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Landing performance and lower extremity injuries in competitive surfing

Lina Elizabeth Lundgren
Edith Cowan University

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LANDING PERFORMANCE AND LOWER EXTREMITY INJURIES IN COMPETITIVE SURFING

LINA E. LUNDGREN

IN FULFILLMENT OF A DOCTORATE OF PHILOSOPHY IN SPORT SCIENCE

SCHOOL OF EXERCISE AND HEALTH SCIENCES
FACULTY OF HEALTH, ENGINEERING AND SCIENCE
EDITH COWAN UNIVERSITY

DATE OF SUBMISSION: 30TH OF AUGUST 2015

SUPERVISORS: JEREMY M. SHEPPARD, SOPHIA NIMPHIUS AND ROBERT U. NEWTON

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

ABSTRACT

Competitive surfing involves high-risk manoeuvres that may impose injury risk, especially in the lower extremity. Although the dynamic environment of surfing is a major factor of unpredictable determinants for injury risk, there may be athlete qualities with importance for prevention. Previous studies suggest that dynamic loading and landing tasks represent major risk factors, and should therefore be included in athlete assessments and risk analysis.

The purpose of this thesis was to investigate landing tasks that may be related to surfing performance and injury risk. It involved studying manoeuvres and landing tasks to establish its relevance for surfing athletes, develop multifactorial assessment protocols, as well as observe mechanisms and factors influencing lower extremity injury risk in high performance surfing.

Study 1 examined manoeuvres of the competitive season of the World Championship Tour, reporting on frequency and scores. Although re-entries were the most common manoeuvres, waves including aerial manoeuvres and tube rides scored higher on average; 7.40 ± 1.53 and 6.82 ± 2.13 respectively, compared to 5.03 ± 2.21 for turning manoeuvre waves. Therefore, aerial manoeuvres and barrel rides are necessary for high performance surfing.

Study 2 evaluated impact forces, accelerations and dorsiflexion range of motion in five different landing tasks. A drop and stick landing, two surf stance landings and two gymnastic type landings were performed by eleven competitive athletes. The peak acceleration was about 50% higher whilst landing on a board in a mini-trampoline gymnastic exercise compared to a surf stance landing from a 50 cm box ($p \leq 0.05$). Furthermore, the dorsiflexion ranges of motion in the gymnastic type landings were lower than the other landing types ($p \leq 0.05$). The greater load observed in the more complex tasks indicate that the risk involved may be higher in these, compared to general landing tasks.

Study 3 provided information of the circumstances of surfing injuries, by video analysis (N=13). Factors that were found to distinguish between injury situations and non-injury situations were deep knee flexion at water contact, upper body lateral displacement, knee valgus, perturbations in the landing and direction of board relative riding direction. For safety, athletes should practice landing competency and increase adaptability to sudden environmental changes.

Study 4 describes the development of a model based on the five measures ankle dorsiflexion range of motion, lower body strength, and time to stabilisation, peak force and a frontal plane video analysis during a drop and stick landing. The model was based on normative data from 71 surfing athletes and developed into a score based on exponential functions for four groups of athletes (male, female, junior and senior). It was concluded easy to implement, and may be useful in the assessment of landing competency of surfing athletes.

Study 5 was a prospective study of competitive surfing athletes, observing injuries during six months. Furthermore, the athletes (N=48) were tested on baseline assessments to reveal whether any of the variables could be useful as indicator of injury risk from closed kinetic chain movements. There were 22 injuries reported during the period, whereof 8 were categorised closed kinetic chain injuries. Two baseline measures were found to be potential risk factors; the model of landing qualities and bilateral squat asymmetry ($p \leq 0.05$). Athletes with excessively poor assessment results on landings and bilateral squat may be alerted of potential injury risk.

Landing competency and other bilateral movements can be tested and trained in the land-based preparation of surfing athletes, and seem to be relevant for competitive surfing athletes. If excessively poor scores on these assessments expose the athlete to injury risk, then athletes should aim for satisfactory scores before successively training high-risk manoeuvres in the surfing context.

Keywords: sports injury, surfing training, athletic assessment, landing competency

The declaration page
is not included in this version of the thesis

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Lina Lundgren

Casuarina beach, August 2015

PUBLICATIONS RELATED TO THIS THESIS

Research Papers

- Lundgren, LE**, Newton, RU, Tran, TT, Dunn, M, Nimphius, S, and Sheppard, JM. (2014). Analysis of manoeuvres and scoring in competitive surfing. *Int J Sport Sci Coach*. 9(4):663-669.
- Lundgren, LE**, Tran TT, Nimphius S, Raymond E, Secomb JL, Farley ORL, Newton RU, and Sheppard JM. Comparison of impact forces, accelerations and ankle range of motion in surfing related landing tasks. *J Sports Sci*. In Press. DOI: 10.1080/02640414.2015.1088164
- Lundgren, LE**, Nimphius, S, Lewis-Jones, G, Whitting, J, Tran, TT, Secomb, JL, Farley, ORL, Newton, RU, and Sheppard, JM. Video analysis of landings: comparison of surfing manoeuvres resulting in injury versus non-injury. *In Review*.
- Lundgren, LE**, Tran, TT, Raymond, E, Secomb, JL, Farley, ORL, Nimphius, S, Newton, RU, Steele, JR, and Sheppard, JM. (2015). Development and evaluation of a simple, multi-factorial model based on landing performance to indicate injury risk among surfing athletes. *Int J Sport Physiol Perform*. 10:1036-1040.
- Lundgren, LE**, Tran, TT, Nimphius, S, Secomb, JL, Farley, ORL, Raymond, E, Steele, JR, Newton, RU, and Sheppard, JM. A prospective analysis of surfing injuries incurred by competitive athletes. *In Review*.
-

Conference Proceedings and Case Reports

Full abstracts and reports can be found in the appendix.

- Lundgren, LE**, Secomb, JL, Tran, TT, Farley, ORL, Nimphius, S, Newton, RU, and Sheppard, JM. (2015). Bilateral Squat Symmetry pre and post a 7 week Training Program for Surfing Athletes. Abstract presented at the European Congress of Sport Science, Malmoe, Sweden.
- Lundgren, LE**, Ferrier, B, Tran, TT, Secomb, JL, Farley, ORL, Newton, RU, Sheppard, JM, and Nimphius, S. (2015). Relevance, Reliability and Limitations of a Drop And Stick Landing Analysis. Paper presented at International Conference on Biomechanics in Sports, Poitiers, France.
- Lundgren, LE**, Butel, M, Brown, T, Nimphius, S, and Sheppard, JM. (2014). High Ankle Sprain: The New Elite Surfing Injury?. *International SportMed Journal*, 15(4), 321-327.
- Lundgren, LE**, Secomb, JL, Tran, TT, Farley, ORL, Nimphius, S, Newton, RU, and Sheppard, JM. (2014). Bilateral Squat Asymmetry in Surfing Athletes. Abstract presented at the European Congress of Sport Science, Amsterdam, Holland.
- Lundgren, LE**, Tran, TT Farley, ORL, Secomb, JL, Nimphius, S., Newton, R. U., Sheppard, JM. (2014). Athletic Movement Competency is Related to General Athletic Performance Variables and Surfing Performance. Paper presented at ASCA International Conference on Applied Strength and Conditioning, Melbourne, Australia.
- Lundgren, LE**, Tran, TT Farley, ORL, Secomb, JL, Raymond E, Nimphius, S., Newton, R. U., Sheppard, JM. (2014). New Assessment Tool for Aerial Surfing Athletes. Abstract presented at 9th Australasian Biomechanics Conference, Wollongong, Australia.
- Lundgren, LE**, Tran, TT, Farley, ORL, Secomb, JL, Nimphius, S, Newton, RU, and Sheppard, JM. (2013). Ankle Range of Motion among Surfing Athletes. Paper presented at the ASCA International Conference on Applied Strength and Conditioning, Melbourne, Australia.
- Lundgren, LE**, Tran, TT, and Sheppard, JM. (2013). Jump Squat Variables for Competitive Surfing Athletes. Abstract presented at the European Congress of Sport Science, Barcelona, Spain.

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LIST OF ABBREVIATIONS

ACL:	anterior cruciate ligament
ASP:	Association of Surfing Professional (hosted WCT until 2015)
ATFL:	anterior talofibular ligament
CNS:	central nervous system
COP:	centre of pressure
ED:	emergency department
FAI:	femoral-acetabular impingement
INJ:	injured athletes
IC:	initial contact
LCL:	lateral collateral ligament
m:	metres
cm:	centimetres
MCL:	medial collateral ligament
mm:	millimetres
N:	newtons
n/a:	data not available
NINJ:	non-injured athlete
s:	seconds
WCT:	World Championship Tour
WSL:	World Surf League

DEFINITIONS AND TERMINOLOGY

Backhand	Surfer turning the board with the heel edge of the board towards the wave face
Forehand	Surfer turning the board with the toe edge of the board towards the wave face
Injury	One day or more absent from training and competition, or work due to painful condition or physical restriction [1].
Injury mechanism	The fundamental physical process responsible for the injury, i.e. inciting event [2].
Ollie	A fundamental skate boarding trick, with the athlete using the feet to get the board into the air at the same time as jumping [3].
Proprioception	The ability to use kinaesthesia to provide the central nervous system (CNS) and peripheral nervous system (PNS) with spatial information about the body segments and joints, their position and movement, and subsequently make postural changes to achieve the task goal [4].

CHAPTER 1 - INTRODUCTION

1.1 BACKGROUND

Surfing is a high performance sport and Australia has the highest number of professional surfers in the world [5]. As a professional athlete, there are high demands on performing well and to do so, one also attempts to avoid injury. Research can help coaches and athletes to find methods of how to train and allow themselves to improve their capability. Research models describe the information requirements for this, such as the Applied Research Model for the Sports Sciences (ARMSS) [6]. This model involves describing definitions, descriptors, predictors, efficacy and implementation in relation to the sport and potential injury risks as part of the research [6].

Surfing has only recently begun to receive increased attention in terms of research [7], as such, there are numerous aspects and characteristics of the sport where more knowledge is required. Between 1971 and 2007 there were 162 research-based publications related to surfing. The vast majority related to coastal and environmental issues, with relatively few related to surfing injuries and fewer involving biomechanical analysis [7]. Since then, more attention to physiological and biomechanical demands of surfing has been given by different research groups around the world, and there has been about 60 new publications of surfing performance related observations, whereof about 14 reported on injury related matters (Google Scholars, Science Direct and Medline). These 14 reports have contributed substantially to the knowledge about issues and risks in relation to surfing and therefore the sport is now ready to be studied with a narrower focus. For example, little research has focused on competitive surfing athletes and the implications of the judging criteria on injury risk.

Although surfing is not an Olympic sport, it is a sport with substantial economic impact, and the prize awards for the World Championship Tour (WCT) totals about eight million US dollars for the Men's and Women's division consisting of 34 male, and 17 female athletes [8]. Furthermore, the surfing industry has expanded to a world wide market, with high profile brands such as Hurley, Quiksilver, Billabong and Ripcurl originating from the surfing community, just to name a few. As a

result of both a large financial impact as well as surfing being an “iconic” sport in Australian culture, Australian Institute of Sport include surfing in the ‘Winning Edge’ concept. Therefore, the sport performance and practice in Australia has become more professional from a sporting organisation perspective. As an example, in 2012 Surfing Australia created a new High Performance Centre with the aim to excel Australian surfing athletes towards becoming World Champions. The centre incorporated surf coaches, strength and conditioning staff and a research unit to be able to maintain in the forefront of surfing research and performance development. The research programme drives research that is directly linked to the elite athlete program and applicable to high performance surfing, with new knowledge being served in this area worldwide. As part of the programme were research questions related to the safety of the modern type surfing, i.e. the risks of radical manoeuvres and landings, and to find methods to assess the athlete’s physical competency related to performance of these types of manoeuvres.

1.2 PURPOSE OF RESEARCH

The purpose of this thesis was to investigate landing tasks that may be related to surfing performance and injury risk. It involved studying manoeuvres and landing tasks to establish its relevance for surfing athletes, develop multifactorial assessment protocols, as well as observe mechanisms and factors influencing lower extremity injury risk in high performance surfing.

The specific aims were:

- To investigate what manoeuvres are performed, their frequency and scores in professional surfing competitions (Chapter 3).
- To evaluate ankle dorsiflexion range of motion, impact forces and accelerations in landing tasks with relevance to surfing (Chapter 4).
- To identify characteristics of injury situations during surfing manoeuvres (Chapter 5).
- To develop and evaluate a model based on physical assessments, with the aim of identifying athletes with potential injury risk due to insufficient landing competency (Chapter 6).
- To provide prospective data of injuries and evaluate the use of functional assessment tasks to indicate lower extremity injury risk for competitive surfing athletes (Chapter 7).

1.3 SIGNIFICANCE OF RESEARCH

This thesis provides information specifically targeting areas in surfing where research has not yet been conducted. While professional surfing is moving towards an augmented high performance approach, relevant assessment tools need to be developed, and injury risks and mechanisms need to be described. This information may assist medical staff, surf coaches, sport scientists and strength and conditioning coaches to make informed decisions in regards to athlete specific issues.

The significance of this thesis is the presentation of the most comprehensive analysis of potential injury risk of the lower body to date for the sport of surfing. The models developed, and tools describes as a result of the series of investigations provide a platform for future research as well as valuable information for current coaches, athletes and sport scientists working with athletes performing aerial manoeuvres.

1.4 DELIMITATIONS

This research was performed as part of the operation at Surfing Australia High Performance Centre. Therefore, development of models and assessments for use in surfing was based on use of existing equipment in the organization. It was decided to not develop new equipment as part of this project. As a result one may consider some measurement tools fundamental, however, this decision has led to the transfer of application into the sport being immediate.

Furthermore, due to the extremely dynamic environment in surfing, the complete model of factors influencing injury risk is complex and includes many uncontrollable variables. As such, delimitations were set during this study to focus mainly on the board riding aspects and in particular landings related to surfing manoeuvres.

1.5 LIMITATIONS

When observing injuries in surfing, it is of little chance to obtain high quality video data from several angles, as would ideally be the case to in detail analyse mechanisms of injury from a biomechanical perspective. Nevertheless, provided the information we have been able to obtain in the studies presented in this thesis, the material contributes with important information although in a more holistic perspective.

I would also like to acknowledge that although this thesis involves an effort to assess injury risk, this is not a measure of true likelihood for an athlete to get injured. There are two major factors that may explain this; the number of and complex interaction of intrinsic and extrinsic risk factors, and the ability to perform high-risk manoeuvres.

1.6 PRESENTATION OF THESIS

The literature review of this thesis is composed to provide an overview of contemporary competitive surfing, present research related to surfing performance and injuries, an extensive outline of studies related to postural biomechanics and mechanics of landings, and sport injury research in general. This background aims to introduce the reader to the scientific rationale behind landing performance and its relation to injury risk, which the five studies presented in this thesis are based on. These studies involve aspects of competitive surfing, landing tasks, assessments for surfing athletes, injuries among competitive surfing athletes and injury mechanisms and risk factors in surfing.

To address the paucity of evidence-based information about surfing performance, the first study (Chapter 3) involves observations of the manoeuvres performed throughout a season of the World Championship Tour. This study establishes the rationale for the types of skills that are subsequently focused on in regards to injury risk. Secondly, we experimented with different types of landing tasks (Chapter 4), to determine which may be suitable to use in the assessment and training of surfing athletes. In addition, to gain insights into factors that may influence situations of lower extremity surfing injury, we analysed a number of videos of surfing injuries to provide descriptive data of these situations. From the conclusion of more complex landing tasks leading to greater variability in the assessments (Chapter 4), and the importance of stability upon landings in surfing (Chapter 5), simple landing tasks were implemented in the development of a model to reflect general landing ability among surfing athletes (Chapter 6). In addition, a series of smaller studies of assessments that may be useful to test surfing athletes were performed simultaneously, although these have not been included as main data in this thesis and are presented in Appendices D-K. The model assessing general landing ability (Chapter 6) and other relevant assessments were used as baseline measures of individual intrinsic characteristics for a group of competitive surfing athletes who were then followed over six months regarding injuries (Chapter 7).

CHAPTER 2 - LITERATURE REVIEW

2.1 COMPETITIVE SURFING

2.1.1 COMPETITION STRUCTURE AND SCORING

Surfing is a multi-faceted sport with several tasks to be performed (i.e. paddling, sitting, duck-diving, catching waves, take-offs, wave riding and manoeuvres), all of which are important for the competitive performance. However, the scoring of competitive surfing is based on the manoeuvres performed on the wave exclusively, as determined by five judges. The wave-riding manoeuvres performed in surfing are scored high if they are performed with speed, power and flow, close to the most critical part of the wave (the breaking point) [9]. The overall ride is judged between 0 and 10 on the difficulty, variation and combination of manoeuvres, such as different kinds of turns, aerials (release from the water and land back into the wave again) and other manoeuvres such as rotations, and tube riding. More specifically, the scoring criteria in surfing is defined as follows [9]:

Judges analyse the following major elements when scoring a ride:

- commitment and degree of difficulty
- innovative and progressive manoeuvres
- combination of major manoeuvres
- variety of manoeuvres
- speed, power and flow

The scale used to describe the scores is: 0–1.9 = Poor; 2.0–3.9 = Fair; 4.0–5.9 = Average; 6.0–7.9 = Good; 8.0–10.0 = Excellent [9].

An athlete can receive a score of 10.0 (perfect) if the performance of surfing in relation to what is offered (mainly referring to wave conditions) is deemed best possible and adhere to the criteria. Therefore, the ability to perform a wide range of manoeuvres, suitable for different conditions of surfing locations and weather is of utmost importance for high-level surfing athletes to achieve

competitive success. The competition structure in surfing is based on heats of 20-40 minutes each, where two, three, or four surfers compete against each other to move forward in the heat structure, depending on the level of competition and structure. Figure 2.1 outlines the format for a men's WCT draw, involving a combination of two and three person heats, elimination and non-elimination rounds. Usually, the top surfer (two surfers in four person heats) will proceed to the next round, and this will be determined by the sum of the two highest wave scores for each athlete [9].

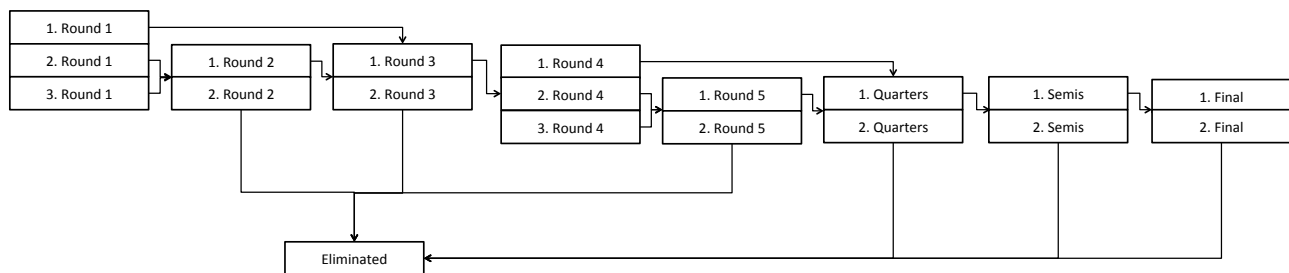


Figure 2.1. Heat system in the men's world championship tour events based on 36 surfers in Round 1.

The highest competitive surfing tour is the WCT, hosted by World Surf League, and involves the 34 highest ranked male surfers in the world as well as the 17 highest ranked female athletes. To qualify for the WCT there is a qualifying tour (WQS), where surfers gather points throughout the season, to replace the bottom ten athletes of the tour for the upcoming year [8]. The two tours have events spread out over the year in different parts of the world, thus requiring the athletes to have healthy travel and physical maintenance skills. This reflects surfing's position as a truly worldwide sport, and the high level of competition among the elite require professionalism in all aspects of athlete performance.

2.1.2 SURFING MANOEUVRES AND MOVEMENTS

The surf stance is generally a sideways stance position in a dynamic squatting position, allowing for a large range of movement in three dimensions, i.e. flexion-extension, lateral movements and rotations. Although the surfing posture and movements will vary between individuals and manoeuvres, the general surfing stance has been described as a squatting position with a wide stance,

knee flexion between 30-100°, and the rear hip somewhat internally rotated and sometimes in a valgus position [10, 11]. From this position, a range of movements will be performed to control the board, generate speed and execute manoeuvres. The surfing athlete is usually barefoot on the board, with only surf wax or a grip pad between the foot and the board.

