on-water kayak rolling motion and facilitate the learning of balance in sprint kayaking.

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# Appendices

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**Appendix 3-1: Forms and questionnaire for on-water analysis of stationary sprint kayak.**

Loughborough University

**Project Title:**

Biomechanics of static balance and postural control in flat-water sprint kayak athlete.

**Participant Information Sheet**

**Investigators details:**

Senior Investigator 1:
Name: Professor M.R. Yeadon
Status: Professor of Computer Simulation in Sport.
Email: M.R.Yeadon@lboro.ac.uk

Senior Investigator 2:
Name: Dr M.A. King
Status: Senior Lecturer in Sports Biomechanics
Email: M.A.King@lboro.ac.uk

Junior Investigator:
Name: Mr Benderi Dasril
Status: Research Student
Email: b.dasril@lboro.ac.uk
Mobile: 07901236448

Department: Sports Biomechanics Research Department, School of Sport, Exercise and Health Sciences, Loughborough University.

The **purpose** of this study is to analyse biomechanical parameters of a sprint kayak athlete performing static balance in a 2-D planar motion.

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Objective 1

To determine centre of rotation of the kayak movement from video recording taken during static balancing control.

Objective 2

To establish criteria that may be used to design, build and evaluate a balance training aid.

This study will involve a biomechanical analysis of human movement. The study will be divided into two parts; firstly, a video recording will be taken of you performing selected sports movements. You will only be asked to perform movements that you are familiar with and comfortable performing. The second part of the study will involve measurements to determine the lengths, widths and circumferences of your body segments (e.g. arms, legs, trunk and head). It may also be necessary to take additional measurements on your preferred boat set-up characteristic. The measurement procedures will be described and demonstrated in advance. The data collected will be used to help increase our understanding of the mechanics of sports movements.

You will perform the data collection in a suitable environment. The risk of injury during the data collection will be minimal since we only ask you to perform movements with which you are familiar and comfortable. It is considered that no increase risks, discomforts or distresses are likely to result from data collection of sports movements above those associated with normal performance of those movements.

The information obtained from the study will be collected and stored in adherence with the Data Protection Act. Whilst certain personal and training information will be required, you will be allocated a reference number to ensure that your identity and personal details will remain confidential. If you agree to take part in this study, you are free to withdraw from the study at any stage, without having to give any reasons. An opportunity will be provided in this event for you to discuss privately your wish to withdraw. A contact name phone number will be provided to you for use if you have any queries about any part of your participant in the study.

*The University has a policy relating to Research Misconduct and Whistle Blowing which is available online at*

*http://www.lboro.ac.uk/admin/committees/ethical/Whistleblowing(2).htm.*

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Loughborough University

Name/Number .....

**Health Screen Questionnaire for Study Volunteers**

Please read through this questionnaire, BUT DO NOT ANSWER ANY OF THE QUESTION YET. When you have read right through, there may be questions you would prefer not to answer. Assistance will be provided if you require it to discuss any question on this form. In this case please tick the box labelled "I wish to withdraw" immediately below. Also tick the box labelled "I wish to withdraw" if there is any other reason for you not to take part.

Tick appropriate box

I wish to withdraw ☐

I am happy to answer the questionnaire ☐

If you are happy to answer the question posed below, please proceed. Your answers will be treated in the strictest confidence.

As a volunteer participating in a research study, it is important that you are currently in good health and have had no significant medical problems in the past. This is (i) to ensure your own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

**Please complete this brief questionnaire to confirm your fitness to participate:**

Tick appropriate box

1. At present, do you have any health problem for which you are?

| | | | | |
|---|---|---|---|---|
| (a) | on medication, prescribed or otherwise ..... | Yes ☐ | No | ☐ |
| (b) | attending your general practitioner ..... | Yes ☐ | No | ☐ |
| (c) | on a hospital waiting list ..... | Yes ☐ | No | ☐ |

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2. In the past two years, have you had any illness which required you to?

| | | | | |
|---|---|---|---|---|
| (a) | consult your GP ..... | Yes ☐ | No ☐ |
| (b) | attend a hospital outpatient department ..... | Yes ☐ | No ☐ |
| (c) | be admitted to hospital ..... | Yes ☐ | No ☐ |

3. Have you ever had any of the following?

| | | | | |
|---|---|---|---|---|
| (a) | Convulsions/epilepsy ..... | Yes ☐ | No ☐ |
| (b) | Asthma ..... | Yes ☐ | No ☐ |
| (c) | Eczema ..... | Yes ☐ | No ☐ |
| (d) | Diabetes ..... | Yes ☐ | No ☐ |
| (e) | A blood disorder ..... | Yes ☐ | No ☐ |
| (f) | Head injury ..... | Yes ☐ | No ☐ |
| (g) | Digestive problems ..... | Yes ☐ | No ☐ |
| (h) | Heart problems ..... | Yes ☐ | No ☐ |
| (i) | Problems with bones or joints ..... | Yes ☐ | No ☐ |
| (j) | Disturbance of balance/coordination ..... | Yes ☐ | No ☐ |
| (k) | Numbness in hands or feet ..... | Yes ☐ | No ☐ |
| (l) | Disturbance of vision ..... | Yes ☐ | No ☐ |
| (m) | Ear / hearing problems ..... | Yes ☐ | No ☐ |
| (n) | Thyroid problems ..... | Yes ☐ | No ☐ |
| (o) | Kidney or liver problems ..... | Yes ☐ | No ☐ |
| (p) | Allergy to nuts ..... | Yes ☐ | No ☐ |

4. Allergy Information

| | | | | |
|---|---|---|---|---|
| (a) | Are you allergic to any food products? | Yes ☐ | No ☐ |
| (b) | Are you allergic to any medicines? | Yes ☐ | No ☐ |
| (c) | Are you allergic to plasters? | Yes ☐ | No ☐ |

**If YES to any of the above, please provide additional information on the allergy**

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5. Are you aware of any other condition or complaint that may be affected by participation in this study? If so, please state below

.....

.....

6. Please provide contact details of a suitable person for us to contact in the event of any incident or emergency.

Name:

.....

Telephone Number: .....

Work ☐ Home ☐ Mobile ☐

Relationship to Participant:

.....

7. Are you currently involved in any other research studies at the University?

Yes ☐ No ☐

If yes, please provide details of the study

.....

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Loughborough University

**Biomechanics of static balance and postural control in flat-water sprint kayak athlete.**

## INFORMED CONSENT FORM (SUBJECT)

### PURPOSE

To obtain biomechanical parameters of a sprint kayak athlete performing static balance in a 2-D planar motion.

### PROCEDURES

The data of sports movements will be obtained using:

- Video recording using one camera

A number of trials will be requested with suitable breaks to minimise fatigue.

The subject specific parameters will be obtained from:

- Anthropometric measurements (using tape measures and specialist anthropometers)

During the measurement two researchers will be present, at least one of whom will be of the same sex as you.

### QUESTIONS

The researchers will be pleased to answer any questions you may have at any time.

### WITHDRAWAL

You are free to withdraw from the study at any stage, without having to give any reasons. An opportunity will be provided in this event for you to discuss privately your wish to withdraw.

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**CONFIDENTIALITY**

Your identity will remain confidential in any material resulting from this work.

