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Reliability of running parameters using fitness watches synced with accelerometers during outdoor runs

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ABSTRACT

Background: To prevent running related injuries and return to sport activities, monitoring the running dynamic parameters (cadence, stride length, ground contact time and vertical oscillation) especially outdoor running is crucial. Previous studies investigated the reliability of these parameters in laboratory settings. However, the nature of outdoor runs is different (curve, uphill, other runners, etc.) and challenging in terms of equipment (simple) and environments (grass, asphalt, rubber, etc.). Therefore, the reliability of these parameters using a fitness watch synced with accelerometer needed to be investigated.

Objective: To investigate the reliability of running parameters measured using fitness watches and accelerometers during outdoor runs.

Materials and methods: 30 healthy volunteers (age 25.8±9.6 years, height 167.2±9.3 cm, weight 62.4±14.2 kg, and body mass index 22.2±3.8 kg/m^2) participated in the study. They wore a fitness watch and attached a synced accelerometer at their pants. They completed 2 running laps (800 meters each) at their comfortable speeds. Resting periods were provided between laps. To control the speed for the second lap, the watch was set the maximum and minimum speed and set vibration and sound alarm mode. Running parameters include cadence, stride length, vertical oscillation, and ground contact time.

Results: The reliability of the four running parameters (cadence, stride length, ground contact time, and vertical oscillation), indicated by the intraclass correlation coefficients (ICC (3,k)) was 0.94, 0.97, 0.98 and 0.99, respectively. Very high reliability values were confirmed.

Conclusion: Using a fitness watch synced with an accelerometer during outdoor runs, running dynamic parameters (cadence, stride length, ground contact time, and vertical oscillation) illustrated very high levels of reliability.

Introduction

The most common running-related injuries (RRIs) include iliotibial band syndrome, Achilles tendinopathy, plantar fasciitis, medial tibial stress syndrome, patellofemoral pain syndrome, and tibial stress fracture.[1] The etiology of RRI is directly related to high impact loads, repetitive use over long periods of time and/or poor structure and biomechanics such as leg length discrepancy, flat foot, tightness and weakness of leg muscles and connective tissues.[2,3] A previous systematic review and meta-analysis of 18 studies involving 1172 volunteers

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reported that high-impact runners were more likely to have injuries than low-impact runners.[4] Therefore, reducing the impact load and loading rate are methods that have been widely researched. Among runners with poor structure and biomechanics, monitoring running biomechanics, especially spatiotemporal or running dynamic parameters, could be a useful strategy to prevent RRIs. The running dynamic parameters examined herein include cadence, stride length, vertical oscillation, and ground contact time.

Several previous studies examined the modification of running dynamic parameters to prevent or reduce RRIs and reported that increasing the number of steps per minute or increasing the cadence while controlling the speed could immediately reduce the impact on the hip and knee joint.[5-9] In addition, reducing the stride length, especially in the overstrike pattern, could reduce the likelihood of the knee being in a very stretched position and decrease the ground reaction force to the knee joint. A ten-percent reduction in stride length can reduce the average ground reaction force on the knee by up to 14.9%.[8,10] The rearfoot strike pattern leads to more injuries, especially patella injuries, than midfoot or forefoot strikes. A decrease in vertical oscillation could also reduce the impact force from the ground by 46-75%[7] and reduce the risk of tibial stress fracture.[11,12] Finally, reducing the ground contact time could reduce the impact from the ground.[13] Therefore, these parameters could be monitored as strategies for the prevention of RRIs and the improvement of running performance.

Fitness watches are especially popular among health-conscious people and runners. They have an optical sensor that penetrates the skin of the wrist to measure heart rate,[14] and they have motion sensors on the wrist to count the number of steps during walking and running.[15] They also use a highly accurate global positioning system (GPS) via satellites to measure running distance. When they are connected or synced to an accelerometer, they can monitor more important running dynamic parameters, including stride length, vertical oscillation, and ground contact time. They can also be used as real-time feedback while running and have vibratory feedback and auditory feedback features to alert runners while training.[16] Interestingly, a feature called lap, which sets all running parameters in the range of distances needed, such as 200, 300, or 400 meters, could be used to analyze the selected data.

