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Setting qualitative performance parameters of elite surfing aerial manoeuvres with 360° rotation

Establecimiento de parámetros cualitativos de rendimiento de maniobras aéreas de surf de élite con rotación de 360 grados

Definição de parâmetros qualitativos de desempenho de manobras aéreas de surf de elite com rotação de 360 graus

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RESUMEN

El objetivo fue analizar parámetros de maniobras aéreas de surf de alto nivel, apoyando el entrenamiento específico y la prevención de lesiones. Utilizando análisis de video de maniobras aéreas completadas por surfistas masculinos de top-5 en 19 eventos durante las temporadas 2018 y 2019 del World Championship Tour, se seleccionaron (n=97): Frontside Air, Frontside Air Reverse 360, Backside Air y Backside Air Reverse 360. Se trata de una investigación de método mixto. Tiene un análisis de tarea cualitativo, realizado a través del análisis en fases, considerando características clave de las acciones corporales y principios de movimiento. A través de la metodología observacional (nomotético, puntual y multidimensional) se midió la altura del aéreo, el ancho del BoS y los ángulos de flexión de la rodilla y del tobillo delanteros. Las referencias en el análisis cualitativo fueron: rotación de cabeza y tronco, triple flexión de miembros inferiores (*preparación*) y más pronunciada en la *recuperación*; flexión de cabeza, tronco y brazos desde el despegue (*preparación*) hasta el pico del vuelo (*principal*) provocando el desplazamiento anterosuperior del CoM; ampliación de la BoS para aéreos frontales (*principal*). El análisis cuantitivo permitió identificar la media de la altura del aéreo (169,60±52,85cm), del ancho de la base de sustentación (BoS) (79,17±13,72cm), y de los ángulos de flexión de la rodilla (113,78±19,90º) y del tobillo (32,74±14,51º) delanteros durante el aterrizaje. El análisis descriptivo puede contribuir al desarrollo de programas de formación específicos para la enseñanza y el aprendizaje, con el objetivo de mejorar el rendimiento de las maniobras aéreas.

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Palabras clave: surf, análisis descriptivo, análisis en fases, rendimiento aéreo, metodología observacional.

ABSTRACT

Purpose was to analyse parameters of high-level surfing aerial manoeuvres, supporting specific training and injury prevention. Using video analysis of aerials completed by top-5 male surfers in 19 events during 2018 and 2019 seasons of the World Championship Tour, were selected (n=97): Frontside Air, Frontside Air Reverse 360, Backside Air and Backside Air Reverse 360. This is a mixed method research. Has a qualitative task analysis, carried out through phase analysis, considering key features from body actions and principles of movement. Through observational methodology (nomothetic, single point and multidimensional) was measured the aerial height, the BoS width, and flexion angles of front knee and front ankle. Qualitative analysis references were: rotation of the head and trunk, triple-flexion of the lower limbs (retraction) and more pronounced in the follow-through; head, trunk, and arms flexion from the take-off (retraction) to the peak of the flight (action) causing the anterosuperior CoM displacement; widening of the BoS for frontside aerials (action). Quantitative analysis allowed to identify the mean of aerial height (169.60±52.85cm), of base of support (BoS) width (79.17±13.72cm), and flexion angles of front knee (113.78±19.90º) and front ankle (32.74±14.51º) during landing.
Descriptive analysis may contribute to the development of specific training programs for teaching and learning, aiming to improve performance of aerial manoeuvres.
Keywords: surfing, descriptive analysis, phase analysis, aerial performance, observational method.

RESUMO

O objetivo foi analisar parâmetros de manobras aéreas de surf de alto nível, dando suporte ao treino específico e à prevenção de lesões. Através da análise de vídeo de manobras aéreas concluídas por surfistas masculinos do top-5, em 19 eventos durante as temporadas 2018 e 2019 do World Championship Tour, foram selecionados (n=97): Frontside Air, Frontside Air Reverse 360, Backside Air e Backside Air Reverse 360. Este é um estudo com um método misto. Temos uma análise da tarefa qualitativa, realizada através da análise por fases, considerando as principais características das ações corporais e dos princípios do movimento. Através da metodologia observacional (nomotético, pontual e multidimensional) foi medida a altura do aéreo, a largura do BoS e os ângulos de flexão do joelho e do tornozelo dianteiros. As referências da análise qualitativa foram: a rotação de cabeça e tronco, tripla flexão dos membros inferiores (*preparação*) e mais acentuada na *finalização*; flexão da cabeça, tronco e braços desde a descolagem (*preparação*) até o pico do voo (*ação principal*) causando o deslocamento antero-superior do CoM; alargamento da BoS para aéreos frontais (*ação principal*). A análise quantitativa permitiu identificar a média da altura do aéreo (169,60±52,85cm), da largura da base de sustentação (BoS) (79,17±13,72cm) e dos ângulos de flexão do joelho (113,78±19,90º) e tornozelo (32,74±14,51º) dianteiros durante a aterragem. A análise descritiva pode contribuir para o desenvolvimento de programas de treino específicos para ensino e aprendizagem, visando melhorar o desempenho das manobras aéreas.
Palavras chave: surf, análise descritiva, análise por fases, desempenho aéreo, metodologia observacional.

INTRODUCTION

Surf is a growing sport all over the world at a recreational and competitive level (Forsyth et al., 2018, 2020), having gained even more notoriety with its recent debut at the 2021 Summer Olympic Games at Tokyo, Japan.

The elite competitive division called Championship Tour (CT), held by World Surf League (WSL) allows 36 top surfers to compete against each other in 11 events worldwide during the competitive season, in

30 to 40 minutes *heats*. The judges score the manoeuvres performed on all the waves that the athletes choose to ride and classify them on a scale ranging from 0 to 10 points. Each surfer best 2 single-wave scores will determine the heat result (out of a possible 20 points), on a 2 to 3 surfers competition *heats* format, through 6 or 7 rounds to reach the final that will crown the event winner (Forsyth et al., 2017, 2018; Lundgren et al., 2014).

The scoring of each wave ridden is based on the manoeuvres performed on it, considering the location and the conditions during the day, and according to the judging criteria of "*Commitment and degree of difficulty; Innovative and progressive manoeuvres; Combination of major manoeuvres; Variety of manoeuvres; Speed, power and flow*" (WSL, 2022).

Because of its difficulty in performing, for more than a decade now, aerial manoeuvres - where the surfer projects himself and the board above the wave's lip, controls the board while airborne and lands back on the wave's surface (Forsyth et al., 2018; Lundgren et al., 2014; Ferrier et al., 2018) - are increasing in competitive surfing. The surfer must control its centre of mass (CoM) during the entire trajectory, including the reception/landing at the wave, keeping the alignment with the boards' centre of buoyancy to ensure balance control (Moreira and Peixoto, 2014). Besides, aerials can present multiple variations (Moreira and Peixoto, 2018), whether they are performed frontside (FS: toes facing the wave) or backside (BS: heels facing the wave) (Warshaw, 2003), and concerning the direction of rotation where a rotation occurred (Air Reverse: rotation of the outside rail towards the shore; Alley Oop: rotation of the inside rail towards the wave (Moreira, 2009).

The high degree of difficulty (Forsyth et al., 2017, 2020; Lundgren et al., 2013, 2014; Ferrier et al., 2018), combined with their low successful completion rates (Lundgren et al., 2013, 2014; Forsyth et al., 2017), and higher risk of lower limb injuries associated (Lundgren et al., 2014; Furness et al., 2015; Nathanson et al., 2007; Hohn et al., 2020), increases aerials scoring potential (Lundgren et al., 2014). Therefore, a successfully completed aerial manoeuvre results in higher heat total (sum of two best scoring waves) and peak scores during elite competitive events, when compared to a wave ridden without the aerial manoeuvre (Lundgren et al., 2014; Ferrier et al., 2018). However, aerial completion rates among elite surfers are as low as 45 to 55% (Lundgren et al., 2014; Forsyth et al., 2017), being the lower limbs the most frequently injured area (Nathanson et al., 2007), affecting mainly the knee (28%) and ankle (26%), and often associated with aerial manoeuvres (Hohn et al. 2020). Moreover, ankle injuries associated to aerial manoeuvres seem to be related to the inability of some surfers to properly absorb the forces generated at landing due to restricted ankle motion (Forsyth et al., 2021).

Landing surfing aerials, successfully and safely, seems to rely not only on physical fitness like lower-body strength and ankle range-of-motion (ROM) (Lundgren et al., 2015; Secomb et al., 2015), but also on technical skills, like surfers' centre of mass (CoM) placement over the surfboard centre of buoyancy, and the ability to absorb generated forces during landing (Forsyth et al., 2018, 2021; Moreira and Peixoto, 2014).

Although Moreira & Peixoto (2014) and Forsyth et al. (2018, 2020, 2021) already high lightened the importance of dry-land surfing simulated aerial tasks to optimize performance and prevent lower limb injuries, there is no technical references to the movements performed by world class elite surfers, which might contribute to a better understanding of body motor actions and support specific training and injury prevention strategies accordingly.

To clearly assess performance, there's a need to use qualitative, quantitative, and predictive methods within biomechanical analysis of the technique, based on observation (Lees, 2008). This can be accomplished not only by the description of the movement in relevant parts - phase analysis - that relies on phases and sub-phases to identify key moments and key features; but also, through the identification of movement principles, based on mechanical relationships and multi-segments interactions of the human body (Lees, 2008).

Therefore, the aim of this study is to establish a descriptive reference (qualitative and quantitative) of aerial manoeuvres with high quality of execution, concerning movement phases, movement principles, and their key features, observed in world class elite surfers during competition.

MATERIALS and METHODS

Design

This is a mixed method research, as it combines qualitative and quantitative approaches (Anguera et al., 2018).

The task analysis with qualitative data starts with sports performance analysis method proposed by Peixoto (1997) with a phase analysis (Knudson and Morrison, 1997; Bartlett, 1997, 2007; Lees, 2002, 2008) which consists in dividing up the movement into three phases for technique description considering key features from body actions and principles of movement (Bortoleto et al, 2011). The description came out from a triangulation of data gathered from the bibliography, the observation and experts' analysis. (Moreira & Peixoto, 2014)

The observational methodology with quantitative data is nomothetic (several participants/ aerial manoeuvres), single point (there's no monitoring of the surfers/ aerials performed) and multidimensional (several dimensions are observed that correspond to the criteria of the validated ad hoc observational instrument – the video-analysis software). (Anguera et al., 2011).