I have read the outline of the procedures which are involved in this study, and I understand what will be required by me. I have had the opportunity to ask for further information and for clarification of the demands of each of the procedures and understand what is entailed. I am aware that I have the right to withdraw from the study at any time with no obligation to give reasons for my decision. As far as I am aware I do not have any injury of infirmity which would be affected by procedures outlined.

Name: .....

Signed: ..... (Subject) Date: .....

In the presence of:

Name: .....

Signed: ..... (Coach) Date: .....

Signature of investigator: .....

Date: .....

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Loughborough University

**Project Title:**

**Biomechanics of static balance and postural control in flat-water sprint kayak athlete.**

**Participant Information Sheet (for Parent)**

**Investigators details:**

Senior Investigator 1:
Name: Professor M.R. Yeadon
Status: Professor of Computer Simulation in Sport.
Department: Sports Biomechanics Research,
School of Sport, Exercise and Health Sciences,
Loughborough University.
Email: M.R.Yeadon@lboro.ac.uk

Senior Investigator 2:
Name: Dr M.A. King
Status: Senior Lecturer in Sports Biomechanics
Department: Sports Biomechanics Research,
School of Sport, Exercise and Health Sciences,
Loughborough University.
Email: M.A.King@lboro.ac.uk

Junior Investigator:
Name: Mr Benderi Dasril
Status: Research Student
Department: Sports Biomechanics Research Department,
School of Sport, Exercise and Health Sciences,
Loughborough University.
Email: b.dasril@lboro.ac.uk
Mobile: 07901236448

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Objective 1

To determine centre of rotation of the kayak movement from video recording taken during static balancing control.

Objective 2

To establish criteria that may be used to design, build and evaluate a balance training aid.

This study will involve a biomechanical analysis of human movement. The study will be divided into two parts; firstly, a video recording will be taken of you performing selected sports movements. Your child will only be asked to perform movements that you are familiar with and comfortable performing. The second part of the study will involve measurements to determine the lengths, widths and circumferences of your body segments (e.g. arms, legs, trunk and head). It may also be necessary to take additional measurements on your child preferred boat set-up characteristic. The measurement procedures will be described and demonstrated in advance. The data collected will be used to help increase our understanding of the mechanics of sports movements.

Your child will perform the data collection in a suitable environment. The risk of injury during the data collection will be minimal since we only ask your child to perform movements with which they are familiar and comfortable. It is considered that no increase risks, discomforts or distresses are likely to result from data collection of sports movements above those associated with normal performance of those movements.

The information obtained from the study will be collected and stored in adherence with the Data Protection Act. Whilst certain personal and training information will be required, all participants will be allocated a reference number to protect their anonymity. The identity of all participants will remain confidential in any material resulting from this work. If you consent for your child to take part in this study, he/she will be free to withdraw from the study at any stage, without having to give any reasons. An opportunity will be provided in this event for your child to discuss privately their wish to withdraw.

The University has a policy relating to Research Misconduct and Whistle Blowing which is available online at:

*http://www.lboro.ac.uk/admin/committees/ethical/Whistleblowing(2).htm*.

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Name/Number .....

Loughborough University

**Health Screen Questionnaire for Study Volunteers (Parents)**

Please read through this questionnaire, BUT DO NOT ANSWER ANY OF THE QUESTION YET. When you have read right through, there may be questions you would prefer not to answer. In this case please tick the box labelled "I wish to withdraw my child" immediately below. Also tick the box labelled "I wish to withdraw my child" if there is any other reason for your child not to take part.

Tick appropriate box

I wish to withdraw my child ☐

I am happy to answer the questionnaire ☐

If you are happy to answer the question posed below on behalf of your child, please proceed. Your answers will be treated in the strictest confidence.

As a volunteer participating in a research study, it is important that your child is currently in good health and have had no significant medical problems in the past. This is (i) to ensure your child own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

**Please complete this brief questionnaire to confirm your child fitness to participate:**

Tick appropriate box

1. At present, does your child have any health problem for which they are?

| | | | | |
|---|---|---|---|---|
| (a) | on medication, prescribed or otherwise ..... | Yes ☐ | No | ☐ |
| (b) | attending your general practitioner ..... | Yes ☐ | No | ☐ |
| (c) | on a hospital waiting list ..... | Yes ☐ | No | ☐ |

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2. In the past two years, has your child had any illness which required them to?

| | | | | |
|---|---|---|---|---|
| (a) | consult your GP..... | Yes ☐ | No | ☐ |
| (b) | attend a hospital outpatient department ..... | Yes ☐ | No | ☐ |
| (c) | be admitted to hospital ..... | Yes ☐ | No | ☐ |

3. Have your child ever had any of the following:

| | | | | |
|---|---|---|---|---|
| (a) | Convulsions/epilepsy ..... | Yes ☐ | No | ☐ |
| (b) | Asthma ..... | Yes ☐ | No | ☐ |
| (c) | Eczema ..... | Yes ☐ | No | ☐ |
| (d) | Diabetes ..... | Yes ☐ | No | ☐ |
| (e) | A blood disorder ..... | Yes ☐ | No | ☐ |
| (f) | Head injury ..... | Yes ☐ | No | ☐ |
| (g) | Digestive problems ..... | Yes ☐ | No | ☐ |
| (h) | Heart problems ..... | Yes ☐ | No | ☐ |
| (i) | Problems with bones or joints ..... | Yes ☐ | No | ☐ |
| (j) | Disturbance of balance/coordination ..... | Yes ☐ | No | ☐ |
| (k) | Numbness in hands or feet ..... | Yes ☐ | No | ☐ |
| (l) | Disturbance of vision ..... | Yes ☐ | No | ☐ |
| (m) | Ear / hearing problems ..... | Yes ☐ | No | ☐ |
| (n) | Thyroid problems ..... | Yes ☐ | No | ☐ |
| (o) | Kidney or liver problems ..... | Yes ☐ | No | ☐ |
| (p) | Allergy to nuts ..... | Yes ☐ | No | ☐ |

4. Allergy Information

| | | | | |
|---|---|---|---|---|
| (a) | Is your child allergic to any food products? | Yes ☐ | No | ☐ |
| (b) | Is your child allergic to any medicines? | Yes ☐ | No | ☐ |
| (c) | Is your child allergic to plasters? | Yes ☐ | No | ☐ |

**If YES to any of the above, please provide additional information on the allergy**

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5. Are you aware of any other condition or complaint that may be affected by your child participation in this study? If so, please state below

.....

.....

.....

6. Please provide contact details of a suitable person for us to contact in the event of any incident or emergency.

Name:
.....

Telephone Number: .....

Work ☐ Home ☐ Mobile ☐

Relationship to Participant: .....

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Loughborough University

**Biomechanics of static balance and postural control in flat-water sprint kayak athlete.**

## INFORMED CONSENT FORM (PARENT/GUARDIAN/COACH)

### PURPOSE

To obtain biomechanical parameters of a sprint kayak athlete performing static balance in a 2-D planar motion.

### PROCEDURES

The data of sports movements will be obtained using:

- Video recording using one camera
- A number of trials will be requested with suitable breaks to minimise fatigue.

The subject specific parameters will be obtained from:

- Anthropometric measurements (using tape measures and specialist anthropometers)

During the data collection your child will be accompanied by your child's coach or by an adult that your child knows and trust. During the measurements two researchers will be present, at least one of whom will be of the same sex as the participant.

### QUESTIONS

The researchers will be pleased to answer any questions you may have at any time.

