REAL-TIME HAPTIC FEEDBACK SYSTEM VALIDITY AND ITS FEASIBILITY FOR RUNNERS IN A REAL-WORLD TRAINING ENVIRONMENT

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This study sought to assess the use of a novel integrated haptic feedback system for use during running; specifically, the study aimed to 1) assess the validity of the system in measuring trunk inclination and step rate during running and 2) assess the feasibility of the system to modify running technique in a real-world training environment. Ten recreational runners initially ran on an instrumented treadmill in a laboratory where trunk angle and step rate data were collected from an IMU-based system and compared against 3D motion capture and instrumented treadmill data. Participants then completed three outdoor training sessions using the haptic system to modify step rate. The haptic system was found to be valid when compared to gold-standard laboratory methods for measuring step rate (max 1.1% difference). It was also found to be feasible and intuitive in providing real-time feedback via a vibrating wrist-mounted unit in a real-world training environment. Overall, the system showed promise for application to real-world gait retraining, however further refinements are needed to improve the validity of trunk inclination measurements.

KEYWORDS: IMU, wearable technology, gait retraining, step rate, trunk angle

INTRODUCTION: Despite the wide-reaching health benefits of running, the rates of injuries which result from prolonged running remain a major concern (van Gent et al., 2007). Improper mechanics are often a key contributor to overuse running injuries, modification of which may reduce injury risk (Davis & Futrell, 2016). Similarly, there is scope to address technique-related faults of uninjured runners in an effort to prevent injury occurrence (McClay, Williams, & Laughton, 1999). Increases in step rate and trunk inclination angle have been suggested to reduce impact loading during running (Bramah, Preece, Gill & Herrington, 2019; Wei et al., 2019). A range of real-time feedback technologies have been successfully used to supplement a runner's own internal feedback and lead to positive biomechanical changes, working towards the prevention or treatment of injuries (Agresta & Brown, 2015). Most systems have used various forms and combinations of audio and visual feedback, however each have limitations in their ability to be translated to a real-world environment. Real-time feedback systems based on haptic feedback (through the sense of touch) overcome the visual and audio feedback constraints and lend themselves to use in real-world training environments.

Recent hardware and algorithm advancements have enabled the potential for real-time haptic feedback systems to be used outside a laboratory environment. While use of similar haptic feedback systems have been previously reported, validation during running and consideration of the feasibility in a real-world environment is lacking (Lindsey, Xu, Chiasson, Shull, & Cortes, 2021; Tan, Strout, & Shull, 2021). Therefore, the aims of this study were to 1) assess the validity of a novel real-time haptic feedback system in measuring trunk inclination and step rate during running and 2) assess the feasibility of the system to modify running technique in a real-world training environment.

METHODS: Ten recreational runners (5 males; 5 females) participated in this study. Participants were all injury free and able to hold a comfortable steady running pace for at least 20 minutes. Runners visited the laboratory once and then ran on a 400m outdoor athletics track on three separate occasions.

Instrumentation and Procedures: To inform the in-laboratory validity testing, inertial measurement units (IMUs) integrated with haptic feedback capability (SageMotion, MT, USA) were attached to the right medio-lateral tibia, the trunk (at the L2 level) and the right wrist. The tibia and trunk sensors collected acceleration data (100Hz) which informed the real-time haptic feedback provided by the wrist unit. Step rate and trunk angle were calculated from the tibia and trunk IMUs, respectively via SageMotion proprietary software. Step rate data were additionally collected via a force instrumented treadmill (Bertec, OH, USA) (1000Hz) simultaneous to 3D trunk kinematics capture using a 9-camera motion analysis system (Vicon, Oxford, UK) (200Hz). Eight reflective markers represented the trunk segment, informing trunk inclination calculation relative to the laboratory axes. An initial static trial was collected to determine baseline trunk angle, which was then used to determine a trunk angle offset to account for individual postural differences. Runners completed a 5-minute run to warmup on the treadmill at a self-selected comfortable pace; baseline force, motion capture and IMU data were collected during the final 2-minutes. Due to haptic system capabilities, trunk angle was measured first followed by step rate within the final 2-minutes.