Accelerometers with smaller sizes and attached locations have been developed. Initially, these accelerometers were designed to attach at the xiphoid process using a chest strap to monitor heart rate and running dynamic parameters. The Garmin HRM-pro plus and the Polar H10 are two such examples. Because the accelerometer and strap are in direct contact with the skin, when runners sweat, particularly during long-distance running, the devices can move and cause friction with the skin, thereby leading to discomfort and skin lesions. Additionally, accelerometers that can be attached to shoes have been developed; these devices are known as foot pods, and examples include the Stryd foot pods and Garmin foot pods. However, while running, there is a considerable amount of impact on the foot, thus causing the sensor to detach or bounce. Recently, an accelerometer named the run pod was developed with a smaller size. It is designed to be clipped on the edge of a runner's pants, thus avoiding the abovementioned problems. However, further research is needed to determine the reliability of running-related dynamic parameters measured by fitness watches and run pod accelerometers.

Previous studies related to the reliability of running parameters were conducted using treadmill runs in the laboratory setting. Running parameters (cadence, vertical oscillation, and foot contact time) measured using a fitness watch combined with an accelerometer mounted on the chest using a chest strap demonstrated very high levels of reliability (ICC>0.95 in all three variables), consistent with our previous research.[18] It was found that the reliability of running parameters (leg cadence, vertical oscillation, stride length and ground contact time) measured using a fitness watch combined with an accelerometer (run pod) was also very high (ICC>0.95 in all four variables).[17,18] Both studies focused on reliability while running on a treadmill at a constant speed. However, this situation is clearly different from running outdoors, where environmental conditions are constantly changing, e.g., the nature of the running surface (stone, ground, sand, road, tire, and swampy terrain), the slope of the terrain (flat, uphill, or downhill), the process of cornering, and the need to avoid people or obstacles. Recently, a systematic review and meta-analysis of 33 studies involving 494 volunteers reported statistically significant differences in the running parameters between treadmill and outdoor runs.[19] The results indicated a decrease in vertical oscillation but an increase in ground contact time while running on a treadmill compared to outdoor runs. These differences could be due to the propulsive nature of treadmill running, during which the belt pushes your legs and body forward. In contrast, when running outdoors, the torso and legs push forward during the propulsive phase. Thus, running on a treadmill involves less forward momentum than running on a real track. There is also the issue of the stiffness of the belt being different from the stiffness of outdoor running surfaces.[19-21] Therefore, this study aimed to investigate the test-retest reliability of running parameters measured using fitness watches and accelerometers during outdoor runs. We hypothesized that even the outdoor runs, the running dynamic parameters would have high levels of reliability.

Materials and methods

Participants

A priori power analysis was conducted using G power version 3.1.9.7 for sample size estimation, based on the intraclass correlation coefficient (ICC) for a one-way random effects model. The ICC was obtained from our previous study by Prasartwuth *et al.* (N=20), which measured the agreement among one rater on twenty subjects.[18] The ICC in Prasartwuth *et al.* study was 0.94-0.98. With significance, criterion of alpha was 0.05 and power was 0.80, the minimum sample size needed with this ICC was approximately thirty.

Thirty healthy volunteers aged 18 years and over participated in this study. All participants engaged in at least 150 minutes of physical activity per week to avoid muscle soreness as unaccustomed to running. During the experiment, they wore comfortable clothes and running shoes and refrained from eating large meals or drinking alcoholic beverages at least 2 hours before the test. They also abstained from vigorous exercise for at least 30 minutes before the test. They completed the history questionnaire, and the researcher collected data such as sex, height, and the arm on which the watch was worn. All volunteers signed informed consent forms before participating in the study. This research was approved by the Research Ethics Committee (AMSEC-64EX-110). Before the actual run, the volunteers performed a warm-up by stretching their lower leg muscles (e.g., calf, hamstrings, quadriceps, etc.) 10 repetitions 3 sets for each muscle, and jogging for at least 10 minutes, and then resting for 5-10 minutes.

Procedures

The volunteers wore a fitness watch (Garmin Forerunner 245, Switzerland) as well as a synced accelerometer (Running Dynamics Pod, United States), which was attached to the top of the backside of their sport pants. The volunteers were then asked to run at the standard 400-meter oval track with lanes in the University running field with other runners for two laps (800 meters each) at a pace that could be run continuously without breaks and without being too tired (comfortable speed), i.e., at moderate intensity, as assessed by the talk test when running. Between laps, there was a rest period equivalent to at least 2-3 times the running time or until the volunteer was no longer tired and was ready to run the second lap. The researchers read the average speed and maximum speed of the volunteers based on the data collected from the watch or from mobile and computer applications (Garmin Connect and Garmin Express). Then, the difference between the two speeds was calculated, and the resulting value from the average speed was subtracted as the lowest speed. Then, the researcher set an alarm on the watch using vibration and auditory signals to control the lowest and maximum speed; this process aimed to ensure that the speed of the second lap was similar to that of the first lap. When the volunteers completed the second lap, they were asked to cool down by stretching and walking slowly for at least 10 minutes.