### WITHDRAWAL

Your child is free to withdraw from the study at any stage, without having to give any reasons. An opportunity will be provided in this event for your child to discuss privately their wish to withdraw.

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**CONFIDENTIALITY**

The identity of your child will remain confidential in any material resulting from this work.

I have read and understood the information on this form and agree for my child to participate in this study. As far as I am aware my child does not have any injury of infirmity which would be affected by the procedures outlined.

Name: ..... (Child)

Name: ..... (Parent/guardian/coach)

Signed: ..... (Coach)

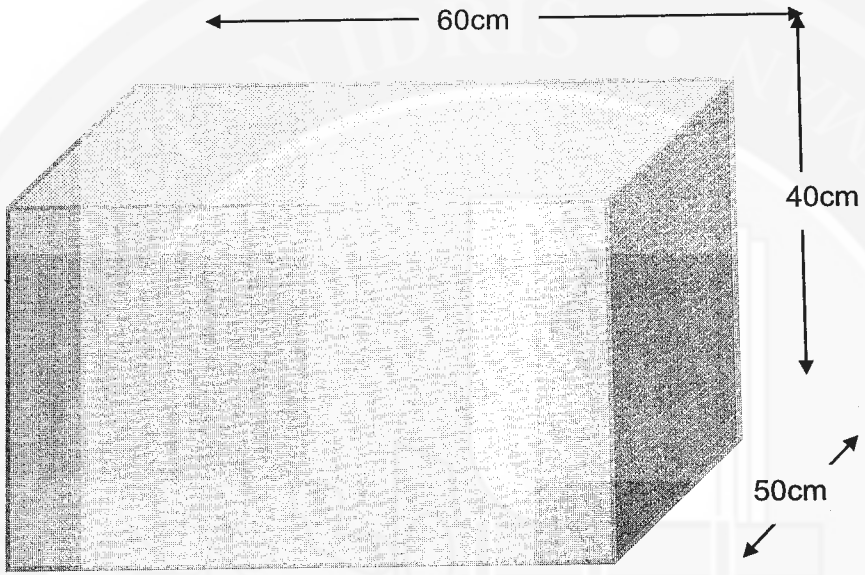
Date: .....

Signature of investigator: .....

Date: .....

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## Appendix 4-1: Component specification for sprint kayak balance training aid safety block




| Item | Description |
|---|---|
| Dimension | 60 cm x 50 cm x 40 cm |
| Materials | Polyethylene foam and Sorbothane® |
| Quantity | 2 unit |



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## Appendix 5-1: Preliminary medial-lateral rolling motion testing and evaluation

Preliminary testing was performed with additional weight ranging from 10 kg to 50 kg. The first objective of this test was to determine the centre of rotation for the on-water kayak oscillation. Secondly, to compare the on-water kayak and balance training aid oscillation characteristics (frequency and amplitude).

*Data collection– on-water kayak*

For ease of on-water kayak data collection a small balancing pool with dimensions that can fit a sprint kayak was purposely built (Figure A5-1). The motion data was obtained using a high speed camera (Phantom software), with frame rate set at 50 Hz. The camera was positioned perpendicular to the collection volume and finely adjusted in order to obtain accurate data. Two 14 mm markers were attached at the left and right posterior cockpit with a measured distance of 40 cm apart to enable an analysis of the actual motion of the on-water kayak. Additional markers were positioned between the two markers with one marker projected 40 cm vertically using a rigid mounted rod. These markers were used for horizontal and vertical scaling. A weight platform (Figure A5-2) was also built to replace the kayak seat and to ensure that the weight plates were securely positioned inside the kayak. The weight platform was design to have a similar height to the original kayak seat. To minimise sway motion, the kayak's bow and stern were firmly anchored to the side of the pool (Figure A5-3).

The first data taken was a static trial with a 0 kg additional weight, followed by the oscillation test for 10 kg, 20 kg, 30 kg, 40 kg, and 50 kg additional weight. Figure A5-4, shows an example of additional weight position for each trial. Static trials were also taken for every additional weight increment. The initial release angle of 25° was standardised for each trial. A maximum of ten oscillations was captured for each trial, but only the first 5 oscillations (5 seconds) data were used for analysis due to the rippling effect on the water surface after each oscillation. This

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rippling effect was more obvious with heavier additional weight especially 40 kg and 50 kg.

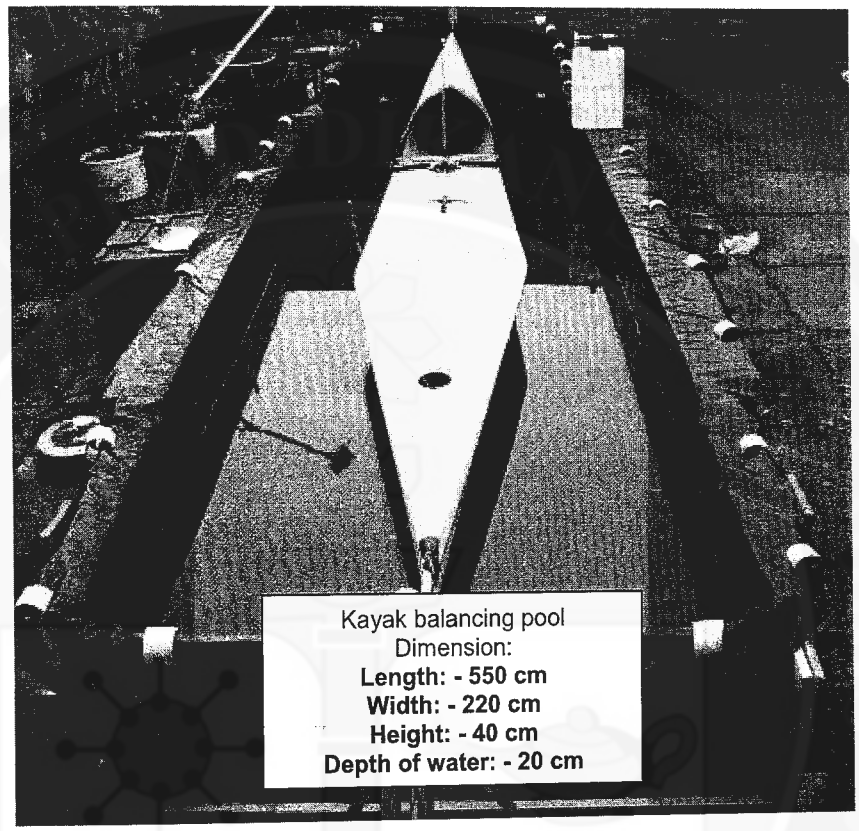



Figure A5-1: Kayak balancing pool set-up for oscillation test.

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Figure A5-2: Anchor system to minimise sway motion.

