Boat instrumentation feasibility study to assess biomechanics of competitive surf lifesavers during inflatable rescue boat activities: Technical Report #5 to Surf Life Saving New Zealand (SLSNZ)

By research team members for TE HOKAI TAPUWAE – REIMAGINING SPORTS INJURY PREVENTION

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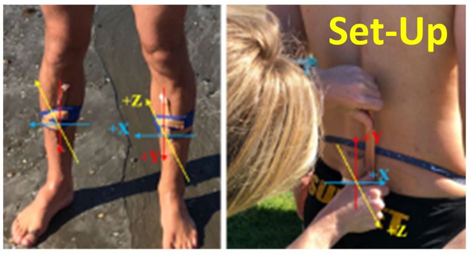
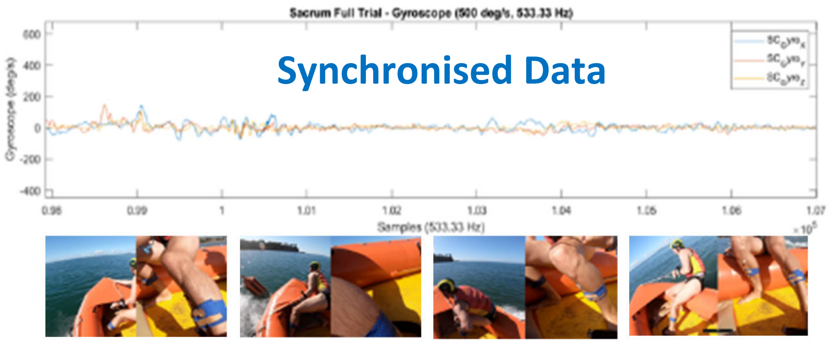


Anthropometrics

Participant	IRB Crew Member	IRB Driver
Age	25 years	27 years
Height	195 cm	194 cm
Femur Length (right)	46.1 cm	47.0 cm
Body Weight	93.5 kg	94.5 kg



Key Findings

- A method to measure crew and boat accelerations and movement patterns was established
- Future studies should use inertial measurement sensors with an acceleration range of ±100 g sampling at 500 Hz
- Frequency analysis (e.g. power density spectrum) may help quantify loads associated with lower back pain
- Future research should standardise water-based maneuvers to compare across populations and conditions

ABSTRACT

Background: Only two studies to date have investigated loads experienced on IRBs during operation.

Purpose: To pilot a data collection system for acceleration and video footage of the IRB and crew on water, to be used in subsequent studies of IRB-related activities.

Methods: A pair of experienced (national champion) surf lifesavers were utilised for this study (an IRB driver and a crew member). The crew member was instrumented with three inertial measurement sensors; left tibia, right tibia, and sacrum. An IRB provided by Sunset Beach Surf Life Saving Club was instrumented with 3 GoPro cameras in order to get a view of the entire IRB, crew member lower extremity, and surf conditions. The surf lifesavers performed typical IRB maneuvers utilized during patrol and/or competition. The collected sensor and video data were imported and analysed for feasibility.

Results: The goal of the analysis of the feasibility study was to first identify if the sensors and video footage captured the necessary information. In order to identify tasks in the IMU data, time stamps were able to be matched with the video footage of interest. Camera footage was useful however locations of the cameras may need to be modified in future studies. Successful collection of accelerometer and gyroscope data demonstrated a need to investigate the vibration exposure of surf lifesavers while operations IRBs. Through a frequency analysis approach, identifying the power spectrum densities of the accelerometer and gyroscope signal may enable the comparisons of vibrations during different IRB crewing tasks under different techniques and body positions. This technique may help to identify age- and gender- specific load prescriptions in order to minimize the risk of developing low back pain.

Discussion: Only the ±16 g accelerometer was analysed as this was a feasibility pilot to assess if the method would work. Future studies should use inertial measurement sensors with an acceleration range of ±100g sampling at 500 Hz. The weather and water conditions were mild; thus future studies are recommended to determine feasibility in varying conditions. Due to the difficulty of assessing kinematics from the GoPro footage, future studies should investigate the different positioning of the crew members in a lab environment to assess potential injury mechanisms while varying IRB orientations.

Conclusions: Inertial sensors attached to surf lifesavers at the sacrum while operating IRBs may help quantify loads and frequencies associated with common injuries; such as, lower back pain and soft-tissue ankle injuries. Future research should standardise water-based maneuvers to compare across populations and conditions. Signal analysis techniques should be investigated under different water and weather conditions.

Recommendations:

1. Future research should be conducted under conditions with waves to assess the magnitude and frequency of biomechanical loading endured by the crew member.
2. Future research should attempt to standardize the manoeuvres in the water to compare across populations and conditions.
3. Future studies should investigate the different biomechanical positioning of the crew members in a lab environment with motion capture (e.g. VICON) to assess potential injury mechanisms.
4. Once the methods have been finetuned, future projects can evaluate boat design or crew movement changes.

INTRODUCTION

Swimming and surfing are an integral part of daily life in New Zealand, with over 14,000 kilometres of coast line extending across two major oceans [1, 2]. Surf Lifesaving New Zealand (SLSNZ) is responsible for the coordination of all surf lifesaving activities taking place at clubs throughout New Zealand. Responsibilities of SLSNZ include oversight of lifeguard certifications, equipment standards, and member training.

Surf lifesavers play an important role in keeping the public safe, and as of recently, rely less on traditional non-powered rescue aids such as life rings and more heavily on powered watercrafts; such as the inflatable rescue boat (IRB) to complete open water rescues. Due to their speed and manoeuvrability, IRBs are ideal for beach patrol and surveillance. An IRB consists of two rigid inflatable pontoons supported by a removable fibreglass laminate floor, fitted with an outboard motor and additional crewing equipment (e.g. foot straps, ropes, etc.). New Zealand surf lifesavers utilise IRBs in over 50% of all rescues per year [3]. The operation of an IRB typically involves two lifeguards; a driver in the stern and a crew member towards the bow, racing through the surf simulating or performing a rescue. The crew member is responsible for keeping the IRB balanced through the surf by utilising their body weight and additional equipment such as bow ropes, foot straps …to stay safely inside the boat. The driver is responsible for navigating the IRB through the surf as efficiently as possible while ensuring the crews' safety. Surf lifesavers participate in regular training to prepare for IRB operation during both patrol and competition.

