

A Case Study on the Kinematics in Deep Water Running

Case Study

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Abstract

Introduction: This field-based case study assessed linear accelerations of the torso centre of mass (CoM) and the tibia using two wearable sensors in a triathlete performing 20 minutes of continuous deep water running.

Methods: One triathlete (36 years; height; 151 cm; weight; 63 kg) participated in this field-based case study. One wearable sensor (an accelerometer) was located on the lumbar five/sacrum one (L5/S1) spinous process as a proxy for the centre of mass (CoM) and on the midpoint of the right tibia to capture linear acceleration magnitudes. The participant then performed 20 minutes of deep water running that was completed at a self-selected pace.

Results: No significant differences ($p < 0.05$) in torso CoM and tibia acceleration magnitudes were detected in 20 minutes of deep water running. Despite this, the magnitude of torso CoM and tibia acceleration, notably in the anteroposterior and vertical directions, increased at the midpoint of the deep water run, possibly indicating the onset of fatigue.

Conclusions: This field-based case study suggests that a wearable sensor can reliably detect variations to the torso CoM and tibia by way of linear acceleration magnitudes in 20 minutes of continuous deep water running. Based on these results, it is possible that the increased acceleration observed at the tibia were due to the onset of fatigue. Future investigations with a larger number of participants are needed to further explore the relationship between torso and tibia acceleration and fatigue in deep water running.

Key Words: Deep water running. Sensors. Acceleration. Centre of Mass.

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Introduction

Deep-water running (DWR) is performed in the deep end of a swimming pool, normally with the aid of a flotation vest or a flotation belt. DWR is commonly used by athletes as a form of complementary training for the maintenance of cardiovascular fitness; to assist in the recovery from injury; or as a means of recovery from strenuous exercise¹. Regardless of how and why DWR is used, the motion of running in a fluid environment is a low impact form of jogging. A reduction in spinal

loading constitutes a role for DWR in the prevention of injury, while an alleviation of muscle soreness confirms its value in recovery training¹. However, DWR is a form of cardiovascular exercise that is useful for the injured runner or triathlete. Consequently, DWR is commonly used as an injury-rehabilitation technique (i.e., limb stress fracture)² and as an applied cross-training technique in order to help athletes retain overall fitness levels. In this regard, DWR is a non-weight bearing form of exercise that can mimic an athlete's dryland-based running technique both a performance and rehabilitation training setting. However, there are many idiosyncrasies to DWR and general aquatic fitness

modalities that should be understood by both the clinician and the athlete due to the unique physiologic and kinematic changes that occur to a body immersed in water. In this regard it is important for the coach or sports medicine practitioner to focus on the underlying physics and biomechanics of running in water to better produce the desired physiological, metabolic, and biomechanical outcomes. For instance, the skill level of the DWR technique, psychological comfort, perception of work, muscular recruitment patterns, and running kinematics are all affected by the physics (i.e., temperature, buoyancy, hydrostatic pressure, specific gravity, and drag) of running in water³. Therefore, the relationship between the biomechanics and the corollary practical kinematic indicators found in DWR must be understood and considered when prescribing training and rehabilitation protocols. Due to their portability, wearable sensors (wearables) are emerging as a digital, low-cost and accurate device that enables field-based measurements in various natural settings. Nevertheless, whereas wearables are commonly used to measure dryland running metrics such as cadence and vertical oscillation, they are not widely used in DWR. Thus, the purpose of this field-based case study was to assess the reliability of wearable technology (an accelerometer) in detecting variations to torso CoM and tibia acceleration magnitudes in 20 minutes of DWR.

Scientific Methods

Participants

One female participant (age, 36 years; height, 151 cm; weight, 65 kg) volunteered for this field-based case study. The female participant was a triathlete who was using DWR to maintain and supplement cardiovascular fitness while recovering from a minor metatarsal fracture (5th metatarsal) of the left foot. The injury was classified as acute and was diagnosed by a medical professional. The participant had previously completed DWR on three days per week that was performed on non-consecutive days. Before data collection, the university research ethics subcommittee approved all procedures proposed in the study (H21114).