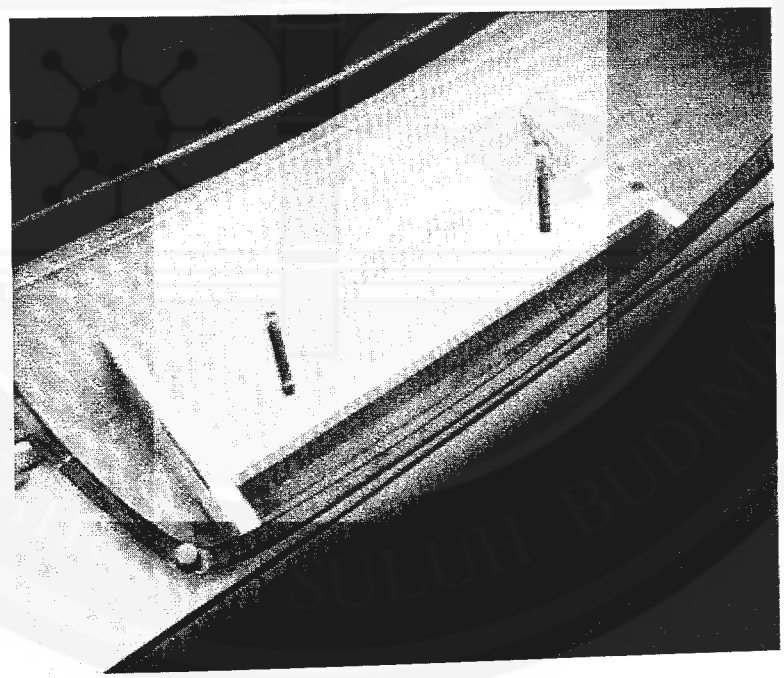


Figure A5-3: Weight platform.

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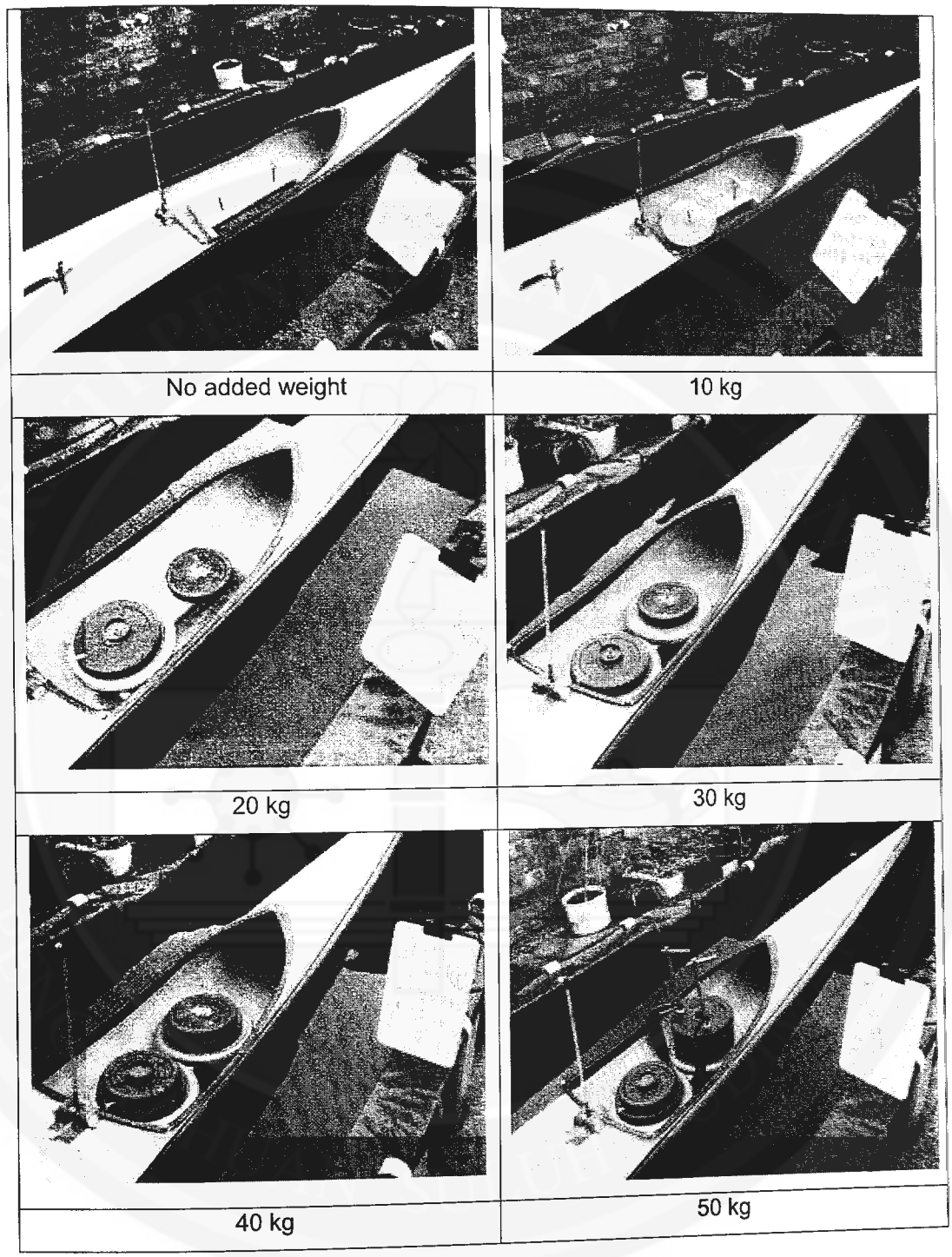



Figure A5-4: Weight increments for on-water oscillation test.

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*Data collection – balance training aid*

Balance training aid motion data were collected at the Robin Hooper Biomechanics Laboratory, Loughborough University using a Vicon motion capture system. Only two 14 mm retro reflective markers were used and positioned at balance training aid resemblance to on-water kayak cockpit marker (Figure A5-5). The weight platform and the additional weight plate set-up were also similar to the on-water kayak data collection set-up (Figure A5-6). Nine Vicon MX cameras were used and data were captured from a number of trials similar to on-water testing at 50 Hz.

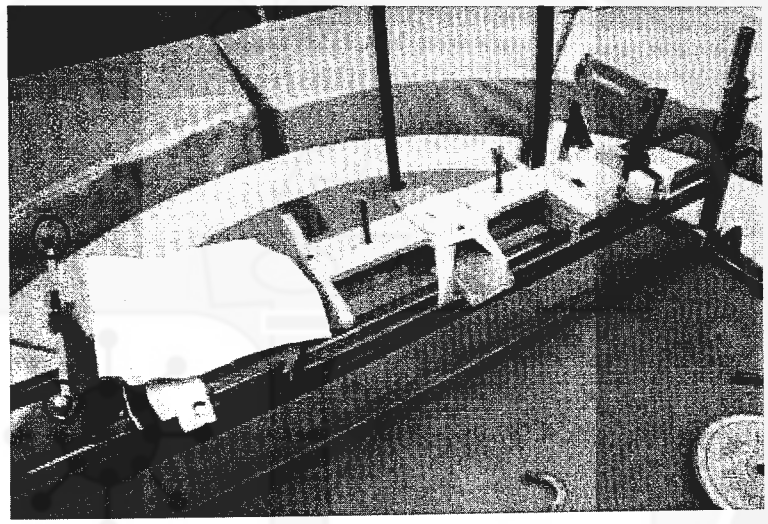


Figure A5-5: Kayak balance training aid set-up for oscillation test.

