Prediction of Ground Reaction Forces in Running from Wearable Instrumentation and Algorithmic Models

Submitted by Daniel Charles Billing

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Declaration

This thesis contains no material that has been accepted for the award of any other degree or diploma in any university or college of advanced education and to the best of my knowledge contains no material previously published or written by another person except where due reference is made.

Name: Daniel Charles Billing

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Abstract

Measurement of ground reaction force (GRF) in running provides a direct indication of the loads to which the body is subjected, at each foot-ground contact, and can provide an objective explanation for performance outcomes. Traditionally, the collection of three orthogonal component GRF data in running requires an athlete to complete a series of return loops along a laboratory based runway, within which a force platform is embedded in order to collect data from a discrete footfall. The major disadvantages associated with this GRF data collection methodology includes, the inability to assess multiple consecutive foot contacts and the fact that measurements are typically confined to the laboratory. The objective of this research was to investigate the potential for wearable instrumentation to be employed, in conjunction with artificial neural network (ANN) and multiple linear regression (MLR) models, for the estimation of GRF in middle distance running. A custom, wearable data acquisition system was developed to acquire in-shoe force (ISF) and centre of mass acceleration (CMA) data simultaneously. Matched data sets from wearable instrumentation (source data) and force plate (target data) records were collected from elite middle distance runners under controlled laboratory conditions for the purposes of ANN and MLR model development (MD) and model validation (MV).

Using a range of source data groupings, including ISF and CMA in isolation as well as in combination, it was found that ISF data, employed separately, provided the highest ANN and MLR model prediction accuracy for all three components of GRF. In general terms, an intra-subject, running speed interpolation based prediction scheme along with the MLR model was found to provide the highest prediction accuracy for the vertical (Correlation Coefficient [CC]: 0.997-1.000, Mean Absolute Error [MAE]: 14.494-46.658N) and medio-lateral (CC: 0.875-0.974, MAE: 10.680-39.890N) components of GRF. Alternatively, under the same prediction scheme, the ANN model provided the most accurate predictions of the anterior-posterior (CC: 0.974-0.992, MAE: 14.910-31.118N) component of GRF. The prediction accuracy of each component of GRF was found to be governed by the inherent signal variability, in which case the vertical and anterior-posterior components were more reliable and subsequently predicted significantly more accurately than the medio-lateral component of GRF. In order to achieve accurate GRF predictions, the wearable instrumentation and algorithmic models need to have sufficient sensitivity to capture this inherent GRF signal variability. Findings from this research provide a proof of concept for the prediction of GRF from wearable instrumentation in middle distance running. The emerging capability for obtaining continuous GRF records from wearable

instrumentation has the potential to permit unprecedented quantification and analysis of training stress and competition demands.

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List of Symbols

A_s: Active Measurement Area of Sensor s	[mm^2]
AE: Absolute Error	[N]
AEs: Absolute Error Signal	-
$a_{A\text{-}P}$: Anterior-Posterior Acceleration	[ms^{-2}]
$a_{M\text{-}L}$: Medio-Lateral Acceleration	[ms^{-2}]
a_V: Vertical Acceleration	[ms^{-2}]
CC: Correlation Coefficient	-
CV: Coefficient of Variation	[%]
$\overline{CV}$: Average Coefficient of Variation	[%]
CVs: Signal coefficient of variation	-
E: Error	[N]
Fs: Sum of the Forces Calculated by the In-shoe Sensors	[N]
$GRF_{A\text{-}P}$: Anterior-Posterior GRF	[N]
$GRF_{M\text{-}L}$: Medio-Lateral GRF	[N]
GRF_V: Vertical GRF	[N]
Hz: Hertz	[s^{-1}]
J: Number of Trials	-
$L1$: Number of Neurons in Layer 1	-
$L2$: Number of Neurons in Layer 2	-
$L3$: Number of Neurons in Layer 3 or Output Layer	-
M: Sample Mean	-
m: Mass	[kg]
MAE: Mean Absolute Error	[N]
Ms: Signal Mean	-
N: Sample Size	-
NE: Normalised Error	[%]
P_s: Pressure at Sensor s	[kPa]
R^2: Variance Explained	[%]
S: Number of Sensors	-
SDs: Signal Standard Deviation	

-

List of Acronyms

AC: Alternating Current

ADC: Analog-to-Digital Converter

ANN: Artificial Neural Network

BW: Body Weight

CGB: Conjugate Gradient Back-propagation with Powell-Beale restarts

CGF: Conjugate Gradient Back-propagation with Fletcher-Reeves updates

CGP: Conjugate Gradient Back-propagation with Polak-Ribiere updates

CMA: Centre-of-Mass Acceleration

CNS: Central Nervous System

DC: Direct Current

EMG: Electromyography

FFT: Fast Fourier Transform

FSR: Force Sensing Resistor

FTM: Force Treadmill

GRF: Ground Reaction Force

HDP: Historical Data Points

HL: Hidden Layer

IC: Integrated Circuit

ISF: In-Shoe Force

L3/L4: 3rd / 4th Lumbar Vertebrae

LED: Light Emitting Diode

LF: Left Foot

LM: Levenberg-Marquardt Back-propagation

LOGSIG: Log-Sigmoid

MD: Model Development

MEMS: Micro-Electro-Mechanical System

MLR: Multiple Linear Regression

MMC: Multimedia Memory Card

MSC: Multi-Sensory Combination

MTH: Metatarsal Head

MV: Model Validation

OSS: One-Step Secant Back-propagation

PNS: Peripheral Nervous System

PS*N*: Prediction Scheme *N*

RF: Right Foot

RMS: Root-Mean-Square

RP: Resilient Back-propagation

S1: Session 1

S2: Session 2

SOM: Self Organising Map

TANSIG: Tan-Sigmoid

USB: Universal Serial Bus