A surfing athlete manoeuvres the board on the wave by manipulating their centre of gravity while maintaining the feet on the board. By doing this, the athlete can make the board assert forces against the water surface that will have effect on the total movement of the board and the athlete on the wave. For example by shifting the weight between the front and rear foot, the athlete will change the rotational torque around the mediolateral axis of the board, also called pitch (Figure 2.2a) and can stall or plane the board to decrease or increase the velocity [12]. Similarly, if the athlete shifts his or her weight anterior or posterior in the sideways stance, this creates a rolling torque around the longitudinal axis of the board (Figure 2.2b), and hence can be used to place the rail into the water surface. Because of the rounded shape of the surfboard rail, and the drag and drive created by the fins on the bottom and back of the board, this action would cause the board to turn. The third dimension of board movement is the flat twist, yaw, as if the board was rotating around a vertical axis when lying on the ground (Figure 2.2c). This type of movement is used to slide the board around from, for example, a switch (fins first) direction of velocity and requires a frictional force between the feet and the board, usually achieved by application of wax on top of the surfboard [12].

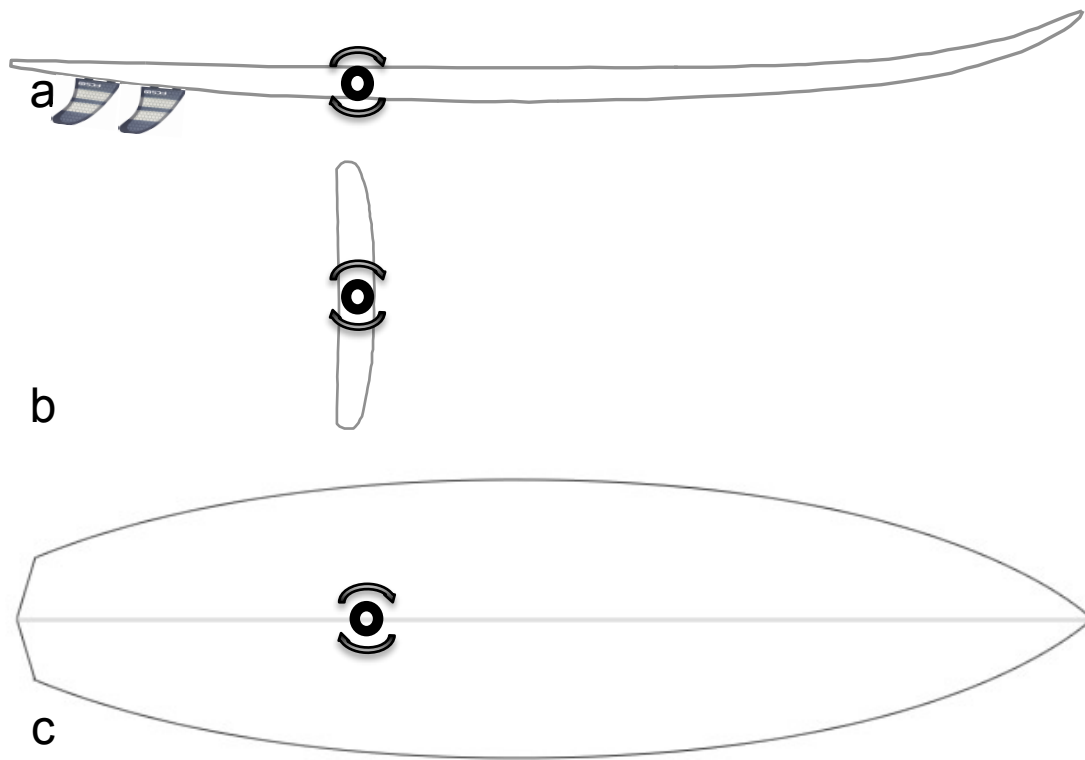


Figure 2.1. The board can rotate around three axes to create pitch (a), roll (b) or yaw (c), which the athlete can use to manipulate the velocity and direction of the board. The centre of rotation may differ depending on the distribution of material in the board.

To generate speed of the board across the wave, which is important for subsequent powerful manoeuvres, the athlete uses the slope of the wave face, the moving water in the wave and a ‘pumping’ action consisting of a flexion-extension movement (Figure 2.3) [10]. When sufficient speed is generated, the athlete can choose between a range of major manoeuvres to perform, however, in many cases the morphology of the wave will determine which manoeuvres are possible to execute for maximum scoring potential [13]. The main categories of major manoeuvres are turns (bottom turn, re-entry, cut back, carve and power slide), tube rides, floaters and aerials, however before the scoring manoeuvres can be performed, the athlete needs to get from a paddling position to a standing position.



Figure 2.2. Athlete using the slope of the wave and the moving water to generate speed across the wave (photo: *Surfing Australia*).

2.1.3 *POP-UP AND TAKE-OFF*

When catching a wave, the surfing athlete is paddling into the wave and ‘popping’ up on the board before taking off. When both hands have left the board, the surfer is standing and therefore deemed riding the wave [9]. The sequence and timing of the pop-up is important for the acceleration down the wave face and position on the wave, just as is the positioning of the take-off on the wave [14]. Generally, the athlete should take off on the peak of the wave, just before it is breaking, to maximise the wavelength and potential to perform scoring manoeuvres. If the athlete is a bit late or slow in the first part of the take-off, a steep wave can require an airborne phase before contact with the water surface is regained. Therefore, the requirements of the athlete for this task is multifaceted and ranges from sprint paddling efficiency and upper body push power to stability in the surf stance and landing.

2.1.4 *BOTTOM TURN*

Most of the turns used in surfing consist of two phases: the bottom turn and the top turn (described below). The role of the bottom turn is to set the trajectory of the top turn, whether it is to be a sharp and vertical re-entry or a drawn-out cut back [14]. Many athletes assume a squatting position throughout the bottom turn with an anterior lean (if riding forehand) to place the side rail of

the board into the water surface. Mechanically this anterior shift of the centre of gravity creates a force vector from the board against the water surface to effectively cut through the water and change the direction of the velocity with minimal loss of speed. This type of turn is possible because of the rounded outer shape of the board rail and the fins [12].

The bottom turn has been shown to be important for the wave score, with longer bottom turns leading up the manoeuvres correlating positively to the score of the wave [15]. The average bottom turn time reported in the literature is 1.05 ± 0.13 s, calculated from four WCT contests in 2009-2010 [15]. The considerable time spent in the bottom turn, provided that this movement is used to change the direction of the surfboard and athlete between 90° and 180° with minimal loss of speed, suggests that athletes will need well developed eccentric and isometric lower body strength to be successful. Furthermore, arranging the body position for an explosive transition to the following turn can make the bottom turn a very important movement to master.

2.1.5 MAJOR MANOEUVRE TURNS

There are numerous variations of turns that surfing athletes use to make every wave score as high as possible according to the judging criteria [9]. Examples of these are re-entries, whereby the athlete re-enters the wave after contacting the lip of the wave, drawn-out carves, where the athletes carve the board on the wave face, and cutbacks where the board carves around to reconnect with the breaking point in a figure eight on the wave surface and the horizontal change of direction is a minimum of 130° [14, 16]. Another major manoeuvre performed as a variation in a turn is the power slide, where the athlete pushes the surfboard tail to release the fins whilst keeping control [16], as well as a 'finner' or 'fin-bust' where the entire rear-portion of the board is released from the wave, above the lip during the turn Figure 2.4. Depending on how vertical, how high and how much spray is shown during these manoeuvres, the wave scores will vary from 'poor' to 'excellent' according to the judging criteria.



Figure 2.3. A major manoeuvre turn with an additional release of the fins above the lip of the wave
(photo: *Surfing Australia*).

Although the types of turns will differ in their execution, essentially a turn is a change of direction movement. They all start with a bottom turn, and then include a flexion – extension movement to gain power and height in the movement and rotation of the body in the proximal to distal kinematic sequence: head – shoulders – hips and feet to board, to allow for maximum rotational momentum in the turn [14]. This kinematic sequence is similar to what has been prescribed in other rotational sports when the aim is to generate rotational power through a short sequence of movements [17]. Furthermore, the final phase of the turning manoeuvres is about regaining stability and preparing for transition to the next section.

2.1.6 *TUBE RIDES*

When the wave forms the shape of a barrel, the surfing athlete can hide inside the hollow area, and then accelerate out of the wave as it starts decreasing in size. Tube riding is a difficult skill to master, and is therefore scored high in competition if successfully performed. Criteria for tube rides are wave size, entry and exit, as well as depth and time spent within the barrel [16]. To successfully perform a tube ride, the athlete has to generate the same speed as the wave, and then adopt a position that allows them to fit inside the tube (Figure 2.5). This position enables the athlete to control the speed and direction of the board, as well as maintaining alignment inside the edges of the board to avoid major body contact with the moving water (although they will often use hands and even hips to ‘stall’ in the wave to not out-run the wave). The weight distribution is generally shifted towards the

front extremity in this position, to allow the rear extremity freedom to move and control the board [10].



Figure 2.4. In a tube ride, the athlete stays inside the wave for as long as possible (*photo: mysurf.tv*).

A tube ride is a critical manoeuvre, because of the difficulty of timing the sequences of the wave and maintaining a position that allows the athlete to stay inside the barrel. If the moving water catches the athlete during the tube ride, this will result in a wipe-out, implicating a low score (due to an incomplete manoeuvre) and the risk of being abraded on a reef below the surface. Furthermore, the lip of the wave may be unpredictable in its movement, and can potentially impact the athlete either from above or from the side, creating substantial compression or shear forces upon the body [18, 19].

2.1.7 AERIAL MANOEUVRES

Aerials are manoeuvres in which the surfer launches above and over the wave face and then lands back into the wave (Figure 2.6). Although aerial moves were likely first performed in the mid 1980's and later performed in elite competition in the early 1990's, it has not been until the past decade that aerials have become a mainstay manoeuvre in competitive surfing [20]. Aerials are high-risk manoeuvres that when completed can be well rewarded by the judging panel, and as such, it is likely the trend will continue towards increased aerials in competition [16]. There are a number of varieties of aerial manoeuvres with different degrees of difficulty, however the straight aerial and air reverse

are usually the first ones in an athlete's repertoire [14]. The straight aerial is the one with least rotation, where the athlete performs a turn in the air before landing back in the slope of the wave (between 90° and 180°) as shown in Figure 2.6. The air reverse on the other hand, involves a rotation of the athlete and board in the air so that the tail end of the board is pointing in the riding direction when landing (also called 'switch'). Other aerial manoeuvres are combinations of acrobatics performed in the airborne phase and are elements of innovation for the surfing athlete [16].



Figure 2.5. Sequence of a typical aerial in competitive surfing involving a take-off, aerial phase and landing.

There is a paucity of published research regarding the details and biomechanics of aerial manoeuvres in surfing, however, a qualitative description of these manoeuvres by Everline (2007), describes them as the result of excessive speed across the wave, that allows the athlete to launch into the air [10]. Furthermore, the athlete must time the take-off from the wave to use a 'ramp' to get maximum height. In the take-off, a whole body flexion-extension movement will assist the athlete in gaining power and thereby height [14]. Whilst in the air, one of the main tasks is to keep the board close to the feet, to remain control upon landing. At times, the athlete grabs the board with one or both hands to assist this task; however a skilled athlete can perform the movement so that the board has the same trajectory through the air as themselves, without holding on to it. My observations of elite surfers performing this task reveal that they typically maintain the proximity of the board to their body by exerting a slight adduction effort, as if the athlete is pulling their feet together. This action may result in an inward knee position, albeit an awkward and injurious looking position. However, this position is adopted during the flight face (non-weight bearing).

The final part of the aerial manoeuvre is to prepare for and perform the landing. This is a crucial part of the manoeuvre and the athlete needs to quickly decelerate the body and regain stability by going through a flexion movement with eccentric muscle action [21]. In many other sports (e.g. gymnastics, handball, snowboard), landings have been shown to carry a great risk of injury to the lower extremities, because of the high impact forces [22], and Furness et al. (2015), have suggested the aerial landing to be a hazardous task also in surfing [23]. Although the mechanisms for these injuries have yet to be identified through extensive observation in the sport of surfing, previous studies on other sports have reported movements involving excessive lower body joint angles such as hyperflexion, hyperextension, joint rotations, knee varus or knee valgus in combination with high loads to be mechanisms of landing injury [24-29].

Furthermore, other board sports have competitive divisions with performance measures based on the style and difficulty of acrobatic movements. In half-pipe snowboarding, two key performance variables of the aerial movement that have been identified are air-time and degree of rotation [30]. Moreover, aerial tasks occur in gymnastics, freestyle skiing and trampoline, with the presence of rotations, or keeping a constant position in the air. For these acrobatic sports (trampoline, freestyle skiing and tumbling), studies have described the air movement as i) initiation of rotation ii) letting rotation go and iii) organizing landing [31]. Using control of the body's angular momentum throughout the movement and adjusting it by rearranging body position in relation to the axis of rotation, somersaults and spins can be performed in a three-dimensional pattern [32]. These actions are performed in interaction with the environment and situation and can be adjusted throughout the movement task [31, 33].

2.1.8 FLOATERS

Floater manoeuvres are often used to effectively move the board over a section of breaking wave, and is essentially a climb up on top of the lip of the wave to traverse the section horizontally and then dropping down just in front of the breaking point to continue the wave ride [16]. Just like the aerial, the floater manoeuvre ends with a landing task after which the athlete has to transition into a next

manoeuvre. Therefore, demands on a quick stabilisation onto the board is a crucial performance parameter for successful performance of this manoeuvre [10].

2.1.9 PHYSIOLOGICAL DEMANDS OF SURFING

Wave riding accounts for most of the acute biomechanical stress on the surfer, and possible risks of injury [18, 23, 34]. Therefore, performance of surfing manoeuvres requires strength, stability, mobility, coordination and power in the lower extremities [10, 11, 21, 35]. However, despite the scoring outcome of a surfing competition being based solely on the wave riding, several studies have shown that the wave riding only makes up about 5-10% of the total time surfing waves [36-38]. Therefore researchers have studied the demands of other aspects of surfing that provide the capability for the surfer to catch the best waves [36-38]. Performance analysis has provided knowledge about activities during surfing and researchers have related physiological characteristics to these activities (Figure 2.7) [37]. For example, surfing athletes need the ability to paddle intermittently around 1,600 m during a competitive heat of 20 minutes, implying that a high level of aerobic capacity is required for maximal performance [37]. Furthermore, the short paddling burst in order to catch a wave seem to require paddle specific strength and power in the upper body [39], and the pop-up action and duck diving underneath waves may require push power in the upper body [40]. Performance aspects of surfing may therefore be complex due to the many tasks that are involved.

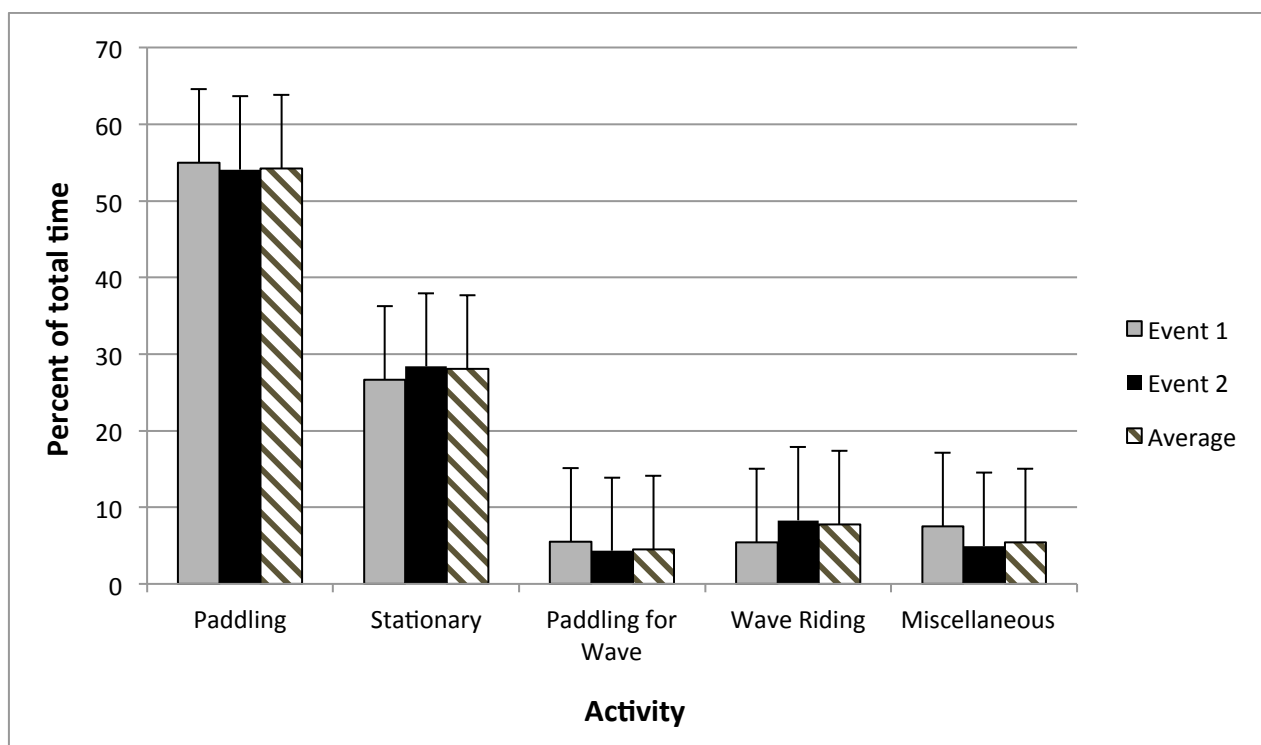


Figure 2.6. Time spent on different activities during two competitive surfing events (data reproduced from Farley, Harris et al. 2012).

In order to withstand the high paddling volume in competition, surfing athletes expose themselves to high volumes of surfing [41, 42]. Unpublished data (training data from Surfing Australia High Performance Centre) suggests that surfing athletes surf on average about 12 hours per week, and sometimes more than two hours per session. It is known that paddling performance and lower body power output declines after a two hour surfing session, thereby lowering the surfing performance capability [38]. Furthermore, a fatigue effect can potentially expose the athlete to injury risk [43], thus suggesting that sessions should be kept to shorter periods of time to maintain physical ability throughout training. Furthermore, with the competitive heats being 20-40 minutes, a more competitive like training environment could be achieved with shorter sessions (20-60 minutes).

2.1.10 PHYSICAL CHARACTERISTICS OF DIFFERENT LEVELS OF SURFERS

Researchers have observed athlete performance in a number of assessments to find out whether high-level athletes demonstrate greater performance than lower level athletes [44-46], which may

help determine which physical qualities are specifically relevant for the sport. A comparative study of lower body qualities between junior surfing athletes at the elite level and the sub-elite level found significant differences in strength and power variables, reporting the higher level juniors to be stronger relative to their body weight and able to jump higher than the lower level junior athletes [47]. This evidence supports the assumption that surfing athletes may benefit from increased lower body strength and power in their surfing performance.

Further, a study suggested that general postural control may be important for surfing athletes to stabilise themselves on the board [10]. However, other researchers have argued that the board cannot be deemed a totally unstable surface at the time the surfer is on the wave, since it planes with speed on the water and becomes more stable [21]. Therefore, it may be questionable how effective a static postural assessment would be compared to a dynamic stability test specifically designed to target this group of athletes. Studies on static postural control among surfing athletes have shown that expert surfing athletes do not possess superior ability on generic static postural control measures compared to recreational athletes, however may have a high level of performance at simultaneous cognitive tasks [48, 49]. However, a study observing dynamic postural control found a difference between levels of surfing athletes when instability was produced in the antero-posterior direction, and even more so when they had their eyes closed. Nevertheless, this study did not show any difference between groups of surfers when the instability was absent or in the mediolateral direction [49]. The study concluded that high level surfing athletes had superior postural ability when vision was reduced and therefore suggested that they rely more on proprioception for postural control compared to their recreational counterparts [49]. However, this was not confirmed by Bruton et al. (2013), who compared the proprioceptive acuity of recreational and competitive surfing athletes [11]. Due to these contradictory results, we developed and evaluated a dynamic sensorimotor assessment for surfing athletes, the 'drop and stick test' [21]. The results showed that elite surfing athletes have a superior ability to quickly and efficiently restabilise themselves after a vertical drop, compared to younger and lower level athletes. However the study did not show any difference in landing peak force between the elite group and the junior group of surfers. A further observational analysis of surfing manoeuvres [10],

explained wave riding as a repeated change of direction task, hence it may be valid to stress the importance for surfing athletes to be able to quickly restabilise themselves from perturbations. Essentially, we can observe surfing (whilst riding the wave) as a dynamic bilateral task, which may suggest that dynamic assessments are preferable to capture the qualities distinguishing the very elite from lower level surfing athletes.