A target threshold of a 10% increase in step rate (Derrick, Hamill, & Caldwell, 1998), and a 10° increase in anterior trunk inclination (Teng & Powers, 2014), were calculated from baseline run data for each participant. Participants completed two modified 5-minute runs at their self-selected pace, with the aim of either increasing step rate or trunk inclination. Haptic feedback via the wrist unit alerted participants if they were below the target threshold. For the modified trials, participants had a 30 second familiarisation period, then data were collected for the remainder of the 5-minute run.

To assess the feasibility of the haptic system, three 10-minute runs were completed on an outdoor track on separate days to assess step rate modifications via the tibial IMU. At each session, participants initially completed one warm-up lap of the track to determine their self-selected comfortable running pace which was recorded via a GPS monitor (Element Bolt, Wahoo GA, USA). Participants then maintained a consistent running speed for 10 minutes, while increasing their step rate in line with the feedback provided via the wrist unit. Following the third haptic feedback session, participants completed one final lap of the track with no feedback to assess changes in step rate compared to baseline.

Data processing and analysis: Trunk angle and instrumented treadmill data were processed using Vicon Nexus (v2.11). Trunk angle was calculated relative to the global vertical axis in the sagittal plane (Shih, Teng, Gray, & Poggemiller, 2019). Raw time series IMU data were extracted, and descriptive statistics were calculated using Microsoft Excel (Microsoft, WA, USA) for the final minute of the in-laboratory baseline and modified trials.

Statistical analysis: Data were analysed using Microsoft Excel. Mean and standard deviations were calculated for trunk inclination angle and step rate across the final minute, for both the baseline and increased threshold conditions. Paired t-tests were conducted to assess differences in measures by the haptic feedback system compared to in-laboratory motion analysis and instrumented treadmill measures. Statistical significance was set at $p<0.05$.

RESULTS: To inform the in-laboratory validation analysis, no significant difference was found between baseline trunk inclination angle measured by the haptic feedback system (0.46 ± 16.44°) compared to motion analysis (8.52 ± 3.05°, p=0.16). Similarly, for the increased trunk inclination angle condition no significant difference was found between measures from the haptic feedback system (16.57 ± 44.12°) and motion analysis (21.09 ± 7.48°, p=0.76). However, the lack of statistically significant differences was likely due to the large variance in the haptic feedback system trunk inclination angle data, as indicated by the standard deviations reported. The haptic feedback system was observed to both under- and over-estimate trunk inclination angle in comparison with the motion analysis system (Fig 1). The measurement differences became more pronounced during the increased lean condition.

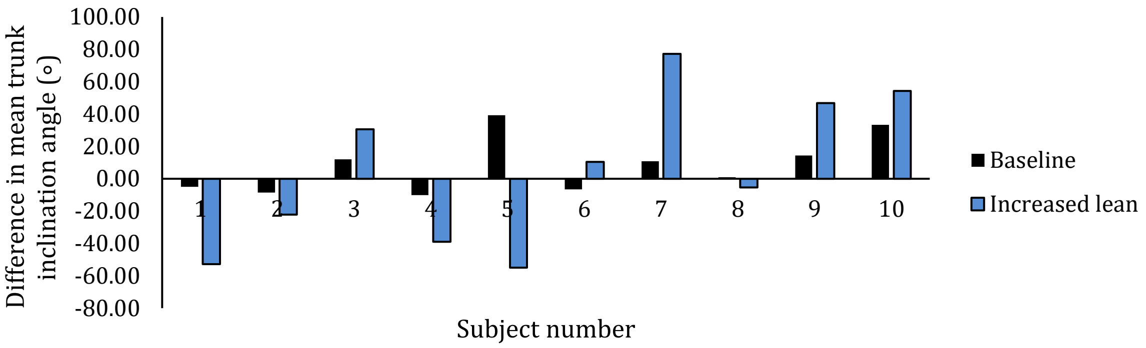

Figure 1: Differences in mean trunk inclination angle measured by the haptic feedback system compared to 3D motion analysis system

No significant difference was found between step rate collected from the haptic feedback system and the instrumented treadmill for both the baseline (haptic system: 163.4 ± 4.8 steps/min; instrumented treadmill: 163.0 ± 4.6 steps/min, p=0.07) and the increased step rate condition (haptic system: 179.0 ± 9.5 steps/min; instrumented treadmill: 179.0 ± 9.5, p=0.98) (Fig 2). These results suggest that the step rate measures from the haptic feedback system are valid within 1.1% of the current gold standard.