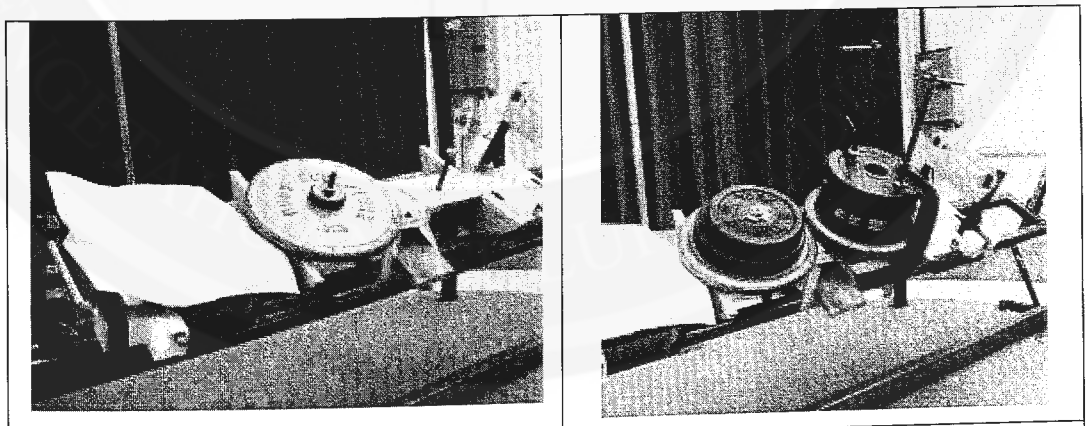



Figure A5-7: Weight increments examples for balance training aid oscillation test.

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Table A5-1, shows the level of setting for the balance training aid for each additional weight. These settings were based from the results of the previous on-water oscillation test.

Table A5-1: Centre of rotation positioning relative to the seat lowest point for different additional weight

| Weight (kg) | CoR – Seat (cm) |
|---|---|
| 0 | 6 |
| 10 | 7 |
| 20 | 8 |
| 30 | 8 |
| 40 | 9 |
| 50 | 10 |

*Data analysis – on-water kayak centre of rotation and oscillation characteristic*

The first stage of analysis was to determine the centre of rotation location for the on-water kayak oscillation with different weight increments. Data analysis method in finding the stationary sprint kayak centre of rotation has been discussed in previous experimental study (Chapter 1). From the study it was found that the mean centre of rotation location relative to seat height for average (77 $\pm$ 7kg) paddlers (n=8) was 11 $\pm$ 1 cm. This result was not enough to develop any statistical relationship between weight and centre of rotation location. For this test, the motion data was collected from the kayak cockpit markers displacement for each weight increment trial. This displacement data was then used to calculate the kayak centre of rotation and the angular oscillation characteristics (amplitude and frequency)

Figure A5-7 illustrates the significant linear relationship between kayak centre of rotation and weight increment with $R^2$ = 0.9657, value of fit is very close to 1.00. From here the data set can be extrapolated so it can cover the required range of

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weight increments. This valuable information can be used as a guide for subsequent level setting of the balance training aid centre of rotation.

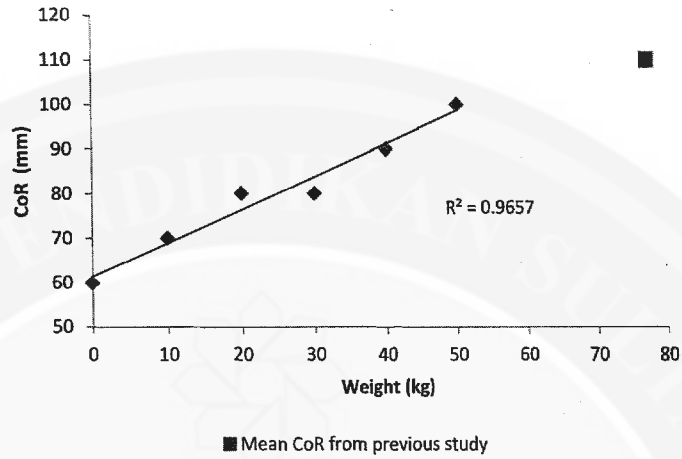



Figure A5-7: Relationship between weight increment and centre of rotation height for sprint kayak oscillation.

*Data analysis – comparison of on-water kayak and balance training aid oscillation*

Figure A5-8 to Figure A5-13, illustrate the oscillation frequency and amplitude of the on-water kayak and the kayak balance training aid, with different additional weight (0 kg – 50 kg) added at the seat height level. At the beginning of oscillation, in all conditions it looks like the peak amplitude was almost the same. However, as the oscillation continue the peak amplitude of on-water kayak decays (loss of energy) much faster than the kayak balance training aid. The decay in peak amplitude of the kayak balance training aid roll angle is linear with time and oscillation cycle, as illustrated by dotted lines in Figure A5-8 to Figure A5-13. On the other hand, on-water kayak peak amplitude decays exponentially with time and oscillation cycle. Differences in decay function are quite obvious in Figure A5-13, when 50 kg additional weight was added to the kayak. This happened because; the on-water kayak had more friction acting on its hull surface due to the viscosity of the water. From the result, it suggested that the kayak balance training aid needed to have more damping so it could match the oscillation decay of the on-water kayak.

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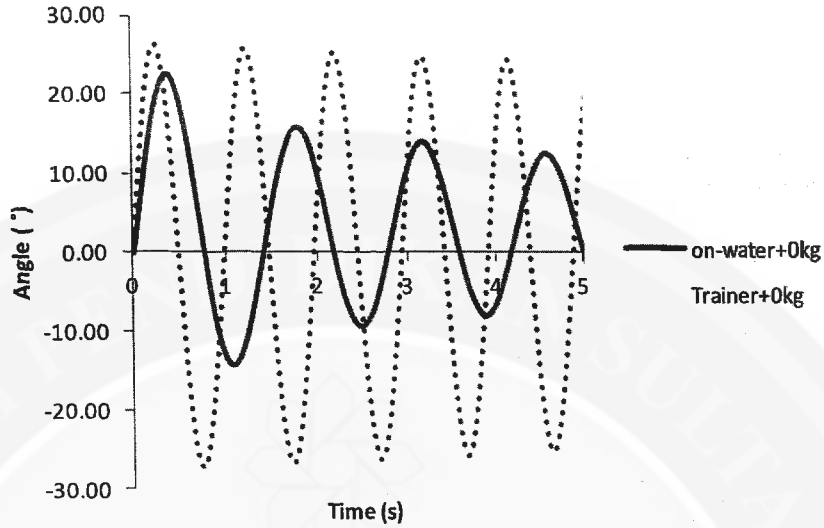



Figure A5-8: Oscillatory motion (angular displacement) of kayak balance training aid and on-water kayak with no additional weight.

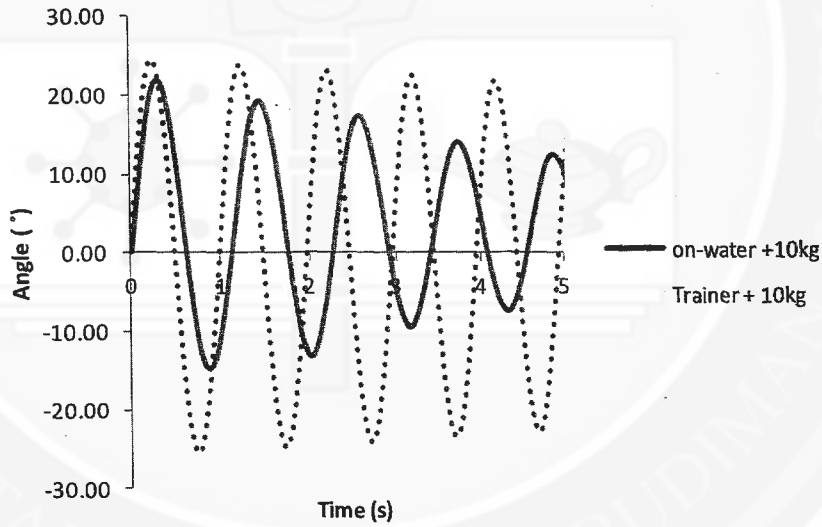



Figure A5-9: Oscillatory motion (angular displacement) of kayak balance training aid and on-water kayak with 10 kg additional weight.