Only two studies to date have investigated loads experienced on IRBs during operation. Yorkston, Arthur [4] utilized a custom-built piezo-electric strain gauge to assess forces experienced at the foot straps during operation, in addition to one on-board video recorder to assess crewing technique. Results indicated that the crew members' left foot was experiencing the greater amount of load (peak force: 415.60 N), compared to the right foot (peak force: 252.94 N). This finding contradicted reported injury results (no accelerations measured in the studies) in several epidemiological studies which indicated a greater number of injuries occurred to the right foot [5, 6], potentially due to the right foot strap design [7, 8]. However, after examining video footage, the authors noticed most crew members adopted a technique in which they did not utilise the right foot strap, which may explain the inconsistent findings.

Ludcke, Pearcy [9] also attempted to quantify the loads experienced by crew members during open water impacts caused by waves using an accelerometer. Previous studies had associated accelerations to injury causes in other motor vehicle activities [8].

A specifically designed accelerometer and data logging unit were built for the investigation; sampling at 1000 Hz within a range of ±50 g. The accelerometer was attached to the floorboard of the IRB. Data collected was used to identify IRB tasks that might cause injury. Conclusions found that the magnitude of accelerations could be a major influence in the cause of impact injuries to surf lifesavers, particularly with the repetitive nature of IRB operation. However, to best assess accelerations experienced by the crew or driver, the sensor should be placed on the participant closest to the area of interest (e.g. ankle or foot). Therefore, the aim of this study was to improve and expand upon data collection procedures used by Ludcke, Pearcy [9] and Yorkston, Arthur [4] to pilot a data collection system to be used in subsequent studies of IRB-related activities. Additional cameras and accelerometers mounted on the boat and the crew were used in our feasibility study.

METHODS

Ethical consent

Ethical consent was obtained from the Auckland University of Technology (AUT) Ethics Committee (#18380) and Loughborough University Ethics Committee (#R18-P233).

Participants

A pair of experienced (national champion) surf lifesavers were utilised for this study (an IRB driver and a crew member). Both participants were current national level competitors for *SLSNZ* (Table 1). Prior to participation in the study, both subjects provided informed consent. Then the participants were briefed of the events of the day, their tasks, and the equipment being used. Participants were required to perform typical IRB manoeuvres. The crew member and driver were asked to drive the IRB for roughly a total of 5 to 10 minutes. During this time, they would perform any manoeuvres commonly utilized during patrol and/or competition (e.g. parallel running, patient pick-up, etc.).

Table 1: Participant anthropometrics.

Participant	IRB Crew Member	IRB Driver
Age	25 years	27 years
Height	195 cm	194 cm
Femur Length (right)	46.1 cm	47.0 cm
Body Weight	93.5 kg	94.5 kg

Foot strap measures

Stance measurements were taken based on techniques described by Ludcke, Pearcy [9]. Measures were taken using photographs and Kinovea (V.0.8.15) assuming the right foot was placed up alongside the inflatable pontoon of the boat with the left foot in the strap. Maximum boat dimension ranges were defined for stance width and stance angle.

- Stance width: 45.2 cm – 57.9 cm
  - Measurement Description: 2nd toe to 2nd toe, left to right foot
  - Max Measurement: Same with right foot out of the foot strap and next to the side of boat
- Stance angle: 14° - 42°
  - Measurement Description: Right foot externally rotated with respect to the left foot; not actual external rotation relative to tibia
  - 42° max measure estimated if right foot was out with lateral border of the foot up against the side of boat (estimate using right foot angle of 85° - measured left foot angle of 43° = 42°).
- Stance direction: 32°
  - Measurement description: Right “strap” angle with respect to the port-starboard plane of the boat using the centre of the left strap as a vertex.

Figure 1: Stance angle and stance direction measures from photograph and Kinovea software.

Figure 2: Stance angle and stance direction measures from photograph and Kinovea software using an estimated right foot position for max ranges on the stance width and stance angle.

Equipment

Table 2 identifies all equipment used for the pilot data collection. All surf lifesaving equipment was provided by Sunset Beach Surf Life Saving Club, including the IRB, personal floatation devices, helmets, and any additional equipment required by the crew members to perform their typical rescue and competition tasks.

Table 2: Equipment used for data collection and analysis.

	Equipment	Description of Use	Quantity Used
Hardware			
	Laptop	Laptops were used for inertial sensor synchronisation, data collection, and note taking	2
	Inertial Measurement Unit / Sensor (IMU)	Shimmer Sense, Dublin, Ireland Sampling Rate (Accelerometer): 533.33 Hz Sampling Rate (Gyroscope): 533.33 Hz	4
	Associated IMU Equipment	Shimmer Sense Base 6	1
	Double Sided Tape		1 Roll
	Cling Film		1 Roll
	Medical Tape (blue)		1 Roll
	Medical Tape (brown)		1 Roll
	GoPro	GoPro Hero 5 GoPro Hero 4 GoPro Hero 6	3
	GoPro Attachments	Flotations Helmet Attachment (Driver) Wrist Band (Crew)	3
	GoPro Memory Devices	SD cards	3
Software			
	ConsensysPro (Shimmer)	Inertial Sensor Software for syncronisation, data import, and analysis	-
	Matlab 2018b (Mathworks)	Inertial data analysis	-
	Microsoft Excel	Inertial data analysis	-
	Kinovea	Video Footage analysis	-

Figure 3: Equipment included GoPro video cameras, IMUs and a laptop

Equipment set-up

Video

Three GoPro cameras were attached to the boat, crew member, and driver to ensure all necessary views were capture. Views to be included were: i) lower extremity of the crew member, ii) view of the entire IRB, and iii) surf conditions (

Figure 4). GoPros were fitted with floats and attached using available equipment (Table 2). All GoPros were started and began recording prior to any activity inside the IRB.

Figure 4: GoPro locations (driver helmet, left pontoon, crew wrist).