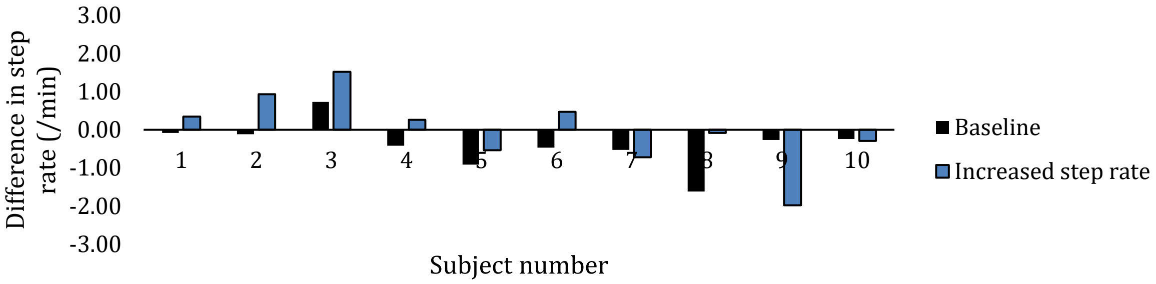

Figure 2: Differences in mean step rate measured by the haptic feedback system compared to the instrumented treadmill

To inform the system feasibility, following the three outdoor training sessions, all participants were able to increase step rate to the target threshold with the use of the haptic feedback system. When feedback and pacing were removed during the final run, there was a 15.9 ±4.4% increase in mean step rate from the laboratory baseline. Individual increases in mean step rate from baseline ranged between 6.7% to 22.0%.

DISCUSSION: The primary aim of this study was to assess the validity of a novel real-time haptic feedback system in measuring trunk inclination and step rate during running. The step rate measures from the haptic feedback system were observed to be valid compared to in-laboratory motion analysis measures within 1.1%. Participants were also able to appropriately respond to the haptic feedback to modify their step rate, lending further support to this as an appropriate feedback modality for runners (Sheerin, Reid, Taylor, & Besier, 2020).

Although no statistically significant differences were found between trunk inclination angle measured by the IMU compared to 3D kinematics, there was a wide variance in the individual trunk inclination angle results measured by the IMU, despite exact experimental procedures being followed for all participants. In some instances, the IMU appeared to underestimate the trunk inclination angle, while at other times overestimating values. No shift or movement in the IMU on the trunk was detected from either the participants or the researchers, so the assumption was that there was an issue with the hardware or algorithms used to calculate trunk angle. Further refinement of the haptic feedback system is required to increase trunk inclination angle validity.

The secondary aim of this study was to assess the feasibility of the haptic feedback system for modifying running technique in a real-world training environment. The results showed that all participants were able to increase their step rate in response to the haptic feedback and maintain an increased step rate without feedback despite a limited number of training sessions. Participants reported the vibration feedback very sensitive and easy to respond to. Given the lack of research examining the use of haptic feedback for gait modification in an outdoor environment, these results provide positive insights that warrant further investigation using a longer intervention protocol and follow-up period.

While these findings suggest that the SageMotion system is feasible for outdoor use, there are some practical limitations. The system is activated by smartphone, powered by a portable battery pack and all sensors are required to be in range of a base station. While not large on their own, together these items form a cumbersome mass that must be secured to the runner. Future development of the system should aim to reduce the awkwardness of having to carry multiple pieces of equipment while running. Ideally, the base station would be self-powered and be smaller in size. Additionally, the system can at this stage only measure one outcome variable at a time, which reduces the diversity of its use.

CONCLUSION: The novel haptic feedback system was found to be valid within 1.1% of the current gold standard for measuring step rate. The system was found to be feasible and intuitive in providing real-time feedback via a vibrating wrist-mounted unit in a real-world training environment. Further development of the system is required to improve the validity of trunk inclination angle measurements.

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