Participants

Two experts with more than 20 years of surfing practice: expert 1 had more than 15 year of movement analysis as a physiotherapist also working with surfers; expert 2 had more than 20 years of movement analysis as a surfing coach and researcher.

Top-5 male surfers from the 2018 and 2019 WSL competitive seasons, who performed 254 aerial manoeuvres, of which the Frontside Air Reverse 360 (FSAR360; n=68) and Backside Air Reverse 360 (BSAR360; n=29) were analysed, in a total of 97 manoeuvres.

Instruments

The video images have been selected from the on-line video content available on the World Surf League (WSL) website, through its "heat analyser" function, and selected videos were downloaded with VideoLAN™ open-source software.

Qualitative descriptive performance analysis of these manoeuvres was carried out using the observational sheet presented bellow (Table 1), adapted from Peixoto (1997) and Knudson (1997; 2013). With VideoLAN™ open-source software *VLC Media Player™* a frame selection was obtained by *freezing*/pausing the video images and saving them with the computers' "screen shot" function (keyboard shortcut windows+shift+s).

Quantitative descriptive performance analysis of all selected manoeuvres was carried out using the open-license video annotation software Kinovea® (version 0.8.15 for Windows) for sport analysis, allowing frame by frame analysis.

Table 1: Observational sheet for surfing manouvers analysis

Surfer's goal	Description of what should be achieved including relation between surfers' movement and boards' movement, riding trajectory and wave movement.
Phase name (retraction, action, or follow-through)	
Frames *(f.)*	Insert the selected frames that better illustrate the action in each phase; numbered with an increase order with same direction as the movement.

Segment actions	Body actions description related with inseted frames, from bottom to top (feet, knees, hip, trunk, arms, and head) and movement description with reference to anatomical posture description, related to the waves or surfboard positioning.
Principles of movement	For each frame, identification of the surfers' Centre of Mass (CoM) position and movement, and Line of Gravity (LG) relation with surfboard and the Base of Support (BoS).
Surfboard action	For each frame,description of the surfboards' movemenst with reference to a floating position, considering its parts (bottom, deck, nose, tail, and rails) and related with wave's face.

Procedures

As a way of knowing which aerials are performed in competition, we observed 19 events carried out during the 2018 and 2019 Men's CT, where all surfed waves containing successfully landed aerial manoeuvres (n=254) were selected from the on-line video content available on the World Surf League (WSL) website, through its "heat analyser" function. To establish a performance quality criterion, only the waves scored equally or over five points, and performed by the top-5 ranked surfers (n=185) were taken in count to analysis. Finally, we used the highest *n* and the *highest scores* also as quality criteria.

From those, 185 aerials were selected for analysis: the Frontside Air Reverse 360 (FSAR360) and Backside Air Reverse 360 (BSAR360), because of their higher frequency of completion (FSAR360: n=68) and scoring (BSAR360: mean score = 7.64±.85pts pts); Frontside Air (FSA) and Backside Air (BSA) for being the genesis of aerial manoeuvres.

For the qualitative analysis, once the four manoeuvres to be analysed were identified, each one was described according to the information available in the bibliography (Warshaw, 2003; Moreira and Peixoto, 2008, 2014; Piter & Testamale, 2012) including the identification of manoeuvres general goal (surfer's goal) and identification of manoeuvres specific goal (execution). With this information, the manoeuvres were divided into three phases (retraction, action, and follow-through), with the identification of the key features that characterize each one of them.

For the select manoeuvres the: *(a) retraction phase*, refers to the body adjustments before take-off; *(b) action phase*, is during airborne movement; *(c) follow-through* phase, refers to landing since the board contacted the wave's surface.

The videos with the best scores for each of the manoeuvres were then viewed and analysed by Expert 1. To choose a video for each manoeuvre, it was checked if the images illustrated the three phases and the respective movements. If this did not happen, the second-best execution was observed, and so on, until a video of each was obtained. As the BSA was not executed in any event, a search was made for videos that were within the previous criteria, choosing one that was available in *Stomp Sessions*™ video tutorials webpage (Stomp Sessions, 2021). The video chosen for each manoeuvre was then downloaded from the internet and recorded on the computer to be viewed with the VideoLAN™ open-source software *VLC Media Player*™.

The observation was done in 5 trials, with real time video replay, from general to specific, with focus on different key features (Knudson, 1997; 2013): observation of movement control and balance; relation between surfers' movement and boards' movement; riding trajectory and wave movement; phases of the movement and frames that better illustrate the action in each phase. An extended observation was done with slow-motion video replay, and frame by frame video replay to select and save the frames of each phase.

The selected frames were inserted at the top of the observational sheet with an increase order with same direction as the movement (i.e., if the surfer rides the wave from right to left, this is the frames order).

For each of these phases the task was analysed based on its key features: *(i) body actions*; (*ii) principles of movement*; *(iii) surfboard movement*. The focus on *body actions* was from bottom to top (feet, knees, hip, trunk, arms, and head) and the movement description was with reference to anatomical posture. The *principles of movement* identified with video analysis were the surfer's centre of mass (CoM), identified using the hem of each surfer's competition rash vest, which was located at the waist of each surfer, and was clearly distinguishable from each surfer's dark wetsuit/ coloured boardshorts; the line of gravity (LG), being the vertical projection of the CoM; and the Base of Support (BoS), defined by the area between both feet placed on the board.

The *surfboard action* was with reference to a floating position, considering the surfboard parts (bottom, deck, nose, tail, and rails).

The Expert 2 review was done through frames observation, from general to specific: confirmation of manoeuvres general goal (surfers' goal); confirmation of manoeuvres specific goal (execution); focus on phases of the movement and confirm if the chosen frames illustrate the action in each phase. Then for each phase the task was analysed based on its key features: *1st) body actions*; *2nd) principles of movement*; *3rd) surfboard action*. After some readjustments the final report was done including a review of all manoeuvre's description with focus on terminology.

After Expert 1 confirmed the final report the key features data analysis was carried out.

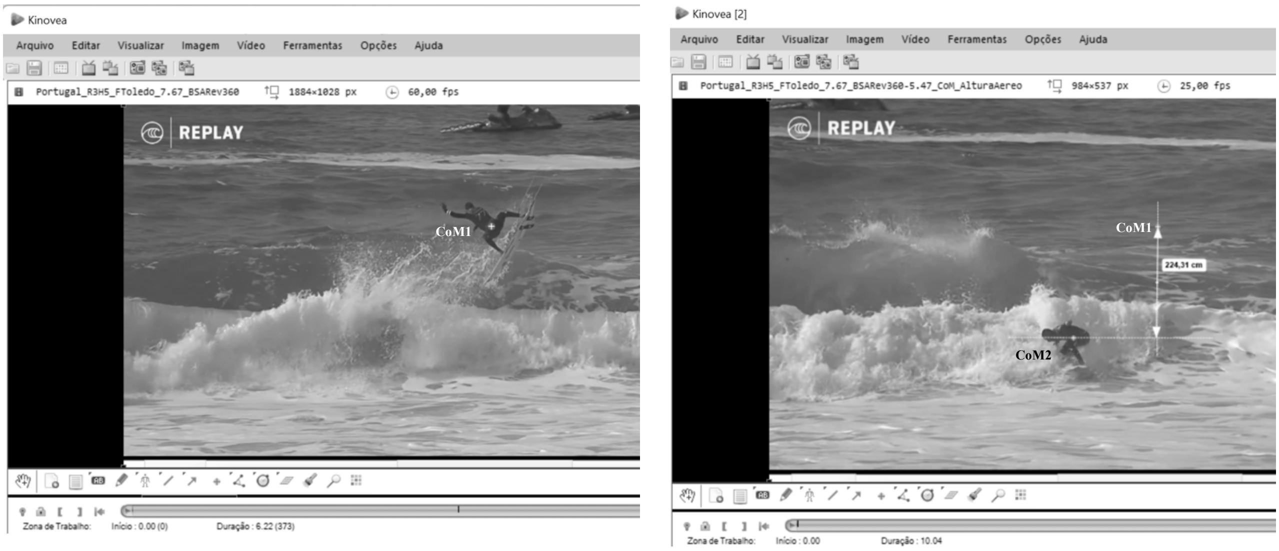
Qualitative analysis does not incorporate any system of codes/categories, as used for some mixed method observations (Anguera et al., 2018), once it was carried out with the phase analysis model (Peixoto, 1997; Knudson and Morrison, 1997, 2013; Bartlett, 1999, 2007; Lees, 2002, 2008; Bortoleto et al, 2011).

Because of the low frequency of FSA (n=12) and BSA (not observed) we opted to address the quantitative analysis only, for both FSAR360 (n=68) and BSAR360 (n=29). The FSA and FSAR360 were when the surfer starts with toes facing the wave, while for BSA and BSAR360, he starts with heels facing the wave.

For scaling purposes, absolute height of top-5 ranked surfers was considered, as described at the WSL website, to calculate leg size (distance from lateral malleolus to lateral condyle of the knee) on the frontal plane. For every surfer, leg size was then utilized in Kinovea® software during video annotation to set the scale to determine the measurements mentioned as below.

For the quantitative analysis data was collected from: aerial height, measuring the surfers' CoM distance from the highest position (CoM1) at *action phase* (utilizing frame A, being the highest point of surfer's trajectory, just before the beginning of going down trajectory) to the lowest position (CoM2) at *follow-through phase* (utilizing frame B, being the lowest point of surfer's trajectory after landing) *(Figure 1);* BoS width, measuring both heels distance (cm) utilizing frame A, being the highest point of surfer's trajectory and in a frontal plane at *action phase* (being the same as at the *follow-through phase,* because feet don't move) (*Figure 2*); knee angle was measured considering zero (0º) as total knee extension (no flexion) at *follow-through phase* (landing) (*Figure 3*); and ankle angle was measured considering neutral position as zero (0º; no plantar/dorsiflexion) up to maximum degree of dorsiflexion, at *follow-through phase* (landing) (*Figure 4*). To measure knee and ankle angles, it was utilized the frame that presents the joint in a sagittal plane, being the surfer at is lowest position after landing. The point selection to determine knee and ankle angles was performed utilizing anatomical references (knee: femur and tibial lines crossing the lateral knee condyle area; ankle: 5th metatarsal and fibula lines crossing the external malleolus area). Due to bad camera angle and/or water displacement covering mainly the back lower limb during landing, only front knee and ankle were considered to angles measuring purposes.