Inertial sensors

Four, 9-axis inertial measurement sensors (Shimmer, Shimmer3 IMU) were utilised for this pilot study. Each sensor contained two 3-axis accelerometers (±16g and ±100g) (533.33 Hz), 3-axis gyroscope (533.33 Hz), and 3-axis magnetometer (533.33 Hz). Prior to collection, each unit was configured using the ConsensysPRO Software (Shimmer, V.1.5.0). After configuration, all four sensors were time synced using the "Base 6" (Shimmer) and removed from the dock. The removal from the "Base 6" established the beginning of the data recording.

Prior to attachment, the sensors were individually wrapped in cling film, to create a waterproof cover (Figure 5). The four IMUs were placed in the following locations: crew member sacrum (SC), crew member left tibia (LT), crew member right tibia (RT), and on the floorboard of the IRB (Figure 6). Orientation of the sensors is displayed in Figure 10. The sensors were each first attached with double-sided tape, followed by medical tape (blue), and medical tape (brown).

Figure 5: IMU sensor waterproofing technique.

Figure 6: IMU locations on crew member.

Figure 7: Crew member and driver with GoPro and inertial sensor attachments.

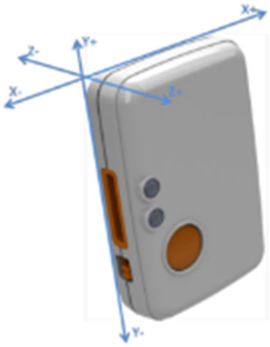


Figure 8: Shimmer3 IMU orientation.

Figure 9: Attachment of IMUs.

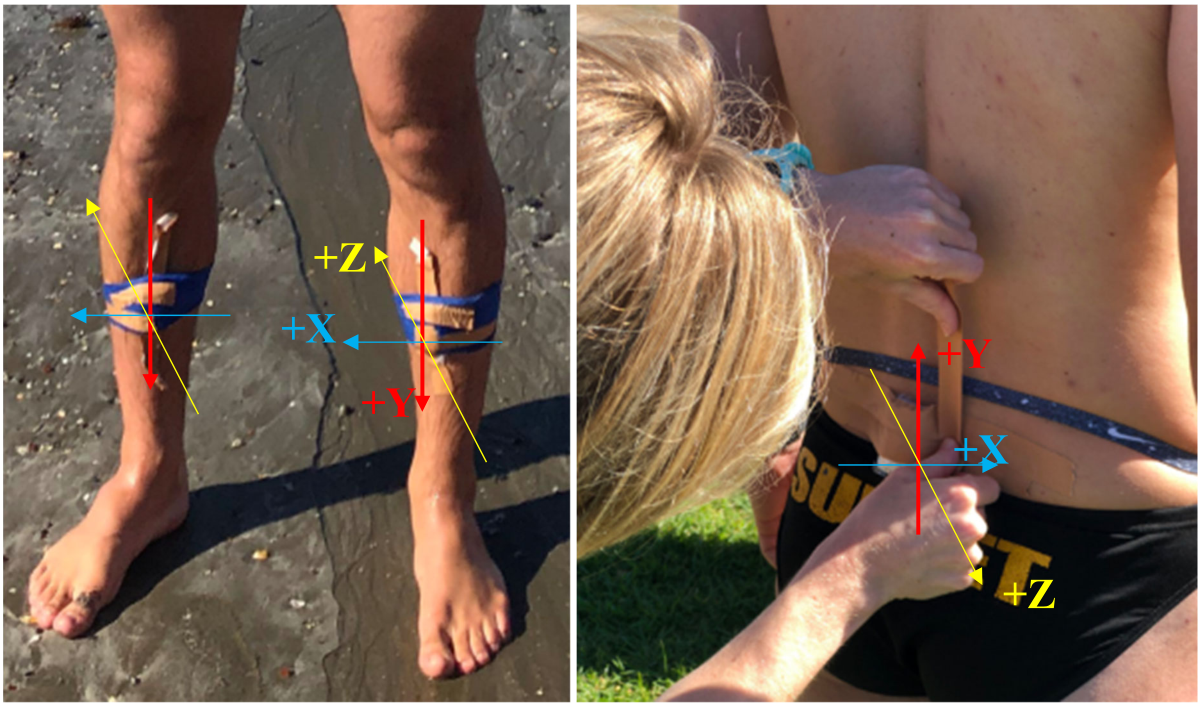


Figure 10: Inertial sensor orientations.

Synchronisation

In order to identify tasks on both the inertial sensor data and GoPro footage, a synchronisation jump was performed. The crew member was instructed to stand in the center of the floorboard inside the IRB, in view of all GoPro cameras. The jump consisted of a 5 second pause, 2 consecutive double-legged jumps, followed by a 5 s pause.

Data extraction

After completion of the trial run, GoPros were turned off and the SD cards were removed. Footage was uploaded to a laptop and analysed using iMovie, and Kinovea. The inertial sensors were unattached and re-docked into the Base6. Data from all four sensors was exported using ConsensyPRO V.1.5.0 (Shimmer) and imported into MATLAB® (MATLAB and Statistics Toolbox Release 2018a, The MathWorks, Inc., Natick, Massachusetts, United States) for further analysis.

RESULTS

The goal of the analysis of the feasibility study was to first identify if the sensors captured the necessary data. The synchronisation point was identified in the *IMU* data for all sensors, as well as in each video footage. All data were trimmed to this point.

Task identification

In order to identify tasks in the IMU data, time stamps were matched with the video footage of interest. Events of interest were marked in the video (e.g. turning, patient extraction), and then identified in the IMU data to assess for acceleration and rotational loads experienced by the crew member.

Filtering

For the purposes of initial analysis (peak detection), no filtering was utilised. However, if future orientation information was to be determined, filtering techniques would need to be applied to the accelerometer and gyroscope data. Further, if positional information was to be determined, sensor fusion algorithms such as the Kalman or Madgwick filter may be applied.

