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The Use of Wearable Technology to Quantify Power and Muscle Load Differences During Running Against Varying Wind Resistances

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ABSTRACT

Background: Wearable technology has increased in popularity due to its live feedback and ability to adjust within training sessions. In addition to heart rate (HR) monitoring, measuring power and internal load may provide useful insight and a more comprehensive view of training differences. **Objectives:** Assess the efficacy of wearable technology in endurance runners to determine changes in performance variables with varying wind resistance. **Methods:** A quasi-experimental study was designed and recruited twelve endurance-trained runners currently running ≥120 min/week for the past 3 months. Participants completed two sessions: $\dot{V}O_{2peak}$ testing, and a 20-min run at 70% $\dot{V}O_{2peak}$. The run was evenly divided into no wind resistance (W_0) and 16.1 km/h wind resistance (W_{16}). Power was assessed via a power meter and internal/external load measured via surface EMG sensor-embedded compression shorts. A HR sensor was used and $\dot{V}O_2$ and RER were monitored using a metabolic cart. Paired t-tests were used to compare differences and Pearson correlations were conducted for each segment. Significance was set a priori at $p<0.05$. **Results:** There were significant differences in power ($W_{16} > W_0$; $p=0.002$), as well as a strong positive correlation between power and internal load for W_0 (r=0.692; $p=0.013$) and W_{16} (r=0.657; $p=0.02$). **Conclusions:** The lack of significance changes in HR, $\dot{V}O_2$, and RER demonstrates a sustained similar physiological response. The significant increase observed in power suggests the power meter can be useful in differentiating wind resistance, and the positive correlations suggest a combination of these devices may be beneficial in distinguishing performance changes during fluctuating conditions.

Key words: Wearable Electronic Devices, Electromyography, Fitness Trackers, Endurance Training, Athletic Performance

INTRODUCTION

As one of the more common methods of exercise, running is feasible and allows for adaptations within the cardiovascular, respiratory, and musculoskeletal systems. Endurance exercise is often performed at submaximal intensities and as an individual adapts, the training progresses and increases can occur in intensity, duration, distance, or weekly volume. Within a typical training session, fluctuations in heart rate occur, increasing as work begins to match the increased work output (Cornelissen, Verheyden, Aubert, & Fagard, 2010). This holds true for changes within a workout when increasing or decreasing pacing.

Changes within training ultimately impacts the acute training load for a session and can have larger chronic impacts when planning and periodization training. Therefore, tracking and monitoring training via wearable technology has become largely popular in determining differences between sessions. Many devices have been validated in both laboratory and field settings and utilize a user-friendly interface to provide a summary and breakdown of performance metrics (Aroganam, Manivannan, & Harrison, 2019; Davarzani et al., 2020; El-Amrawy & Nounou, 2015; Henriksen et al., 2018; Xie et al., 2018).

Many runners track their training sessions to monitor their progress. They often use wearable technology to accomplish this, which can include sport watches, phone apps, heart rate monitors, and power meters (Henriksen et al., 2018; Pobiruchin, Suleder, Zowalla, & Wiesner, 2017). When wearable technology usage was surveyed within marathon runners, the most common were sport watches and phone apps (Pobiruchin et al., 2017). Wearable technology can be used to quantify both external and internal workloads (Aroganam et al., 2019). This in turn gives insight to the changes in physical measures (distance, pace) physiological response of the body (heart rate, blood pressure) (Saucier et al., 2021; Seshadri et al., 2019).

There have been recent increases in wearable technology to monitor athletes compared to the traditional methods of

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heart rate monitoring. This includes power meters worn on the shoe, as well as sensor-embedded compression shorts. However, to properly apply the use of wearables to monitor and track sport performance, the technology should be both valid and reliable to collect measurements. This would provide accurate training data that can be used to adjust training as needed. A novel athlete monitoring system, the Strive Sense3 has emerged as a method to assess internal and external load via surface electromyography embedded into compression shorts and thus calculate training (external) and muscle (internal) load (Aquino & Roper, 2018; Davarzani et al., 2020; Lynn, Watkins, Wong, Balfany, & Feeney, 2018).

The Strive Sense3 shorts have been previously used in basketball players over the course of the season and was able to detect differences in muscle usage and load between positions, indicating its use in athletic populations to monitor and track performance (Saucier et al., 2021). However, the translation from a team sport into endurance athletes is scarce in the literature regarding the use of these wearables, and therefore of interest to the current study. The differences in demands as well as recruitment may provide differences particularly in fluctuating environmental conditions. Additionally, the use of power meters in runners has grown in popularity. Recent research has investigated the use of a Stryd power meter regarding fluctuating conditions and found close agreement between measured and theoretical values, as well as sensitivity to the changing conditions (Cerezuela-Espejo et al., 2020). While this study incorporated an environmental component, it only assessed changes from an indoor to an outdoor track. The changes between participants with regards to environmental conditions on the outdoor track may have fluctuated and influenced the measures of the Stryd meter, therefore it is of interest to the current study to control and manipulate potential environmental changes.