Figure 1 – Aerial height (frames captured from Kinovea® analysis software)



Frame A *Frame B*

Frame A: surfers' CoM1 (action phase); Frame B: surfers' CoM2 & aerial height (follow-through phase)

Figure 2 – BoS width (frames captured from Kinovea® analysis software)

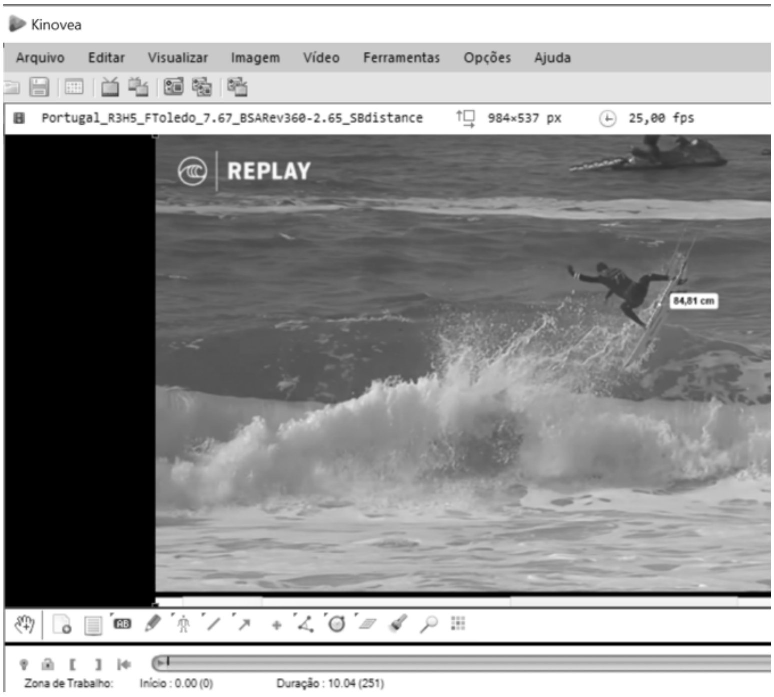


Figure 3 – Front Knee flexion angle (frames captured from Kinovea® analysis software)

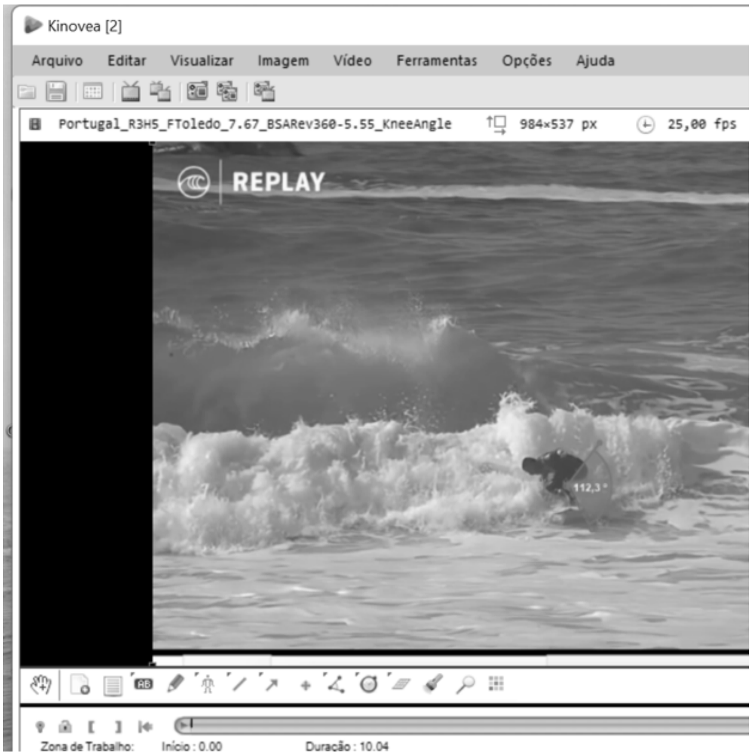
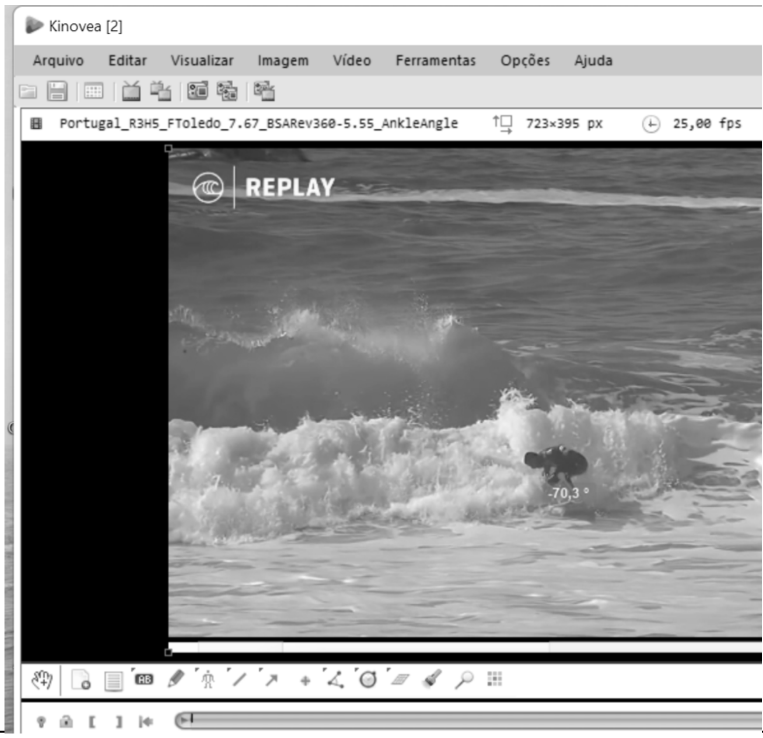


Figure 4 – Front Ankle dorsiflexion angle – scores measured from 90º neutral position. e.g.: 90º-70.3º= 19.7º dorsiflexion (frames captured from Kinovea® analysis software)



Statistical Analysis

To characterize the aerials according to the different variables of height, BoS width, knee and ankle angles at landing, descriptive statistics, mean and standard deviation were used; to compare those variables between the FSAR360 and BSAR360, the *t test* was used. A significance level of 5% was considered in all tests.

Although there is no previous reference or gold-standard procedure description on how to measure surfing aerials variables, interclass correlation coefficient (ICC) was calculated to determine intra-observer validity, being the ICC estimates and their 95% confident intervals based on a two-way mixed effects model, single measurements, absolute agreement. To gauge ICC, 20% of the videos (n=19) were selected "by convenience" to ensure there was an adequate image for observation of joint angles. The measurement of the four variables was conducted by expert 1 two times (observation 1 and observation 2), with a two-week interval (Cejudo et al, 2012).

The statistically analysis was computed with Statistical Package for the Social Sciences (v 28.0; SPSS Inc.) software.

RESULTS

The ICC and its 95% confidence interval (IC) was considered "excellent" (Koo, 2016) , as it was higher than 0.90 for all variables measured (Table 2).

Table 2: Interclass coefficient agreement between 2-week observations interval

Variables	Observation 1 (mean±SD)	Observation 2 mean±SD)	ICC (95% CI)
Aerial height (cm)	187.54±45.68	188.15±45.81	0.989 (0.974 - 0.995)
BoS width (cm)	78.06±16.69	78.13±16.88	0.997 (0.992 - 0.999)
Front knee Flexion (º)	116.58±20.83	116.40±21.18	0.990 (0.986 - 0.998)
Front ankle DFlexion (º)	31.36±13.24	31.56±13.72	0.990 (0.981 - 0.997)

Abbreviations: cm: centimetres; º: degrees, measured at landing; SD: Standard-deviation; DFlexion: Dorsiflexion. *Significant difference: $p<0.05$

For both 2018 and 2019 competitive seasons, 3 of the top-5 surfers were the same, from Brazil, and performed 72.16% (n=70) of the four different aerials selected for analysis (n=97), according to the criteria previously defined. Scores and frequencies, shown on Table 3, point out the differences between the aerials performed, as the highest frequency of performance (FSAR360), and highest wave riding score (BSAR360). The FSA and the BSA are at the genesis of the aerial manoeuvre, and although the BSA wasn't performed by any top-5 surfers during 2018 and 2019 competitive seasons, since it's in the genesis of all back-side air manoeuvres, it is crucial to understand how it is performed, through phase analysis, as shown on Table 5.

Table 3: Frequencies and scores of 3 aerial manoeuvres for the top-5 2018 and 2019 WSL surfers.

	2018 season		2019 season		*Mean score*
	n	*score*	*n*	score	
FSA	4	7.74±1.95	8	7.55±1.48	7.64±1.71
FSAR360	36	7.13±0.96	32	7.32±1.31	7.22±1.13
BSAR360	7	7.99±2.38	22	7.29±1.33	7.64±1.85
Total	47		62		

Abbreviations: FSA: Frontside Air; FSAR360: Frontside Air Reverse 360; BSAR360: Backside Air Reverse 360

Qualitative analysis allowed us to describe the surfer’s goal for each manoeuvre. For any aerial, the surfers’ goal is to project itself and the board, flying above the wave for passing over a wave section in the air, with a 90° rotation (FSA and BSA) or 450º rotation (FSAR360 and BSAR 360) on the anteroposterior axis of the board towards the side of the outer rail (Moreira, 2009; Moreira and Peixoto, 2014), with the feet maintaining the same relative position with the board throughout the movement.
The surfer has a forward and side shift depending on the waves’ peel angle. To be successful, for all four aerials, the surfer approaches the lip of a wave with enough wall and power, with maximum speed; keeping the section he wants to use has launch pad targeted, he must extend the bottom turn to aim above it, with maximum speed and a launching angle of approach of 45° to the lip (Moreira and Peixoto, 2008, 2014; Piter and Testemale, 2012).