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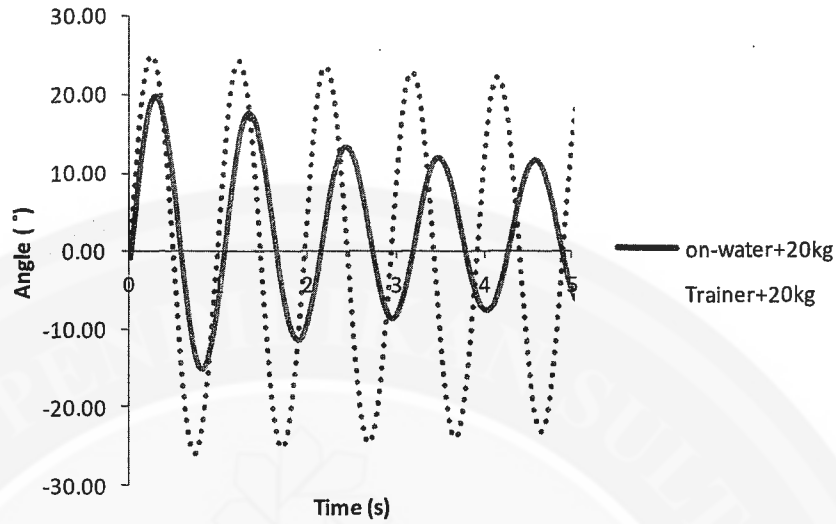



Figure A5-10: Oscillatory motion (angular displacement) of kayak balance training aid and on-water kayak with 20 kg additional weight.

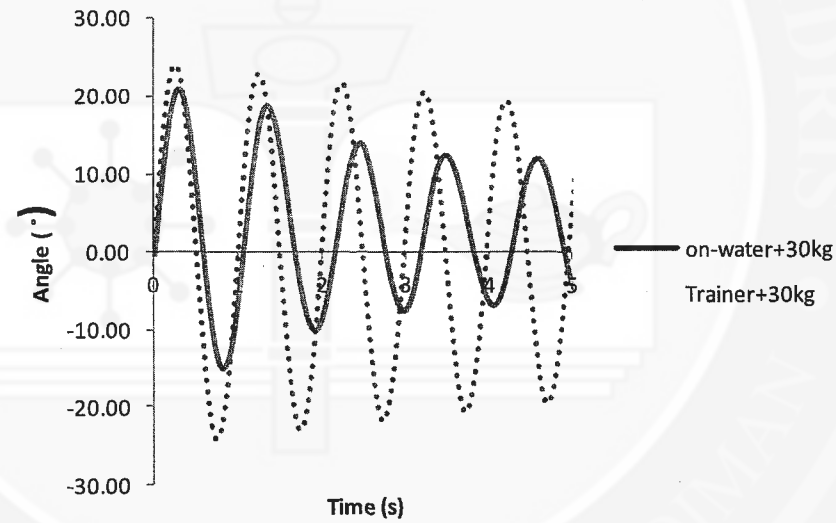



Figure A5-11: Oscillatory motion (angular displacement) of kayak balance training aid and on-water kayak with 30 kg additional weight.

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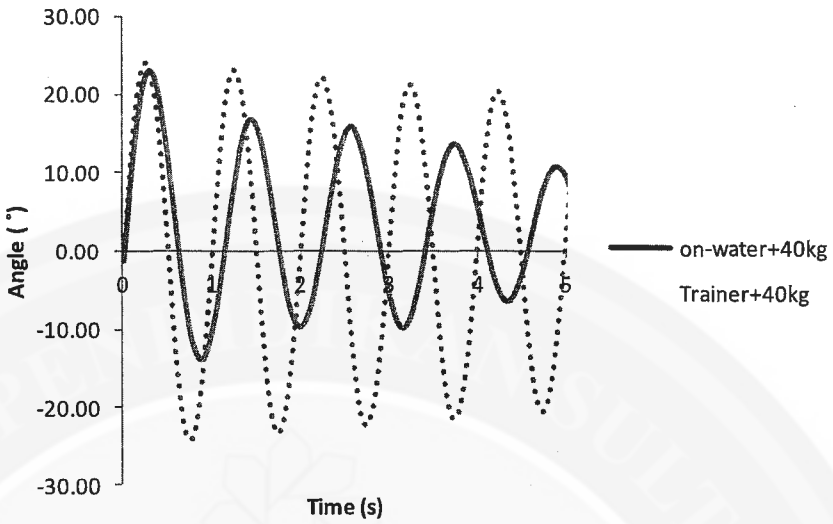



Figure A5-12: Oscillatory motion (angular displacement) of kayak balance training aid and on-water kayak with 40 kg additional weight.

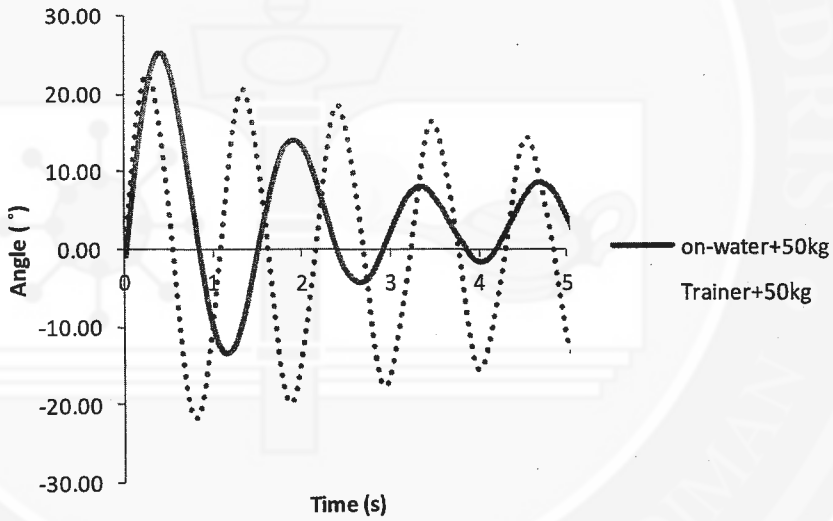



Figure A5-13: Oscillatory motion (angular displacement) of kayak balance training aid and on-water kayak with 50 kg additional weight.

Table A5-2 and Figure A5-14, below show the effects of additional weight on oscillation frequency of the on-water kayak and the kayak balance training aid. It was clear that the kayak balance training aid produced much higher frequency

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compared to on-water kayak. The frequency different is obvious when there was no weight added to the system, and same condition happen when 50 kg weight was added. This suggested that the balance training aid need to have more friction so it can oscillate much slower. However, there was only slight different was observed when 20 kg or 30 kg weight were added. So, it was decided that more experimental assessment need to be done on the balance training aid with a damping system.