Protocol

The participant performed 20 minutes of continuous DWR. A duration of 20 minutes was selected due to the participant regularly completing a 5 km dryland run in approximately 20 minutes. In this instance, the DWR protocol was selected to simulate the running patterns adopted on dryland and was consistent with the participant's prior DWR experience. The protocol comprised of repeated bouts of DWR that entailed back and forth motion of 25 m (i.e., where total displacement equaled zero). The participant wore a flotation belt (Aquajogger, Excel Sports Science, Inc, Springfield, OR, USA) (Figure 1) that was securely fastened around the waist so that the belt straps sat aligned with the posterior superior iliac spine (Figure 2). The participant was instructed to adopt a "high knee" gait and stride turnover that was to be performed at a self-selected pace in order to stay afloat. The participant was asked not to adopt too much of a forward lean³. Session rating of perceived exertion (SRPE) was used to quantify the internal training load. Session RPE represents the session intensity and requires a simultaneous measure of the same session duration (i.e., 20 minutes) by the participant. Session RPE has been used in both a competitive⁴ and rehabilitation setting⁵ to measure an individual's effort and exertion, breathlessness and fatigue during physical work. The scale is based on a numerical range from 6–20 where 6 means "no exertion at all" and 20 means "maximal exertion"⁶. No additional instructions were provided to the participant.

Figure 1. Aqua belt used in the study



Figure 2. Participant in the pool performing DWR.



The study was conducted in the deep end of a recreational outdoor 50 m swimming pool (maximum depth 2.2 m) that was habitually frequented by the participant. The participant completed a pre-exercise screening questionnaire and signed an informed consent declaration. Preceding the start of the DWR protocol, the participant completed approximately five minutes of self-selected dynamic stretches as a warmup. Once the warmup was completed, the sensors were manually fitted to the participant by the principal author. To assess torso CoM motion, one sensor was positioned over the participant's spinous processes, defined as the lumbar vertebrae position five (L5) and sacrum vertebrae position one (S1)⁷. The accelerometer was then secured into a moisture proof ziplocked metallic matte foil airtight bag (Ferenli, Miami, FL, USA). The bag was attached using double-sided adhesive tape to ensure fixation and to reduce unwanted movements. To assess tibial acceleration, an additional sensor was secured into another moisture ziplocked bag before being attached to the midpoint of the right tibia, between the participant's patella and talus. Both sensors were located so that the y axis was positioned with the + y in the vertical direction, thus aligned with the vector representing the gravitational constant. An ambient temperature of 26 degrees Celsius was recorded as the participant commenced the DWR at 1300.

Advances in accelerometers offer real-time detection of motion⁸. Both torso CoM and tibia acceleration were measured using two ActiGraph GT9X + accelerometers (ActiGraph, LLC, Pensacola, FL, USA). These devices (3.5 x 3.5 x 1 cm, 14 grams) measure the magnitude of linear acceleration during movement. Prior to testing, the sensors were initialized according to manufacturer instructions to record accelerations at a sampling frequency of 100 Hz. The raw accelerometry signals from the torso CoM and tibia were downloaded and then converted from gt3x files to CSV format and saved and exported to Microsoft Excel (Microsoft Corporation Redmond, Washington DC, USA version 4.90.4, build 6470.27615). Raw data was then analyzed using the ActiLife software program (Version 6.13.4, ActiGraph, LLC).