The phase analysis was carried according to the three phases and key features of each of the four aerials, as detailed on Tables 4, 5, 6 and 7.

Table 4: Frontside Air – phase analysis

Surfer’s Goal: to project itself and the board, flying above the wave for passing over a section in the air. It must have a 90° rotation on the anteroposterior axis of the board towards the side of the outer rail (Moreira, 2009), with the feet maintaining the same relative position with the board throughout the movement.
The surfer has a forward and side shift depending on the waves’ peel angle; approaches the lip of a wave with enough wall and power, with maximum speed and toes facing the wave; keeping the section he wants to use has launch pad targeted, he must extend the bottom turn to aim above it, with maximum speed and a launching angle of approach of 45° to the lip (Warshaw, 2003; Piter & Testamale, 2012).
Note: frames displayed, numbered and sequenced according to the direction of the movement

Retraction phase	
Frames *(f.)* (wave riding from right to left)	  
Segment actions	***f.1***: the back foot is on the boards tail and perpendicular to the stringer; the front foot is at the centre of buoyancy of the board and oblique to the stringer; both knees, hips and trunk are flexed; both arms are obliquely and inferiorly aligned, in line with the boards’ inner rail; the neck is extended and slightly rotated to the front shoulder, with the eyes focused on the waves’ lip. ***f.2***: the back foot’s ankle is flexed back; the front knee is slightly extended; the trunk is extended and rotated outwards, with the head following and the eyes focusing the boards’ nose; both arms are raised, with the front arm being at on the side of the outer rail and the back arm on the side of the inner rail ***f.3***: the front knee and hip are flexed; the back foot´s ankle is more flexed back; both hands are raised up

Principles of movement	***f.1***: the CoM is projected down towards the back foot, passing the inner rail and projecting itself on the waves' face; the LG falls out of the inner rail in the middle point between both feet - the BoS ***f.2***: the CoM goes up with vertical speed; the LG falls out on the back foot´s heel ***f.3***: the CoM is projected up and forward the surfer's body; the LG falls out back of the boards' tail
Surfboard action	The board slides through the waves' face. ***f.1***: the board is set horizontally with the inner rail at the waves face ***f.2***: the board is oblique with the inner rail and bottom in contact with the wave. ***f.3***: the board is almost vertical with the tails' inner rail area in contact with the wave

	Action phase
Frames *(f.)* (wave riding from right to left)	   
Segment actions	***f.4***: the front foot, knee and hip are flexed in a way that the thigh is close to vertical; the trunk is vertical, as both arms are horizontally aiming close to the boards' nose. The back foot is near the tail, at the same position as before. ***f.5***: both hips and knees are flexed, rotated towards the front leg and close to a sitting position, with ankles in dorsiflexion; the trunk is flexed beyond vertical and rotated outwards; arms are rotated in and aiming both inside (front arm) and outside (back arm) rails; the head is neutral with the eyes focusing the inner rail. ***f.6***: both arms are rotated out and raised and straight up, in line with the over vertical flexion of the trunk. ***f.7***: knees and hips are slightly extended; trunk is extended close to vertical; arms are raised in line with the head, with the hands up; the head is flexed with eyes focusing the impact area.
Principles of movement	The CoM is projected forward towards the board (***f.4*** to ***f.7***); the LG falls out of the boards' tail (***f.4***), outside of the outer rail (***f.5***), moving towards the board and the front foot (***f.6*** & ***f.7***).
Surfboard action	The board is airborne. ***f.4***: it is vertically and long axis 90° rotated outwards to the outer rail ***f.5***: it is anteroposterior axis 90° rotated outwards and oblique with the waves´ bottom (transverse axe rotation); the sliding direction is inverted. ***f.6*** & ***f.7***: it is set with an angle close to the waves' steep.

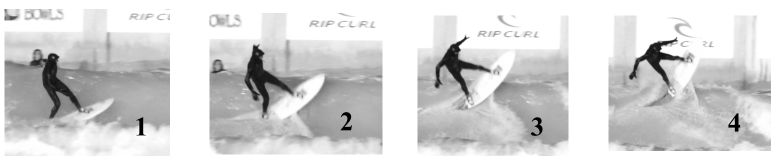
	Follow-through phase
Frames *(f.)* (wave riding from right to left)	  
Segment actions	***f.8***: the back foot, knee and hip are more flexed than the front ones; the trunk is slightly flexed, as both arms are obliquely and inferiorly aligned, in line with the boards' inner rail; the head is flexed and rotated outwards with the eyes focusing the boards´ nose. ***f.9***: both forearms are extended and raised head high towards the inner rail. ***f.10***: both feet are in dorsiflexion; knees and hips are flexed close to a sitting position; trunk is flexed over the vertical; both arms are obliquely and inferiorly aligned, in line with the boards' inner rail, with both hands touching the water.
Principles of movement	The CoM is projected forward above the centre of the board (***f.8***) as it goes down (***f.9***) and close to the inner rail (***f.10***); the LG falls close to the front foot (***f.8*** & ***f.9***), as it goes

	forward to the inner rail(***f.10***). The BoS is set with both feet perpendicular to the board's navel, and it's wide enough so that the front foot is in front of the CoB, and the back foot is placed at the board's track pad, close to the tail.
Surfboard action	The board gets in contact with the wave surface. ***f.8***: it is oblique and perpendicular, aligned with its current steep. ***f.9***: all the bottom of the board is in contact with the waves' face, more shifted to the inner rail. ***f.10***: the board is slightly rotated to the inner rail.

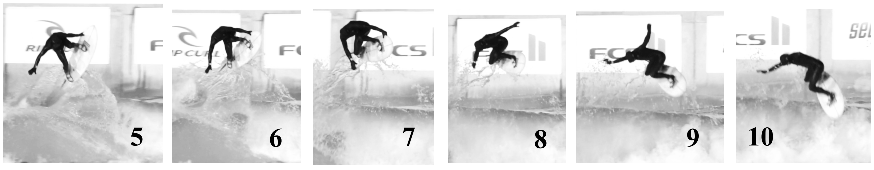
*Abbreviations:**CoB: Centre of Buoyancy; CoM: Centre of Mass; **LG: Line of Gravity – vertical projection of the CoM; ***BoS –Base of Support. *Images courtesy of World Surf League (WSL)*

Table 5: Backside Air – phase analysis

Surfer's Goal: to project itself and the board, flying above the wave for passing over a section in the air. It must have a 90° rotation on the anteroposterior axis of the board towards the side of the outer rail (Moreira, 2009), with the feet maintaining the same relative position with the board throughout the movement.
The surfer has a forward and side shift depending on the waves' peel angle; approaches the lip of a wave with enough wall and power, with maximum speed and heels facing the wave; keeping the section he wants to use has launch pad targeted, he must extend the bottom turn to aim above it, with maximum speed and a launching angle of approach of 45° to the lip (Warshaw, 2003; Piter & Testamale, 2012).
Note: frames displayed, numbered and sequenced according to the direction of the movement

	Retraction phase
Frames *(f.)* (wave riding from left to right)	
Body actions	***f.1***: the back foot is over the boards' tail and perpendicular to the stringer with the ankle in dorsiflexion; the front foot is at the CoB of the board and oblique to the stringer, the back knee is more flexed than the front knee, and the back hip is less flexed than the front hip, and rotated inwards; the trunk is rotated inwards and slightly flexed towards the boards' nose; the front arm is apart and perpendicular to the trunk, as the back arm is obliquely and inferiorly aligned, in line with the boards' inner rail; the neck is extended with the eyes focused on the waves' lip. ***f.2***: the back knee and hip are slightly flexed and rotated inwards; the front knee and hip are close to extension; the trunk is rotating and slightly flexed towards the outer rail; the front arm is apart and perpendicular to the trunk, as the back arm is apart and the elbow flexed, inferiorly aligned, in line with back leg; the neck is extended with the eyes focused on bards' nose. ***f.3***: the back foot is extended, as the back knee and hip are slightly extended and rotated outwards; the trunk is rotating and flexed towards the outer rail, close to the back foot; the front arm is apart and perpendicular to the trunk, as the back arm is apart and perpendicular to the trunk, being the elbow slightly flexed; the neck is extended with the eyes focused on waves' face. ***f.4***: the front knee is flexed; the trunk is rotated and flexed towards the outer rail, between both feet; both arms are apart and perpendicular to the trunk in line with the stringer; the neck is flexed with the eyes focused on the waves' face.