Statistical analysis

In this study, the watch was set to have a run lap every 200 meters to omit the first 200 meters and the last 200 meters. The average data was chosen at the mid-400 m range, and the SPSS statistics version 26 program was used to analyze the data. The test-retest reliability was determined using intraclass correlation coefficients (ICC (3,k)). The ICC values below 0.50 indicate poor reliability, between 0.5 and 0.75 moderate reliability, between 0.75 and 0.9 good reliability, and any values above 0.9 indicate excellent reliability. The absolute reliability was determined using standard error of measurement (SEM), calculated as SD/√n, where SD=standard deviation. Additionally, a Bland-Altman plot was constructed to show the difference in parameters between the first and second runs and to calculate the limit of agreement (LoA). The mean, standard deviation, minimum and maximum values for each running parameter were obtained from the fitness watch and accelerometer.

Results

The test-retest reliability of the running parameters measured using a fitness watch synced with an accelerometer was examined. Among thirty healthy volunteers (19 males and 11 females), the mean age was 25.8 ± 9.6 years, the mean weekly duration of physical activity was 184.67±69.37 minutes. Demographic data of the volunteers are shown in Table 1.

Table 1. Demographic data of volunteers (mean±SD and range).

	Volunteers (N=30)	
	Mean±SD	**Range**
Age (years)	25.8±9.6	18.0-58.0
Height (cm)	167.2±9.3	150.0-186.0
Weight (kg)	62.4±14.2	41.0-107.0
Body mass index (kg/m^2)	22.2±3.8	15.9-35.0

In the first run, the average speed was 10.1±0.7 kilometers per hour. The minimum and maximum speeds were 8.0 and 15.6 kilometers per hour, respectively. For the first and second run, the running parameters (cadence, stride length, ground contact time, and vertical oscillation) were shown in Table 2. The speed of the second run was controlled using a vibrating and auditory alarm setting to control the minimum and maximum speed; therefore, the average speed for the second run was 10.0±0.72 kilometers per hour. The minimum and maximum speeds were 7.1 and 15.6 kilometers per hour, respectively. The reliability of the four running parameters (cadence, stride length, ground contact time, and vertical oscillation), indicated by the intraclass correlation coefficients (ICC (3,k)), was 0.94, 0.97, 0.98 and 0.99, respectively. The standard error of measurement (SEM) values was 1.38, 0.04, 5.68 and 0.28, respectively. All four parameters had very high reliability values and low standard error of measurement (SEM) values, as shown in Table 2. In addition, the Bland-Altman plot showed the reliability of these parameters. Two laps at the 95% confidence level of limits of agreement (LoA) are shown in Figure 1. The ground contact time, stride length, and vertical oscillation were overestimated in the second run, whereas the cadence was underestimated in the second run.

Table 2. Mean and SD of running parameters in the first and second run, ICC(3,k), limits of agreement (LoA), and standard error of measurement (SEM).

Measured variables	First run	Second run	Bland-Altman (LoA)	ICC (3, k)	SEM
Cadence (steps/min)	172.4±7.5	174.6±8.3	-2.23 (-8.90)	0.94	1.38
Stride length (m)	1.0±0.2	1.0±0.2	0.02 (-0.07)	0.97	0.04
Ground contact time (msec)	239.6±31.1	237.7±30.0	1.93 (-17.87)	0.98	5.68
Vertical oscillation (cm)	9.3±1.5	9.2±1.5	0.10 (-0.58)	0.99	0.28