As environmental and running conditions change, runners may adapt to maintain their current workload. This may include fluctuations in physical or physiological factors and over time these slight alterations can lead to a significant chronic difference in desired workload or training volume, and possibly result in overtraining or injuries (Drew & Finch, 2016; Seshadri et al., 2019). Due to the rising interest of wearables and the applications in athletes, the purpose of this study was to examine the efficacy and correlation of wearable technology at determining physical and physiological loads of endurance runners while running without and against wind resistance. It was hypothesized sensor-embedded compression shorts would detect differences in muscle load, and training load, while the power meter would detect difference in power output between wind resistances. Further, it was hypothesized there would be small to moderate correlations between the wearable technology used.

METHODS

Participants

Twelve recreationally endurance-trained male (n=7) and female (n=5) were recruited for this quasi-experimental study. Sample size was determined a priori using G*Power 3.1.9.6 software and following previous research showing a strong correlation using the Stryd device when comparing environmental conditions (Cerezuela-Espejo et al., 2020). Assuming an effect size of 0.3 with an alpha level of 0.5 using differences in and correlations between power output and internal/external load as our primary outcomes, 12 participants were required with 80% power. Participants were included if they were currently running 120 minutes per week at minimum the previous three months. Participants were excluded if they had any medical conditions or musculoskeletal injuries that limited them from fully participating in the study. Written consent was provided by all participants prior to participating. This study was conducted in accordance with the ethical standards of the Helsinki Declaration and approved by the Institutional Review Board at Mississippi State University (IRB-19-561).

Study Design and Protocol

This study utilized a quasi-experimental design, with each participant first completing a $\dot{V}O_{2peak}$ protocol followed by a 20-minute run incorporating varying wind resistance at 70% $\dot{V}O_{2peak}$. Each participant completed both wind speeds, and the order of the wind speed was randomized between participants. There was a minimum of five days between sessions. Participants arrived at the research lab at least two hours fasted, were asked to maintain the same dietary intake, and avoided exercise for 24 hours prior to each of their sessions. During the first session, a $\dot{V}O_{2peak}$ protocol was completed to determine peak oxygen consumption and prescribe the pace for the experimental session. Wind speed was used as the independent variable; mean power, internal load, and external load were assessed as dependent measures.

$\dot{V}O_{2peak}$ Testing

Prior to the start of the $\dot{V}O_{2peak}$ protocol, participants were asked to report their estimate times and pace for a half marathon, 10K run, and 5K run. Researchers monitored gas exchange variables using a MOXUS metabolic cart (AEI Technologies, IL, USA), and heart rate was recorded using a chest strap heart rate (HR) monitor (H10; Polar Electro Inc., Kempele, Finland). The protocol began at half-marathon pace for five minutes with 0% grade. The second stage increased to 10K pace while maintaining 0% grade for three minutes. The third stage increased further to 5K pace at 0% grade for an additional three minutes. If the end of the third stage was reached, the grade was increased 1% every minute thereafter until volitional fatigue. This protocol was adapted for runners from previous research (Robergs et al., 1991).

Experimental Session

During the second session, participants completed a 20-minute run at 70% $\dot{V}O_{2peak}$, with the run split into two 10-minute segments. Each segment included running with either no wind resistance (W_0), or a wind resistance of 16.1 km/h (W_{16}) determined by the highest setting of an industrial fan placed one meter in front of the treadmill. Order of wind speeds in the experimental session were randomized among participants. To monitor 70% $\dot{V}O_{2peak}$, participants were connected to a respiratory gas analyzer to assess oxygen consumption ($\dot{V}O_2$) and respiratory exchange ratio (RER). Participants also wore a HR monitor to assess any potential changes throughout the run.

Wearable Technology

During the experimental session, each participant wore a pair of compression shorts with built-in surface EMG sensors (Sense3, Strive Inc., Seattle, WA) to monitor muscle usage. The Sense3 uses dry surface EMG sensors aligned with the quadriceps, hamstrings, and glutes, calculating muscle load and training load following a proprietary algorithm. Training load (external load) reflects the summation of physical actions performed by an athlete, whereas muscle load (internal load) using the shorts is calculated using physiological values including HR and usage of each muscle group. The EMG signals were recorded with a sample rate 1024 Hz. The analog signal was amplified and passed through a bandpass filter of 70 – 500 Hz. It then reached the microprocessor and was digitally converted by a 12-bit analog-to-digital converter. The EMG signal completed processing and was sent through third-party analysis algorithms to provide desired performance metrics. The Sense3 contains a small, detachable device located on the front of the waistband that housed the EMG processing hardware, the accelerometer, and the wireless transmission nodule. The device used Bluetooth transmission to transmit data to the data box connected to the associated company website with protected cloud access. Data collected were recorded on an Apple iPad for each session. Each participant also wore a Stryd power meter (Stryd, Boulder, Colorado, USA), a foot-mounted inertial sensor firmly attached on the right shoe regardless of foot dominance and according to manufacturer recommendations. Data was transmitted from the device via Bluetooth to collect mean power for each segment. Participant information (body height and body mass) were filled in prior to its use as requisites for the power output estimation.