In regards to upper body physical qualities, such as pull-up strength and paddling performance, studies have shown that these can characterise levels of surfing athletes. A study comparing elite junior athletes with sub-elite junior athletes showed greater capacity of the elite group on all paddling variables [35], suggesting that higher sprint and endurance paddle velocities are important for overall success in surfing. The previously mentioned strong relationship between sprint paddle time and upper body pull strength [39] may further suggest that upper body pull strength is a physical attribute beneficial for sprint paddling, hence surfing performance. However, in regards to endurance paddling, the results have been somewhat contradictory, in particular when surfing athletes have been tested on their VO_{2max} using swim ergometers [50-52]. Therefore, ergometer VO_{2max} may not be as effective as a discriminator of surfing level as are sprint paddling, endurance paddling in a pool, pull-up strength and lactate accumulation at a given work load. However, whether these variables actually have a direct relationship to competitive performance remains to be established.

2.2 COMPETITIVE SURFING INJURIES

As in any other sports, injuries occur also in surfing. The fundamental perspective of this thesis is that injured athletes cannot perform or train at their maximum potential, hence injury prevention efforts are essential to performance. Below is a summary of the research that has been published on surfing injuries.

The one prospective study of injuries sustained during surfing competitions showed that sprains and strains are the most common types (39%), and that the most common location of injuries are the lower extremities, representing 39% of all injuries and 44% of the sprains and strains [18]. Studies observing recreational surfers report more lacerations and cuts [53].

A literature search for studies reporting data on lower extremity surfing injuries identified 13 publications, which are summarised in Table 2.1. Some are referring to competitive surfers, other to recreational surfers and some included mixed surfing populations. The overall injury rates among competitive surfing athletes have been reported as between 1.1 and 6.6 injuries per 1000 hours of participation [18, 23, 54, 55], where the higher incidence was observed prospectively during competitive heats [18], and the lower reported from retrospective studies [41, 54].

In the early stages of injury research, it is useful to perform retrospective research, in order to gather information from large numbers of participants [56, 57]. However, to achieve more detailed information about the athletes and the injury situations, a prospective approach is more appropriate to reduce recall bias [58]. For example, retrospective questionnaires may say little about the actual prevalence and injury mechanisms, unless records have been kept and video recordings exist. The main reason for this retrospective bias is that athletes may forget injuries and details of the circumstances in a longer period of time [58, 59]. A prospective approach may instead enable all injuries to be documented as they occur, and baseline measures can therefore be related to the outcome of an injury. This information can contribute to identification of plausible risk factors, in addition to the injury incidence data [60]. Ideally the injured athletes should be assessed by a medical professional to determine the exact diagnose of injury, however, given the spread of athletes across a large geographic area, this is not always possible [61]. An alternative solution could be to employ a self-reporting tool for athletes to log information about the injury soon after the event [61].

Previous studies have attempted to report information on the mechanisms of surfing injuries, such as what task was performed at the time of injury and the object, if any, causing the injury [18, 23, 41]. However, the details of the situations were not reported (Table 2.1). In relation to the definition of the term ‘injury mechanism’ adopted for this thesis, i.e., ‘*the fundamental physical process responsible for the injury, i.e. inciting event*’ [2], a lack of information that elaborates on surfing injury situations and especially the mechanisms of lower extremity injury, remains. Only one study was found that included details about injury mechanism in combination with outcome, body region and diagnosis; a case study describing the development of a bony spur following a long term landing injury in surfing

[62]. In other sports, specific injuries have been attributed to certain mechanisms, such as a particular movement, external load or perturbation [24-29]. The sport of surfing would likely benefit from such knowledge, although it may be a difficult task to obtain high quality observations of true injury situations due to the dynamic environment of the sport.

Table 2.1. Summary of previous studies of surfing injuries, relating to musculoskeletal injuries (sprains, strains and fractures) in the lower extremities

Author/Year	Type of study	N injuries/N participants	Injury rate	Type surfer	% Ankle*	% Knee*	% LE Fract/ Sprain/ Strain*	% Manoeuvre	Cause
Base, 2007	R	112/36p	0.76/1000 days	Recreational	n/a	n/a	80% /35% of all	41%	Impact with surfboard, manoeuvres, seabed
Brooks, 2009	Case	1/1p	n/a	Recreational	100%	0%	100%		Landing (initial injury)
Furness, et al., 2014	R	477/1348p	n/a	Mixed	6%	16%	n/a	22%	Turning manoeuvres, aerials, certain stances, prolonged sitting on the board, trauma from the wave, duck diving, take-off
Furness, et al., 2015	R	512/1348p	1.53/1000h	Competitive	15%	14%	30%	58%/37% of all	Turning manoeuvres, aerials, floaters, direct trauma/contact with board, others' board, seafloor, sea surface, take-off, duck diving
Hay, et al., 2009	ED	212/212p	n/a	Recreational	17% LE	17% LE	9%	n/a	n/a
Lowdon, et al., 1983	R	318/346p	1.3/1000h	n/a	12%	10%	12% of all	34%/15% of all	Manoeuvres, contact with own board, others' boards, rocks
Lowdon, et al., 1987	R	187inj/86	1.1/1000h	Competitive	10%	28%	43%/33% of all	37%/16% of all	Manoeuvres, contact with own or others' board, rocks
Meir, et al., 2012	R	389/685p	3.5/1000h	Mixed	15%	16%	42%	n/a	n/a
Nathanson, et al., 2007	P	116/15675 heats	6.6/1000h	Competitive	19% LE	19% LE	36%/19% of all	61%	Impact with board, ocean floor, body motion, wave force.
Nathanson, et al., 2002	R	1237/1348p	n/a	Mixed	35%	30%	40%/8% of all	62%	Impact with board, manoeuvres, ocean floor
Roger and Lloyd, 2006	ED	303	n/a	Mixed	n/a	n/a	n/a	n/a	Past injury other boards
Steinman, et al., 2000	R	927/930p	n/a	Mixed	17% of ligaments	52% of ligaments	52%/11% of all	64%	Manoeuvres, impact with board
Taylor, et al., 2004	R	168/646p	1.1/1000h	Mixed	16%	25%	54%/25% of all	n/a	Contact with own or others' board, wiping out, striking seabed

Abbreviations: n/a: data not available, P: prospective, R: retrospective, ED: Emergency Department, p: participants, LE: lower extremities, fr: fractures, sp: sprains, str: strains

*Percent of sprains/strains/fractures if information provided. Otherwise given as percentage 'of all'.

Factors that have been found to influence injury risk in surfing are wave size [18], type of ocean floor (rocks and reef increase injury risk), level of surfing (advanced surfers are at more risk) [23, 54, 63], past injury [53] and total surfing hours [54]. These risk factors are similar in nature to those described for lower extremity injury sports such as soccer, basketball and [64], as well as for snowboard [65]. The most common causes of lower extremity injuries are manoeuvres (Table 2.1). Although not specified in all of the studies, collectively they establish that tube rides, floaters, pumps and aerials are the manoeuvres contributing to most of the lower extremity injuries [18, 66, 67], likely due to the closed kinetic chain movements occurring during these tasks. More research on which athletes incur these injuries and characteristics of these situations is needed to provide a comprehensive understanding of injury events.

2.2.1 HIP INJURIES AND BIOMECHANICS

Among competitive surfing athletes, approximately 9% of acute injuries are located around the hip joint [23]. Although studies on surfing injuries to date have not specified the injury mechanisms or diagnosis, research on other sports involving dynamic bilateral tasks have directed more attention towards these issues. One chronic condition that can arise, either due to repeated impacts in hip flexion and internal rotation is the cam-type femoral-acetabular impingement (FAI), which is an impingement of the femoral head and can create tears in the labrum [68]. In other instances subluxation or even posterior dislocation of the acetabulum can occur. Sometimes this issue arises due to a high impact scenario such as a fall or tackle with the hip in flexion and adduction, and other times due to low energy repetitive loading [69]. Due to the nature of surfing, with repeated landings and falls, this may be a condition to consider for these athletes. Furthermore, the muscles around the hip joint are susceptible to injury during athletic activities, due to the wide range of motion that often occurs. Especially exposed are the rectus femoris and proximal part of the hamstring muscles because of their important function during loaded tasks such as running, kicking, jumping and landing [68].

The hip joint is a mobile, but stable joint, designed to allow for movement in three dimensions. Mechanically, the mobility of the hip is due to a ball and socket joint, with very low intra-articular friction. Strong ligaments and muscles surround the joint to keep the two joint surfaces in contact with each other, and the main movement functions are achieved due to the multi-directional muscle fibres relative to the joint [70]. As the femoral head sits deep in the pelvic acetabulum, and is surrounded by the acetabular labrum, the range of motion is restricted to around 130° of flexion-extension, 70° of adduction-abduction and 65° of internal-external rotation, with individual variation [71]. When the hip joint is weight bearing, tension is created in the iliofemoral, pubofemoral and ischiofemoral ligaments to provide more stability, because of their rotated position around the joint [70]. In surfing the hip joint function may be particularly important during manoeuvre performance, as this is a lower body closed kinetic chain movement. Although the muscular actions around the hip joint is position specific, the agonist muscles working across the hip joint are: the iliopsoas and rectus femoris (flexion), gluteus maximus (extension/abduction/external rotation), hamstrings (extension), gluteus medius and minimus (abduction/internal rotation), adductors (adduction/internal rotation) and piriformis (external rotation) [70].

2.2.2 KNEE INJURIES AND BIOMECHANICS

Excessive movements and forces in the knee joint during load may result in injury. About 14-19% of competitive surfing injuries have been reported to be knee injuries (Table 2.1), and most of these are sprains [18, 23]. The specific types of knee injuries from surfing have not yet been reported, however a commonly injured knee ligament in sport is the anterior cruciate ligament (ACL) [72]. At the time of anterior cruciate ligament injury, the knee joint rotation has been observed past 25° of external rotation and 20° abduction [73]. Athletes who injured their ACL were observed to have approximately 8° more knee abduction on average during landings than healthy controls [73, 74]. Furthermore, research has shown that females at risk of ACL injury often display an increased ground reaction force and knee joint moment during landing

tasks, compared to non-injured female athletes [74]. Posterior collateral ligament (PCL) injuries have been observed in sports such as kitesurfing, wakeboarding and Australian football league injuries, although less frequently than ACL injuries [75-77]. The lower frequency of PCL injuries may be due to its different anatomical function and stronger tissue, as it is mainly resisting a posterior shift of the tibia relative to the femur, as well as assisting during hyperextension and varus/valgus stress. These injuries occurs most often in high energy trauma or by a direct force posteriorly shifting the tibia [78].

Another structure at risk of injury in sport is the medial collateral ligament (MCL), which is typically injured by an external force to the lateral aspect of the knee in a flexed position, or as the result of axially loaded knee abduction [79]. MCL injuries heal relatively well, which minimizes the time of return to sport [80]. The meniscus can be damaged either in combination with an ACL or MCL injury, or isolation. The meniscus is located in between the joint surfaces of femur and tibia, acting as a shock absorber [70]. Mechanisms for meniscus injuries can be a translation movement between femur and tibia that creates a wedge of the meniscus and tear if a simultaneous contraction occur [81]. Other acute knee injuries that can occur as a result of agile sporting activities are, for example, osteochondral bruising or fracture, lateral collateral ligament (LCL) and patellar subluxation [82].

The knee joint is designed to function as a shock absorber in closed kinetic chain movements with high impacts, although some movements occur in an open chain. Normal knee joint range of motion has been reported to be approximately 145° in flexion-extension, reaching from 0° of flexion to 145°, and the joint allows for very limited rotational and translational movements [71]. To keep the joint movement mainly in the sagittal plane, there are several muscular and ligamentous tissues that surround the knee joint to allow flexion-extension movement and maintain stability. Medially located is the MCL, that restricts knee abduction when the knee joint reaches 20° or more flexion [79]. The LCL stabilises the adduction movements of the knee joint together with the popliteal ligaments [79]. Additionally, the ACL

and PCL are located in the center of the knee joint, in a cross figure to each other, hence acting as stabilizers in rotation and anterior/posterior translation of the tibia relative femur [83]. Muscles contribute to the stabilizing function, but also acts as prime movers of the knee joint. The four quadriceps-muscles that act as main extensor muscles of the knee joint are working in conjunction with the hamstrings muscles to control the movement of tibia in relation to femur. Other muscles that work across the joint are sartorius, gracilis, gastrocnemius, and tensor fasciae latae [70].

2.2.3 ANKLE INJURIES AND BIOMECHANICS

Fractures and ligament sprains are the most common injuries in the foot and ankle region, and with ankle ligament sprain injury being the single most common sports injury [84]. Among competitive surfing athletes, around 15% of injuries seem to be ankle injuries, and most of these sprains and fractures [23]. Ligamentous damage may occur acutely in the foot or ankle in situations when the joint movement is forced outside of its range of motion. Typically, isolated ankle sprains are most commonly seen in the lateral compartment [85], which usually occur during supination movements and typically affects the anterior talo fibular ligament (ATFL) [86]. Ligaments of the medial ankle compartment (the deltoid ligament) are damaged during a variety of foot movements such as pronation-abduction, pronation external rotation and supination external rotation. Deltoid ligament injuries are usually seen alongside other ankle fractures [87]. Syndesmosis sprains (or 'high ankle sprains') of the distal tibiofibular joint may occur during axial loading of the ankle in foot eversion, dorsiflexion and forced external rotation. Like medial ankle sprains, high ankle sprains rarely occur in isolation. They are often seen alongside other medial sprains and/or in combination with fractures to the malleoli [87].

Fractures in the foot and ankle can occur during high load situations or repetitive loading. With common sites being the malleolus (especially the lateral), calcaneus, navicular and the metatarsals [88, 89]. A typical fracture among snowboard athletes is the lateral process of the talus, which have been shown to occur due to axial loading with the ankle in dorsiflexion,

inversion and external rotation [90]. Among competitive surfing injuries, fractures have been reported to constitute 24% of ankle injuries [23], however no previous research publication on surfing injuries have specified the type of fractures that occur. Although this type of injury is less common than the sprain, it typically requires immobilization for 6 weeks [88], which is a considerable time for a competitive athlete to be unable to fully practice their sport.

The foot and ankle joint complex comprises of seven bones as well as tibia, fibula and the metatarsals. These are shaped into a three-dimensional puzzle to allow for high load bearing and specific movements [70]. Tibia, fibula and talus bones form a hinge type joint, the talocrural joint, which mainly allows for dorsiflexion and plantar flexion and limited rotation and inversion/eversion movements. Because of talus placement in the joint, it forms a wedge between the medial and lateral malleolus (Figure 2.8). Thus, a forceful rotation of the talus could potentially create a fracture of one of the malleoli, or tear the syndesmosis ligaments holding the two long bones together. Although the majority of the talocrural movement occur in the sagittal plane, the axis of rotation is oblique through the medial and lateral malleoli, thereby involving some movement also in the transverse and frontal planes [91]. The range of movement reported in dorsiflexion ranges from 13-33°, and for plantar flexion between 23-56° [71, 92].

There are three ligaments around the talocrural joint to provide stability in the mediolateral direction; the medially located deltoid ligament, and laterally the posterior and anterior talo-fibular ligaments. In combination, these ligaments restricts excessive movements of abduction of talus, plantar flexion, dorsiflexion, as well as internal and external rotation of talus [93].

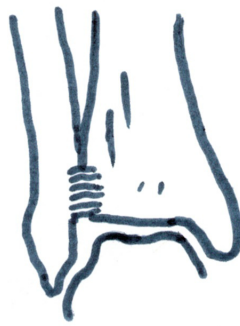


Figure 2.7. Schematic figure of the left ankle joint from a posterior view. The shape of talus creates a wedge in between the medial and lateral malleolus, which upon rotation may cause a separating force of the tibia and fibula.

Inferior to talus, reaching posterior is the calcaneus, which has an important function in weight bearing, and is the attachment of the triceps surae muscles via the Achilles tendon. Triceps surae and the Achilles tendon can withstand forces up to 17 times body weight in eccentric contraction during dorsiflexion, which makes this complex important in landing tasks [94].

The subtalar joint allows for supination and pronation movements [95]. The joint axis of rotation for this movement is an oblique infero-postero-lateral to supero-antero-medial direction (Figure 2.9) [96]. The function of this movement is to transfer internal and external rotation of the lower leg to a subtalar joint movement to take up weight bearing loads [92, 97]. Studies have reported the anatomy of this joint complex vary among individuals [92], and a laterally shifted joint axis has been suggested as an explanation for increased risk of lateral ankle sprain. This is because of increased supination moment a greater distance between the medially located centre of pressure (COP) incur [98, 99]. Similarly, excessive pronation movement during loading has implications for the biomechanics of lower body movement by increasing the amount of tibial internal rotation and thereby the stress on the knee and hip joint [100]. Furthermore, this movement pattern may predispose athletes to injuries on the medial side of the lower extremities [100, 101].

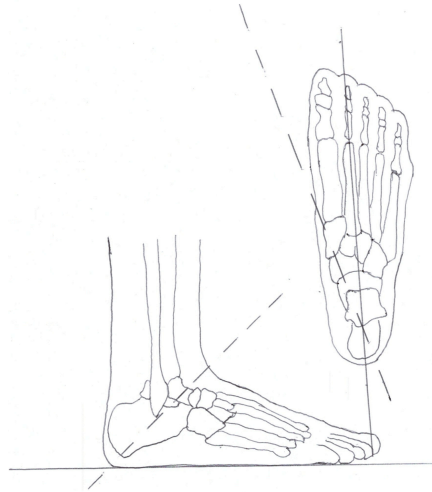


Figure 2.9. Rotation axes (---) of the subtalar joint movements supination/pronation in the sagittal and horizontal planes.

Although there are several other joints in the foot that contribute to small amounts of ankle movement, those aforementioned joints are where the majority of ankle movement occurs. Nevertheless, the arch of the foot is another important load bearing mechanism that effectively reduces the amount of force being transmitted proximally during impacts. The spring like deformation of the arch during weight bearing is mostly stabilised by the plantar fascia, together with the plantar and spring ligaments as well as the tibialis posterior and flexor muscles [94]. As the foot undergoes mechanical loading the tissues stretch under load and the arch decreases [102, 103]. The actual strain of the plantar fascia during 0-700 N axial loading has been reported to increase linearly to ~2% [103], and strain up to 12% has been observed during walking [104].

2.3 LANDING MOVEMENT

2.3.1 *LANDING TASKS*

Landing movements occur in many sports besides surfing and are essentially a deceleration of the body accomplished mainly by the lower extremity muscles. The landing task can be

performed either as a land-and-go task, as occurs in a take-off in long jump, or a land-and-stop task, which is performed in gymnastics for example. Although the landing task may seem simple, it is a complex skill that requires practice. The simplest form of landing is the bilateral stick landing, which can be performed after a jump or as a drop down from a box. This task is relevant for sports such as surfing, since several manoeuvres finish with an airborne phase then a stick phase, where the athlete has to stabilise themselves on the board [10, 21]. The drop and stick task has been widely researched, and vertical ground reaction forces have been reported between 2-10 times the body weight of the athlete [105, 106].

When landing on a surfboard, the stance width should be wider than hip wide, hence the area of support is increased compared to most sports where the athlete is landing directly on the ground [14]. This will assist the surfing athlete in keeping the COM within the area of support. However, the athlete is landing barefoot on a board with nine degrees of freedom of motion, and the board, fins and water surface determine the mechanical boundaries of the surface movement. Therefore, the surfing athlete may face external perturbations during the landing movement, which are unpredictable and variable over time. Although the biomechanical implications of these factors have not been reported in previous research, some landing variables have been assessed in other board sports. Ground reaction forces measured during snowboarding landings have been reported as between 3.7-4.8 times body weight, and similar for skateboard athletes (4.5-5.0 times body weight) landing after an ollie of 0.5 m. Higher loads (8.0 times body weight) were reported among skateboard athletes landing from a steep rail descent [3, 107, 108].