Table A5-2: Frequency different between on-water kayak and kayak balance training aid with increase additional weight

| Weight (kg) | Frequency (Hz) | |
|---|---|---|
| | On-water kayak | Kayak balance training aid |
| 0 | 0.72 | 1.01 |
| 10 | 0.88 | 1.04 |
| 20 | 0.94 | 1.02 |
| 30 | 0.94 | 1.00 |
| 40 | 0.88 | 1.00 |
| 50 | 0.68 | 0.93 |

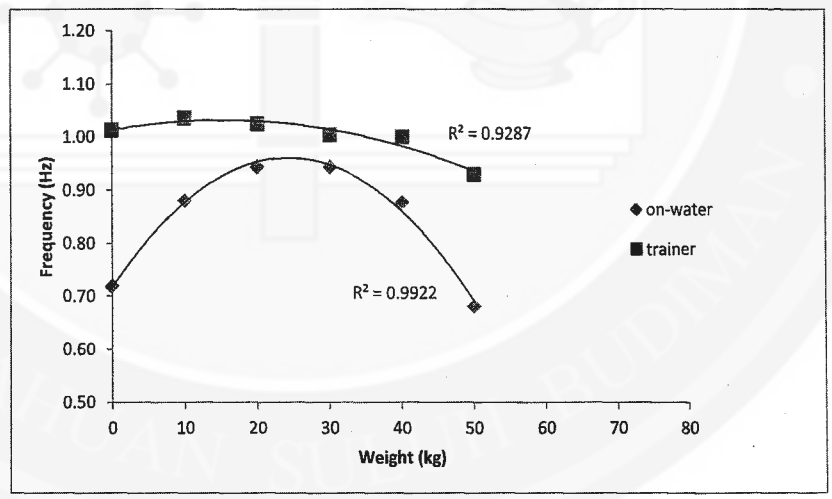



Figure A5-14: Plots of the oscillation frequency as a function of weight for on-water kayak and kayak balance training aid.

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## Appendix 6-1: Pilot test for balance training aid assessment

The initial pilot test was conducted at the same time as the recruitment process of participants for the main study. Different subjects were recruited for the pilot test and they experienced the same proposed procedures which have been detailed in Chapter 6. The pilot test involved an experimental comparison of one control subject (age – 22 years; height – 173 cm; sitting height – 89 cm; weight – 62 kg) and one experimental subject (age – 22 years; height – 170 cm; sitting height – 87 cm; weight – 63 kg).

### Results

The pilot test was successfully conducted and both subjects manage to complete the training and the data collection phases within a four week period. The control subject was able to complete the whole on-water kayak training and assessment in six (6) sessions, meanwhile the experimental subject managed to completed the whole session (training aid + on-water) in eight (8) sessions. Table A6-1, shows the detailed results of the pilot assessment for both control and experimental subjects. The on-water training session for the experimental subject was shorter than the control subject (4 vs. 6).

The Vicon data collection was also successfully administered, and the marker positioning was good and was clearly tracked by the Vicon system for the whole duration of the data collection. Finally, to ensure that the subjects' balance abilities were genuine and to show that the training session in the training pool was equivalent to the real training environment; both subjects were tested and

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asked to balance the sprint kayak in an Olympic size swimming pool. The result in Table A6-1 shows that both subjects had no difficulty in achieving the maximum target time in two consecutive assessment sessions.

Table A6-1: Pilot test - training and data collection session details

| **Control Subject** | | | | | **Experimental Subject** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Post training assessment | | | | | Post training assessment | | | | |
| Session | Trial 1 (s) | Trial 2 (s) | Trial 3 (s) | Notes | Session | Trial 1 (s) | Trial 2 (s) | Trial 3 (s) | Notes |
| 1 | 1 | 2 | 13 | On-water (training pool) | 1 | 22 | 20 | 2 | Training Aid |
| 2 | 7 | 30+ | 10 | | 2 | 4 | 30+ | 30+ | |
| 3 | 13 | 20 | 22 | | 3 | 30+ | 30+ | 30+ | |
| 4 | 15 | 22 | 30+ | | 4 | 30+ | 30+ | 30+ | |
| 5 | 30+ | 30+ | 30+ | | Vicon progression data collection | | | | |
| 6 | 30+ | 30+ | 30+ | | 5 | 13 | 20 | 22 | On-water (training pool) |
| | | | | | 6 | 11 | 30+ | 30+ | |
| | | | | | 7 | 30+ | 30+ | 30+ | |
| | | | | | 8 | 30+ | 30+ | 30+ | |
| Vicon post intervention data collection | | | | | | | | | |
| | 30+ | 30+ | 30+ | Swimming pool assessment | | 30+ | 30+ | 30+ | |
| | 30+ | 30+ | 30+ | | | 30+ | 30+ | 30+ | |

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## Appendix 6-2: Forms for balance training aid assessment.

Loughborough University

**Sprint kayak balance training for beginners**

**INFORMED CONSENT FORM**

(to be completed after Participant Information Sheet has been read)

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Approvals (Human Participants) Sub-Committee.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence and will be kept anonymous and confidential to the researchers unless (under the statutory obligations of the agencies which the researchers are working with), it is judged that confidentiality will have to be breached for the safety of the participant or others.

I agree to participate in this study.

Your name _____

Your signature _____

Signature of investigator _____

Date _____

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Loughborough University

**Sprint kayak balance training for beginners**

**Participant Information Sheet**

**Investigator Contact Details:**

Main investigator:
**Benderi Dasril** – Room: JB.0.19 – email: B.Dasril@lboro.ac.uk – Phone: 07901236448

Supervisors:-
**Dr Mark King** – Room: UU.1.08 – email: M.A.King@lboro.ac.uk
**Prof Fred Yeadon** – Room: UU.1.17 – email: M.R.Yeadon@lboro.ac.uk

**What is the purpose of the study?**
The purpose of this experimental study is to investigate the performance of the sprint kayak balance training aid in a training programme for complete beginners. Comparisons will be made with the performance of the actual on-water control group.

**Who is doing this research and why?**
This study is conducted by the main investigator and assisted by individuals from the Sports Biomechanics and Motor Control research group. It is part of a PhD research project examining the balance of stationary sprint kayak, and supported by Loughborough University.

**Are there any exclusion criteria?**
Only male participants may volunteer to take part in this study. Anyone who has participated in or experienced any sprint kayak training before cannot take part in this study. In addition, anyone that has a current injury that would make performing a balancing in unstable conditions, uncomfortable or unsafe should not take part in this study.

**Once I take part, can I change my mind?**
Yes! After you have read this information and asked any questions you may have we will ask you to complete an Informed Consent Form, however if at any time, before, during or after the sessions you wish to withdraw from the study please just contact the main investigator. You can withdraw at any time, for any reason and you will not be asked to explain your reasons for withdrawing.

**What will I be asked to do?**
The study will be divided into three stages:-

- *Initial-assessment stage* - measurements of morphological characteristic and initial assessment on subjects static balance ability.
- *Training + post-training assessment stage* - learn to balance for 30 minute (maximum) in each training session, which consist of 5 – 10 minute self-support warm-up balancing exercise; 10 minute balance adaptation (discovery learning); and 5 – 10 minute post-training assessment. Participants are expected to complete the training within 12 sessions (3 days per week for 4

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weeks). After each session, participant will be assessed for their balance ability.

- *Post-intervention assessment* – biomechanical data will be collected from each participant while performing the balance control on the kayak balance training aid.