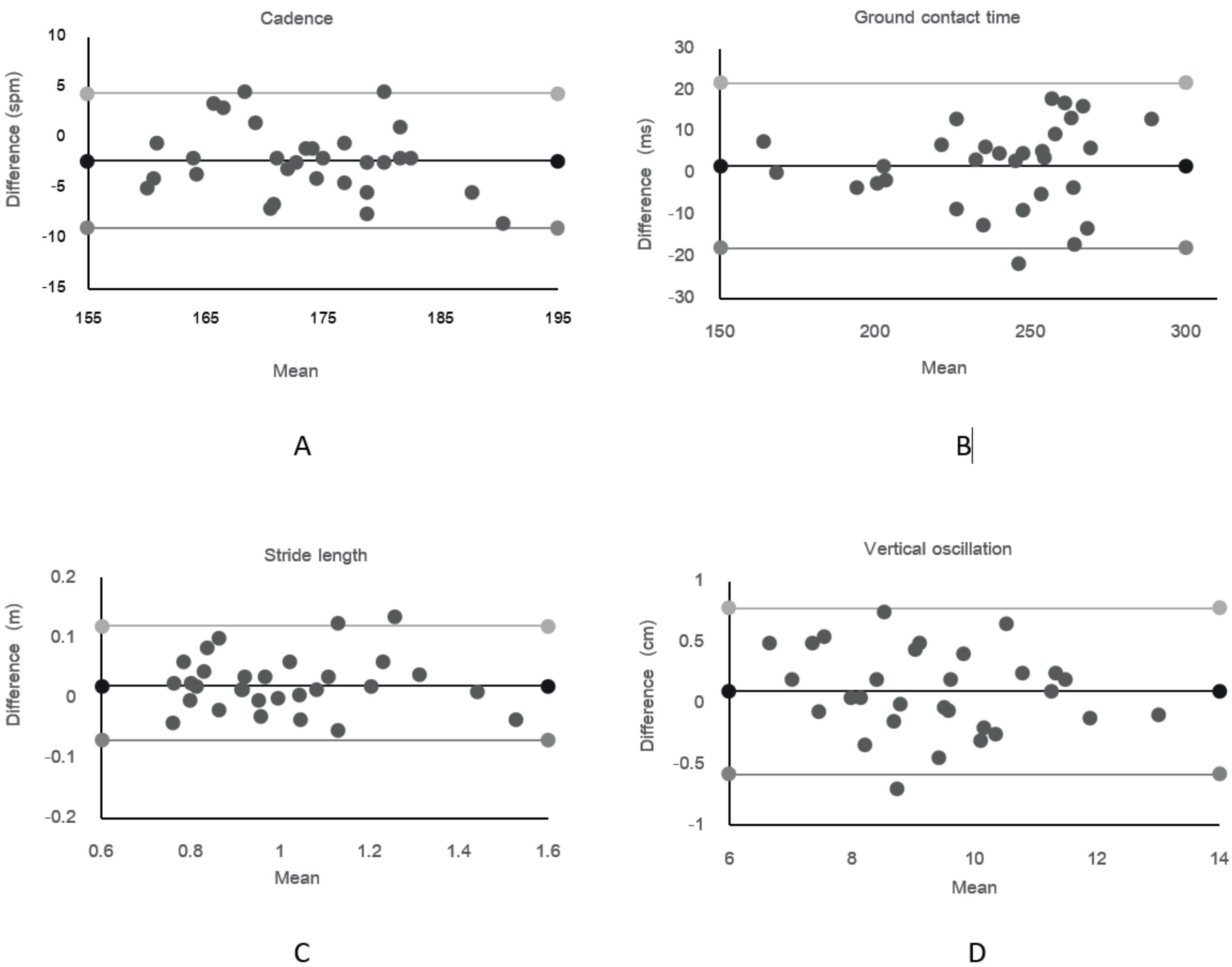

Figure 1. *Bland-Altman plots of the reliability of running parameters. The horizontal gray line shows 95% limits of agreement (LoA) of the mean difference. The horizontal black line represents the bias of the mean difference. A: cadence, B: ground contact time, C: stride length, D: vertical oscillation.*