Frequency analysis

Evidence from SLSNZ studies found a high rate of lower back ACC claims, as well as SLSNZ members reporting of chronic injury symptoms. There is evidence that severe and/or prolonged exposure increases the risk of low back pain and early spine degeneration [10]. Vibration, like that experienced while operating an IRB, can increase the risk of low back pain; the lumbar part of the vertebral column being the most effected. However, literature has found it to be nearly impossible to identify an exact exposure-effect relationship from epidemiological studies. Thus, research has focused on identifying vibration exposure during different sporting activities. Tarabini, Saggin [11] found that kite surfing vibration exposure was highly dependent on sailing speed, with less of a correlation to wind or water speed. Furthermore, the posture of the athlete may significantly affect the aetiology of back disorders. In postures during kitesurfing and alpine skiing (forward leaning trunk with knees bent to absorb vibration), the power absorption of different body segments during the sport activity may be different from that of people in actual working conditions [11]. Controlling and/or reducing the frontal and lateral bending, torsion of the trunk, and peak loads during activity may reduce chronic injuries to the lower back. Superior core and lumbar stability might effectively control spinal movement and avoid unwanted amplitudes [12]. However, methods of quantifying the occurrence of chronic injuries is unclear.

Frequency analysis of sporting actions have been used to assess chronic injury symptoms [13]. One example from the literature used a power density spectrum for turning tasks during alpine skiing to assess average frequency values across a number of skiing activities. Furthermore, multiple IMUs can be used to assess the vibrations experienced at different locations on the body. For example, Supej [13] showed that the power spectrum intensifies in the knee joint compared to that in the ski boot when alpine skiing. This phenomenon can be described by the fact that the skier dampens the vibrations through their musculoskeletal system where the knee joint; with the relative movement of the ankle joint towards the hip joint, also moves in the sagittal and/or transverse plane. This increases the amplitudes of the movement and consequently also the acceleration which appears at the same time in all three directions. Surf lifesavers may experience similar vibrations and dampening approach through the musculoskeletal system, in which a power density spectrum analysis may be used for accelerometer signals from multiple IMUs attached to a surf lifesaver while operating an IRB.

Therefore, it would be beneficial to investigate the vibration exposure of surf lifesavers while operations IRBs. Through a frequency analysis approach, identifying the power spectrum densities may enable the comparisons of vibrations during different IRB crewing tasks under different techniques and body positions. Moreover, this technique may help to identify age- and gender-specific load prescriptions in order to minimize the risk of developing low back pain.

DISCUSSION

Weather and water conditions

The water and weather conditions were both mild on the day of data collections with wave heights <0.2 metres, clear visibility, and air temperature approximately 16^{o}C.

Task identification

Raw accelerometer and gyroscope data were visually assessed for task identification utilising the synchronised GoPro footage (**Error! Reference source not found.** - **Error! Reference source not found.**). Only the ±16g accelerometer was analysed as this was a feasibility pilot to assess if the method would work.

The greatest peak linear accelerations and angular rotations occurred when entering the water and starting the IRB and exiting the IRB. Interestingly, while on open water, the accelerations felt by the left and right tibia in all three axes were below 10g's. The sacrum seemed to experience the greatest of loads, particularly when turning. Furthermore, the frequency in oscillations, particularly at the sacrum, demonstrates a need for frequency analysis (e.g. power spectrum density), in order to understand potential acute and chronic injury mechanisms. One landing was identified in the video footage, in which the accelerations experienced do not reach above 10g. This however may be due to the flat water conditions. **Error! Reference source not found.** shows a simulated training sequence including entering the water, open water turns, patient extractions, and returning to shore.