Principles of movement	***f.1***: the CoM goes up and forward with a linear speed; the LG falls towards the back knee on the tail pad, close to the back foots' toes. ***f.2***: the CoM goes up and forward with a linear speed; the LG falls on the back foot, between the boards' stringer and outer rail. ***f.3***: the CoM goes up and forward with a linear speed; the LG falls outside the surfboard, close to the tail pad. ***f.4***: the CoM goes up and forward with a linear speed; the LG falls outside the surfboard, behind the tail pad.
Surfboard action	The board slides through the waves' face. ***f.1***: the board is set oblique and with the inner rail at the waves' face ***f.2***: the board is oblique with the inner rail and bottom in contact with the waves' face, but with the outer rail out of the water. ***f.3***: the board is more oblique with the tails' inner rail area in contact with the wave ***f.4***: the board is more oblique, close to vertical with the tails' inner rail and fins area in contact with the wave

	Action phase
Frames *(f.)* (wave riding from right to left)	
Body actions	***f.5***: the front knee and hip are flexing to a sitting position as the foot is in dorsiflexion; the back foots' extended with its inner area in contact with the boards´ deck, as the knee and hip are flexing and rotating in; the trunk is flexed and rotating towards the outer rail; the front arm is extended and with the hand grabbing the inner rail, the back arm apart and perpendicular with the trunk; the head is facing down with the eyes towards the waves´ bottom ***f.6***: the back knee and hip are more flexed and rotated in, closer to the boards' deck, between both feet, and near the trunk; the trunk is flexed and rotated towards the inner rail, between both feet; the front arm is extended and grabbing the inner rail, as the back arm apart and above the back knee. ***f.7***: the back knee and hip are more flexed maintaining its inner rotation; the back arm extended with the hand above the outer rail. ***f.8***: both hips are flexed and parallel to boards' deck, as both knees and ankles are more flexed; the trunk is flexed and rotated towards the front; both arms are apart oblique and inferiorly aligned to the trunk ***f.9***: both hips start to extend as both knees; the trunk is slightly flexed; both arms are apart, extended and raised head high. ***f.10***: both hips and knees are extending, as ankles come close to neutral position; both arms flexed in line with the head and coming down.
Principles of movement	The CoM goes up and forward towards the waves' face and over boards' CoB (***f.5*** to ***f.10***); the LG falls out of the boards' tail (***f.5 to f.6***), outside of the outer rail in front of the back foot (***f.***7), moving towards the point between both feet (BoS) (***f.8*** & ***f.9)***), and to front foot, outside the boards' outer rail (***f.10*** & ***f.11***).
Surfboard action	The board is airborne. ***f.5***: the board's nose is pointing up; it is rotated more than 130°; ***f.6***: it is rotating outwards and oblique with the waves' bottom. ***f.***7 & ***f.8:*** it is rotated 90° outwards and with the outer rail perpendicular to the waves' bottom. ***f.9:*** the board's nose is pointing down; it is rotated more than 90º outwards ***f.10:*** the board's nose is pointing down; it is rotated 100° to 120° outwards;

Follow-through phase	
Frames *(f.)* (wave riding from right to left)	   
Body actions	***f.11***: the back foot, knee and hip are more flexed than the front ones; the trunk is slightly extended, as both arms are above the head and in the front of the trunk; the head is flexed with the eyes focusing the wave. ***f.12***: both arms are perpendicular and in front of the trunk. ***f.13***: both feet, knees are flexed; hips are flexing; trunk is flexed and parallel to the waves' trough; both arms are inferiorly aligned in front of the trunk and out of the board, with both hands touching the water; the head is extended with the eyes focusing the wave between both hands. ***f.14***: the trunk is flexed over the front knee; both arms are apart, obliquely and inferiorly aligned with the trunk, with the hands outside the outer rail; the head is extended with the eyes focusing the wave; the hips are flexed and parallel to boards' deck, as both knees and ankles are more flexed;
Principles of movement	The CoM is projected forward and down towards the outer rail (***f.11*** *to* ***f.13***) as it goes down and closer to the boards' stringer (***f.14***); the LG falls close to the front foot and outside the outer rail (***f.11***), as it moves further out the outer rail (***f.12*** & ***f.13***) and back close to the front foot (***f.14***). The BoS is set with both feet perpendicular to the board's navel, and it's wide enough so that the front foot is in front of the CoB, and the back foot is placed at the board's track pad, close to the tail.
Surfboard action	The board gets in contact with the wave. ***f.11*** & ***f.12***: it is oblique and rotated 90° to the outer rail, aligned with the waves´ current steep. ***f.13*** **&** ***f.14***: all the bottom of the board is in contact with the waves' trough

*Abbreviations:**CoB: Centre of Buoyancy; CoM: Centre of Mass; **LG: Line of Gravity – vertical projection of the CoM; ***BoS –Base of Support. *Images courtesy of Stomp Sessions*

Table 6: Frontside Air Reverse 360 – phase analysis

Surfer's Goal: to project itself and the board, flying above the wave for passing over a section in the air. It must have a 450° rotation on the anteroposterior axis of the board towards the side of the outer rail (Moreira, 2009), with the feet maintaining the same relative position with the board throughout the movement.
The surfer has a forward and side shift depending on the waves' peel angle; approaches the lip of a wave with enough wall and power, with maximum speed and toes facing the wave; keeping the section he wants to use has launch pad targeted, he must extend the bottom turn to aim above it, with maximum speed and a launching angle of approach of 45° to the lip (Warshaw, 2003; Piter & Testamale, 2012).
Note: frames displayed, numbered and sequenced according to the direction of the movement

Retraction phase	
Frames *(f.)* (wave riding from left to right)	   
Body actions	***f.1***: the back foot is on the boards tail and perpendicular to the stringer; the front foot is at the centre of buoyancy of the board and oblique to the stringer; both knees, hips and trunk

	are flexed; both arms are obliquely and inferiorly aligned, in line with the boards' inner rail; the neck is extended with the eyes focused on the waves' lip. ***f.2***: both knees and hips are flexed and the trunk is extended, with the head following and the eyes focusing the boards' nose; both arms are apart and raised, perpendicular with the trunk ***f.3***: the trunk is rotated outwards, with the front arm being extended on the side of the outer rail and the back arm on the side of the inner rail, with the elbow flexed at the head level. ***f.4***: the front hip is more flexed; the trunk is rotated outwards and slightly flexed towards the boards´ nose; the arms have an upwards movement above the head; the head is flexed and rotated outwards, with the eyes focusing the waves´ bottom
Principles of movement	***f.1***: the CG is projected down towards the back foot's toes, passing the inner rail and projecting itself on the waves' face. ***f.2***: the CG is projected on the boards' deck, over the tail close to the back foot´s heel. ***f.3***: the CG goes up and forward with vertical speed; the LG falls out back of the boards' tail ***f.4***: the take-off angle is less than 180°
Surfboard action	The board slides through the waves' mid-face. ***f.1***: the board is set slightly oblique with the inner rail at the waves´ face ***f.2***: the board is oblique, close to a 45° angle, with the inner rail and bottom in contact with the wave. ***f.3& f.4***: the board is rotated outwards to the outer rail.

	Action phase
Frames *(f.)* (wave riding from left to right)	
Body actions	***f.5***: the front foot, knee and hip are flexed close to a sitting position; the trunk is flexed towards the front knee and close to vertical; both arms are apart and raised, perpendicular with the trunk, with both elbows flexed; the head his flexed with the eyes focusing the waves´ bottom; the head and the shoulders are rotating outwards. ***f.6***: both hips and knees are rotated more to the outer rail; the front arm is wide apart, perpendicular to the trunk. ***f.7***: the front hip and knee are flexed and rotated outwards, as the front foot is dorsi-flexed; the back hip is apart with the back knee almost fully extended and the back foot is plantarflexed; the trunk is flexed and deviated to the back hip; the shoulders are parallel to the stringer and both arms are apart and lateral raised, with both elbows flexed; the head his flexed with the eyes focusing the waves´ face. ***f.8***: both legs are flexed with feet in dorsiflexion; the body is in the same position maintaining the rotation in the long axis. ***f.9***: the front hip and knee are slightly less flexed and more rotated outwards; the trunk is slightly less flexed close to vertical with more velocity; the head his rotated towards the boards' nose, with the eyes searching for the landing zone.
Principles of movement	The CG is in aerial trajectory. The CG is behind the board projected in the waves face (***f.4*** & ***f.5***); The CG is over the board projected in the front foot toes (***f.6***), change to the outside of the inner rail between both feet (BoS) (f.7), until closer to the back foots´ toes, over the board again (***f.8***). The BoS is set with both feet (back one perpendicular and front one obliquus to the board's stringer), and it's wide enough so that the front foot is slightly ahead of the boards centre of buoyancy, and the back foot is placed far back at the board's track pad, close to the tail.
Surfboard action	The board is airborne.

	f.5: it is rotated outwards to the outer rail and around 45° oblique with the waves' face; ***f.6***: it is rotated 90° outwards and oblique with the waves´ bottom; ***f.7***: it is rotated 180° outwards and oblique with the waves´ bottom; the sliding direction is inverted. ***f.8***: it is rotated 270° outwards and oblique with the waves´ bottom; ***f.9***: it is rotated 360° outwards and oblique with the waves´ face; the sliding direction is restored.
Follow-through phase	
Frames *(f.)* (wave riding from left to right)	   
Body actions	***f.10***: both feet are in dorsiflexion; both hips and knees are flexed close to a sitting position; the trunk is vertical and aligned with the boards' stringer; the front arm is obliquely and inferiorly aligned with the trunk, being the elbow flexed; the back arm is apart and horizontally aligned with the trunk; the head is extended and rotated outwards, with the eyes focusing the wave's face. ***f.11***: both hips, knees and feet are more extended; the front arm is apart and horizontally aligned with the trunk, which is slightly flexed. ***f.12***: both feet are again in dorsiflexion; knees and hips are flexed close to a sitting position; trunk is flexed over the vertical; both arms are straight in front and horizontally aligned with the trunk; ***f.13***: the trunk is rotated outwards and flexed over the front knee; both arms are apart, obliquely and inferiorly aligned with the trunk, outside the inner rail (back arm) and outside the outer rail (front arm), the head is extended with the eyes focusing in front of the boards' nose.
Principles of movement	The CG is projected forward to the centre of the board (***f.9*** *&* ***f.10***) as it goes down (***f.11***) and close the inner rail (***f.12***); the LG falls at the centre of the board (***f.9*** to ***f.11***) as it gets close to the front foot (***f.12***). The BoS is set with both feed perpendicular to the board's navel, and it's wide enough so that the front foot is in front of the CoB, and the back foot is placed at the board's track pad, close to the tail.
Surfboard action	The board gets in contact with the wave's face. ***f.10***: it is horizontal and perpendicular aligned with its current steep. ***f.11*** to ***f.13***: it is horizontal and parallel aligned with its current steep it is rotated 450° outwards; the bottom of the board gets in contact with the waves' face, more shifted to the inner rail. ***f.12*** to ***f.13***: all bottom of the board is in contact with the waves' face.

*Abbreviations:**CoB: Centre of Buoyancy; CoM: Centre of Mass; **LG: Line of Gravity – vertical projection of the CoM; ***BoS –Base of Support. *Images courtesy of World Surf League (WSL)*

Table 7: Backside Air Reverse 360 – phase analysis

Surfer's Goal: to project itself and the board, flying above the wave for passing over a section in the air. It must have a 450° rotation on the anteroposterior axis of the board towards the side of the outer rail (Moreira, 2009), with the feet maintaining the same relative position with the board throughout the movement.