**What type of clothing should I wear?**
During the initial-assessment and training sessions participant should wear an appropriate training clothes (example: t-shirts with shorts/jammers/track bottom). Spare changing clothes are required in case the training clothes get wet. For the post-intervention assessment EMG sensors and reflective motion markers will be placed on the skin, therefore shorts will be required for testing sessions to allow placement of markers on the hip and trunk area.

**Are there any risks in participating?**
You will perform the activities in a suitable and safe environment. The risk of injury during the data collection will be minimal since we only ask you to perform basic balancing movements which you are comfortable and at your own pace. The training and testing area is surrounded by a matted area to prevent injury in the unlikely event that a participant will lose control and fall off the kayak/device.

**Will my taking part in this study be kept confidential?**
All data collected in this study will remain confidential and secure. Participants will be allocated an identification number for recording and storage of data, and no participant will be referred to by name outside of data collection sessions, such as publication of the study.

**What will happen to the results of the study?**
All data collected conforms to the university's guidelines on data collection and storage, and will therefore be stored securely in its original state for the duration of the collection, analysis and publication of the study.

**I have some more questions who should I contact?**
Any questions regarding the testing procedures or handstand practice should be first addressed to Benderi Dasril (B.Dasril@lboro.ac.uk); alternatively, further queries may be addressed to other investigators listed above.

**What if I am not happy with how the research was conducted?**
If you have any concerns regarding your participation in this study, or the conduct of any of the investigators involved, please refer to the Secretary for the University's Ethics Approvals (Human Participants) Sub-Committee:

Research Office, Rutland Building, Loughborough University
Tel: 01509 222423. Email: Z.C.Stockdale@lboro.ac.uk

The University also has a policy relating to Research Misconduct and Whistle Blowing which is available online at:

http://www.lboro.ac.uk/admin/committees/ethical/Whistleblowing(2).htm.

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Name/Number .....

## Health Screen Questionnaire for Study Volunteers

As a volunteer participating in a research study, it is important that you are currently in good health and have had no significant medical problems in the past. This is (i) to ensure your own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

If you have a blood-borne virus, or think that you may have one, please do not take part in this research ***[only include for projects involving invasive procedures].***

**Please complete this brief questionnaire to confirm your fitness to participate:**

1. At present, do you have any health problem for which you are:

| | | | | |
|---|---|---|---|---|
| (a) | on medication, prescribed or otherwise ..... | Yes ☐ | No ☐ |
| (b) | attending your general practitioner ..... | Yes ☐ | No ☐ |
| (c) | on a hospital waiting list..... | Yes ☐ | No ☐ |

2. In the past two years, have you had any illness which required you to:

| | | | | |
|---|---|---|---|---|
| (a) | consult your GP..... | Yes ☐ | No ☐ |
| (b) | attend a hospital outpatient department..... | Yes ☐ | No ☐ |
| (c) | be admitted to hospital ..... | Yes ☐ | No ☐ |

3. Have you ever had any of the following:

| | | | | |
|---|---|---|---|---|
| (a) | Convulsions/epilepsy ..... | Yes ☐ | No ☐ |
| (b) | Asthma ..... | Yes ☐ | No ☐ |
| (c) | Eczema ..... | Yes ☐ | No ☐ |
| (d) | Diabetes ..... | Yes ☐ | No ☐ |
| (e) | A blood disorder ..... | Yes ☐ | No ☐ |
| (f) | Head injury ..... | Yes ☐ | No ☐ |
| (g) | Digestive problems ..... | Yes ☐ | No ☐ |
| (h) | Heart problems ..... | Yes ☐ | No ☐ |
| (i) | Problems with bones or joints ..... | Yes ☐ | No ☐ |
| (j) | Disturbance of balance/coordination ..... | Yes ☐ | No ☐ |
| (k) | Numbness in hands or feet ..... | Yes ☐ | No ☐ |
| (l) | Disturbance of vision ..... | Yes ☐ | No ☐ |
| (m) | Ear / hearing problems ..... | Yes ☐ | No ☐ |
| (n) | Thyroid problems ..... | Yes ☐ | No ☐ |

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(o) Kidney or liver problems ..... Yes ☐ No ☐

(p) Allergy to nuts ..... Yes ☐ No ☐

4. Has any, otherwise healthy, member of your family under the age of 35 died suddenly during or soon after exercise? ..... Yes ☐ No ☐

**If YES to any question, please describe briefly if you wish (eg to confirm problem was/is short-lived, insignificant or well controlled.)**

.....

.....

5. Allergy Information

(a) are you allergic to any food products? Yes ☐ No ☐

(b) are you allergic to any medicines? Yes ☐ No ☐

(c) are you allergic to plasters? Yes ☐ No ☐

**If YES to any of the above, please provide additional information on the allergy**

.....

Please provide contact details of a suitable person for us to contact in the event of any incident or emergency.

Name: .....

Telephone Number: .....

Work ☐ Home ☐ Mobile ☐

Relationship to Participant:.....

Are you currently involved in any other research studies at the University or elsewhere?

Yes ☐ No ☐

If yes, please provide details of the study

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## Appendix 6-3: Subject's demographic characteristics and balance training aid set-up for training and assessment session

**Control Group (CG)**

| Subject | Age (year) | Height (cm) | Sit. Height (cm) | Weight (kg) | Centre of rotation height (cm) | Foot-brace to seat distance (cm) |
|---|---|---|---|---|---|---|
| CG01 | 24 | 166 | 86 | 68 | 10 | 79 |
| CG02 | 23 | 172 | 89 | 73 | 11 | 82 |
| CG03 | 28 | 169 | 89 | 71 | 10 | 81 |
| CG04 | 32 | 168 | 85 | 76 | 11 | 80 |
| CG05 | 32 | 171 | 90 | 74 | 11 | 82 |
| CG06 | 21 | 183 | 94 | 67 | 10 | 87 |
| CG07 | 20 | 172 | 92 | 60 | 10 | 82 |
| CG08 | 20 | 169 | 86 | 53 | 9 | 80 |
| CG09 | 20 | 172 | 86 | 68 | 10 | 82 |
| CG10 | 23 | 168 | 86 | 95 | 12 | 80 |
| Mean | 24 | 171 | 88 | 70 | | |
| SD | 5 | 5 | 3 | 11 | | |

**Experimental Group (EG)**

| Subject | Age (year) | Height (cm) | Sit. Height (cm) | Weight (kg) | Centre of rotation height set-up (cm) | Foot-brace to seat distance (cm) |
|---|---|---|---|---|---|---|
| EG01 | 20 | 172 | 86 | 65 | 10 | 81 |
| EG02 | 26 | 179 | 89 | 76 | 11 | 85 |
| EG03 | 30 | 165 | 83 | 53 | 9 | 78 |
| EG04 | 29 | 169 | 83 | 75 | 11 | 80 |
| EG05 | 29 | 173 | 91 | 66 | 10 | 82 |
| EG06 | 21 | 184 | 93 | 89 | 12 | 87 |
| EG07 | 18 | 183 | 93 | 78 | 11 | 87 |
| EG08 | 20 | 193 | 99 | 99 | 12 | 92 |
| EG09 | 18 | 182 | 99 | 82 | 11 | 87 |
| EG10 | 31 | 170 | 88 | 71 | 10 | 81 |
| Mean | 24 | 177 | 90 | 75 | | |
| SD | 5 | 8 | 6 | 13 | | |

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