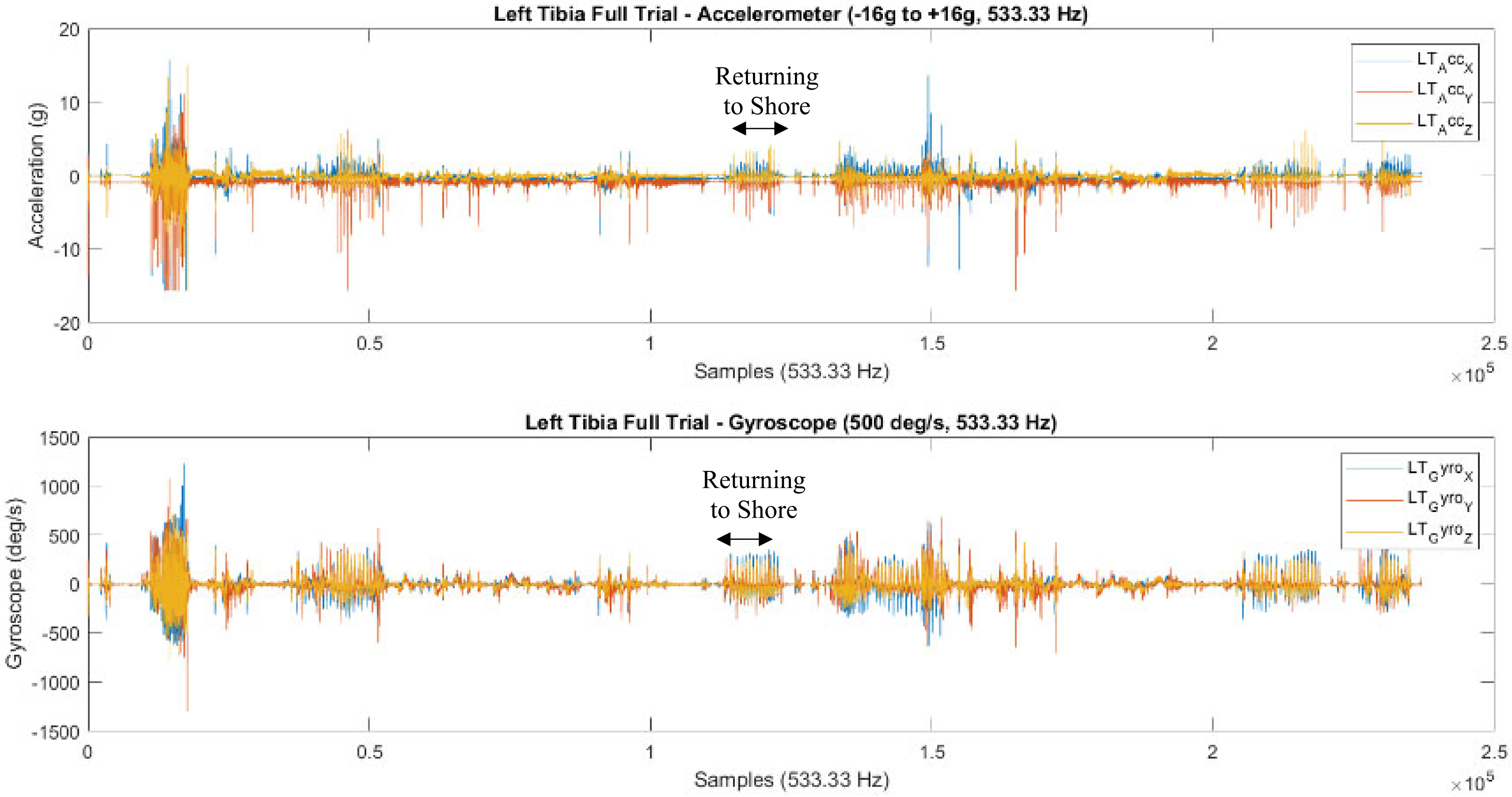


Figure 11: Left Tibia - Full Trial Accelerometer and Gyroscope Raw Data (7:23)

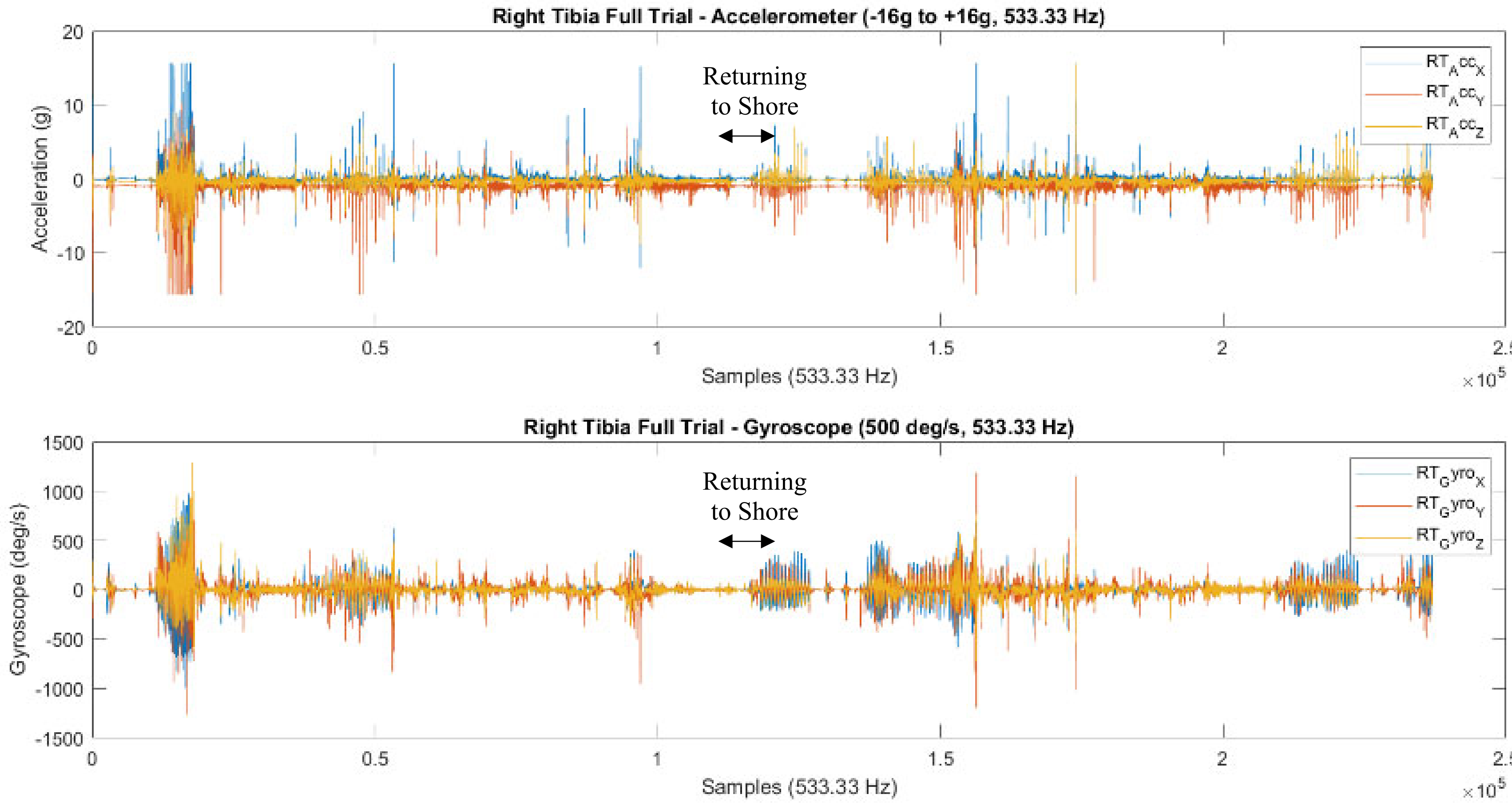


Figure 12: Right Tibia - Full Trial Accelerometer and Gyroscope Raw Data (7:23)