Although landing tasks in surfing are typically performed sideways, as other board sports, it is likely relevant to also compare them to landings as performed in gymnastics, and other bilateral land and stop tasks. For example, landing tasks in gymnastics have been reported to reach compression forces at the L5/S1 joint up to 30 times body weight and estimated even higher when preceded by a rotation [109]. The compression force can be reduced significantly if

the athlete uses efficient motor patterns in the lower extremity and trunk and lands on a soft surface [109]. Details around these aspects are discussed in the following sections.

2.3.2 LANDING TECHNIQUE

The landing movement will generally be performed by eccentrically decelerating the body with hip, knee and ankle flexion, although different landing strategies can be applied depending on the purpose of the task, the environment, visual conditions and anatomical alignment. The efficiency of the landing can be explained as the amount of energy being actively absorbed by muscle and tendon structures, as compared to dissipating through passive bone and ligament structures [110]. This has been exemplified in studies observing changes of landing kinematics during fatigue, where athletes adopt an altered movement pattern [111, 112]. As an example, the changes of neuromuscular fatigue can manifest itself in a single leg landing as an increase in hip flexion and hip internal rotation at initial contact (IC), and increases in peak knee abduction, knee internal rotation and ankle supination [111]. Furthermore, the vertical ground reaction force increases with less biomechanical efficiency in the landing, which can be assessed using a force plate, as the example illustrated in figure 2.10 [112].

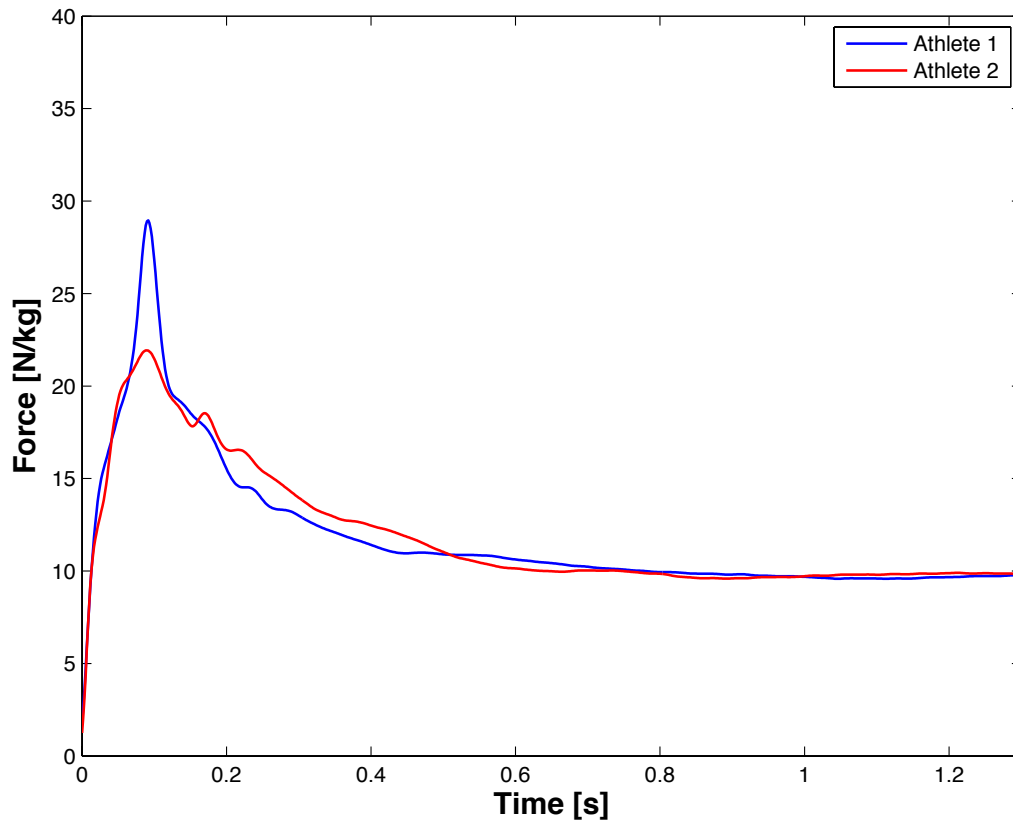


Figure 2.8. Vertical ground reaction force of two athletes landing a drop off a 0.5 m box.

The ideal landing movement from an injury prevention perspective has been identified as a symmetrical bilateral movement, with joint alignment allowing the large muscles around the hip, knee and ankle joint to work optimally and through a large range of motion [113]. However, in sports performance it is rarely possible to exactly follow a standard protocol, because the preceding jump usually involves another primary task, such as hitting a ball, or performing a rotation or manoeuvre in the air. Therefore, the athlete will have to adapt the landing movement to suit the situation, whilst maintaining sufficient safety to successfully perform the task and avoid injury upon impact. This adaptation might sometimes involve landing unilaterally, with horizontal or rotational momentum, or with the upper body displaced laterally. Such adaptations change the biomechanics of the task, hence, elite surfing athletes should be competent in complex landings, both with and without external perturbations.

Studies have shown that there is a pre-activation prior to touchdown of the peroneus longus, gastrocnemius, vastus lateralis, biceps femoris and gluteus maximus muscles [114-117]. Immediately after touchdown the vastus muscles reach their peak activation and later (about 0.05 s) the tibialis anterior and other muscles of the lower leg also do so [112, 114, 115, 118, 119]. Activation of the hamstrings may serve as joint stabilization of the knee joint during an extension moment around the knee, and assist the gluteal muscles in creating an extension moment around the hip [22]. In addition, research has shown that failed landing trials (loss of control) are characterized by delayed onsets of the lower extremity muscle activation prior to the landing, which may also be a risk factor for lower extremity injury [110, 120].

Lower extremity joint positions at IC of a vertical jump have been observed among elite volleyball athletes to be approximately 25-35° of ankle plantar flexion, 25-35° of knee flexion, and 25-35° of hip flexion. These angles may be considered desirable to allow for sufficient range of motion and muscular efficiency [121]. During landing, the hips, knees and ankles undergo flexion controlled by eccentric contraction of the extensors [70]. Furthermore, the muscles around the hip have an important role to guide the movement of the femur during the landing movement, in order to avoid hip adduction and internal rotation, which increase the risk of knee valgus [122, 123]. In the typical bilateral landing situation most of the knee movement occurs in the sagittal plane, however, there are some translational and rotational movements also in the frontal and transversal planes. In healthy subjects, these translations have a range of approximately 1-5 mm during the landing movement [118, 124]. The rotation of tibia in relation to femur has been reported to vary between 5-15° during landings, and the range of varus/valgus movement is normally 5-15° in healthy subjects [118, 124, 125].

The foot and ankle joint has an important function in the shock absorption, and this task requires dorsiflexion range of motion in order to allow the centre of mass to decelerate over a longer distance, without shifting the centre of gravity posterior [126]. Increased vertical displacement will allow decreased ground reaction force and more stability after the landing,

because of the lower centre of mass [126]. In addition, research has shown that tight gastrocnemius muscles can influence hip and knee joint movement during landing, by increasing the amount of hip flexion and adduction in the stance phase [127, 128]. As described above, hip adduction in a loaded situation causes implications for the knee and foot position and can lead to excessive pronation of the foot [129]. Although debate continues in the scientific literature concerning whether pronation itself is an injury risk for sport participation [129], there is evidence to suggest a relationship between excessive pronation and knee injury [130, 131]. Therefore, it may be suggested that athletes who incorporate landing tasks in their sport, such as surfing athletes, have a well-maintained ankle dorsiflexion range of motion, as well as joint function.

When the landing is preceded by a rotation, adaptations are seen in the landing strategies of gymnasts because of the limited time to prepare for contact [22, 119]. Insufficient time to extend the legs prior to foot contact may result in increased joint flexion and requirements for the lower extremity muscles to generate torque at different muscle length [119]. Furthermore, increased flexion at IC of the landing limits the remaining range of motion for the lower extremity joints to move through and thereby limits the amount of force that can be attenuated by the musculature [132]. In addition, an almost extended knee joint at IC has been associated with ACL injury, especially when occurring in combination with a valgus movement [133]. It may seem that every deviation from the biomechanically effective landing pattern as described above could impose increased injury risk for the athlete. However, injury occurs very rarely even during imperfect landings, and is usually coincided with an external perturbation [134]. Nevertheless, the lower body movement pattern and ability to restabilise from a perturbation has an effect on the performance of both simple and complex landings [135, 136], although its impact is not yet established for surfing athletes.

Upper body position and movement in landing tasks will influence the total and individual joint loads. For example, excessive trunk flexion movement during landing has been shown to

reduce the peak landing force, as compared to a self-selected flexion movement during landing [137], but it has also been shown to be a compensation for ACL deficient athletes [138]. Because such movement will increase the hip joint flexion, it would allow the strong hip extensor muscles to provide more torque. However, one must also consider the task performance, and in a sport such as surfing excessive trunk flexion movement may anteriorly displace the centre of mass to impair balance, hinder forward sight, and thereby impede a fast transition to the next manoeuvre. Furthermore, athletes may accidentally land with trunk flexion outside their active range of motion. In a study on gymnasts, this movement has been suggested as cause of increased ground reaction force during landing tasks [139]. Nevertheless, the pre-landing trunk position and muscle activation evidently has great impact on the subsequent landing task. For example, one study has shown that more skilled athletes pre-activate the erector spine muscles just before landing, in order to add stability to the lumbar joints [109]. Based on these findings, it may be beneficial for the athlete to have an effective trunk muscle function, although higher level of muscle activation also increases the spinal compression.

2.3.3 LANDING SURFACES

Besides landing technique, several other factors influence the load on the athlete in a landing task, such as falling height, landing surface and shoe properties [105, 140]. An increase in falling height will increase the whole body velocity at touch down, hence the total impulse that needs to be attenuated. Therefore, it is likely that increased falling height leads to higher ground reaction forces, as has been shown by several studies [110, 141]. It has also been reported that that increasing falling height increases lower extremity muscle activation, but does not influence the kinematics of the tibiotalar and talonavicular joints, only the amount of eversion at the calcaneocuboid joint [115].

The effect of the falling height can be manipulated by changing the landing surface, which will influence ground reaction force by dissipating more or less energy itself [22]. A softer landing surface for example, assists the athlete in the absorption of energy, hence there is less

impulse for the internal structures of the athlete to absorb [142-144]. Furthermore, the morphology of the surface will alter the loading pattern on the athlete. For example a surface with a lateral elevation has been shown to increase the mediolateral ground reaction force as well as the amount of valgus movement during drop landings [140, 145]. Differences in lower limb muscle activation patterns, as well as forefoot kinematic differences with medial and lateral elevations, were also observed both pre and post IC [145]. For example, the peroneus longus muscle showed less activation when landing on a lateral elevated surface [145], indicating that the motor control patterns adapt to the new condition and makes pre-landing adjustments. Therefore, the ability of a surfing athlete to predict and quickly adapt to changing landing conditions may be of great relevance, both for performance aspects and injury prevention. In addition, the excessive shear forces and valgus movements that may occur while landing on uneven surfaces have been suggested to be risk factors for lower extremity injury during landing [74, 146]. However, one may also propose that athletes who are competent in landings and able to adjust to these conditions may be less prone to these types of injuries. This reasoning was also suggested as a result of a study showing that high stiffness variability of indoor dancing surfaces incurred more injuries than both stiffer and softer surfaces with more consistency [147].

2.4 ANALYSIS OF INJURY RISK, ATHLETE AND SPORTS PERFORMANCE

Methodologies to analyse sports injuries and injury risks are limited and require availability of information about the situations and circumstances in which injuries occur. This information can be difficult to find, however crucial from a holistic sporting performance perspective [2]. General models show how intrinsic and extrinsic factors influence injury outcome for an individual (Figure 2.11) [2, 60]. Every sporting situation is unique in its requirements and what combinations of intrinsic factors contribute to more or less injury risk, suggesting the need for a detailed analysis. The individual with a particular combination of intrinsic measures (risk factors) may be classified as a person predisposed to injury. However, injury will not occur until the athlete is also exposed to external risk factors and an inciting event (mechanism of injury) [2, 60]. Injury mechanisms have been exemplified as contact or impact, dynamic overload,

overuse, structural vulnerability, flexibility, muscle imbalance and rapid growth [2, 148]. The knowledge about risk factors and mechanisms in a specific sport can then be applied so that athletes who are identified with increased risk may undergo a targeted intervention.

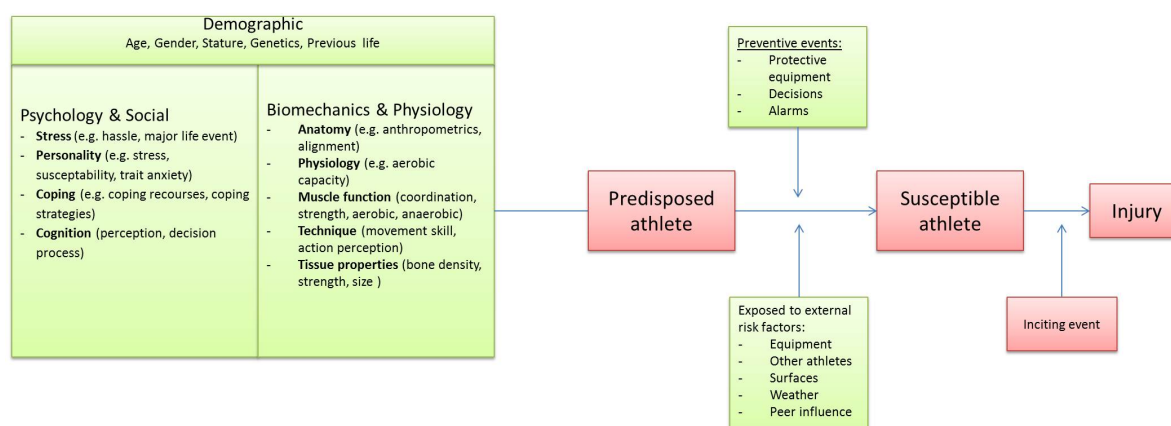


Figure 2.9. Model of internal and external factors influencing injury risk. Modified from Bahr & Crosshaug, 2005.

When describing an injury situation and the inciting event for analysis it is essential to use the information available including a) the sporting situation, b) the action and interaction with external factors, c) the whole body biomechanics for the situation, and d) the detailed biomechanical situation (joint/tissue biomechanics) [2]. Thus far, these models have mainly been used to analyse injuries retrospectively, whereas the long-term goal should be to adopt the models for preventive purposes.

Procedures to conduct research for injury prevention were outlined in the model: Translating Research into Injury Prevention Practice (TRIPP), which has added two steps to the earlier four stage approach proposed by van Mechelen, 1992 (Figure 2.12) [56, 57]. Besides the first four stages of van Mechelens model, this model emphasizes the need to implement the research into the sporting context and get approval from a full spectrum of people, from the sporting community to the athletes [57].

TRIPP-model of injury prevention research design

- Injury surveillance
- Establish aetiology and mechanisms of injury
- Develop preventive measures
- “Ideal conditions”/scientific evaluation
- Describe intervention context to inform implantation strategies.
- Evaluate effectiveness of preventive measures in implementation context

Figure 2.10. The TRIPP-model describes the procedure to conduct injury research [57].

A similar, but more detailed model is Applied Research Model for the Sport Sciences (ARMSS), originally developed for performance research in sport. It includes the use of predictors for sport performance [6]. This approach would be suitable to integrate into the TRIPP-model, before an intervention is implemented, in order to identify elements that may be indicative of injury risk (Figure 2.13).

	Stage
Describe	1 Defining the problem
	2 Descriptive research (hypothesis development)
	3 Predictors of performance (injury risk)
Experimental	4 Experimental testing of predictors
	5 Determination of key performance (injury risk) predictors
	6 Efficacy studies (laboratory or in field)
Implementation	7 Barriers to uptake
	8 Implementation studies in the real sport setting

Figure 2.11. The ARMSS model described by Bishop, 2008. The proposed study will start in an implemented sport setting and move through stage 1-5.

There are a number of ways proposed to prevent injuries and many prevention strategies for high-risk sports involve education and use of protective equipment [18, 149]. Protective equipment can protect from traumas due to violent physical contact with equipment,

environment or other external factors. However, other preventive strategies can be used to help the athlete avoid or to better cope with hazardous situations, such as improvement of specific skills or physical capacities [150]. A comprehensive review article of injury prevention studies by Klügl, et al. (2010), divided the strategies into three main areas of injury prevention: equipment, training and rules and regulations [151], where the training protocols mainly target the intrinsic characteristics. However, before intervening with athletes using a training program, it has to be clear what the risk factors for injury are for a specific task [134, 152].

Intrinsic risk factors are often assessed using quantitative and qualitative methods. A range of data types can be compiled, including demographical characteristics and psychological and physical qualities related to the sport performance. Data can be objectively and subjectively gathered, either sampled from a measurement unit or from the athletes' own perspective. Sports performance analysis can be structured in similar ways, with observations being a common methodology used to describe and analyse different aspects of performance [33]. The relationship between athletes and their sports performance can be described as the interaction between these two factors. As such, the sports performance will determine the characteristics and qualities needed for the athlete to succeed [153].

2.4.1 QUALITATIVE METHODS IN INJURY RESEARCH

Qualitative approaches are useful in describing and mediating information about movements occurring over a period of time. The movement itself may be one factor assessed, however the interaction between the athlete, the task and the environment, the movement production, is the end product [154]. Traditional scientific methods can provide useful qualitative insights, especially observations allowing multiple analyses, such as video analysis, as well as questionnaires, interviews and focus groups [155].

Video analysis has been utilised to gather information about whole-body postures and large-scale movement, and especially to capture incidents in its context without any artefacts attached to the athlete [156, 157]. Furthermore, the ability to rewind and go through the

movement again is helpful both within research, and for the athlete to become aware of his or her actual performance and how to improve [31]. Questionnaires are especially useful to cover a large number of possible, widely dispersed respondents. However, questionnaires have some constraining features. For example, the questions have to be carefully designed in order to be interpreted as intended, and they should be quick to answer [158]. Therefore, it is recommended to use questionnaires in addition to other measurement methods [159]. Interviews and focus groups are established methods in human factors, orthopaedic and physical therapy research, and have benefits especially for capturing a large number of subjective variables among a small sample of a population [155]. Provided the participants are analytical and, if needed, experts in their domain, these tools are useful to gather supplementary data to get another dimension of evidence around a case [155]. Within this project, qualitative data was collected by the means of questionnaires, video, interviews and discussion groups, and used both as main and supplementary material.

2.4.2 QUANTITATIVE METHODS IN INJURY RESEARCH

In the literature, athlete and sports performance are often reported in terms of various quantitative variables, derived either directly from the measurement tool or converted via algorithms to estimated variables. For example, surfboard paddling intensity has been described in terms of velocity, which was derived from measurements of position and time via a global positioning system (GPS) [37]. Because the velocity is defined as the derivative of distance over time, this is a correct estimation provided the raw data is detailed and accurate enough to give a valid estimate of the velocity [160].

Modern technology offers various solutions to capture motion more accurately and quickly than our eyes are capable of doing. The quantitative observation of these variables can be facilitated through numerous technological solutions, and it is up to the researcher or coach to

choose the most suitable one for the situation. Furthermore, the sensor solutions are becoming smaller and portable, thus allowing for assessment outside the laboratory [161]. A list of measurement tools with potential to detect movement variables and that can be used in the analyses of athlete and sport performance are listed in Table 2.2.

Table 2.2. Sensor systems used to capture human motion within the research area of biomechanics of sport performance.