The surfer has a forward and side shift depending on the waves' peel angle; approaches the lip of a wave with enough wall and power, with maximum speed and heels facing the wave; keeping the section he wants to use has launch pad targeted, he must extend the bottom turn to aim above it, with maximum speed and a launching angle of approach of 45° to the lip (Warshaw, 2003; Piter & Testamale, 2012).

Descriptive analysis of surfing aerials

Note: frames displayed, numbered and sequenced according to the direction of the movement

Retraction phase	
Frames *(f.)* (wave riding from right to left)	
Body actions	***f.1***: the back foot is over the boards' tail and perpendicular to the stringer with the ankle in dorsiflexion; the front foot is at the CoB of the board and oblique to the stringer, the front knee and hip are almost extended; the back knee and hip are flexed, as the hip is rotated inwards; the trunk is rotated inwards and slightly flexed towards the boards' nose; the front arm is apart and perpendicular to the trunk, as the back arm is obliquely and inferiorly aligned, in line with the boards' inner rail; the neck is extended with the eyes focused on the waves' lip. ***f.2***: the back foot is extended, as the back knee and hip are slightly extended and rotated outwards; the trunk is rotating and flexed towards the outer rail, close to the back foot; the front arm is apart and perpendicular to the trunk, as the back arm is apart and perpendicular to the trunk, being the elbow slightly flexed; the neck is extended with the eyes focused on waves' face. ***f.3***: the front knee is flexed; the trunk is rotated and flexed towards the tail, between both feet; both arms are apart and perpendicular to the trunk and to the stringer; the neck is neutral with the eyes focused on the waves' face.
Principles of movement	***f.1***: the CoM goes up and forward with a linear speed; the LG falls towards the back knee on the tail pad, close to the back foots' toes. ***f.2***: the CoM goes up and forward with a linear speed; the LG falls outside the surfboard, close to the tail pad. ***f.3***: the CoM goes up and forward with a linear speed; the LG falls outside the surfboard, behind the tail pad.
Surfboard action	The board slides through the waves' face. ***f.1***: the board is set oblique and with the inner rail at the waves' face ***f.2***: the board is more oblique with the tails' inner rail area in contact with the wave ***f.3***: the board is more oblique, close to vertical with the tails' inner rail and fins area in contact with the wave

Action phase	
Frames *(f.)* (wave riding from right to left)	
Body actions	***f.4***: both feet are in dorsiflexion with both knees and hips are flexed close to a sitting position; the trunk is flexed and rotated towards the outer rail, almost parallel with the waves' bottom; the front arm is apart and obliquely aligned to the trunk with the elbow slightly flexed, as the back arm rotated out to the back, parallel to the trunk; the head is extended with the eyes focused at the waves' crest. ***f.5***: the back foots' extended with its inner area in contact with the boards´ deck; the back knee is extended being the back hip apart and raised beyond horizontal; the front foot is neutral, being the front knee and hip flexed and rotated outwards; the trunk is flexed to the side towards the back leg; the front arm is apart and raised up obliquely with the trunk, as the back arm is obliquely and inferiorly aligned, close to the trunk ***f.6***: both feet, knees and hips are flexed close to a sitting position; the trunk is flexed towards the outer rail; both arms are straight raised above the head and in front of the

	trunk; the head is neutral with the eyes focusing the outer rail. ***f.7***: knees and hips are slightly extended but rotated outwards (front knee) and inwards (back knee); trunk is slightly flexed to the side towards the front leg; the back arm is apart and raised up obliquely with the trunk, as the front arm is apart and perpendicular to the trunk; the head is flexed with eyes focusing the impact area. ***f.8***: the back knee and hip are more extended and rotated out, as the front hip and knee are more flexed and rotated in; the trunk is extended close to vertical and both arms are apart and raised up obliquely with the trunk.
Principles of movement	The CoM goes up and forward towards the waves' face (***f.4*** to ***f.8***); the LG falls out of the boards' outer rail, to the bottom of the wave (***f.4***), moving towards the point between both feet (BoS) falling out of the boards' inner rail (***f.6***), and to back foot, over the boards' tail (***f.7*** & ***f.8***).
Surfboard action	The board is airborne. ***f.4***: it is rotated 90º outwards and with the outer rail perpendicular to the waves´ bottom; ***f.5***: it is rotated 180º outwards and oblique with the waves´ face and bottom; ***f.6***: it is rotated 270º outwards and oblique with the waves´ bottom ***f.7 & f.8***: it is rotated almost 360º outwards and oblique with the waves´ face.

Follow-through phase	
Frames *(f.)* (wave riding from right to left)	  
Body actions	***f.9***: both feet are close to neutral position; both hips and knees are almost extended, being the back hip and knee more flexed; the trunk is almost vertical and aligned with the boards' stringer; both arms are apart and raised up obliquely with the trunk; the head is slightly flexed and rotated with the eyes focusing the impact area, in front of the boards´ outer rail. ***f.10***: both feet are in dorsiflexion; knees and hips are flexed; trunk is flexed over the vertical and towards the outer rail; both arms are straight in front and horizontally aligned with the trunk. ***f.11***: knees and hips are flexed close to a sitting position; trunk is flexed over the vertical; both arms are oblique and inferiorly aligned with the trunk, being the front elbow flexed and above the front knee, and the back arm is straight and behind the back knee; the head is slightly extended and rotated towards the front knee.
Principles of movement	The CoM goes down and forward towards the waves' face (***f.9*** & ***f.10***) as it goes down (***f.10***) and closer to the CoB (***f.11***); the LG falls closer to the back foot (***f.9***), as it gets close to the CoB (***f.10*** & ***f.11***). The BoS is set with both feet perpendicular to the board's navel, and it's wide enough so that the front foot is in front of the CoB, and the back foot is placed at the board's track pad, close to the tail.
Surfboard action	The board gets in contact with the wave's face. ***f.9***: it is horizontal and perpendicular aligned with its current steep; the boards' tail is in contact with the surface. ***f.10***: it is obliquely aligned with its current steep, rotated up to 45º outwards; all bottom of the board is in contact with the waves' face. ***f.11***: it is horizontal and perpendicular aligned with its current steep; the bottom of the board is in contact with the waves' face, more shifted to the inner rail.

*Abbreviations:**CoB: Centre of Buoyancy; CoM: Centre of Mass; **LG: Line of Gravity – vertical projection of the CoM; ***BoS –Base of Support. *Images courtesy of World Surf League (WSL)*

Descriptive analysis of surfing aerials

Besides the qualitative description of the four aerials key features (Tables 4-7), our analysis also included four parameters of the principles of movement for both FSAR360 and BSAR360, as show on Table 8.

Table 8: Mean and standard-deviation of 4 parameters of the principles of movement related to lower limb kinematics addressed with video-analysis for FSAR360 and BSAR360 aerial manoeuvres.

	Total		FSAR360		BSAR360		Mean difference
	n	Mean ± SD	n	Mean ± SD	n	Mean ± SD	FSAR360 - BSAR360
Aerial height (cm)	94	169.60±52.85	66	160.69±50.97	28	190.59±52.11	-29.90*
BoS width (cm)	89	79.17±13.72	63	81.28±14.11	26	74.05±11.42	7.22*
Front Knee flexion (º)	47	113.78±19.90	33	110.57±19.94	14	121.36±18.30	-10.78
Front Ankle DFlexion (º)	17	32.74±14.51	11	27.68±13.29	6	42.05±12.64	-14.37*

Abbreviations: n: number of analysed manoeuvres; BOS: supporting base; cm: centimetres; º: degrees, measured at landing; SD: Standard-deviation; DFlexion: Dorsiflexion. *Significant difference: p<0.05

The results on this table show a statistically significant difference (p<0,05) between both aerials, for three parameters (aerial height, BoS width and front ankle dorsiflexion), meaning that: top-5 surfers seem to reach roughly 30cm higher on BSAR360 when comparing to the FSAR360 (t(92)=-2.58; p=0.011); the surfers' BoS width (feet distance), while performing the aerials, was 7.2cm higher for the FSAR360 (t(87)=2.31; p=0.023). There was a low rate of observation for the knee (48%) and ankle (18%) angles reached while landing, at follow-through phase, being able to be measured only for the front lower limb. However, mean difference front ankle dorsiflexion ROM on BSAR360 was 14.37º more when comparing to the FSAR360 (t(15)=-2.16; p=0.047). Although front knee flexion ROM was in average 10.78º higher for the BSAR360 when comparing to the FSAR360, there was no statistically significant difference.

DISCUSSION

The fact that for both 2018 and 2019 competitive seasons, 3 of the Top-5 surfers were from Brazil and performed the majority of aerials analysed may lead us to conclude that Brazilian surfers might benefit from their country practice environment constraints (e.g.: beach break, fast and short waves, cross-shore winds), which seem ideal to train aerial manoeuvres.

Regarding phase analysis of aerial manoeuvres, previous studies already identified some key features common to both frontside air and the frontside air reverse that determine a successful landing, like "*landing with lead ankle in dorsiflexion*" (Forsyth et al., 2018) and "*landing with the centre of mass over the centre of buoyancy the surfboard"* (Moreira & Peixoto, 2014).

Besides these previous findings, our analysis shows that a few body actions and principles of movement seems to be common to all aerials: greater flexion of the posterior hip, knee and ankle and the rotation of the head and trunk (retraction phase); flexion of the head, trunk and arms from the take-off (retraction phase) to the peak of the flight (action phase) causing the anterosuperior displacement of the athlete's CoM; triple-flexion of the lower limbs (hip, knee and ankle) at the beginning of the retraction phase and more pronounced at the end of the follow-through phase; widening of the BoS for frontside aerials through all of the action phase.

This type of combined performance analysis data with quantitative variable results might also contribute to reduce the total load over the lower limbs, as pointed out previously by several authors (Forsyth et al., 2018, 2021; Furness et al., 2015; Nathanson et al., 2007; Inada et al., 2018; Ha et al., 2022), but future studies should address more complete "on water" quantitative analysis concerning also other body segments, like hips, trunk and head.