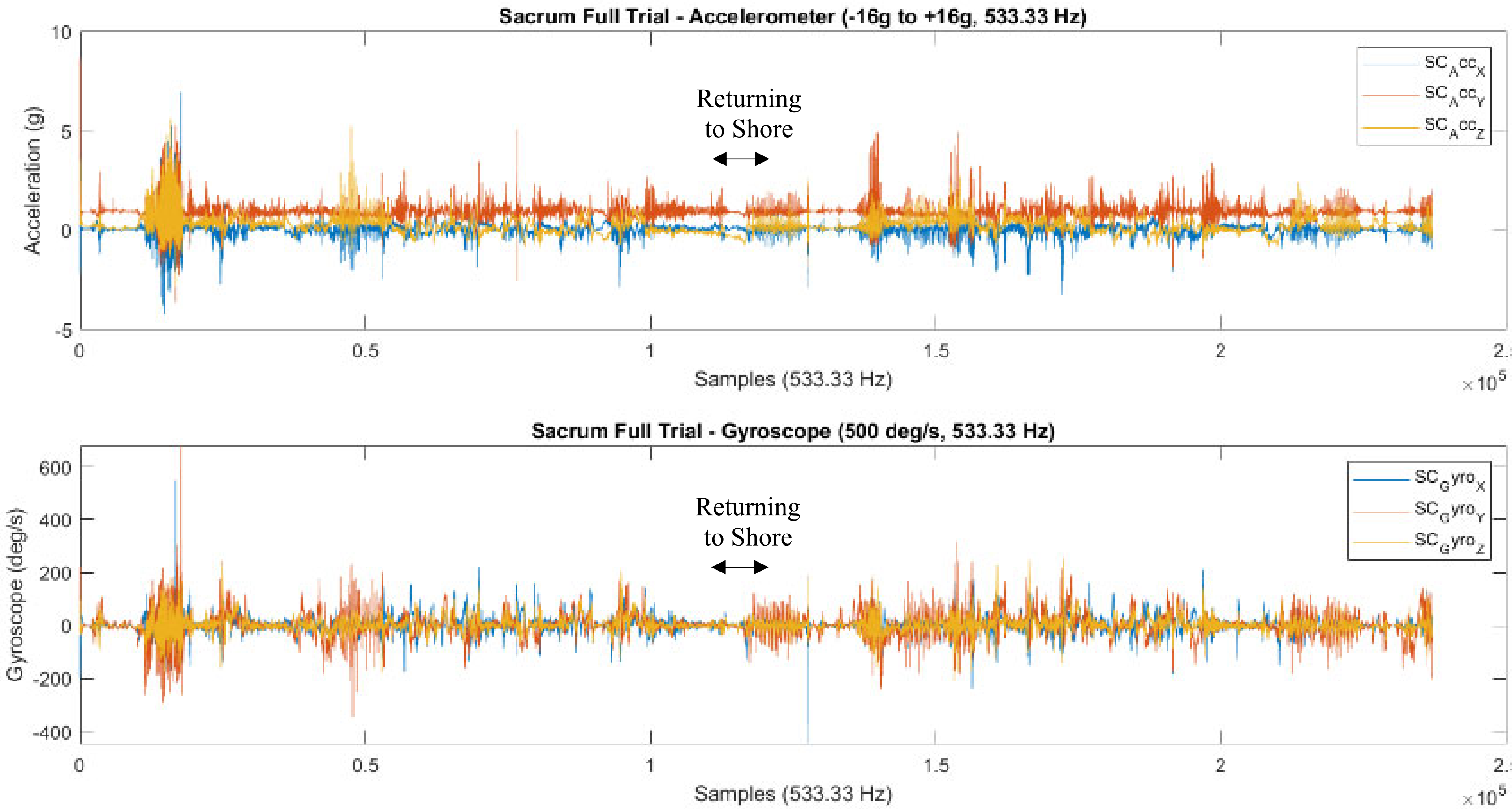


Figure 13: Sacrum - Full Trial Accelerometer and Gyroscope Raw Data (7:23)

