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Biomechanical loads in running-based sports: estimating ground reaction forces from segmental accelerations (PhD Academy Award)

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WHAT DID I DO?

The overall aim of this thesis was to investigate if ground reaction forces (GRFs) can be estimated from segmental accelerations, to provide further insight in the feasibility of using body-worn accelerometers to monitor whole-body biomechanical loading during running-based (team-) sports.

WHY DID I DO IT?

Although the physiological demands of training have been investigated extensively, biomechanical loads are still poorly quantified and, therefore, not well understood [1]. GRF is a well-established measure of external biomechanical loading which drives and is affected by muscular actions, and at the same time contributes to internal loads acting on individual structures (e.g. muscles, tendons and bones). GRF thus forms an overall measure of the biomechanical loads experienced by the body as a whole and might be used to investigate the relation between whole-body loading and musculoskeletal responses. However, valid methods for accurately estimating GRF outside laboratory settings are currently unavailable. Given the direct relationship between GRF and segmental accelerations according to Newton's second law, currently popular body-worn accelerometers [2] could open the door to estimating GRFs in the field to eventually be used for performance enhancement, injury prevention and rehabilitation.

HOW DID I DO IT?

The first two studies validated if a two mass-spring-damper model can accurately replicate GRF profiles for high-intensity running tasks that are frequently performed during running-based sports [3], and investigated if accelerations measured from a trunk-mounted accelerometer can be used to drive this model to predict GRF [4] (Figure 1A). The third study examined if a direct mechanical method can provide valid GRF estimates from multiple segmental accelerations measured with a three-dimensional motion capture system, and established the minimal number of segments required [5] (Figure 1B). The final study explored if generalised segmental acceleration patterns across different running tasks and their specific contribution to the GRF can be identified, using a multivariate principal component analysis [6] (Figure 1C).

WHAT DID I FIND?

The main findings were that:

1) A two mass-spring-damper model can be used to accurately reproduce overall GRF profiles and impulses measured with a force platform for a range of high-intensity running tasks [3], but this model cannot be used to predict GRF from trunk accelerations measured with a trunk-worn accelerometer [4].
2) Using a direct mechanical approach, GRF profiles and loading characteristics can be estimated with reasonable accuracy across various dynamic and high-intensity running tasks from fifteen

segmental accelerations measured with a motion capture system, but errors substantially increased when the number of segments was reduced [5].

3) A multivariate principal component analysis approach can reveal generalised acceleration patterns and specific segmental contributions to GRF features, but their relative importance for different running activities is mainly dependent on the type of movement performed [6].

WHAT IS THE MOST IMPORTANT CLINICAL IMPACT / PRACTICAL APPLICATION

- It is not straightforward to predict GRF from trunk-worn accelerometers, or even multiple segmental accelerations measured with a motion capture system, using different mechanical approaches.
- These findings warrant caution for researchers and practitioners when using acceleration signals from a single segment and accelerometry derived load metrics to quantify and evaluate the external whole-body biomechanical loads that are experienced during training and/or competition in running-based (team-) sports.
- To estimate GRF as a measure of whole-body biomechanical loading from body-worn accelerometers across various running activities, task identification algorithms and/or advanced sensor or data fusion approaches are likely required.

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FIGURE CAPTIONS

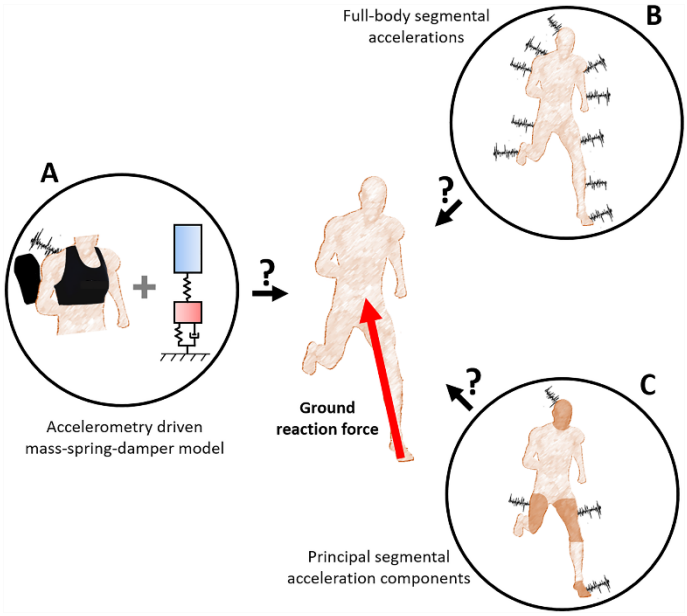

Figure 1 The three approaches used in this PhD to estimate ground reaction forces (GRFs) from segmental accelerations. **A**: A two mass-spring-damper model was used to predict GRF from trunk-accelerometry. **B**: GRF was estimated from full-body segmental accelerations using a direct mechanical approach. **C**: Generalised segmental acceleration patterns and their contributions to GRF were identified using a multivariate principal component analysis.