The proper analysis of landing biomechanics might lead to the understanding of optimal and successful landing, as identified also in study. Similarly to our descriptive analysis, Lockwood *et al.* (2006) identified key performance indicators for figure skating like "balance and control", stability", "landing time" and "body position geometry during landing", describing them in terms of optimal performance characteristics.

Likewise, Benet-Vigo et al (2021), also video-analysed jump and landing patterns on basketball, volleyball and handball players concluding that this was a valuable method to identify neuromuscular and biomechanical alterations on jump-landing patterns.

This indicators analysis based on a proper understanding of landing biomechanics can be used by coaches and athletes to evaluate, training and optimize successful landing strategies.

As to performance, Maneiro et al. (2021), utilized the method of video-analysis to address corner kicks execution, since it's one of the most repeated actions in high-level football players. By comparing FIFA World Cup 2010, 2014 and 2018 corner-kicks, their results demonstrated that, due to corner-kick training tasks the technical and tactical behaviours associated evolved along the years, and that those results should be used by coaches to create different training situations to improve these actions.

An observational method, based on movement description and video-analysis was also used by Tuquet et al. (2021) in handball players, to identify determinant factors that affected throwing actions used to score goals, as well as the factors contributing to the effectiveness of throwing. Besides finding that success of this action depends on the distance and the type of throw, the authors highlighting the importance of identifying these variables as they can contribute to optimize training sessions for goal-scoring situations.

Our main findings lead us to theorize that *a)* top surfers seem to master aerial performance; *b)* they do not preform BSA in competition; and *c)* FSA and BSA are base manoeuvres for both FSAR360 and BSAR360, since they present common features for all aerials.

The aerial mean height of 169.60±52.85cm during action-phase (Table 2) can be considered as performance indicator for aerial manoeuvres since it's based on the mean of top-5 surfers and, to the date, there's no other evidence of how high do surfers fly during aerials.

The fact that BSAR360 height is higher might be associated with the beginning of the movement being with the surfers' back to the wave, but the rotation of the trunk is towards the front edge, which can allow a better use of the take-off moment, just before being airborne, and consequently obtain a higher height. The position of the trunk in the retraction phase can also enhance the action-reaction effect, which increases the speed of rotation of the surfer and the board, facilitating the execution of the 360. Thus, with the facilitated rotation, the surfer can focus his attention on the take-off moment.

Video analysis also allowed to observe, for both FSA and FSAR360, the front foots' displacement towards the boards' nose, widening the surfers' BoS, during the action phase; the reason why this wasn´t observed for the BSAR360 might be because, while airborne, the surfer prioritizes board rotation over feet placement, to ensure aerial completion. This "one of its' kind" analysis also allowed us to measure the BoS width (feet distance) (mean 79.17±13.72cm), significantly higher for the BSAR360, which might be associated with the need of ensuring better control and stability for landing (follow-through phase).

The mean front knee flexion angle (113.78±19.90º) and front ankle dorsiflexion (32.74±14.51º) reached while landing, should be reenforced with more research. However, it can be theorized that the significantly higher ankle dorsiflexion angle for the BSAR360, might be due, not only to higher height reached in this manoeuvre that forces the surfer to dissipate more load to the lower limbs' joints while landing; but also to the fact that the surfers need to ensure the boards sliding through the waves' face after the aerial completion (follow-trough phase), being in a backside position.

On their study addressing landing mechanics for simulated catch and shoot manoeuvres in basketball and netball, Meghan *et al.* (2019) demonstrate that whole-body rotation increases contralateral knee (back knee in surfing) loading, as it helps to decelerate medial-lateral velocity; but also that trunk rotation also increases ipsilateral knee (front knee in surfing) loading, as a great percentage of bodyweight is shifted to the front leg, increasing vertical ground force, knee abduction and internal rotation. As in surfing, these biomechanical patterns tend to stress the knee joint with greater load, increasing ACL injury occurrence.

Considering de FSAR360, and when compared to Forsyth *et al.* (2021), who measured these variables indoors through simulated aerial tasks, their results show mean lower front knee flexion (91.60±17.20º); and much lower (8.80±4.70º) for the front ankle flexion angle.

However, their indoor aerial task simulation shouldn't be comparable to a real on-water situation, because data collection was based on a very different model: a mini-trampoline was utilized to create the aerial projection, that only occurred in a linear way, aiming a mat to land close to it, missing the participants' side shift; the rotation they performed is not a "full rotation" (360º) and it seems only close to the FSA, with a lower height projection, in which the surfer grabs and rotates the board after jumping, placing it under his feet, just before landing; the participant is not rotating with the board with the feet maintaining the same relative position with the board throughout the movement; at landing the CoM was behind the board and without the need to dissipate forces to knees and ankles, as if they were landing on water.

It also can be theorized that, on water, to successfully land an aerial manoeuvre, the surfer must control his board, not only airborne with his feet during a non-linear and side shift dislocation, but also while landing (wave's face/bottom) in a hard surface (surfboard), over an unstable and moving environment (water); during landing the surfers CoM is displaced outside the board, in a way that forces an increase in ankle dorsiflexion, to overcompensate unbalance and prevent guarantee the manoeuvres' completion.

As described by Tabacchi *et al.* (2019), physical fitness allows the bodies to move effective and synchronized related to daily life activities. Therefore, not only body composition, cardiorespiratory endurance, flexibility, muscular endurance, power, and strength are needed to achieve optimal physical fitness levels; speed, balance, agility, coordination, and reaction time are also determinant to ensure higher levels of performance.

And as pointed by Cejudo's (2021) study with basketball players, evaluating and understanding the athlete's ROM, for instance, is crucial not only to identify flexibility-related risk injuries, as well as to optimize and improve physical and technical performance in jumping, balance, and agility tasks. Likewise, Marques-Sule *et al.* (2022) on their study about canoe polo athletes, highlighted the importance of knowing these athletes' physiological and performance characteristics, which involve high-intensity bursts of sprinting, and short periods of low-to-moderate intensity paddling during rowing tasks (like paddling in surfing), and that can be determinant to increase performance.

Therefore, setting quantitative parameters for aerials height can be useful for performance optimization, as well as training these manoeuvres with the appropriate BoS width and aiming maximum compression angles of knee and ankle, might reduce injury risk related to landing aerials.
Previously, Gomez-Ruano et al. (2020) thoroughly addressed the importance of performance analysis in sport to understand its performance-related variables, that can be used by coaches and athletes', to set specific performance-driven training routines than can also be applied in competition.
However, the fact that quantitative results are based on the available video footage through the "heat-analyser" function of the WSL website, limited the total number of analysed events (19 out of 22) of the WSL for the 2018 and 2019 competitive seasons. Another limitation is related to the impossibility of collecting data on all the sampled aerials (as shown in table 3). In these cases, it was not possible to identify the points for data collection due to the quality of the images. The lack of quality is related to the back light exposure (sunlight), camera angles, and overlapping parts of the wave on the segments under analysis. This low observation rate for knee (48%, n=47) and ankle (18%, n=17), due to the environmental constrains of the available footage is a challenge surfing science face. Therefore it should be optimized in future studies with more advanced and reliable measuring technics, like for example, the use of water-proof body sensors placed over the surfers' body segments and joints. Wave pools can also be of interest to the development of kinematic analysis, as they might provide the ideal camera setting (light exposure and angles) that allows consistent and reliable movement analysis.

CONCLUSIONS

This is the first study of a kind to clearly approach four main aerial manoeuvres utilizing a new conceptual design approach, concerning not only their qualitative description, body actions identification, principles of movement and surfboard actions through phase analysis model; but also, quantitative variables (aerial height, BoS width and knee and ankle angles at landing), that may contribute to better understand aerials and its successful landing, based on elite surfers' performance.
It seems important that elite and aspiring pro surfers seek to training in ideal conditions that allow them to reproduce aerial manoeuvres according to its key features, appropriately using body actions and principles of movement, whether it is on land (e.g., skates, trampolines) or on water (e.g., wave pools).
More research should be carried out considering the descriptive analysis of the manoeuvres to ensure the representativeness of the tasks analysed in the laboratory.

PRACTICAL APLICATIONS

This study findings should contribute to improve training so that surfers can achieve better results, on learning process and at a high-performance level, through the replication of these key features in simulated aerial tasks.
Specific and adequate training also should be further investigated, concerning, not only dry-land aerial simulation tasks, like previously proposed by Moreira & Peixoto (2014) and Forsyth *et al.* (2020) to optimize performance and increase completion rates, but also fitness training addressing lower limbs flexibility and range of motion to ensure related injury prevention.