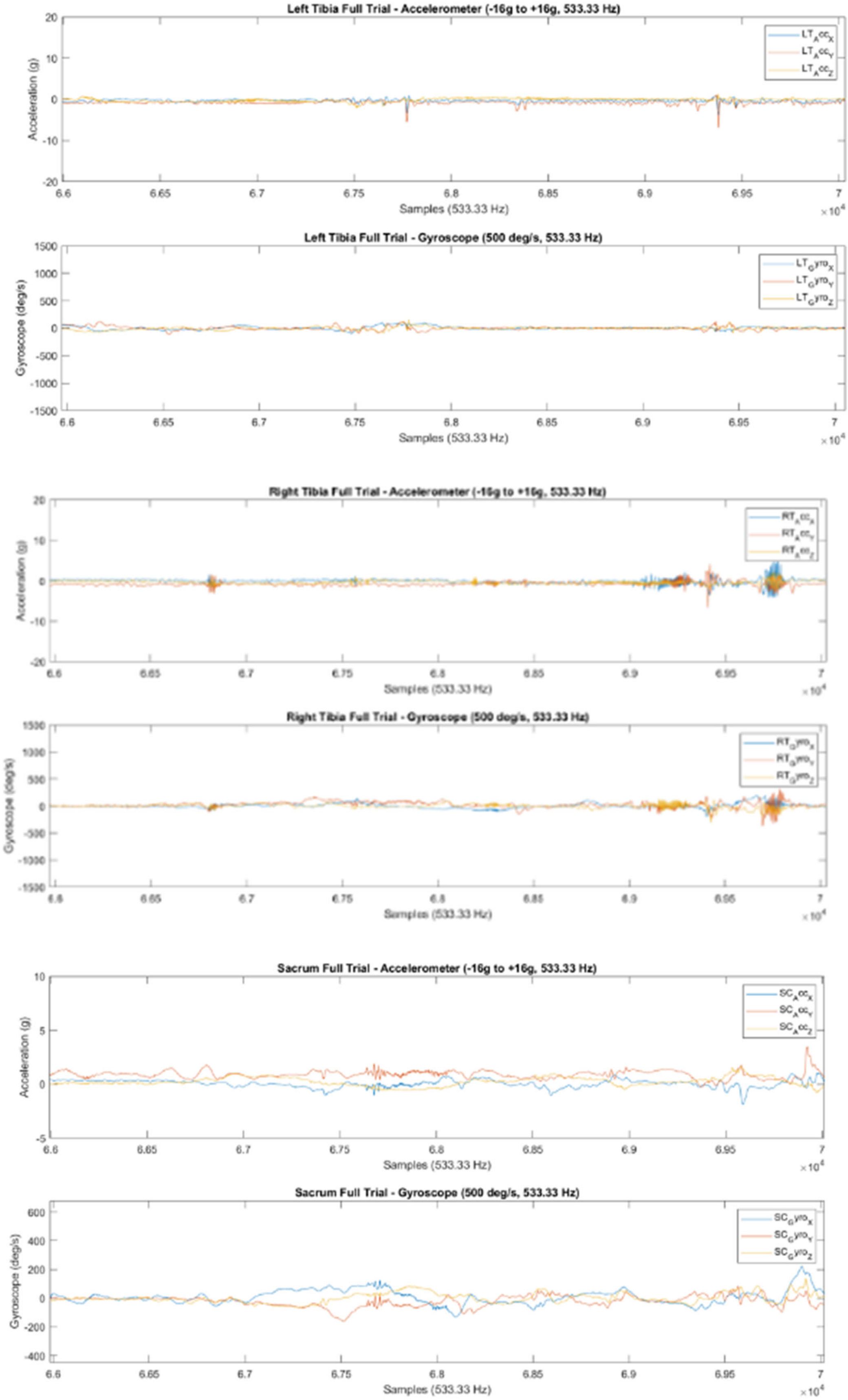


Figure 14: Landing in the IRB (Left Tibia, Right Tibia, Sacrum)

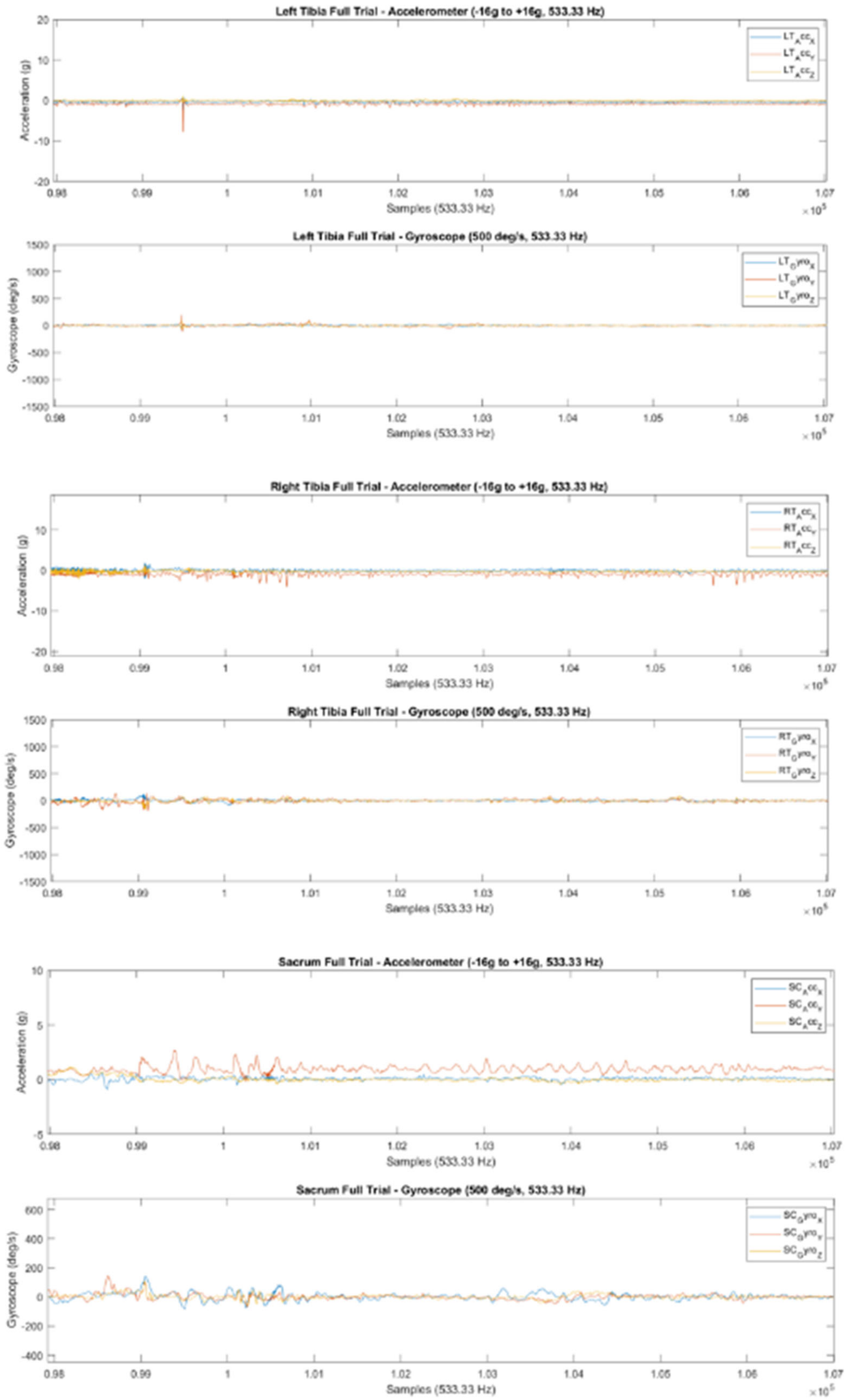


Figure 15: Turning Maneuver (Left Tibia, Right Tibia, and Sacrum)