Statistical Analysis

To avoid non-steady0state measures associated with the beginning of exercise, as well as the anticipation of completion of the protocol, the middle 10 minutes of the experimental session were analyzed for session means. Paired t-tests were used to evaluate differences between wind resistances for all variables. Effect sizes (ES) were calculated for all variables and presented as follows: small = 0.20; medium: 0.50; large = 0.80. Pearson correlations were conducted for power vs. muscle load, and power vs. training load. Correlations (r) are presented as follows: 0.30-0.50 = weak; 0.50-0.70 = moderate; 0.70-0.90 = strong. Significance was set a priori at $p<0.05$.

RESULTS

Participant demographics can be found in Table 1. No significant sex differences were observed for any variables. There were no significant differences found in HR ($p = 0.923$), $\dot{V}O_2$ ($p = 0.577$), or RER ($p = 0.053$). Further, there were no significant differences seen between wind speeds for muscle load ($p = 0.986$; ES = 0.001) or training load ($p = 0.111$; ES = -0.21) as measured by the Strive Sense3 shorts. There was a significant difference in mean power measured by the Stryd power meter, with W_{16} demonstrating greater mean power compared to W_0 (347.33±72.70 vs. 334.33±67.50 W; $p = 0.001$; ES = 0.19).

Demographics are presented as mean ± standard deviation.

A significantly moderate correlation was found for muscle load and mean power for both W_0 (r = 0.693; $p = 0.013$) and W_{16} (r = 0.657; $p = 0.020$). These results are shown in Figure 1. A significantly strong correlation was also seen between training load and mean power for W_0 (r = 0.840; $p < 0.001$) and W_{16} (r = 0.847; $p < 0.001$). These results are shown in Figure 2.

DISCUSSION

The use of wearables to provide feedback and enhance training has only grown in popularity as technological advances occur. The current study aimed to observe the efficacy of wearable technology using variable wind resistance. Primary findings indicate the use of Stryd in differentiating power output in varying environmental conditions. However, Strive Sense3 demonstrated no significant differences in any of the

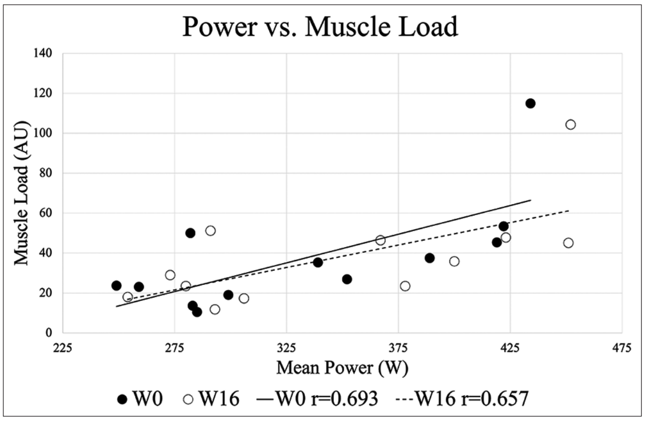

Figure 1. Correlations between mean power and muscle (internal) load

Table 1. Subject demographics

Age (yr)	Height (cm)	Weight (kg)	$\dot{V}O_{2peak}$ (ml/kg/min)	HR_{max} (bpm)
30.5±14.4	1702.2±9.1	68.5±6.9	49.7±10.9	186±15

Demographics are presented as mean±standard deviation

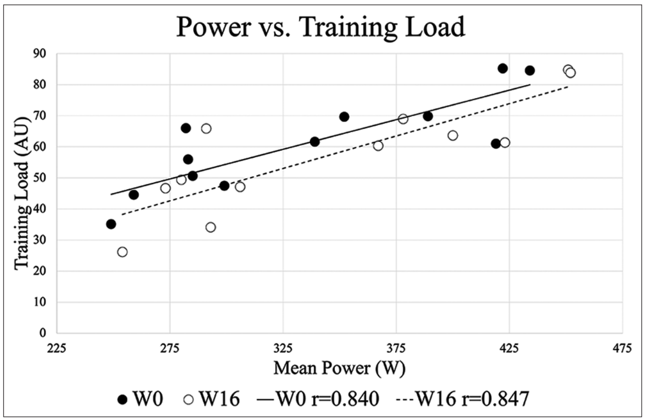

Figure 2. Correlations between mean power and training (external) load

measured variables. Secondary findings exhibited a moderate correlation between the power and muscle load, but a strong correlation between power and training load.