Statistical Analysis

Data are presented as means $\pm$ SD. The normality of appropriate data sets was established by the Shapiro–Wilk test using the Analyse-it statistical software package (Leeds, United Kingdom, version 4.92). As the normality of data was not evenly distributed, non-parametric tests were used. Thus, a Wilcoxon signed-rank test was used while the nonparametric Friedman test was selected to compare the variations between acceleration magnitudes in both torso CoM and tibial motion. An interquartile range (IQR) was used to identify the range of the average performance. The coefficient of variation (CV), that is – the ratio of the standard deviation to the mean acceleration magnitude (in x, y, z) relative to the torso CoM and tibia were used to show the extent of data variability. The standard error of measurement (SEM) and the minimal detectable change (MDC) were calculated, the latter of which was used to assess the minimal magnitude of change required to be 95% confident that the observed change reflects a true change in acceleration and not measurement error⁹. The MDC was calculated as: $1.96 \times \text{SEM} \times \sqrt{2}$. The vector magnitude was calculated as $\sqrt{(x^2 + y^2 + z^2)}$. Despite the sole participant featured in the study, in order to review the variability and possible meaning of the acceleration data, significance was set at $\alpha = 0.05$. The use of statistical significance was therefore used as a general value that could indicate a significant and quantifiable amount of data variation.

Results

Table 1 presents the results from the magnitude of torso CoM and tibial acceleration magnitude. Of note are the relatively high magnitudes of acceleration in both torso and tibia motion from minutes 10-15.

Interestingly, the 10–15-minute epoch was observed to have the largest $\pm$ SD in both torso CoM and tibia movements, the latter recording the highest vector magnitude.

Table 1. Mean $\pm$ SD of acceleration and vector magnitudes of the torso CoM and tibial in 20 minutes of deep water running. Where is SE is the standard error. MDC = minimal detectable change. RPE = Ratings of perceived exertion. Acceleration presented in m/s^2

	Mean Acceleration m/s^2	SE	MDC	Resultant vector	Session RPE
Torso CoM acceleration					
Minutes 0-5	0.89 ± 0.4	0.17	0.58	1.03	
Minutes 5-10	0.94 ± 0.5	0.13	0.50	1.03	
Minutes 10-15	0.91 ± 0.5	0.12	0.49	1.03	
Minutes 15-20	0.86 ± 0.4	0.12	0.48	1.03	
Tibial acceleration					
Minutes 0-5	6.63 ± 2.5	0.87	1.31	6.93	
Minutes 5-10	6.02 ± 2.0	0.48	0.97	6.72	
Minutes 10-15	8.05 ± 2.7	0.68	1.16	8.39	
Minutes 15-20	7.30 ± 2.4	0.60	1.09	7.93	
					13 (somewhat hard)