Discussion

This study used a within-subjects design to examine runners without musculoskeletal injuries and to determine the reliability of running dynamic parameters recorded from fitness watches in combination with accelerometers during outdoor runs. The running parameters examined herein included cadence, stride length, ground contact time, and vertical oscillation. To assess test-retest reliability, the volunteers ran 2 rounds on the actual track with uncontrollable environments, e.g., the curvature of the field, and/or ran to avoid crowds. This study attempted to control the speed of the second round to be close to the speed of the first round by setting vibration- and sound-based alerts on the watch to indicate the minimum and maximum speed. The results showed that the speeds of the first and second laps were 10.1 and 10.0 km/h, respectively. This difference of only 0.1 km/h indicated that the speeds were very similar. The results of this study revealed that the ICC (3,k) of all four running dynamic parameters from two rounds ranged from 0.94-0.99, indicating excellent reliability, and there was a low standard error of measurement (SEM). Bland-Altman analysis revealed that most of the data were within the limits of the agreement, indicating that the measured parameters were consistent across the two rounds. Our findings were consistent with a recent study from Sama et al 2022, which found that an Apple smart watch had excellent reliability (ICC=0.94-0.97); however, their study did not explicitly state the running parameters examined.[22] In addition, in a previous study in the field, test-retest reliability was measured by an accelerometer (Myotest), and the level of reliability was good (ICC>0.75) for cadence and moderate (ICC> 0.50) for ground contact time.[23] Another study conducted at an indoor facility (60 meter run) used an accelerometer (Myotest) among individuals running at different speeds (12, 15, 18, and 21 km/h), and the levels of reliability for ground contact time and cadence were good (ICC>0.80).[24] Even studies in a laboratory setting (i.e., treadmill runs, during which the belt speed can be adjusted as needed and kept constant) have shown excellent reliability when the running parameters were measured by a fitness watch combined with a chest-mounted accelerometer as well as a fitness watch combined with a pants-mounted accelerometer.[17,18] Taken together, even if there are the differences in brands of the fitness watch or accelerometer, in positions to attach with the body, and in environments (indoors or outdoors), the running parameters showed excellent level of reliability and could be useful for future research.

The reliability was very high when measuring running dynamic parameters with fitness watches and accelerometers in this study. The standard error of measurement was low and there was consistency across all parameters measured over the two rounds during outdoor runs. Possible explanations could be that for cadence, the fitness watch uses a motion sensor attached to the watch (wrist), and cadence is calculated based on how many times the arm swings up and down per minute. This arm swing is related to the number of steps while running. The swing of the arm wearing the watch up equals 1 step, and when the arm is down, the stride of the other leg equals 1 more step. Therefore, in 1 minute of running, for example, 170 arm swings up and down results in a cadence of 170 steps per minute. Even when runners turned a curve, ran on different surfaces, or changed speeds to avoid other runners, the cadence was not affected in both rounds. The stride length in running is defined as the distance between the left and the right leg, i.e., the distance between the heels. The pants-mounted accelerometer synced with the fitness watch was used and played an important role in measuring the stride length, vertical oscillation, and ground contact time. Therefore, the combination of the accelerometer and the fitness watch can be used to measure stride length due to the accuracy of the global positioning system (GPS), which is used to measure the running distance. The stride length can be easily calculated by dividing the running distance by the cadence. For example, if someone runs 200 meters using 200 steps, the stride length would be 1 meter. Both an accurate distance (obtained via GPS on the accelerometer) and a reliable cadence (measured using the motion sensor of the fitness watch) could explain a very high reliability in the stride length. The vertical oscillation was calculated as the difference in the position of the accelerometer that moves the maximum and minimum while running. Similarly, the ground contact time was calculated by the amount of time between when the feet started to touch the ground until the time the feet started moving off the ground. This parameter is indicated by the average amount of time (in milliseconds) the right and left feet touch the ground. We observed that the measurement of three running dynamic parameters using the accelerometer had very high reliability (ICC>0.97), while the measurement of the cadence using only the motion sensor in the fitness watch had lower reliability (ICC=0.94). Finally, in this study, we only analyzed data from the middle 400 meters of the 800-meter run; we did not analyze data from the first 200 meters or the last 200 meters. This technique of selecting data analysis could also contribute to a very high level of running parameter reliability.

Limitations

The limitations of this study are as follows: the running track used herein is a smooth surface with an oval path and a constant distance of 400 meters per lap, and it is used for exercise purposes only. If possible, future studies should consider using natural routes with slopes and rough surfaces, such as trails. Additionally, it could be challenging to examine longer distances, such as 5K runs, or to examine runs at different speeds (slow to high speed). Therefore, there are still issues that require further research. In addition, future studies should test the validity of these running parameters with the gold standard instruments e.g., 3-dimensional motion capture and inertial measurement unit (IMU). Lastly, from now on, as excellent reliability, the application of the fitness watch and accelerometer could be used to monitor the progression of training either in rehabilitation program for returning to sport or in performance training of athletes.

Conclusion

Running dynamic parameters (cadence, stride length, ground contact time, and vertical oscillation) measured using a fitness watch synced with an accelerometer were found to have very high test-retest reliability during outdoor runs.

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Conflict of interest

No

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