Measurement system	Measures	Applications (examples)
Accelerometer	Acceleration	Change in movement state, such as angular displacement from the vertical, impact. Have been used to measure tibial acceleration in jump landings [135].
Force plate	Force	Measures ground reaction force in three dimensions. Often combined with motion capture systems and has been used to assess ground reaction force while landing jumps [162].
Global Positioning System	Position	Locates position on the surface of earth over time using satellite data. Has been used for time motion analysis in surfing and other sports [37, 38].
Goniometer	Relative orientation	Can assess angular velocity between two segments (if measured over time), or show orientation of segments in relation to each other. Have been shown to be reliable for measuring ROM in hip joint [163]
Gyroscopes	Angular velocity	Often integrated with accelerometers to measure body orientation, angular displacement and angular velocity. Have been used to measure air time and degree of rotation in snowboard [164, 165].
Inclinometer	Gravitational tilt	Used to measure posture and segmental orientation compared to gravity. Shown to be reliable for measuring ROM in hip joints [163].
Linear encoder	Displacement	Records time for a specific linear movement. Have been used to measure sprint paddle time and velocity among surfing athletes [39].
Marker-based Motion Capture	Marker position	Image based system to capture data of marker position over time. Have been used to derive joint kinematics in sports [166].
Measuring tape	Length	Used to measure any distance, such as body height.
Pressure sensors	Pressure distribution	The pressure distributed over an area can be measured to show points of increased loading and determine force. Have been used in a snowboard application to determine phases of the jump and loads acting [107].
Strain gauge	Force	Strain gauges are included in many force measurement applications (force plates, load cells etc.). Has been used to measure harness line force in wind surfing [167].
Timer	Time	Timing races, often combined and added in other systems to display data over time
Video	Images	Visual images over time. Have been used to measure jump height and degree of rotation in snowboarding [168].

Although these measurement tools offer possibilities to do sophisticated analyses either in the field (sports context) or in the laboratory, there are limitations of the utility and data validity in most cases [165]. Usually these limitations are due to the inherent noise associated with all data collection, which effect may be minimized by standardising the measurements as much as needed without loosing validity [169]. In the surfing context, the tools to be used are determined by factors such as availability, relevance for the sport, validity, reliability and sensitivity. To date, surf coaches and sport scientists implement video, timers and GPS in the surfing context [37], however, in the future there may be other applicable tools as the technological advancement and usability of measurement units in marine environments continues. For the reason of limited time in this project, it was decided to not develop any equipment. Therefore, all observations from the field (i.e., while surfing) utilized existing video data, whereas the more experimental parts of this study were performed in land-based settings. The data collection tools used for each section of this study are described more in-depth within each of the following chapters.

At the author's request,
Chapters 3 – 7 have not been included in this version of the thesis.

CHAPTER 8 - DISCUSSION AND CONCLUSION

8.1 OVERALL DISCUSSION

The purpose of this thesis was to investigate landing tasks that may be related to surfing performance and injury risk. It involved studying manoeuvres and landing tasks to establish its relevance for surfing athletes, develop multifactorial assessment protocols, as well as observe mechanisms and factors influencing lower extremity injury risk in high performance surfing.

The series of studies within this thesis showed that lower extremity injury can occur as a result of competitive surfing manoeuvres, and that landing tasks are situations where these injuries commonly occur. Although this has been established previously [18, 23, 54, 55], this thesis contributes with detailed knowledge about the type of surfing injuries, their mechanisms and potential risk factors. The single most common injury type observed in this research (Chapter 5 and 7) was MCL injury, due to knee abduction load during a turn or landing. These injuries were in general of moderate severity, however may cause the athlete to miss important competitions and training. This observation is in line with results from previous studies of sports such as soccer, snowboard and alpine skiing. However, in the present study of surfing athletes, fewer incidents of ACL-injuries were observed [170-172]. The prospective study (Chapter 7) reported only one minor ACL injury, thus suggesting that the mechanisms previously described for ACL ruptures do not appear frequently in surfing at the elite level [25, 173, 174]. The major cause of ACL injury in snowboarding was 'flat landing' [175], which is a scenario corresponding to the one ACL injury described in Chapter 5. The reason for fewer ACL injuries in surfing may be related to the mechanical constraints between the board and the feet being only the frictional and normal force, thus allowing the surfer to fall off at any time prior to the impact, however it could also be an effect of the low numbers of injury. Furthermore, the majority of lower extremity surfing injuries observed in this study (Chapter 5) occurred with a

deep knee flexion angle (close to horizontal thigh position), as opposed to many reported ACL-injuries in other sports [25, 173, 174].

Instead, it seems that high ankle sprain, or syndesmosis injury, can occur as a result of landings with deep knee flexion angle (Chapter 5). Deep knee flexion requires a large amount of ankle dorsiflexion, which in combination with external foot rotation and axial load may lead to separation of tibia and fibula with subsequent injury risk [27, 176]. To prevent this type of injury, it may be of importance for athletes to practice landing technique with focus on improving strength, ankle dorsiflexion flexibility, whole body movement patterns, and sensorimotor abilities, as was suggested in Chapter 7. Although it was not part of this study to observe how these qualities influence athletes in other sports, it may be relevant to briefly discuss further use of the qualities in the proposed model (Chapter 6) in testing protocols and training for other sports involving landing tasks. For example a study of basketball players showed significant improvements in landing quality following a three months training program with focus on landing technique, evaluated using a similar protocol as the video analysis protocol in this study [177]. Further supporting the importance of movement quality in landings is a study observing that young athletes who subsequently became injured scored worse on the Landing Error Scoring System in the pre-season testing [178]. However, as discussed previously in this thesis, there are several factors involved in the concept of landing quality, such as lower body strength, neuromuscular strategies and flexibility. Therefore, the recommendations for development of athlete testing protocols are to include the proposed variables into the testing protocol, in addition to any other variables that may have potential of detecting deficiencies that can affect performance negatively, or even contribute to injury risk. However, any concept implemented in a new context has to be validated in relation to the specific use.

We found that surfing athletes who display deficiencies in dynamic bilateral tasks, such as bilateral squat pattern and landing technique are at higher risk of injury compared to other athletes, if taking level of surfing into account. These results are of highly practical importance

because these variables could be included in the assessment of surfing athletes, and may also be implemented in the training program. Previous studies on risk factors and its indicative and preventative function show inconsistent results, with some studies having difficulties to confirm relationships between certain skills and injury risk [179-181], and others finding specific measures with indicative characteristics [85, 113, 182, 183] and preventative effects [184-187]. Although further research should confirm and expand on the findings of this thesis related to finding valid risk factors among surfing athletes, the results thus far support the implementation of these dynamic bilateral assessments and training modalities in the physical preparation of surfing athletes.

Landing training may be designed to progress from simple to more complex and sport specific with skill level, as was suggested in study 2 (Chapter 4). The reason being that a complex landing, such as landing on a board after a trampoline jump, was shown to induce higher peak acceleration in the landing situation, corresponding to higher load. This finding is in agreement with other studies of landing tasks, where perturbations and preceding rotations have shown to increase the peak force in landing [119, 145]. Furthermore, the reduced ankle dorsiflexion that was observed at IC while landing on a board, compared to without a board, may require a more effective force absorption by the knee and hip joints instead [188]. Because this is a specific requirement for the sport of surfing, athletes should learn to adapt their movement patterns to effectively execute this task. Although the knee joint kinematics was not specifically observed in this study (Chapter 4), the results of the prospective study (Chapter 7) suggest that knee abduction in combination with high loads may cause injury to the MCL in surfing athletes. We recommend further research to investigate the role of knee abduction movement in surfing and other board sports, as this has been previously discussed as an injury risk factor [10]. Other work that may be useful to further the knowledge of surfing landing tasks is to investigate neuromuscular aspects, as well as kinetics whilst actually performing the sport.

Surfing athletes also need to be able to adapt to changes in the environment while riding the board, and while landing from an aerial phase, as was shown in study 3 and 5 (Chapter 5 and 7). This phenomenon is present in other sports, however, sometimes due to an unpredictable opponent or ball movements rather than a variable surface [2, 24]. However, variable mechanical surface parameters have been shown to be an injury risk among dancers [147], thus suggesting that surfing athletes who can anticipate changes in the environment and quickly adapt to the new conditions may be at an advantage in landing tasks. This was also suggested by Morey-Klapsing et al., 2007, who found that forefoot anticipatory strategies resulted in changes of lower limb muscle recruitment before and during landing [145].

The studies in this thesis focused on implementing multi-factorial models rather than single measures of a skill to be used as indications of a deficiency that needs attention. As has been described before, there are many factors involved in the process leading up to an injury event [2], and although the sport scientist and sports medicine professional would prefer to monitor as many of these variables as possible, this is not feasible from a practical point of view. Consequently, we chose to use tools based on: i) previous research, ii) task specific characteristics and iii) its practical feasibility in regard to available equipment, safety and time to apply. As such, a limitation of these studies was the choice of equipment. However, although more advanced measurement tools may have provided more detailed biomechanical information, the assessments proposed as a result of this study can be implemented with immediate effect in the elite athlete programme at Surfing Australia High Performance Centre. Consequently this research has had a direct impact on the progression of competitive surfing.

Another limitation that has been discussed previously is the number of participants in the prospective study (Chapter 7). Although it is recommended to have at least 20 injury cases when relating variables to statistical significance of injury risk [134], these limitations are difficult to escape with time and participant number constraints. Because surfing is an individual sport with few structured activities, and generally extensive travel for its participants, it is a challenge to

achieve high compliance in prospective studies. In the longitudinal study (Chapter 7) a compliance rate of 70% was obtained. To increase this rate and follow athletes more closely, future studies could consider having the athletes partake in regular training.

8.2 FUTURE DIRECTIONS

Although recent research has focused on some aspects of surfing; its performance and injuries related to the sport, there are many areas with paucity of evidence-based information. For example, there are only a few research papers describing the actual competitive surfing performance, with the majority reporting on time motion analyses of surfing [36-38], scoring analyses [189, 190], and only two studies of the actual board riding movement [10, 15]. Therefore, further studies of the biomechanics of high performance surfing may assist coaches in developing effective training strategies to improve specific skills. Furthermore, surfing performance in relation to the use of equipment and protective equipment and garments is an unexplored area, with only a few scientific papers published [191-194].

Another area that needs attention is the inclusion of female athletes, as most surfing research has used male populations, and the specific characteristics that may be important for female surfers remain relatively unidentified. Studies that have compared male and female surfing athletes have found large differences in physical performance, such as upper and lower body strength and power [11, 40, 195], as well as paddling ability [196], however no differences in visual and auditory reaction time [197]. The female specific characteristics and performances need more attention in surfing research, to increase the knowledge about the limitations and opportunities of improvement of female surfing. There may be small adjustments in technique or training that have large impacts on performance for this population.

This thesis provided normative data of surfing athletes in regards to some important qualities, with regards to male, female, junior and senior populations. The future of surfing research should aim to develop this information and provide data of skills and characteristics that may be required for surfing athletes in order to achieve a high level of success.

8.3 CONCLUSIONS

Manoeuvres in surfing involve dynamic bilateral movements and landing tasks. As such, they are a necessity in high performance surfing. The studies in this thesis show that manoeuvres and landings are causes of lower extremity injuries such as MCL, ACL, syndesmosis and lower back ligament strains, thus suggesting that these athletes need to achieve movement competency and strength in these tasks. Landing competency and other bilateral movements can be tested and trained in the land-based preparation of surfing athletes. It seems that excessively poor scores on the proposed assessments expose the athlete to injury risk, and therefore athletes may benefit from firstly achieving satisfactory scores before successively training high-risk manoeuvres in the surfing context. Improved skills can be achieved by implementing movement training and landing training in the competitive preparation, and sub-elements such as landing technique, rotations, adaptations to sudden environmental changes, ankle dorsiflexion range of motion and strength can be focused on separately in strategic programming schemes. Furthermore, the results suggest that landing on a board is a complex task due to greater peak impact and intra-individual variability, and may therefore require progressive training from simple to more complex, to achieve high performance and safety in these tasks. In conclusion, surfing athletes should be assessed on their bilateral asymmetry and landing skills as part of their high performance evaluation, and the result may be used to inform coaches about future training directions with respect to their level of competition.

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APPENDIX A: ETHICS APPROVAL LETTER

8700 LUNDGREN ethics approval

Research Ethics

Sent: Wednesday, 31 October 2012 19:05
To: Lina LUNDGREN; 'lina@surfingaustralia.com'
Cc: Jeremy SHEPPARD; Sophia NIMPHIUS; Rob NEWTON; Research Assessments
Attachments:  [Conditions of approval.pdf \(50 KB\)](#) [Open as Web Page]

Dear Lina

Project 8700 LUNDGREN **Injury mechanisms and preventive measures in advanced surfing maneuvers**

Student Number: 10265566

The ECU Human Research Ethics Committee (HREC) has reviewed your application and has granted ethics approval for your research project. In granting approval, the HREC has determined that the research project meets the requirements of the *National Statement on Ethical Conduct in Human Research*.

The approval period is from 31 October 2012 to 31 March 2015.

The Research Assessments Team has been informed and they will issue formal notification of approval. Please note that the submission and approval of your research proposal is a separate process to obtaining ethics approval and that no recruitment of participants and/or data collection can commence until formal notification of both ethics approval and approval of your research proposal has been received.

All research projects are approved subject to general conditions of approval. Please see the attached document for details of these conditions, which include monitoring requirements, changes to the project and extension of ethics approval.

Please feel free to contact me if you require any further information.

Regards
Kim

Kim Gifkins
Research Ethics Officer
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Fax: (08) 6304 5044
Email: research.ethics@ecu.edu.au

APPENDIX B: BASELINE QUESTIONNAIRE

The baseline questionnaire form was filled out as a first element of the assesement procedure and contained questions around the following topics:

Q1. Name and contact details

Q2. Date of birth, gender

Q3. Surfing experience, profession

Q4. Surf stance

Q5. Dominant hand

Q6. Level of surfer (competitive level)

Q7. Surfing competency (manoeuvres in repertoire)

Q8. Local training beach

Q9. Appreciate your average involvement in activities during the past month

- Surfing
- Strength training
- Conditioning
- Mobility
- Other sporting activities

Q10. Details of previous injuries:

- Joint/Segment
- Which limb?
- Which side of joint/segment?
- Type of injury?
- How long ago?
- Further information (occurrence, surgery, reoccurrence, still affecting surfing/daily life)

APPENDIX C: QUESTIONS IN INJURY REPORT

The report form was created in Qualtrics with multiple-choice buttons and filled out online.

Q1. Name

Q2. Date of injury

Q3. Surf stance

Q4. Was this a new or recurrent injury?

Q5. Was this an acute (happened at a specific occasion), or a long-term occurring (overuse etc.) injury?

Q6. Time loss due to injury (days)

Q7. What is the current status of this injury (fully rehabilitated, sometimes affecting surfing, sometimes affecting daily life, can still not surf)?

Q8. Did this injury occur while surfing? (If yes, jump to 10)

Q9. What activity were you doing when the injury occurred?

Q10. Location at which the injury happened (surf spot)?

Q11. When did the injury happen (different surfing manoeuvres and activities listed)? (If any landing included – Q12)

Q12. Did you complete the manoeuvre?

Q13. At what stage of the manoeuvre did the injury occur?

Q14. Did you land/try to land on the board?

Q15. What is correct about your landing at the time when the injury occurred (several potential factors listed)?

Q16. About where (on the wave) did you land?

Q17. What size of wave was it when the injury occurred?

Q18. Which side of your body was injured?

Q19. What type of injury (injury types listed)?

Q20. Which joint(s) was affected?

Q21. Which segment(s) was affected?

Q22. Which side of the joint/segment was affected?

Q23. Have you been seeking medical advice for this injury?

Q24. What diagnose (name) did your medical doctor or physiotherapist give the injury?

Q25. Have you had surgery for this injury?

Q26. Please describe in your own words what happened at the time of your injury.

APPENDIX D CONFERENCE ABSTRACT

Lundgren, LE, Secomb, JL, Tran, TT, Farley, ORL, Nimphius, S, Newton, RU, and Sheppard, JM. (2015). Bilateral Squat Symmetry pre and post a 7 week Training Program for Surfing Athletes. Abstract presented at the European Congress of Sport Science, Malmoe, Sweden.

EUROPEAN DATABASE of SPORT SCIENCE

20th Annual ECSS-Congress, Malmö 2015

Scientific programme

Abstract details

Abstract-ID: 1243

Title of the paper: **BILATERAL SQUAT SYMMETRY PRE AND POST A 7 WEEK TRAINING PROGRAM FOR SURFING ATHLETES**

Authors: Lundgren, L.1,2, Secomb, J.L.1,2, Tran, T.T.1,2, Farley, O.R.L.1,2, Nimphius, S.1, Newton, R.U.2, Sheppard, J.M.1,2

Institution: Computing, Health and Science

Department:

Country: Australia

Introduction Surfing involves asymmetrical positions, which may cause bilateral differences among competitive surfing athletes. Previous studies have found that an imbalance of approximately 6% exists in the ground reaction force among college athletes' squat pattern (Newton et al., 2006). Furthermore, it has been reported that bilateral squat asymmetry can be corrected using feedback systems (McGough et al., 2010). The purpose of this study investigated whether a seven-week training program incorporating strength and gymnastics could decrease the asymmetry between the left and right side. Methods Seven junior competitive surfing athletes (6 males and 1 female) participated in the study (age: 16.4 ± 0.67 y, weight: 67.3 ± 7.7 kg, height: 1.74 ± 0.06 m) and were tested pre- and post-training on symmetry during bilateral squats. Using a split stance between two force plates (Fitness Technology, Adelaide) recording at 600 Hz, the athletes performed 10 repetitions, first without any external load (BW) and secondly with an external load (EL) corresponding to 25% of their BW. From the average force of the left and right side of the six mid repetitions, symmetry index (SI) was calculated (McGough et al., 2010). The seven-week training program consisted of two sessions per week of gymnastics and lower body strength exercises. Paired non-parametric statistical tests (Wilcoxon) were used to evaluate differences from pre- to post-training, with significance criteria set at $p < 0.05$, and effect size $r > 0.5$ considered large. Results A decrease in SI was found for the BW bilateral squat task ($p = 0.01$, $r = 0.59$), however not for the EL bilateral squat task ($p = 0.15$, $r = 0.19$). The mean pre- to post-training SI for the BW squat changed from 8.3 ± 11.1 to 4.2 ± 5.2 , and from 7.8 ± 8.2 to 6.3 ± 7.4 for the EL squat, with a large individual variation. Discussion Although the number of athletes that participated in this study was low, there seems to be a trend showing that asymmetry can be reduced with lower body strength and gymnastics training in seven weeks. The role of a symmetrical squatting pattern for surfing athletes remains unknown, and should be investigated further. Previous studies have proposed that there may be a relation between lower extremity asymmetry and injury risk for athletes (Brumitt et al., 2013), which stresses the need to implement a bilateral screening tool and lower body strength program for athletes. References Newton RU et al. (2006). J Strength Cond Res, 20(4), 971-977. McGough, R, Paterson K, Bradshaw EJ, Bryant AL, Clark RA (2010). J Strength Cond Res, 26(1), 47-52. Brumitt J. et al. (2013). Int J Sports Phys Ther 8(3), 216-227. Contact lina@surfingaustralia.com

Abstract text

Topic: Training and Testing

Keyword I: assessment

Keyword II: strength

Keyword III: asymmetry

APPENDIX E: CONFERENCE PAPER

RELEVANCE, RELIABILITY AND LIMITATIONS OF A DROP AND STICK LANDING ANALYSIS

Lina E Lundgren^{1,2}, Brendon Ferrier^{1,2}, Tai T Tran^{1,2}, Josh Secomb^{1,2}, Oliver RL Farley^{1,2}, Jeremy M Sheppard^{1,2}, Robert U Newton², Sophia Nimphius²

Surfing Australia High Performance Centre, Casuarina beach, NSW, Australia¹
Centre of Exercise and Sport Science Research, Edith Cowan University,
Joondalup, NSW, Australia²

The vertical force data from a drop and stick landing can be used to derive a number of variables. Previous studies have generally focused on the time to stabilisation and peak force aspects, and issues related to reliability have been reported. This study investigated reliability for time to stabilisation, peak force, time to peak force, stiffness, rate of force dissipation, impulse and eccentric power (EP) among five professional elite surfing athletes. This data was also compared to data of aerial success in World Championship Tour competitions. The results revealed the best relationship between relative stiffness as well as eccentric power and completion rate of aerial manoeuvres. Further, eccentric power had the best reliability of the variables and may therefore be an interesting variable to study further.

KEY WORDS: landing, surfing, aerial, sport performance.

INTRODUCTION: Drop landings are essential in a number of sports, and have therefore been studied in different types of assessment variations (Ebben et al., 2010; Flanagan et al., 2008). At the Surfing Australia High Performance Centre, the drop and stick test (DS) is part of the general movement assessment, as it has been shown to discriminate between levels of surfers (Tran et al., 2014a) and may be important in screening athletes for excessive lower extremity injury risk (unpublished data).