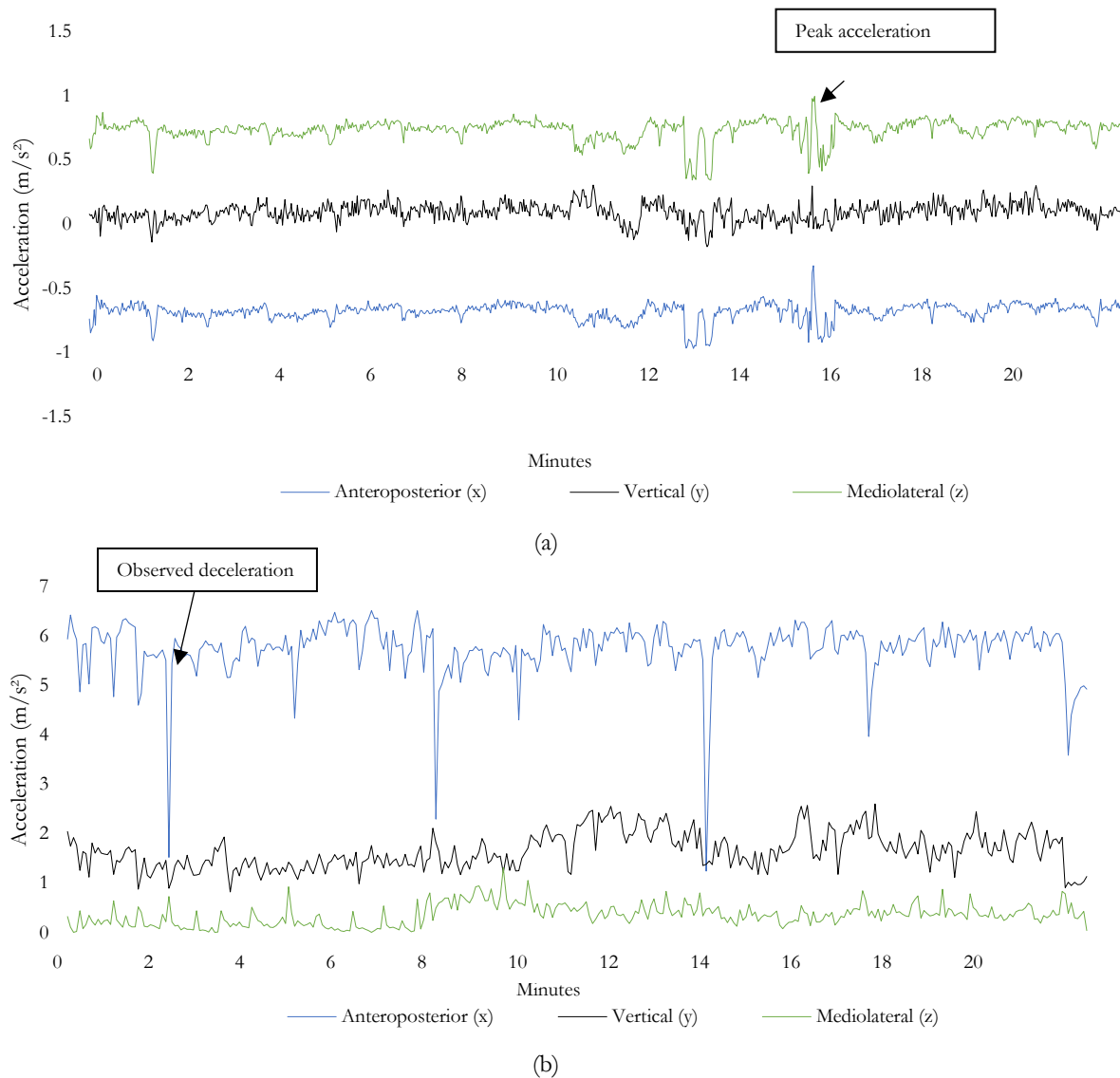
The magnitude of acceleration profiles in the torso CoM and tibia did not show any significant difference in the 20 minutes of DWR. Despite this, maximal acceleration of the tibia was reached at minutes 10-15 in the vertical and anteroposterior channels. Across the axes, the mediolateral direction was observed to have the largest combined coefficient of variation (Table 2).

Table 2. Mean $\pm$ SD of the magnitude of torso and tibia acceleration in 20 minutes of deep water running. Where AP (x) is anteroposterior, VT (y) is vertical and ML (z) is mediolateral. CV is coefficient of variation; IQR is the interquartile range. Where p is significant at ≤ 0.05 .

	AP (x) m/s ²	CV (%)	IQR	p	VT (y) m/s ²	CV (%)	IQR	p	ML (z) m/s ²	CV (%)	IQR	p
Torso CoM acceleration												
Minutes 0-5	0.04 $\pm$ 0.2				0.79 $\pm$ 1.2				0.05 $\pm$ 0.2			
Minutes 5-10	0.05 $\pm$ 0.1				0.83 $\pm$ 1.1				0.06 $\pm$ 0.2			
Minutes 10-15	0.04 $\pm$ 0.2				0.81 $\pm$ 1.0				0.05 $\pm$ 0.6			
Minutes 15-20	0.04 $\pm$ 0.3				0.77 $\pm$ 0.9				0.03 $\pm$ 0.7			
		4.7	0.03	0.62		3.3	0.04	0.62		17.7	0.01	0.71
Tibial acceleration												
Minutes 0-5	1.32 $\pm$ 1.1				5.11 $\pm$ 2.1				0.19 $\pm$ 1.1			
Minutes 5-10	1.25 $\pm$ 1.0				4.30 $\pm$ 1.2				0.46 $\pm$ 1.2			
Minutes 10-15	1.87 $\pm$ 2.1				5.76 $\pm$ 2.3				0.42 $\pm$ 2.1			
Minutes 15-20	1.68 $\pm$ 2.0				5.16 $\pm$ 2.1				0.44 $\pm$ 1.0			
		19.2	0.51	0.09		11.8	1.45	0.09		32.6	0.16	0.41