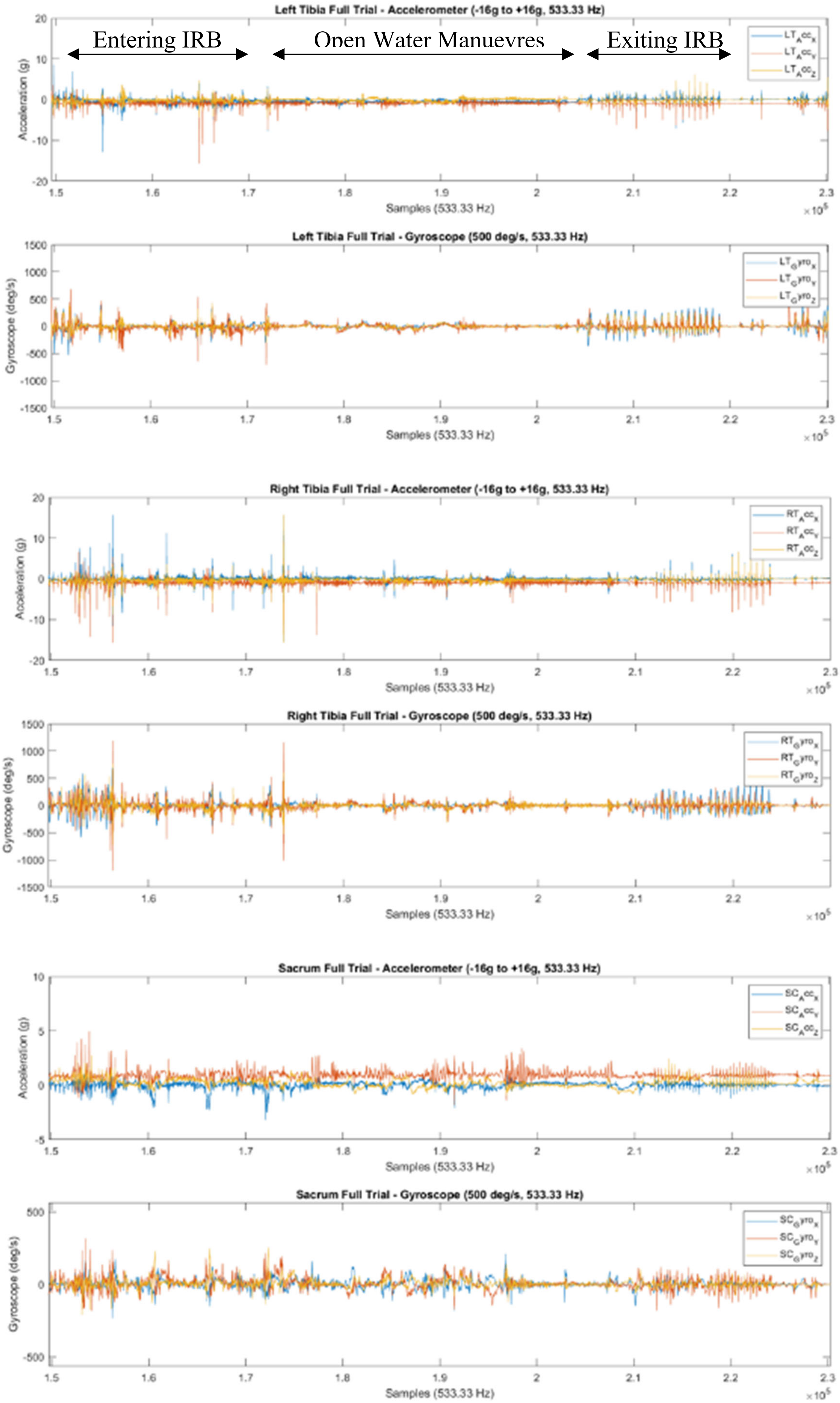


Figure 16: Simulated Training Sequence

Inertial measurement data

Inertial measurement accelerometer and gyroscope signals are presented in **Error! Reference source not found.** to **Error! Reference source not found.**. Contrary to expected, peak accelerations exceeding 50g were not common, and occurred mostly entering and exiting the IRB (**Error! Reference source not found.**). Landing in the IRB while on the water has been identified as a potential mechanism of lower extremity injury. However, the accelerometer data did not demonstrate high peak accelerations at landing (**Error! Reference source not found.**). This may be due to the calm conditions, as seen in the GoPro footage. Future research should assess accelerations in varying conditions to determine if greater peak accelerations are experienced at landing.

Interestingly, the occurrence of vibrations can be seen in the sacrum accelerometer signal during a turning manoeuvre (**Error! Reference source not found.**) (Figure 19 to Figure 25). Although the amplitude of the accelerometer signal does not exceed 5g, the oscillations may be a contributing factor to injury and should be examined further with frequency analysis techniques.

GoPro Footage

After collection and synchronisation, the GoPro footage was combined into one split screen video (.mp4) format. Although insightful, the footage from the crew member's wrist was not utilized. In the future, this camera should be moved to the front of the pontoon to view the water conditions and any obstacles in the water. The GoPro attached to the drivers' helmet provided a better picture of the water conditions and obstacles; however, this camera would also be better suited in a steadier position (e.g. rear of the pontoon).

The left pontoon GoPro footage provided the best view of the crew member lower extremity biomechanics. Although in extreme ranges, the view was not fully captured, this may be improved by altering the camera viewing mode (e.g. from landscape to fisheye). Ranges of lower extremity motion were assessed from Figure 18 to Figure 25. Video footage identified large ranges of motion and ankle joint flexibility required by the crew member. Several compromising positions during varying tasks were identified in which the right ankle is at a high degree of dorsiflexion (Figure 24).

Figure 17: Ideal GoPro Locations

Figure 18: Crew position while returning to shore

Figure 19: Crew standing position while preparing for a turn

Figure 20: Crew position while preparing for a turn

Figure 21: Crew position while preparing approaching a buoy and turn

Figure 22: Crew position while executing buoy turn

Figure 23: Crew position after buoy turn

Figure 24: Crew position after buoy turn

Figure 25: Crew position after buoy turn

Limitations and future recommendations

There were limitations with the pilot data collection that need to be addressed when conducting further research. The weather and water conditions may have not accurately reflected the accelerations and loads typically seen during patrol and operation. Future research should be conducted under different conditions to assess the magnitude and frequency of biomechanical loading endured by the crew member. Regarding the inertial measurement sensors, a range of ±50g may be required to capture peak accelerations (during entering and exiting of the IRB) while on flat water. However, a range of ±100g should be utilised during all conditions to ensure the capture of all data.

Another limitation existed in the GoPro footage. Due to the positioning of the cameras, it was difficult to assess the full range of motion, as part of the lower extremity was out of view. In addition, a clear view of the conditions traversed should be captured during operation of the IRB. Future research should attempt to standardize the manoeuvres in the water to compare across populations and conditions. The crew member exhibited large ranges of motion during turning manoeuvres specifically. However, the angle of the cameras did not allow for accurate measurement of joint kinematics in all three planes of movement. Future studies should investigate the different biomechanical positioning of the crew members in a lab environment with motion capture (e.g. VICON) to assess potential injury mechanisms.

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