It is believed that DS landing improvement through development of different physical aspects may transfer to the task of landing manoeuvres on a surfboard (Tran et al., 2014a). However, this needs to be confirmed by further research. Despite the recognition of the importance of landing tasks, it is important to find landing measures that are reliable and valid to assess landing performance for the specific group of surfing athletes, because landing skills will increase scoring potential during wave riding (Lundgren et al., 2014). Furthermore, the DS is a test that can be used both in dry land training and testing, and may serve as a quick and standardized method to assess landing ability.

Previous studies have reported landing variables such as peak force (PF), time to stabilisation (TTS), and stability index to assess the dynamic stability in a landing task (Flanagan et al., 2008; Tran et al., 2014a; Wikstrom et al., 2005). Tran et al. (In Press) reported differences between junior and senior surfing athletes regarding TTS, with senior athletes stabilizing faster than juniors (Tran et al., 2014a). Observed reliability of PF ($\alpha = 0.57$) and TTS ($\alpha = 0.68-0.97$) has been reported in these studies, however with highest and lowest trials excluded before data analysis (Flanagan et al., 2008; Tran et al., 2014a). In order to avoid fatigue influencing the results while testing athletes, it is important to find valid assessments that can be performed within a minimum number of trials.

This research aimed to further investigate the DS landing assessment, with the intention of observing a number of variables derived from the vertical force-time vector that may be useful for landing assessments of surfing athletes. The study also aimed to assess the relationships between landing performance and performance variables in surfing, such as success rate and scoring of aerial manoeuvres.

METHODS: Five professional male surfing athletes in the top 32 in the World (age: 29 ± 3 y, mass: 80.7 ± 3.0 kg and stature: 1.78 ± 3.4) were assessed on a DS landing task. Each

athlete completed five trials, on three separate days during the first week of the 2014 competitive year. Sixty seconds of recovery were provided between trials. Furthermore, all aerial manoeuvres from the World Championship Tour (WCT) for these athletes during the 2014 competitive year were analysed, and the success and wave scores were recorded for each of those waves.

The DS task was performed via a forward drop off a 0.5 m box and barefoot landing onto a force plate (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia) recording at 600 Hz (Tran et al., 2014a). The instruction for completion of the DS was to 'land soft' and reach a squat position with the upper thighs parallel to the floor. Each athlete was familiarized with the landing task to increase competency and the repeatability of the task.

The vertical force data was processed in Matlab R2013a (Mathworks, Massachusetts, USA) and a Butterworth filter of 27.2 Hz was applied (Yu et al., 1999). The force-time graph was processed by dividing the force by body mass, and then integrated to reveal velocity and displacement during the landing. This data was further analysed for the variables time to stabilisation (TTS) (Flanagan et al., 2008), peak force (PF), relative peak force (rPF), stiffness (k), relative stiffness (rk), rate of force dissipation between PF and TTS, impulse (Imp) from initial contact to TTS and eccentric power (EP) between PF and TTS was extracted. Cronbach's alpha was used to assess reliability of landing variables and observed for trend to correlation (due to insufficient statistical power to perform a correlation analysis) with average score of aerial waves, success rate of aerials and number of aerials during the full year of WCT competitions (n=11). Cronbach's alpha was interpreted according to the scale of $\alpha \geq 0.9$ – Excellent, $0.7 \leq \alpha < 0.9$ – Good, $0.6 \leq \alpha < 0.7$ – Acceptable, $0.5 \leq \alpha < 0.6$, and $\alpha < 0.5$ – Unacceptable (Kline, 2013). All statistical analyses were performed using SPSS 22 (IBM, Chicago, Ill.).

RESULTS: The five athletes attempted a total of 48 aerial manoeuvres, whereof 14 were successful, during the 2014 WCT competitions. These 14 successful waves had an average wave score of 5.80 out of 10 possible. There was an observed trend between success rate of aerials and rk (Figure 1) and EP, however no other clear trends were observed in these data.

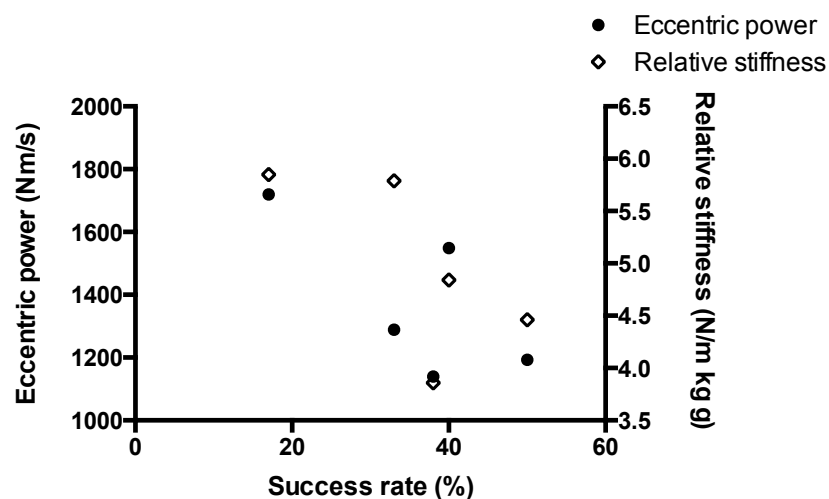


Figure 1: Trend of a relationship between relative stiffness (rk) and success rate of aerial manoeuvres in elite surfing competition.

Reliability analysis of the five trials on three different days revealed acceptable to excellent reliability within days, and poor to good reliability between days, depending on variable (Table 1). The most reliable variable was EP

Table 1
Mean (\pm SD) and Cronbach's alpha for all variables derived from the force data

Item	Mean (\pm SD)	α (within days)	α (between days)
Displacement (m)	0.51 \pm 0.03	0.77	0.70
Time to stabilization (s)	0.92 \pm 0.17	0.67	0.69
Peak force (N)	1910 \pm 165	0.71	0.84
Relative peak force (N/kg \cdot g)	2.39 \pm 0.20	0.71	0.84
Time to peak force (s)	0.09 \pm 0.02	0.80	0.60
Stiffness (N/m)	3933 \pm 622	0.71	0.58
Relative stiffness (N/m \cdot g)	4.93 \pm 0.77	0.71	0.56
Rate of force dissipation (F/s)	1465 \pm 333	0.74	0.88
Impulse (Ns)	949.4 \pm 150	0.71	0.76
Relative impulse (Ns/kg)	11.6 \pm 1.53	0.63	0.66
Eccentric power (Nm/s)	1353 \pm 229	0.90	0.81

DISCUSSION: Although the number of athletes in this study is a limitation, the results show a great potential for further investigation of some of these DS variables. Only professional surfing athletes were included in this study for the purpose of having the highest possible sport specific skills and competitive demands, and knowing that they all participated in the same competitions. The results show that there may be a transfer of skill from land-based landing task performance to the landing of aerials on the water with regards to the parameters relative stiffness (rk) and eccentric power (EP). However, it is suggested to include more athletes to confirm this. There may be also be other associations between variables and aerial landing performance that could not be observed in this data set, due to the limited number of athletes.

The data in this study showed that athletes who were landing more ridged and had a higher eccentric power in the DS landing, had lower success rate in their competition aerials throughout the year. Although these athletes belong to the top surfing athletes in the world, these results may raise awareness that surfing athletes would benefit from landing technique training, to increase their general landing skills, as this have been previously shown to be a highly trainable skill (Aerts et al., 2010).

An interesting finding was that among these elite surfing athletes, the TTS was not related to the success of aerials, or scores of aerial waves, although dynamic postural control would be expected to be a highly relevant skill for a surfing athlete in order to quickly regain stability in a landing task. A previous study did confirm that there are differences in DS TTS between surfing levels of junior surfing athletes, indicating that there may be a practical use for this variable when tracking development of younger athletes (Tran et al., 2014b). In this study, the TTS was used as a time limiting variable for the integration of force-time data in this study, and showed usefulness in this regards due to the potential interaction between aerial success rate, rk and EP.

A concern with the DS assessment is the moderate reliability of the TTS and PF that has been reported previously (Flanagan et al., 2008; Tran et al., 2014a), which was also confirmed in this study. However, this study showed an improvement in the PF variables reliability, which may be due to different filtering frequency of the force data, or due to a higher level of surfing athletes. Additionally, this study displayed good to excellent within-day reliability for most variables except for TTS and relative impulse. It seems therefore, that it may be difficult, even for high level athletes to precisely repeat a landing movement several consecutive times, and more so between different days. A further development of this analysis could therefore include qualitative video analysis, which has been proposed as a reliable method to assess DS landing ability (Aerts et al., 2010).

CONCLUSION: The variable eccentric power was the only variable derived from the vertical force data that had excellent within-day reliability (while maintaining good between-day reliability), and most of the DS variables included in this study showed acceptable or good reliability. Furthermore, the data in this study showed that athletes who had greater relative stiffness and increased eccentric power during the drop and stick landing assessment had lower success rate in their competition aerials throughout the year.

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APPENDIX F: CASE REPORT

High ankle sprain in elite surfing

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Case report

High ankle sprain: The new elite surfing injury?

^{1,2*} Ms Lina Lundgren, Lic. Eng., ³ Mr Matt Butel, M Chiro, ^{2,4} Mr Tim Brown, APA SP,
¹ Dr Sophia Nimphius, PhD, ^{1,2} Dr Jeremy M Sheppard, PhD

¹ Centre for Exercise and Sport Science, Edith Cowan University, Joondalup, Australia

² Hurley Surfing Australia High Performance Centre, Casuarina beach, Australia

³ Currumbin Beach Chiropractic Clinic, Australia

⁴ Mermaid Physiotherapy and Sports Medicine Clinic, Gold coast, Australia

***Corresponding author. Address at the end of text.**

Abstract

Competitive surfing includes high-risk manoeuvres, such as aerials, that require landing from height onto the water surface, absorbing high loads through the lower limbs. The injuries reported during aerial manoeuvres have been mainly located in the knee and ankle joints; however, there is a lack of information about the types and mechanisms of these injuries. This case report describes two cases of Anterior Inferior Tibio-Fibular Ligament (AITFL), or syndesmosis, injuries that occurred during one professional surfing competition. Video recordings and clinical examination information were used to analyse the two cases. Both injuries were due to unsuccessful landings of aerial manoeuvres, and the video recordings showed similar movement patterns with the landing occurring in an already compressed position. The result suggests that the performance of aerial manoeuvres in competition can lead to high load compression injuries, and that syndesmosis injury may be a typical surfing injury due to the modern type of manoeuvres. This information can be used to direct training interventions and landing strategies for surfing athletes, to make them more effective in coping with the dynamic high load compression forces that occur during aerial manoeuvres. **Keywords:** surfing, injury, syndesmosis ankle, AITFL, video analysis, landing

***Ms Lina Lundgren, Lic Eng**

Ms Lina Lundgren, Lead Biomechanist, Surfing Australia High Performance Centre, PhD Student Edith Cowan University, Australia. Her research interests are injury prevention and landing biomechanics in board sports.

Mr Matt Butel, M Chiro

Director Currumbin Chiropractic Clinic. His main research interest is injury prevention in surfing
Tel: +61 (0)7 55250622
Email:

Mr Tim Brown, APA Sports Physiotherapist

Director Mermaid Beach Sports Medicine and Physiotherapy Clinic, Mermaid beach, Australia,
Physiotherapist Hurley Surfing Australia High Performance Centre. His main research interests are injury prevention in sport and running biomechanics
Email: mermaidphysio@mermaidphysio.com.au



Dr Sophia Nimphius, PhD

Senior Lecturer and researcher at Centre for Exercise and Sport Science, Edith Cowan University, Australia. Her main research interests are biomechanics and training adaptation of youth and elite, measurement and development of strength and power

Email: s.nimphius@ecu.edu

Dr Jeremy M Sheppard, PhD

Head of Sport Science at Surfing Australia High Performance Centre, Senior Lecturer and researcher at Centre for Exercise and Sport Science, Edith Cowan University, Australia. His main research interests are strength and power training and adaptation and physical preparation for elite surfers.

Email: Jeremy@surfingaustralia.com

Introduction

Competitive surfing includes numerous dynamic movements performed through various types of manoeuvres. Despite the sport having been a professional sport for over 40 years, surfing injuries have not been extensively studied, including injuries sustained by elite surfers. In competition, the surfers are judged on their ability to perform '*radical controlled manoeuvres in the critical sections of a wave with speed, power and flow*'¹, which have led to the modern type of surfing that contains various aerial manoeuvres and aggressive turns with high speed. The biomechanical loads from these types of manoeuvres are likely high, and will expose the athletes to risk of injury similar to other sports that include landings in a dynamic environment²⁻⁴. Although the evidence on which types of injuries are common for these athletes is limited, studies have shown that participation in barefoot sports which have elements of compression forces and landings, involve high risks of foot and ankle injury⁵. In fact, in most barefoot sports, the foot and ankle are the most commonly injured body regions: kitesurfing (17-28% of all injuries)^{6,7}, windsurfing (28-37%)⁸⁻¹⁰, wakeboard (22-57%)¹¹, skimboard (43%)¹², gymnastics (32%)¹³, martial arts (21%)¹³. However, more information about specific types of injury and mechanism is needed for these sports.

In the sport of surfing, there are a few studies describing injury prevalence, however, not to the detail of injury diagnosis or mechanism. One study on competitive surfers reported 17% of all injuries during competitions being lower extremity sprains⁴, and another recent study on a mixed surfing population reported about 16% of all injuries located to the knee, and 15% to the ankle and foot¹⁴. The most common causes of surfing injuries during competition are i) collision

with the surfer's own board, ii) contact with the ocean floor, or iii) by the surfer's body motion. Furthermore, it was shown that about 20% of all injuries related to a turning manoeuvre⁴.

Although the information available at present about surfing injuries contributes with useful knowledge about general injury risks, types and incidence for surfing athletes, it needs to be completed with detailed information of diagnosis and mechanisms. Detailed information about acute lower extremity injuries from landings, such as knee and ankle sprains, have been reported in many sports (i.e., soccer^{15,16}, team handball^{17,18}, gymnastics¹⁹, snowboarding²⁰, alpine skiing³, volleyball^{18,21}, football²² and basketball^{18,23}), describing the mechanisms, events and kinematics leading up to the injury situation.

Among ankle injuries the lateral sprains have been reported as most frequent, whereas high ankle sprains, or syndesmotic injuries are less frequent in most sports (around 5-10% of all ankle injuries), although believed to be underestimated²⁴⁻²⁸. On the contrary, national level hockey players seem to have a higher incidence of syndesmotic sprains than lateral sprains²⁹. The syndesmotic injury have shown to require a longer recovery period, making it a significant injury for the affected athletes^{25,29}. The most common mechanisms for syndesmotic injuries are external rotation of the foot, most often in combination with dorsiflexion, or excessive dorsiflexion alone³⁰.

To assist the forthcoming work around competitive surfing athletes and injury risk, this study aims to describe in detail two cases of acute ankle injuries from aerial manoeuvres sustained at a professional surfing event. The information can provide much needed insight



into the area of aerial surfing injuries, and be used to create prevention strategies.

Procedure

Two acute injuries from aerial manoeuvres were reported during a professional male surfing event, both of them affecting the ankle joint. Examination was performed on site, via palpation, anterior drawer test, talar tilt test, squeeze test and external rotation test³⁰⁻³², and both athletes were sent to undergo an MRI-scan. The official video recordings from the event were used to describe the injury situation, together with the on-site clinical examination. Descriptive information and variables such as time, and approximate angles and distances was measured in the two-dimensional video recording using Tracker 4.80 (Open Source Physics, 2013).

Case reports

Case 1:

The surfer, 19 years of age, performed an aerial manoeuvre with an unfinished rotation and landed in the white water of the wave. The attempted manoeuvre was a backhand air reverse, however it was landed with 90° of the rotation remaining to be completed. The take-off angle on the approximately head-high wave face was about 46° to the lip line of the wave with the feet in a wide stance on the board and the knees slightly abducting. The rotation started just before the board released from the wave, leading into an inverted position in the air. The front foot (right) lost contact with the board in the early air phase, and the rear foot slid anteriorly on the footpad. As the rotation continued, the rear foot moved medially towards the front of the board, however the surfer tried to catch the front part of the board again before the landing. As the height of the manoeuvre did not give time to finish the rotation (time in the air was 0.1-0.2 seconds), the board landed in the breaking wave, perpendicular to the riding direction, a direction in which the water easily catches the fins. At the time of landing, the surfer was in a flexed position, facing his posterior side from the broken wave. The foot positions were not fully visible in the video material during the landing

phase, however, the rest of the body was in a fully flexed position and since the front foot previously slid off the board, the landing force was most likely mainly on the rear leg. The landing finished with the surfer falling backwards.

After the unsuccessful rotation, the surfer continued the heat, and surfed two more waves. When coming back to the beach, he was limping and came to the event medical staff for examination of the left ankle, or rear foot in his surfing stance. The athlete showed tenderness around AITLF and pain on anterior side of foot. The anterior drawer test and talar tilt test were both negative, but the external rotation test was positive. The report given was a full thickness tear of the AITFL and a minor soft tissue oedema about the distal tibiofibular articulation; however, all other ligaments and tissues appeared intact. The athlete was able to continue surfing after two days, although against medical advice, and appeared restricted in performance.

Case 2:

This surfer, aged 20 years, performed a front hand aerial rotation manoeuvre and landed in the white water of the wave. The manoeuvre started with a take-off having the board on an angle about 45° to the lip line and a wide stance width (65-70 centimetre between heels), with almost extended knee and hip joint. About 0.3 seconds into the air phase, the front foot lost contact with the board and started sliding posteriorly. However, the surfer flexed the hip and knee joint and reached out to grab the board with his rear hand to the front rail to regain the position. The grab was held all the way through to the surfboard reaching the broken wave, keeping the surfer in full hip and knee flexion – approximately 45-50° angle between femur and tibia (Figure 1). As the landing occurred, about 1.5 seconds after take-off, the full rotation was accomplished (in total about 500° from the take-off), however unbalanced towards the rear foot. The surfer could not absorb the compression force to ride out of the manoeuvre, but fell forward when reaching full flexion of the rear knee and ankle. The surfer landed just in front of the white wash from the broken wave.





Figure 1: Body position throughout the aerial manoeuvre and into the landing

The surfer immediately left the water and came limping to seek the medical staff. He was tender around the AITFL, PITFL, and dorsally on the mid-foot, and showed pain on the external rotation test on his right ankle (rear). The report after further examination and MRI suggested full tear of the three inferior tibiofibular ligaments and stripping of the interosseus membrane. The athlete returned to competition after about 80 days.

Furthermore, two additional surfing athletes came to the medical staff during the event, showing symptoms of high ankle sprains (tender when palpating and pain in hyper flexion); however, they had sustained their injury a few weeks prior to the event. Both of these athletes explained the injury situation as a compression injury from an aerial manoeuvre. One of them was sent for an MRI-scan which showed a partial tear of the AITFL and PITFL.

Discussion

These cases all reported during the same event and having similar cause, could be a result of the modern type of competitive surfing, including high compression forces from aerial manoeuvres. The injuries differed in severity, and one athlete was even able to continue surfing in the event although restricted, and against medical advice. This case was contradictory to the usual observation of high

ankle sprain as these are most often classified as moderate or severe injuries in terms of a long recovery period³³. However, several studies have reported low amount of lay-off days due to this injury^{28,34}. However, the injury is known to create chronic instability if insufficient rehabilitation is applied³⁴.

The high ankle sprain, or injury of the AITFL, is common in sports such as football, ice hockey and soccer, and is known to require a longer recovery period than lateral ankle sprains^{22,25,29,35}. The mechanism for this injury is described as any movement that tends to separate tibia and fibula, which has been reported to be external rotation of the talus or internal rotation of tibia, excessive dorsiflexion with axial loading, or a combination^{22,30,36}. Although the video recordings reported on in this study were two-dimensional and therefore could not clearly show the feet positions in the landing, they still provide useful information to confirm the mechanism leading to AITFL injury specifically for surfing (landing in a fully compressed position). Whether this type of injury is about to be the new "typical injury" for elite surfing athletes is yet to be determined until more extensive surveillance studies are undertaken. However, the described cases suggest that surf coaches and sport scientists related to surfing should learn from these experiences and take the information into consideration when preparing athletes for high performance surfing.