The lack of significance in HR, $\dot{V}O_2$, or RER demonstrates these runners sustained a similar physiological response for both wind speeds, aligning with the intentions of the study to isolate the performance variables and the potential changes due to the added wind resistance. Despite this, there was a significant increase in power output with the addition of the wind, suggesting a greater physical demand on the body. This also agrees with a previous study that suggests the use of a power meter in fluctuating environmental conditions to quantify and determine differences in work and power (Cerezuela-Espejo et al., 2020). While the literature is scarce on the Stryd power meter, the current study demonstrates the sensitivity of Stryd and its beneficial use in runners when tracking their power output. The use of this power meter, particularly when combined with the common use of a HR monitor, can help provide live feedback to runners and alter their pace accordingly depending on that day's training goal.

The Strive Sense3 shorts did not demonstrate efficacy in determining differences between wind resistances. Although the research on sEMG-embedded compression shorts has been mixed regarding its validity, it has exhibited good concurrent validity and interrater reliability in comparison to laboratory EMG methods (Davarzani et al., 2020). While previous research has found differences in external and internal loads with basketball players, there were not consistent findings regarding muscle load and training load when separated by position (Saucier et al., 2021). This may contribute to the lack of significance found in the current study, as the shorts may not be sensitive enough to detect smaller changes.

Despite the lack of significant differences in training load or muscle load between wind resistances, several correlations were observed between devices. The moderate correlations observed between training load and muscle load suggest a positive linear relationship with the power meter. Perhaps a run that is longer in duration would reveal larger differences and further strengthen these findings. The correlations found in the current study suggest the use of these wearable technology devices in conjunction may provide greater insight as to the overall physical and physiological response to training than either device independently. While Strive Sense3 has been validated (Davarzani et al., 2020) and utilized in strength training populations and team sports (Aquino & Roper, 2018; Saucier et al., 2021), a longer run time may present significant differences in the performance metrics as measured by Strive and advocate for its use in the endurance-trained populations.

The use of these wearables over multiple sessions may also demonstrate individual differences that can play a more chronic role in training. The acute: chronic ratio has been used in previous research to observe injury rates, as calculated by a one-week to four-week workload ratio (Drew & Finch, 2016; Malone, Roe, Doran, Gabbett, & Collins, 2017). In a study of competitive runners, workload was measured using training duration and intensity, and even small increases in the ratio resulted in a greater risk of injury (Dijkhuis, Otter, Aiello, Velthuijsen, & Lemmink, 2020). While this ratio can be useful, there are large individual variations in injury risk that are not accounted for by typical training variables. Therefore, the use of Strive Sense3 and Stryd in combination as monitoring devices may help quantify the acute: chronic ratio in addition to the widely used measures of training duration and intensity.

A main limitation to the current study is the fitting and preparation of sensors on the Strive Sense3 shorts. The proper fitting and wetting of sensors are important factors in the use of Strive Sense3 and may have impacted the output recorded in the current study (Davarzani et al., 2020; Saucier et al., 2021). Runners' shorts were fitted based on personal preference, and therefore could result in a looser fit and result in less accurate sEMG readings and a lower output. The compression shorts are also subject to normal wear and tear, which can stretch the sensors and require replacement. It is also unknown how much individual characteristics such as anthropometrics can influence the recorded values.

The Strive Sense3 shorts demonstrate its potential use in monitoring training, although further fluctuations in conditions or external variables are needed to fully validate its efficiency in detecting differences. As mentioned above, the proper fitting and preparation of sensors on the shorts is needed for accurate recording of variables. This may have limited the accuracy of the shorts with regards to detecting small differences between the wind speeds. Contrarily, the power meter was able to detect differences between wind conditions, suggesting its use in runners to make changes to maintain intensity and performance to optimize their training. Further, the moderate to strong correlations between the sensors advocate for the use together to create a comprehensive view of both internal and external variables that may influence performance.

CONCLUSION

The current study supports the use of a power meter to provide live feedback during training and may be beneficial in assessing overall training stress. The differences seen in power between testing sessions indicates the potential of the Stryd technology to assess miniscule changes in performance. Further, the accumulation of differences in workload as measured by Strive over time may result in a more robust physiological response. These results suggest the combination of both the Stryd power meter and the Strive Sense3 compression shorts may be beneficial in determining changes in in performance metrics during fluctuating conditions that can influence the physiological toll in a runner.

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