REFERENCES

1. Anguera, M.T.,Hernández-Mendo, A. (2013). La metodología observacional en el ámbito del deporte. *E-balonmano.com: Revista de Ciencias del Deporte, 9(*3), 135-160. https://dx.doi.org/10.4321/S1578-84232015000100002

2. Anguera M.T., Portell M., Chacón-Moscoso S., Sanduvete-Chaves S. (2018). Indirect Observation in Everyday Contexts: Concepts and

Methodological Guidelines within a Mixed Methods Framework. *Front. Psychol., 9:13.* https://doi.org/10.3389/fpsyg.2018.00013

3. Bartelett, R. (2007) Introduction to Sports Biomechanics: Analysing Human Movement Patterns. Routledge: London
4. Benet-Vigo, A., Arboix-Alió, J., Montalvo, A. M., Myer, G. D., Fort-Vanmeerhaeghe, A. (2021). Detección de déficits neuromusculares a través del análisis del patrón de salto y aterrizaje en deportistas adolescentes. *Cuadernos de Psicología del Deporte*, *21*(3), 224–232. https://doi.org/10.6018/cpd.462711
5. Bortoleto, M., Peixoto, C., Moreira, M.. (2011) Modelo teórico para analise qualitativa das ações motoras acrobáticas: aplicação ao salto mortal a retaguarda. *Motriz, Revista de Educação Física*, UNESP, Rio Claro, Brasil., Jan/ Mar 17, 1 (Supl.1), S13.
6. Cejudo, A. (2021). Lower Extremity Flexibility Profile in Basketball Players: Gender Differences and Injury Risk Identification. *Int. J. Environ. Res. Public Health, 18*, 11956. https://doi.org/10.3390/ijerph182211956
7. Cejudo, A., Baranda, B, Ayala, F., Santoja, F. (2012). Absolute reliability of 2 clinical tests for assessing ankle range of motion in handball player. *Cuadernos de Psicología del Deporte*, 12(2), 23-30. https://doi.org/10.1016/j.ft.2021.07.004
8. Ferrier, B., Sheppard, J., Farley, O., Secomb, J., Parsonage, J., Newton, R., Nimphius, S. (2018). Scoring analysis of the men's 2014, 2015 and 2016 world championship tour of surfing: the importance of aerial manoeuvres in competitive surfing. *J Sports Sci*., 36(19): 2189-2195. http://doi.org/10.1080/02640414.2018.1443747
9. Forsyth, J., Riddiford-Harland, L., Whitting, J., Sheppard, J., Steele, J. (2018). Understanding successful and unsuccessful landings of aerial maneuver variations in professional surfing. *Scand J Med Sci Sports*, May 28(5):1615-1624. https://doi.org/10.1111/sms.13055
10. Forsyth, J., Riddiford-Harland, D., Whitting, J., Sheppard, J., Steele, J. (2020). Training for success: Do simulated aerial landings replicate successful aerial landings performed in the ocean? *Scand J Med Sci Sports*, 30(5):878–884. https://doi.org/10.1111/sms.13639
11. Forsyth, J., Harpe, R., Riddiford-Harland, D., Whitting, J., Steele, J. (2017). Analysis of Scoring Manoeuvres Performed in Elite Men's Professional Surfing Competitions. *Int J Sports Physiol Perform*, 12(9): 1243-1248. https://doi.org/10.1123/ijspp.2016-0561
12. Forsyth, J., Richards, C, Whitting J, Riddiford-Harland D, Sheppard J, Steele J. (2021). Rate of loading, but not kinematics or muscle activity, is moderated by limb and aerial variation when surfers land aerials. *J Sports Sci*, 39(15); 1780-1788 https://doi.org/10.1080/02640414.2021.1898167
13. Forsyth, J., Tsai, M., Sheppard, J., Whitting, J., Riddiford-Harland, D., Steele, J. (2021). Can we predict the landing performance of simulated aerials in surfing? *J Sports Sci,* 39(22): 2567-2576. https://doi.org/10.1080/02640414.2021.1945204
14. Furness, J., Hing, W., Walsh, J., Abbott, A., Sheppard, J., Climstein, M. (2015). Acute Injuries in Recreational and Competitive Surfers: Incidence, Severity, Location, Type, and Mechanism. *Am J Sports Med*, 43(5): 1246-54. https://doi.org/10.1177/0363546514567062
15. Gomez-Ruano, M-A., Ibáñez, S., Leicht, A. (2020) Editorial: Performance Analysis in Sport. *Front. Psychol,*11:611634. https://doi.org/10.3389/fpsyg.2020.611634
16. Ha, S., Kim, M., Jeong, H., Lee, I., Lee, S. (2022). Mechanisms of Sports Concussion in Taekwondo: A Systematic Video Analysis of Seven Cases. *Int. J. Environ. Res. Public Health, 19*, 10312. https://doi.org/10.3390/ijerph191610312
17. Hohn, E., Robinson, S., Merriman, J., Parrish, R., Kramer, W. (2020). Orthopedic Injuries in Professional Surfers: A Retrospective Study at a

Single Orthopedic Center. *Clin J Sport Med,* 30(4):378-382. https://doi.org/10.1097/jsm.0000000000000596

18. Inada, K., Matsumoto, Y., Kihara, T., Tsuji, N., Netsu, M., Kanari, S., Yakame, K., Arima, S. (2018). Acute injuries and chronic disorders in competitive surfing: From the survey of professional surfers in Japan. *Sport Orthop Traumatol*, 34(3): 256-260. https://doi.org/10.1016/j.orthtr.2018.03.107
19. Knudson, D., Morrison, C. (1997). Qualitative Analysis of Human Movement. Champaign, IL: Human Kinetics.
20. Knudson, D. (2013). Qualitative Diagnosis of Human Movement (3rd Edition): Improving Performance in Sport and Exercise, IL: Human Kinetics
21. Koo, T., Li, M. (2016). A Guideline of Selecting and Reporting Interclass Correlation Coeficients for Reliability Research. *Journal of Chiropractic Medicine,* 15, 115-163. https://doi.org/10.1016/j.jcm.2016.02.012
22. Lees, A. (2002) Technique analysis in sports: a critical review, Journal of Sports Sciences, 20:10, 813-828. https://doi.org/10.1080/026404102320675657
23. Lees A. (2008). Qualitative biomechanical analysis of technique. In: Hughes M, Franks M, ed. *The Essentials of Performance Analysis: an introduction*. New York: Routlegde, 162-179 https://doi.org/10.4324/9781315776743-12
24. Lockwood, K., Gervais, P., Mccreary, D. (2006). Skating, *Sports Biomechanics*, 5:2, 231-241. https://doi.org/10.1080/14763140608522876
25. Lundgren, L., Tran, T., Farley, O., Secomb, J., Nimphius, S., Newton, R., Sheppard, J. (2013). Ankle Range of Motion Among Surfing Athletes. *J Aust Strength Cond,* 21(S2):121-124
26. Lundgren, L., Newton, R., Train, T., Dunn, M., Nimphius, S., Sheppard, J. (2014) Analysis of Manoeuvres and Scoring in Competitive Surfing. *International Journal of Sports Science & Coaching*, 9(4): 663-669. https://doi.org/10.1260/1747-9541.9.4.663
27. Lundgren, L., Tran, T., Nimphius, S., Raymond, E., Secomb, J., Farley, O., Newton, R., Steele, J., Sheppard. J. (2015) Development and Evaluation of a Simple, Multifactorial Model Based on Landing Performance to Indicate Injury Risk in Surfing Athletes. *Int J Sports Physiol Perform,* 10(8): 1029-1035. https://doi.org/10.1123/ijspp.2014-0591
28. Maneiro, R., Losada, J., Portell, M., Ardá, A. (2021). Observational Analysis of Corner Kicks in High-Level Football: A Mixed Methods Study. *Sustainability, 13*, 7562. https://doi.org/10.3390/su13147562
29. Marques-Sule, E., Arnal-Gómez, A., Monzani, L., Deka, P., López-Bueno, J., Saavedra-Hernández, M., Suso-Martí, L., Espí-López, G. (2022). Canoe polo Athletes' Anthropometric, Physical, Nutritional, and Functional Characteristics and Performance in a Rowing Task: Cross-Sectional Study. *Int. J. Environ. Res. Public Health, 19*, 13518. https://doi.org/10.3390/ijerph192013518
30. Critchley, M., Davis, D., Keener, M., Layer, J., Wilson, M., Zhu, Q., Dai, B. (2019). The effects of mid-flight whole-body and trunk rotation on landing mechanics: implications for anterior cruciate ligament injuries. *Sports Biomechanics*, 19 (4), 421-437. https://doi.org/10.1080/14763141.2019.1595704
31. Moreira, M., Peixoto, C. (2008). Inventory of Surf Techniques. In: *13th Annual Congress of the European College of Sport Science*. Estoril, Portugal. Book of Abstracts, p. 701.
32. Moreira, M. (2009). Surf da ciência à prática. Cruz Quebrada: *Edições FMH*.
33. Moreira, M, Peixoto, C. (2014). Qualitative task analysis to enhance sports characterization: A surfing case study. *J Hum Kinet*, 42(1):245–57. https://doi.org/10.2478/hukin-2014-0078
34. Nathanson, A., Bird, S., Dao, L., Tam-Sing, K. (2007). Competitive surfing injuries: A prospective study of surfing-related injuries among contest surfers. *Am J Sports Med*,

35(1):113–7. https://doi.org/10.1177/0363546506293702

35. Peixoto, C. (1997). Sistemática das Actividades Desportivas. Modelos e Sistemas de Análise do Desempenho Desportivo. Cruz-Quebrada: *Edições FMH*.
36. Piter, D., Testemale, B. (2012). Maneuvers. In: Secrets to Progressive Surfing. Sandbar; p.125-126.
37. Secomb, J., Farley, O., Lundgren, L., Tran, T., King, A., Nimphius, S., Sheppard, J., Meir, R., Triplett, T. (2015). Associations Between the Performance of Scoring Manoeuvres and Lower-Body Strength and Power in Elite Surfers. *International Journal of Sports Science and Coaching*, 10(5):911-918. https://doi.org/10.1260/1747-9541.10.5.911
38. Stomp Sessions. (2021). Surfing, Airs, Backside Straight Air. website: https://stompsessions.com/videos/surfing-backside-straight-air-trick-tips-by-josh-kerr
39. Tabacchi, G., Sanchez, G., Sahin, F., Kizilyalli, M-, Genchi, R-, Basile, M., Kirkar, M., Silva, C., Loureiro, N., Teixeira, E., Demetriou, Y., Sturm, D., Pajaujene, S., Zuoziene, I., Gómez-López, M., Rada, A., Pausic, J., Lakicevic, N., Petrigna, L., Feka, K., Ribeiro, A., Alesi, M., Bianco, A. (2019). Field-Based Tests for the Assessment of Physical Fitness in Children and Adolescents Practicing Sport: A Systematic Review within the ESA Program. *Sustainability*, 11(24):7187. https://doi.org/10.3390/su11247187
40. Tuquet, J., Lozano, D., Antunez, A., Larroy, J., Mainer-Pardos, E. (2021). Determinant Factors for Throwing in Competition in Male Elite Handball. *Sustainability,* 13, 10913. https://doi.org/10.3390/su131910913
41. Warshaw, M. (2003). *The Encyclopedia of Surfing*. Hartcourt, Inc., Orlando.
42. World Surf League. WSL Rule Book (2022). [Internet]. In: Chapter 13: Judging. Santa Monica: © Copyright 2022 Association of Surfing Professionals LLC. p. 83-85. website: http://worldsurfleague.com