Prevention strategies that can be used to reduce the occurrence of ankle injuries in surfing is suggested to be developed and evaluated, which should target the capacity for the athletes to handle compression forces and dynamic landing situations. The training could include landing exercises and movement preparation to increase the ability to use a biomechanically efficient movement pattern when absorbing compression forces, as well as lower extremity strength, power and mobility training to improve the capacity of handling the transfer of high energy through the lower limbs. Improving these skills would most likely increase the ability to complete the landing within a range of motion that is safe for the lower extremities to handle force, i.e., avoiding landing with excessive flexion and rotation angles. As has been previously reported, fatigued subjects tend to need an increased range of motion to absorb compression force, leading to greater knee flexion and ankle dorsiflexion, and therefore risk of injury³⁷. Furthermore, a neutral alignment around the antero-posterior axes of the ankle and knee joints are to endeavour, since these joints have a limited range of motion with mainly ligaments to stabilize the abduction/adduction and inversion/eversion movements³⁸.

The two cases of AITFL injury occurring during one professional surfing competition shows that the performance of aerial manoeuvres in competition can lead to high load compression injuries. Both injuries occurred during unsuccessful landings with the lower extremity fully compressed at the time of landing, likely in combination with external foot rotation. As syndesmosis injuries can lead to chronic ankle instability or pain, it is of utmost importance for the athletes to be aware of the risks involved in aerial landings. Preferably athletes and coaches should use this information to direct training interventions and landing strategies for surfing athletes, to make them more efficient in handling the dynamic compression forces, especially when preceded by a rotation or external disturbances. The authors of this article suggest land-based training of jump landings to improve the ability to handle different types of disturbances, as this can be performed in a controlled environment and gradually progress from an individual level of advancement.

Address for correspondence:

Ms Lina Lundgren, Surfing Australia High Performance Centre, PO Box 6013, Casuarina Beach, NSW, 2487, Australia
Tel.: +61 (0)266 710000
Email: l.lundgren@ecu.edu.au

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APPENDIX G: CONFERENCE ABSTRACT

Lundgren, LE, Secomb, JL, Tran, TT, Farley, ORL, Nimphius, S, Newton, RU, and Sheppard, JM. (2014). Bilateral Squat Asymmetry in Surfing Athletes. Abstract presented at the European Congress of Sport Science, Amsterdam, Holland.

BILATERAL SQUAT ASYMMETRY IN SURFING ATHLETES

Lundgren, L.1,2, Secomb, J.1,2, Tran, TT.1,2, Farley, O.1,2, Nimphius, S.1, Newton, RU.2, Sheppard, JM.1,2

1: ECU (Joondalup, Australia), 2: Surfing Australia HPC (Casuarina beach, Australia),

Introduction

Surfing athletes (SA) have an asymmetrical stance while surfing, which may cause these athletes to prefer an asymmetrical posture. Previous studies have found about 6% imbalance on average regarding ground reaction force (GRF) among college athletes (Flanagan and Salem, 2007; Newton et al., 2006), and that bilateral squat asymmetry can be corrected (McGough et al., 2010). This study investigated bilateral asymmetry for SA and compared between left and right side, front and rear side and between groups of athletes, such as divisions and training status.

Methods

Athletes (n=26) from four division based groups, i.e., male and female professional seniors (n=8 and 3, age: 24.5±3.2 and 25.8±6.6 y respectively) and juniors (n=8 and 7, age: 16.0±1.3 and 15.8±0.7 y) performed bilateral squats with their stance split between two force plates (Fitness Technology, Adelaide) recording at 600 Hz. The athletes performed 10, first without any external load (BW) and secondly with an external load (EL) corresponding to 25% of their BW. From the average force of the left and right side a symmetry index (SI) was calculated (McGough et al., 2010). Comparison between SA who strength trained regularly (n=11) versus inconsistently (n=15) was performed using independent t-test. Bilateral asymmetry between feet was analysed using paired t-test.

Results

The average SI for all SA was 6.8±4.4% and 8.2±5.8% for the BW and EL squat respectively. There was no significant preference for the front or rear stance leg (p=0.19), or the left or right (p=0.14). Of all SA, 9 athletes had a SI >5% to the rear leg, 6 had a SI >5% to the front leg, and 11 SA were within 5%. The group of female junior surfers (n=7) had a larger average SI than that of the other groups averaging 10.5±4.2% and 10.9±5.7% for the BW and EL conditions (p≤0.01). Of these, 5 preferred their back foot and 2 their front foot. Those who had been strength training regularly during the past six months had a lower SI (3.5±2.7%) compared to the other athletes (9.4±4.5%, p≤0.001).

Discussion

The result of this study suggests that there are bilateral asymmetries in the squat movement for most SA, similarly to that identified in previous research, however larger for the group of female juniors. The asymmetry seems to be minimized in those performing regular lower body strength training exercises. The hypothesis that most surfing athletes would prefer their rear stance leg more than the front turned out to be unconfirmed in this study.

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Contact

lina@surfingaustralia.com

APPENDIX H: CONFERENCE PAPER

Journal of Australian Strength and Conditioning

Athletic movement competency is related to general athletic performance variables and surfing performance.
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ATHLETIC MOVEMENT COMPETENCY IS RELATED TO GENERAL ATHLETIC PERFORMANCE VARIABLES AND SURFING PERFORMANCE

Lina E. Lundgren^{1,2}, Tai T. Tran^{1,2}, Oliver R. L. Farley^{1,2}, Josh Secomb^{1,2},
Sophia Nimphius¹, Robert U. Newton¹, and Jeremy M. Sheppard¹

¹Centre for Exercise and Sport Science Research, Edith Cowan University, Joondalup, WA, Australia

²Hurley Surfing Australia High Performance Centre, Casuarina Beach, NSW, Australia

INTRODUCTION

In the athletic development pathway, there are several components to master in order to achieve high performance and resiliency. For a majority of sports, the foundation is movement, i.e., an athlete who can move well, can progress through complex tasks and add load to increase the intensity of training, will increase the efficiency and adaptation to high load situations (14). However, athletes who demonstrate limitations in movement patterns may not move as efficiently, and thus place themselves at risk of injury, or ineffective while performing high performance tasks (13).

Movement competency as a term within sport science that can be used to describe an athlete's ability to perform basic movement tasks with satisfactory biomechanical alignment, stability and efficiency (19). Some may consider 'functional movement' being similar in nature; however, the tasks are not necessarily specific or related to training tasks, giving the term functional an incorrect meaning in the sporting context. Therefore, we defined movement competency as the ability to perform basic dynamic movements at different levels of difficulty with biomechanical alignment, stability and appropriate range of movement. These skills are trainable, and assessments may provide guidance to the coach as to whether the athlete is ready to withstand loading in particular exercises. In other words, a model with information about an athlete's fundamental movement skills, may not predict injury, but provide an evidence base as to whether the athlete has the competency to add further complexity (through load or motion complexity) to their major movement patterns.

There are several ways to assess movement competency and in the practical application the assessment is often based on a subjective scoring system, with thoroughly defined criteria (16). A system widely used to assess movement proficiency is 'Functional Movement Screen', or FMS (4). Although this may be a relevant system to use in many sports applications (e.g. with very large numbers of athletes and numerous practitioners working with this population), there are other basic exercises that may be targeting the requirements for the movements that are involved in the sport. Surfing Australia High Performance Centre (HPC) have adopted a Long Term Athlete Development Scheme (LTAD), in which a movement competency profile is included, as well as several athletic performance tests chosen from a knowledge of the performance components of surfing (7). Athletic performance tests are often goal-oriented and quantitatively measured variables, such as explosive power or strength. Sheppard and colleagues, have previously reported that several of the athletic performance variables used in the HPC LTAD performance protocol (20) are related to actual surfing performance level and thereby relevant for the surfing athlete. However, the relevance of scoring movement competency for these athletes has not yet been described.

The purpose of this study was to establish if there are significant associations between movement competency assessment results for lower body dominant exercises, with results from lower body athletic performance tests included in the HPC LTAD. The hypothesis was that relationships exist between the movement competency and athletic performance test results among elite surfing athletes.

METHODS

Elite and pre-elite surfers, over 16 years of age, with a ranking on the World Championship Tour, World Qualifying Tour, or World Pro Junior Tour of surfing were recruited for this study. The group consisted of 12 female athletes (age: 20.1 ± 3.7, mass: 59.8 ± 3.9 kg, height: 165.2 ± 4.9 cm), and 23 male athletes (age: 22.7 ± 4.9 y, mass: 74.4 ± 7.5 kg, height: 177.6 ± 3.9 cm).

The athletes were assessed on a movement competency protocol as well as performance tests, as described in the HPC LTAD (7, 20). Only lower body dominant exercises were used for the analysis. The movement competency test consisted of four exercises: bilateral squats, single leg squats, lunges and drop and stick landing. These exercises were assessed at four different levels, depending on the athlete's previous results and current level (i.e. Foundation, Emerging, Pre-elite, and Elite stage which can be viewed as levels 1-4), with increasing difficulty as the athletes' master and progress through each stage. During evaluation, each task was performed according to the protocol for that particular stage with instructed emphasis on correct movement form (Figure 1). Two observers scored the tasks on a scale from 0-3, where 0 represents not being able to perform the task, or inability to perform the amount of repetitions to reach any score (1-3). Conversely, a score of 3 represented correct form and stability throughout the full repetitions of the exercise; however, points were scaled to reflect the number of repetitions where the athlete may have compensated to complete the movement (e.g., weight shifting to one side during the squat movement). For example, if

the athlete performed 7 repetitions with correct form, and 3 with a deviation from correct form, their score reflected this (i.e. score of 1 out of 3 maximum). The final movement score (MS) was the product of the Level x Sum of the scores of each exercise. Hence, a maximum score of 60 was possible.

		Foundation	Emerging	Pre-Elite	Elite
Bilateral Squat	How	Hands behind head	Snatch squat	Snatch squat 25% BW	Snatch squat 50% BW
	3	10 or >	10 or >	10 or >	10 or >
	2	8-9	8-9	8-9	8-9
	1	6-7	6-7	6-7	6-7
	0	5 or <	5 or <	5 or <	5 or <
Unilateral Squat	How	Squat off box	Squat off box	Squat off box 5kg out front	Squat off box 5kg overhead
	3	5 or >	10 or >	10 or >	10 or >
	2	4	8-9	8-9	8-9
	1	3	6-7	6-7	6-7
	0	2 or <	5 or <	5 or <	5 or <
Lunge Pattern	How	Return lunge hands on hips	Walking lunge hands on hips	Walking lunge 10kg overhead	Walking lunge 10/20kg single arm
	3	10 or >	10 or >	10 or >	10 or >
	2	8-9	8-9	8-9	8-9
	1	6-7	6-7	6-7	6-7
	0	5 or <	5 or <	5 or <	5 or <
Landing Competency	How	Double leg drop and stick	Double leg drop and stick	Double leg drop and stick	Double leg drop and stick
	3	0.5m	0.5m	0.7m	0.9m
	2	0.5m	0.5m	0.6m	0.8m
	1	0.3m	0.5m	0.5m	0.7m
	0			0.4m or <	0.6m or <

Figure 1 - Evaluation scoring criteria used for lower body dominant movement competency tests, based on four exercises performed at 4 different levels.

The athletic performance tests used to assess the relationship with MS were countermovement jump (CMJ), drop and stick landing (DS) and isometric mid-thigh pull test (IMTP) on a force plate (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia), and derived variables were CMJ height, time to stabilisation (TTS) and relative peak force (rPF) for the DS, and PF for the IMTP absolute and relative to body mass. These tests have previously been shown to be valid to test unloaded explosive power, landing ability and isometric lower body maximal strength respectively (9, 17, 20).

The test results were analysed through correlation of the movement competency scores with CMJ height, DS TTS, DS PF and IMTP PF respectively, as well as with the surfing performance ranking in the group based on their World Tour ranking around the time of testing. The statistical analysis was made on females and males separately. Pearson's r was used to analyse the normally distributed variables, whereas Spearman's r_s was used to find potential correlations with surfing ranking. Statistical significance was set at $p \leq 0.05$. Strength of the relationships were classified as trivial: ≤ 0.10 , small: 0.10–0.29, moderate: 0.30–0.49, large: 0.50–0.69, very large: 0.70–0.89, and nearly perfect: >0.90 (11).

RESULTS

There were significant correlations ($p \leq 0.05$) between jump height, isometric PF, (both absolute and relative to body mass), and MS ($r = 0.72$, 0.53 and 0.58 respectively) for the male group. Significant correlations between MS and CMJ height as well as TTS in a drop landing ($r = 0.63$ and -0.84 respectively, $p \leq 0.05$) were observed for the females. However, no statistically significant relationship could be established between MS and isometric strength for females ($r = 0.2$, $p = 0.53$). Furthermore, neither the male nor female groups' MS were related ($p > 0.05$) to the maximum rPF in the DS landing ($r = -0.22$, $p = 0.324$ and $r = 0.06$, $p = 0.99$).

The ranking of athletes within the group based on their World Tour ranking at the time of testing showed a significant correlation to MS for the male group, and a stronger correlation for the female group ($r_s = -0.44$, $p = 0.05$ and $r_s = -0.62$, $p = 0.04$). Furthermore, significant relationships were observed between ranking and performance test results for the male athletes ($r_s = -0.60$, $p \leq 0.01$ and $r_s = -0.75$, $p \leq 0.001$ for the CMJ height and IMTP PF respectively), however not for the female group or any other variables.

DISCUSSION

This study revealed a strong relationship between movement competency and jumping tasks, isometric lower body maximal strength, and sport performance in surfing, indicating that movement is an important foundation to achieve in a long term athlete development perspective. These facts are well known in regards to motor competency and physical fitness among children (5, 22), however less research have been published on elite athletes. Previous studies on athletes both support (6) and contradict (2, 10, 18) the findings of this study, although noteworthy is that all of these studies used the Functional Movement Screen (FMS) as the movement competency assessment in contrast to this study. Studies that used more dynamic tasks, such as landings and general movement tasks found relationships between movement competency and jumping, strength and sport performance (12, 15). Furthermore, movement competency has been shown to be important for injury prevention (3, 4, 8, 13). The relevance of movement competency in surfing is obvious from any study of videos and photographs showing the positions that the athletes need to adopt during performance (Figure 2). However, being able to assume and resume those positions with great stability and control can be challenging and requires practice out of the water.



Figure 2 - The surfing athlete will assume postures requiring great range of motion and stability during performance.

The results in this study showed that both male and the female group had similar correlations between the tested variables, although the female group did not show a significant relationship between MS and isometric strength, which the male group did. Previous studies with similar results have not provided information whether they used male or female athletes (12), or only male athletes were used (6, 15), hence no such analysis was made. The female group not showing the MS vs strength relationship may be due to several factors, i.e. a smaller group (N=12) was used, the group may have been more spread in their skill, or the movement deficiencies identified in their tests may not have been influential on the strength component. For example, the strength of an athlete who shows a deviated movement pattern in squatting exercises due to loss of flexibility in the ankle region, may not necessarily be affected although that would produce a lower MS (1, 14).

The testing protocol used in this study was chosen due to its relevance to surfing. Several test protocols have been proposed for movement competency in general, however, we would like to emphasize that an assessment should be relevant to the sport where it is applied, and may therefore have to be adapted depending on the application (15). For example, surfing athletes need sufficient flexibility and stability, so we perform an overhead squat, (without or with load depending on the level) because performance of their sport will include tasks with similar requirements (Figure 2). Furthermore, that same concept can be applied to every task that needs to be mastered in a sport, and so adaptations from sport to sport is logical.

There are other movement competency assessments that have been described in the research literature, mainly as a means to assess injury risk among athletes (4, 16). Although it is of utmost importance to find assessments that can assist with information about the likelihood for an athlete to get injured, it should be noted a range of variables will have influence on this, one of these being injury history as this is the greatest practical predictor of future injury (21). The sport of surfing in particular, contains many other factors influencing both injury risk and competitive performance, such as environmental, tactical, technical, physical and mental factors (7). Although the fundamental movements are a major part of athletic performance and injury risk management, there are also other variables that need just as much attention. The assessment outlined in this study in our view is not a screen for injury risk, but an assessment of how the athlete is progressing in their sport-relevant athletic tasks.

CONCLUSIONS

Movement competency in lower body dominant exercises is important for surfing athletes, and seems to contribute to a high performance level in jumping, strength and competitive surfing, especially for male surfers. The female athletes showed no relationship between movement competency and strength; however, the female athletes with higher movement score had a quicker stabilization time in a drop and stick landing. In conclusion, a high movement score does

not make you an excellent surfer, but if you are an excellent surfer that can move well, you have better prerequisites to be successful on the World Tour.

PRACTICAL APPLICATION

We suggest movement competency to be one of the main foci of every athlete's development pathway, because it is part of the athletic foundation and can be implemented early. According to the results of this study, movement competency may also be important for development of performance related variables. Therefore, our recommendations are to involve an adapted movement assessment as part of the overall assessment protocol for any athlete, and work on deficiencies in movement patterns that may help improve performance or safety issues. Some practitioners may choose to do this in an informal manner (e.g. 'I assess movement every time I coach'), and there may be no need to formalize this process. In other instances where a long-term pathway is being implemented, formalization of an athletic competency curriculum might be a useful means to align multiple practitioners across a region or country.

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APPENDIX I: CONFERENCE ABSTRACT



NEW ASSESSMENT TOOL FOR AERIAL SURFING ATHLETES

Lina Lundgren^{1,2}, Tai T. Tran^{1,2}, Josh Secomb^{1,2}, Oliver R. Farley^{1,2}, Ellen Raymond², Sophia Nimphius¹, Robert U. Newton¹

And Jeremy M. Sheppard^{1,2}

¹ Centre for Exercise and Sport Science Research, Edith Cowan University, WA, Australia

² Surfing Australia High Performance Centre, Casuarina beach, Australia

email: lina@surfingaustralia.com

INTRODUCTION

Aerial performance is a major factor in competitive surfing, as it is a high-risk manoeuvre bringing the element of innovation to the performance [1]. To date, there has been no general assessment tool described, for land-based examination of an athlete's potential for aerial performance published for the surfing community. The purpose of this study was to test if a simple assessment of rotational skill, the Jump Rotation Test (JRT) is related to self-estimated aerial performance. In addition, we wanted assess differences in the JRT for the left and right direction respectively between the athletes using a 'natural', or 'goofy' surf stance (left or right foot forward on the board).

METHODS

Sixty-one male surfers (age: 22.3 ± 7.5 y, mass: 71.6 ± 11.2 kg, height: 177.0 ± 7.3) participated in this study. Athletes were asked about their aerial performance and to estimate to which extent (from 0-100%) they successfully complete their aerial manoeuvres. They were also assessed on the JRT, hence instructed to jump vertically and rotate 360 degrees with the goal to land on the same spot from which both feet started. The distance from the right and left foot from the landing position to the starting position in cm was added to the degrees of angle of change between landing and start. A smaller JRT result was assumed to indicate a better rotation skill. Two trials were allowed in each direction after familiarization of the task, whereof the best was used for the analysis. The aerial performance percentage estimate was correlated to the result of the JRT assessment using Pearson's product-moment coefficient with a minimum level of significance set to $p \leq 0.05$. Intraclass correlation (ICC) and coefficient of variation (CV) was assessed with a separate group of 10 surfing athletes performing the test three times to the right and to the left with 5 minutes rest

in between trials. The two best trials were used for analysis.

RESULTS AND DISCUSSION

The results of the JRT assessment was found to weakly correlate with self-estimated aerial completion rate with a coefficient of $r = -0.287$ ($p = 0.03$) and $r = -0.332$ ($p = 0.01$). The average test results were 49.3 ± 37.7 and 48.4 ± 32.8 to the left and right side respectively. There were no statistical differences found in JRT results between the athletes using a 'natural' stance compared to those with a 'goofy' stance. The ICC of the JRT assessment was deemed to be moderate (ICC: 0.91; CV: 36%).

CONCLUSIONS

The significant correlation between self-reported aerial performance completion and result at the jump rotation test (JRT) shows that the JRT could be relevant to use as a part of the physical assessment of surfers, although there are several other factors influencing aerial performance, hence why the relationship, despite significant would be considered small. For a surfer to have awareness of the aerial phase, feet position and amount of rotation should be crucial in situations where rapid tasks are executed in a dynamic environment. Therefore a multiple regression including other variables than surfing technique or JRT, such as strength and power, landing ability, decision-making and risk management are most likely important to improve aerial performance.