When the magnitude of both torso and tibia acceleration was examined at five-minute epochs, the participant was observed to alter torso CoM motion and consequently acceleration, specifically from the midpoint of the DWR (Figure 3a). Relative to tibia motion, when the participant reached the 25 m turnaround point a visible reduction in acceleration at the tibia, notably in the anteroposterior axis, can be seen.

Figure 3. Raw data based on triaxial acceleration magnitudes of the torso CoM in 20 minutes of deep water running (a). Raw data based on acceleration magnitude of the tibia in 20 minutes of deep water running (b). Where AP (x) is anteroposterior, VT (y) is vertical, and ML (z) is mediolateral



Discussion

The purpose of this field-based case study was to determine how the magnitude of torso CoM and tibia acceleration varied during 20 minutes of continuous DWR using sensor technology. While no significant differences between the torso CoM and tibia acceleration were observed throughout the 20-minutes of DWR, the results from this case study suggest that a wearable and unobtrusive sensor (an accelerometer) is a reliable device that can be used to capture dynamic motion in a fluid environment. Moreover, that the device detected changes to both torso CoM and tibia acceleration suggest that sensor technology could be used in further DWR research design protocols in an



observational and interventional based perspective. Relative to torso CoM motion, although no significant differences were observed in all of the acceleration channels, torso acceleration increased from minutes five to 15. The reasons for this increase in acceleration are unclear and warrants additional research. One explanation could be that as the participant performed a continuous bout of DWR, a conceivable inclination, that is - a slight change in torso position occurred due to the onset of fatigue. If torso fatigue was experienced by the participant, this would theoretically tilt the torso and alter the acceleration magnitude. In contrast, increased acceleration of the tibia occurred from minutes 10-15 in all acceleration channels. While the reasons for this increase are not fully understood, the authors speculate that this was also linked to the onset of fatigue which subsequently produced increased movement of the tibia. This aligns with previous research that has shown that peak tibial acceleration increased over the duration of a fatiguing run¹⁰. Despite the obvious differences in mechanical loading, specifically the axial loads experienced when running on dryland compared to DWR, the relationship between tibia acceleration in the two conflicting settings is an area for future investigation.

The reliability of sensors was assessed throughout the 20-minutes of DWR, that is – the ability of wireless sensors to track linear acceleration in a fluid environment. Thus, the outcomes of this field and sensor-based case study show that changes in magnitudes of the torso CoM and tibia during DWR can be reliably detected despite the lack of participant lower-limb loading. Future studies should examine the effects in a longitudinal-based study design to observe if similar results to those obtained from this study can be drawn.

Conclusions

The magnitude of torso CoM and tibia acceleration was not significantly different in 20 minutes of continuous DWR. Despite this, at the midway point of DWR the magnitude of tibial acceleration was observed to increase in all axes, conceivably due to the commencement of fatigue. While a wearable sensor was able to clearly identify peak acceleration changes in both torso CoM and tibia motion, additional research is needed to identify possible trends in acceleration and fatigue. Collectively, this case study suggests that using a wearable sensor to detect linear accelerations in DWR could be used to detect the onset of fatigue. Despite this, little is known on the effectiveness of DWR despite it gaining popularity. Consequently, further examinations that explore the differences in physical functional outcomes with validated measurement tools for DWR are needed.

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