ACKNOWLEDGEMENTS

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APPENDIX J: CONFERENCE PAPER

Journal of Australian Strength and Conditioning

Ankle range of motion among surfing athletes. J. Aust. Strength Cond. 21(S2)121-124. 2013 © ASCA.

ANKLE RANGE OF MOTION AMONG SURFING ATHLETES

Lina Lundgren^{1,2}, Tai T. Tran^{1,2}, Oliver Farley^{1,2}, Josh Secomb^{1,2}, Sophia Nimphius¹, Robert U. Newton¹
and Jeremy Sheppard^{1,2}

¹Centre for Exercise and Sport Science Research, Edith Cowan University, Joondalup, WA, Australia

²Hurley Surfing Australia High Performance Centre, Casuarina Beach, NSW, Australia

INTRODUCTION

In surfing, the athlete rides a board across the wave, performing manoeuvres that require lower-body strength and power. The lower limb position on the board will range from fully flexed to completely extended [1], demanding full range of motion of the lower extremity joints. Furthermore, the athlete will need to produce and arrest high forces throughout this range of motion, due to the complex manoeuvres that are required to ensure success in competition. High-risk manoeuvres, such as vertical turns, aerials and tube-rides, all score high in competition [2, 3], however, such tasks require high velocity change of direction, landing and compression, which may put the surfer in a vulnerable position for lower extremity joint injury unless proper development of strength and flexibility is implemented. Among all injuries in surfing, about 40% occur in the lower extremities [4], with approximately 15-20% occurring specifically in the ankle and foot [5]. Although only a few studies have used weight bearing ankle dorsiflexion as a measure to predict injury risk, initial evidence has shown that limited dorsiflexion range of motion (ROM) increases injury risk [6, 7], suggesting that this may be an important measure for athletes, especially those using the full ROM at the ankle joint. Ankle dorsiflexion ROM can be measured in different ways, however a weight bearing assessment that has been shown to be highly reliable for both injured (ICC 0.99) and non-injured populations (ICC 0.99), and moderately reliability for a younger age group (ICC 0.83), is the knee to wall measurement (KW) [8-10]. Previously Hoch, et al. [11] reported on KW measurements for 14 males and 21 females around 25 years of age. They found an average knee to wall distance of 11.9 ± 2.8 and 12.0 ± 2.8 cm for the left and right limb respectively, with the maximum score just above 17 cm [8]. Furthermore, they did not find any statistical relationship between KW and age, limb length, height, mass or posterior talar displacement, indicating that these measures do not influence the KW score [8]. Another study that compared ballet dancers to a control group found that the control achieved 3.8 ± 2.2 cm and the dancers 6.4 ± 2.8 cm [12].

Since surfing manoeuvres are highly dynamic movements, surfing athletes need a large ROM in the ankle joint to be able to assume a fully compressed position. To the authors' knowledge, there is no data published that describes the ankle ROM among surfers, and compares different groups of surfers. Whether ankle ROM is an important measure for surfing athletes to perform at their highest level and to avoid ankle injury is yet to be determined. However, this study aimed to describe the ankle ROM among different groups of surfers, compare the ankle ROM to previously published data and surfers with a previous ankle injury, and last compare the weight bearing ankle dorsiflexion ROM test measured with two different systems (KW and inertial sensors).

METHODS

Maximum ankle dorsiflexion was measured with a weight bearing knee to wall test (KW), as this test has shown high reliability and validity in previous studies [8-10]. Eighty athletes ranging from recreational to professional level of surfing from 13 to 40 years of age had their KW measured at least once by a researcher with previous experience of measuring KW. Before the analysis, athletes with previous ankle injuries still affecting their ankle motion were separated and grouped into one study population. The remaining athletes were divided into three groups; female athletes, >18 years of age male athletes and <18 years of age male athletes, as adolescent athletes may deviate in their anthropometric proportion compared to the adults. Within these groups, the comparison of higher and lower level surfers was made, depending on their ranking, or competition level. For the adult group, the distinction was made between those who are competing, or recently have, at least in the World Qualifying Series (professionals), and those who are not (recreational). For the <18 group the juniors that achieved the national selection camp and those competing at pro junior level were considered higher level surfers. As the females were all <19 years of age, they followed the same protocol as the <18 males. The within-group analyses that showed significant differences between groups were split up in their respective level for further analysis.

The KW test was performed with the subject in a short lunge position with the front knee projected forward with the subject trying to reach the wall. The maximum distance between the tip of the first metatarsal and the wall when the subject could reach their knee to the wall was measured [11]. The recordings of KW were made for the front and rear foot in the surf-stance, as some surfers stand in in a 'natural' position (left foot forward), and others in a 'goofy' position (right foot forward). Furthermore, the same test was performed with 11 of the participating athletes using the kinematic measurement units XSens MVN Biomech (XSens Technology, Enschede, Netherlands) to measure the actual ankle dorsiflexion angle.

All statistical analyses were performed using a statistical analysis package (SPSS, Version 21.0; Chicago, IL). One-way analysis of variance was performed to determine differences between and within the groups of surfing athletes. Furthermore, correlation between KW and height was performed to reveal eventual co-variations, and was corrected for in the ANOVA model. Criterion for statistical significance was set at $p < 0.05$.

RESULTS

The demographics and KW measurements of the groups of athletes are presented in Table 1.

Table 3 - Athlete demographics and KW for the groups of participants.

	<18 Male (n=33)	>18 Male (n=24)	Female (n=15)	Previously injured (n=8)
Age (years)	14.9 (± 1.4)	26.7 (± 5.4)	15.0 (± 2.2)	17.1 (± 6.4)
Stature (cm)	167 (± 10.6)	176.9 (± 5.3)	161.4 (± 7.1)	165.1 (± 13.3)
KW Front foot (cm)	13.9 (± 2.8)	15.4 (± 3.4) ^{a,b}	11.9 (± 3.6) ^a	11.6 (± 4.0) ^b
KW Rear foot (cm)	14.3 (± 3.9)	15.3 (± 3.6) ^c	12.8 (± 3.6)	11.4 (± 4.4) ^c

^{a,b,c} Significant difference ($p < 0.05$) with Sidak adjustment.

In the group of adult surfing athletes (>18 years old), the professional surfers had significantly larger weight bearing ankle dorsiflexion ROM measured with KW ($p < 0.01$) as shown in Figure 1. Although there was a significant correlation between KW and stature of the athlete ($r = 0.52$ and 0.63 for the front and rear foot respectively, $p < 0.01$), the corrected statistical model still showed significance between the professional and recreational athletes ($p < 0.05$).

Furthermore, there was a tendency ($p = 0.09$) for the recreational group to have a larger discrepancy between feet, although there was no significant consistency in which one of the ankles that had the greater ROM (Table 2).

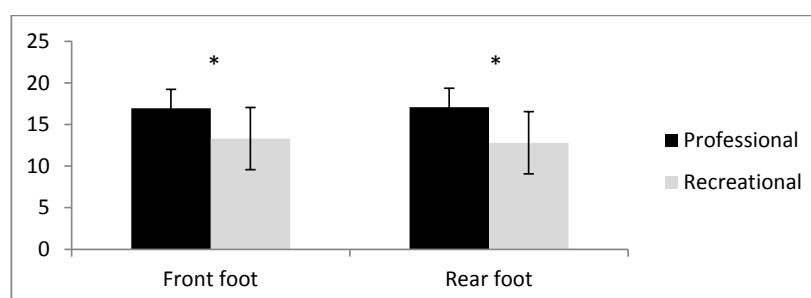


Figure 1 - Average KW for the professional and recreational groups of surfing athletes. Statistical significance (*) was found between the groups for both feet.

Table 4 - The average absolute difference (\pm SD) between front and rear foot for the groups of surfing athletes.

	Mean absolute difference (cm)	Difference rear to front (cm)
Professional >18	0.93 (± 1.07)	0.29 (± 1.44)
Recreational >18	1.80 (± 1.32)	0.00 (± 2.31)
Male <18	1.00 (± 1.00)	0.36 (± 1.38)
Female	0.7 (± 0.65)	0.23 (± 0.94)
Previously injured	1.81 (± 1.41)	0.31 (± 2.37)

For the group of surfing athletes under 18 years of age, there was no difference to be found between higher-level competitive surfers and lower-level competitive surfers for KW or difference in KW between legs. Furthermore, there was no correlation between stature and KW in this group.

The female group of surfing athletes were all under 19 years of age, and therefore comparable in age to the under 18 male group. However, no statistical difference in KW was found between the male and female groups. The statistical model comparing the lower level competitors with the higher-level competitors in the female group did not show any statistical difference when corrected for height and age, as the higher level of surfers in this group were older, and thereby taller.

Comparing previously published information on normative KW data, both groups exhibited a greater KW, as did the group of young surfers in comparison to other children and young dancers (Figure 2).

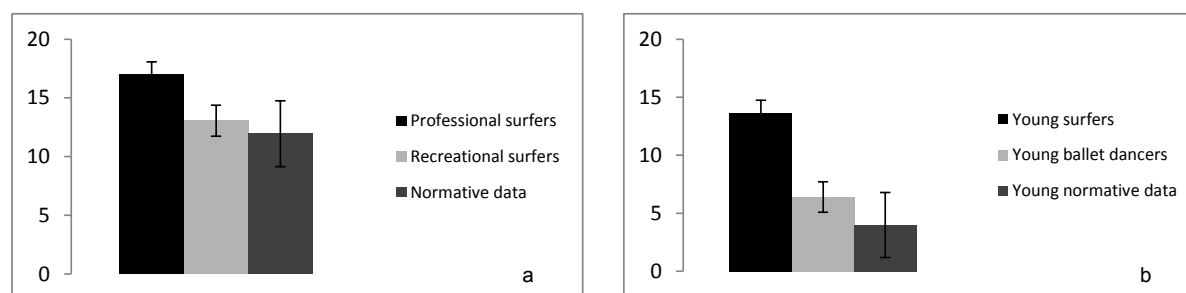


Figure 2 - Comparison of KW measure results from this study in comparison to previously published material for a. adults (11), and b. children from 7-15 years of age (10, 12).

KW measured in combination with the angle of ankle dorsi flexion using inertial sensors showed a strong relationship between the two ($r=0.84$). The angle of maximum ankle dorsiflexion in this group ranged from 29-55° (Figure 3).

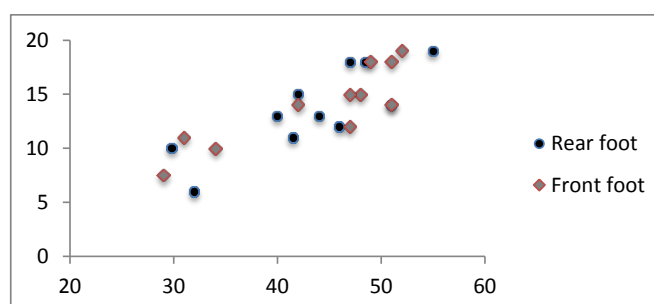


Figure 3 - KW measure in relation to the angle measure with XSens MVN Biomech for 11 of the surfing athletes.

DISCUSSION

This study aimed to describe the ankle ROM among different groups of surfers and the results showed that the group of professional surfers had a greater KW than the recreational group. Although there are limitations in comparing results to previous studies, as these might have used slight differences in their measurement technique, it seems that surfing athletes in general have a greater dorsiflexion ROM than populations such as ballet dancers and 'healthy adults'. The greater KW exhibited in surfing athletes may be due to long term participation in a sport requiring a great range of ankle dorsiflexion, however it may also indicate that surfing athletes will likely be exposed to joint movements where the ankle is under load through a large range of motion. In order to avoid injury under such circumstances, it will be of utmost importance that the surfing athletes have well-developed and symmetrical strength and proprioceptive skills for their lower extremities, as a lack of these qualities has been shown to contribute to an increase of risk of ankle injury in other sports (7, 13).

To date, it is not known whether ankle ROM is more important for surfing athletes than athletes in other sports, however, the results of this study suggest this may be the case. The reason for this is likely a combination of several factors unique for surfing and similar sports, such as the dynamic environment, barefoot connection to the board, production and arresting of force in vertical and/or horizontal directions, and the variations of manoeuvres to make them look more complex (grabbing the board, tweaking the board, etc.). The latter is an external factor derived from the sport being scored based on subjective judgement, where risk-taking and variation are two important criteria.

The recreational, and previously injured groups of surfers had a mean absolute difference, or asymmetry, around 1.8 cm between feet (Table 2), which according to the previous studies should be considered a deficit (8). For the injured group this may be due to loss of ROM from the injury, whereas for the group of recreational surfers it might be an asymmetry due to long term use of a specific movement pattern without sufficient complimentary training. Furthermore, although there was no statistical difference between the front and rear foot KW in any of the groups, it is still noticeable that the mean value of all groups, except the recreational group, is positive i.e. a slightly higher average KW in the rear foot as compared to the front. As surfing is an asymmetrical sport, with athletes always assuming a 'regular' or 'goofy' stance the rear to front asymmetry may be a characteristic due to the nature of the sport. The results of this study did not imply any current typical asymmetry for surfing athletes, however, this is a factor worth tracking for injury prevention purposes.

CONCLUSIONS

Our results suggest professional surfing athletes have a greater range of dorsiflexion compared to recreational surfers, ballet dancers and mixed populations. We also demonstrated that the weight-bearing knee to wall test of ankle dorsiflexion ROM is valid to show differences in absolute angle measurement for the same position, although

the stature of the person must be considered. The KW measure does not discriminate between higher and lower level adolescent surfers, however it appeared higher for young surfing athletes compared to other age matched groups such as dancers and previously published normative data.

PRACTICAL APPLICATION

We suggest ankle dorsiflexion range of motion is of importance for surfing athletes, and can be validly assessed with the weight bearing knee to wall test (KW). Surfers that have limitations in their ankle dorsiflexion ROM may be inhibited to perform some of the movements required to become a successful professional surfer, as several maneuvers require the athletes to control fully compressed body positions while being barefoot on the board. It is recommended that strength and conditioning professionals keep track of surfing athletes' KW measure, as well as their symmetrical strength and postural control in the lower extremity and implement appropriate training interventions if deficits are detected.

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APPENDIX K: CONFERENCE ABSTRACT

JUMP SQUAT VARIABLES FOR COMPETITIVE SURFING ATHLETES

Lundgren, L.1,2, Tran, T.1,2, Sheppard, J.1,2

Computing, Health and Science

1: ECU (Joondalup, Australia), 2: Hurley Surfing Australia HPC (Casuarina beach, Australia) Introduction Performance testing for surfing athletes should include lower extremity strength and power, because of the need for the athlete to produce and arrest force, primarily through the lower body, to execute manoeuvres. The jump squat and isometric mid-thigh pull tests (IMTP) have been validated previously as worthwhile discriminators between performance levels (Sheppard et al. In press). The aim of this study was to analyze variables that may have an effect on jump squat height (JH) in Junior to Elite surfers. Methods Twenty eight competitive surfers (11 Females and 17 Males), divided into two age groups (<16 and ≥ 16 , $n=15$ and 13), performed three jump tests and IMTPs where the maximum score was used for analysis (JH and Peak Force (PF) respectively). The jump test was a countermovement jump on a unidirectional force plate (Fitness Technology 400S, Adelaide Australia), with a linear encoder (IDM Instruments) attached to a wooden dowel that was held onto the back to measure height and velocity. Data was recorded simultaneously by personal computer (BMS Software, Innervations). The IMTP was performed as previously described (Haff et al., 1997), using an identical force plate. Variables extracted for correlation to JH was Peak Power (PP), Peak Force (PF), Peak Velocity (PV), Maximum Negative Velocity (MNV), Flight Time (FT), Rate of Force Development in take-off (RFDTO) and IMTP PF (normalized and relative to BW). Results The group means for JH were $0.35 \text{ m} \pm 0.03$ for the $<16 \text{ F}$, $0.39 \text{ m} \pm 0.06$ for the $<16 \text{ M}$, $0.40 \text{ m} \pm 0.05$ for the $\geq 16 \text{ F}$ and $0.52 \text{ m} \pm 0.09$ for the $\geq 16 \text{ M}$. The variables that had a moderate to strong correlation with JH ($p<0.05$) for the <16 group were PP ($r=0.60$), PV ($r=0.73$), MNV (-0.91) and FT ($r=0.67$). For the group of ≥ 16 the variables that had a strong correlation with JH ($p<0.001$) were: PP ($r=0.87$), PF ($r=0.95$), PV ($r=0.90$), MNV ($r=-0.88$) and RFDTO ($r=-0.88$). IMTP PF normalized for BW had a moderate correlation to JH for the older group ($r=0.66$, $p<0.05$). Discussion The variables that showed effect on jump height for both groups were PP, PV, MNV and FT, which is in accordance with previous results (González-Badillo and Marques, 2010). The correlation between JH and MNV shown in this study was very strong in comparison to other studies (González-Badillo and Marques, 2010), and may indicate that surfing athletes with the physical capabilities to execute a faster descendent phase during the CMJ may lead to greater JH. Also, possessing a greater isometric is likely important for JH performance for older athletes. References Haff GG, Stone MH, O'Bryant HS, et al. (1997). *J Strength Cond Res*, 11, 269-271. González-Badillo JJ, Marques MC. (2010). *J Strength Cond Res*, 24(12), 3443-3447. Sheppard JM, Nimphius S. et al. (In press) *Int J Sport Perf Phys*.

HEART RATE VARIABILITY AND PRECOMPETITIVE ANXIETY IN JUDO

Morales, J.1, Garcia, V.2, Buscà, B.1, García-Massó, X.3, Alamo, J.M.4, González, L.M.3

1: Ramon Llull University 2: Universitat de Girona, 3: Universitat de València, 4: Universitat de Barcelona

Introduction Anxiety in sports is a complex phenomenon that is related to emotional and cognitive processes that can cause physiological changes in the participating athletes (Cervantes, Rodas and Capdevila, 2009). Judo is an activity with a high level of uncertainty and high physiological and psychological demands. Heart Rate Variability (HRV) parameters are sensitive to changes in rates of anxiety as measured through CSAI-2R in pre-competitive situations (Mateo et al., 2011). The aim of the study was to examine HRV in stressful situations before judo competitions and to observe the differences among judo athletes in official and unofficial competitions. Material and Methods 24 national-standard judo athletes participated in this study. All subjects underwent measurements of pre-competitive anxiety and HRV in the official and unofficial competition days. The HRV was recorded at rest with each participant using a cardio tachometer and the RR signal (beat to beat) for 10 minutes. HRV was analysed using time, frequency and nonlinear domain variables. Afterwards, the Revised Competitive State Anxiety-2 (CSAI-2R) was administered prior to weight control. A repeated measures ANOVA was performed to assess the effects of the competition type on the dependent variables related to pre-competitive anxiety (CSAI-2R) and derived from the HRV. Results The ANOVA showed significant main effects of the type of competition in CSAI-2R, in HRV time domain, in HRV frequency domain and in HRV nonlinear analysis ($p<0.05$). Judo athletes have lower somatic anxiety, cognitive anxiety, heart rate and low-high frequency-high frequency ratio in unofficial than in official competitions ($p<0.05$). The parameters of the nonlinear analysis were significantly greater ($P<0.05$) in the unofficial competitions than in the official competitions Discussion The major findings of this study is the observation of higher levels of pre-competitive anxiety in judo athletes is related with a increase in sympathetic nervous activity and decreased parasympathetic nervous activity. The relationship between CSAI-2R and HRV show that pre-competitive anxiety scores vary depending on the importance of the competition. These results are consistent with studies that have used a psycho physiological approach, in which the two methods have similar behaviours: in comparison with hormone levels (Filaire et al., 2001) or when using HRV (Oreshnikov, Tihorov and Agafonkina, 2009). References 1. Cervantes JC, Rodas G, Capdevila L. (2009) *Psicothema*, 21, 531-536. 2. Filaire E, Sagnol M, Ferrand C, Maso F, Lac G. (2001) *J Sports Med Phys Fit*, 41, 263-268 3. Mateo M, Blasco-Lafarga C, Martínez-Navarro I, Guzmán JF, Zabala M. (2011) *Eur J Appl Physiol*, 11, 1-11. 4. Oreshnikov E, Tihonov V, Agafonkina T. (2009), *Hum Physiol*, 35, 517-519.