THE VALIDITY OF MEASURING SKIPPING CADENCE WITH A NOVEL WEARABLE SENSOR - SINTEC SMART PATCH

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The aim of this study was to test the validity of running cadence assessed with a novel smart patch designed within a SINTEC Horizon 2020 project. Participants performed 3 consecutive 20-seconds skipping with increasing intensity (slow, medium, fast). Cadence was derived from raw data from a “SINTEC” smart patch, Dytran accelerometers, and HBM bilateral force plates. Data from all devices were compared using Bland-Altman analysis and Wilcoxon signed-rank test. The mean bias between cadence measured with Dytran accelerometer and force plates with ‘’SINTEC’’ smart patch was 0.08 and -0.17 steps/min, respectively. In addition, there were no statistically significant difference between the mean cadence determined with different sensors/devices. Therefore, we can conclude that the measurement of cadence using a novel SINTEC smart patch showed good validity.

KEYWORDS: running, cadence, validity, force plate, accelerometers.

INTRODUCTION: The survival of our health care and long-term care systems due to ageing populations and increased chronic non-commutable diseases is at stake. Physical activity is one of the key contributors to health and quality of life (Booth idr., 2012). Running represents an efficient and affordable modality of physical activity. It improves health and increases longevity, therefore may be cost-effective lifestyle medicine (Lee *et al*, 2017). (Pedisic *et al*, 2020) showed that running participation is associated with 27%, 30% and 23% lower risk of all-cause, cardiovascular and cancer mortality, respectively, compared with no running. However, if done improperly, it may induce injuries leading to lower life quality and additional health and social costs which is even more important nowadays due to the COVID-19 pandemic. Skipping is an alternative movement pattern that can reduce stress. Skipping incorporated components of both walking and running and is considered a more stable movement pattern than running and has been used in rehabilitation as a transition from walking to running after injury.

Biomechanical testing is usually performed in the laboratory environment, using treadmills, force plates and motion capture systems (Vannatta *et al*, 2020). Testing in the laboratory environment is typically expensive and inaccessible to practitioners. Therefore, alternative, low-cost methods that allow for outdoor assessment should be considered.

A “SINTEC” smart patch is a novel wearable sensor that provides various metrics, one of which is running dynamics. The “SINTEC” sensor was developed as part of the European Horizon 2020 Project “SINTEC” and represents a completely new field of state-of-the-art equipment for use in sports. The new sensor is based on stretchable electronics which is a very promising technology to reshape the balance between performance and obtrusiveness of wearable sensing. A stretchable substrate based on a novel soft, stretchable, and sticky material (3S – PDMS) provides compliant and comfortable patches on the skin that do not move relative to the skin even at excessive movement and strong sweating. The SINTEC sensor is very small, thin, and flexible, therefore it can be used in places on the body where other sensors cannot be as the metatarsal part of the foot.

Before a new device can be used in sports or clinical applications, it must be tested for validity and reliability. Wearable sensors are currently leading trend in fitness worldwide and are being

used by various groups to monitor variables related to health and physical activity. Unfortunately, wearable sensors are often marketed with aggressive and exaggerated claims that lack a solid scientific basis, and the unreliable data they provide offer little or no benefit to the customer (Düking *et al*., 2018).
Therefore, we present the first comparison of the skipping cadence acquired with a novel SINTEC smart patch compared to cadence obtained with a "gold standard" MEMS accelerometer, and bilateral force plates equipped with HBM load cells.

METHODS: 15 healthy and physically active volunteers (males and females, age = 23 ± 3 years, body mass = 74 ± 17 kg, body height = 176 ± 10 cm) participated in this study which was approved by the Ethics Committee for Sport at the University of Ljubljana, Slovenia (033-16/2021-2), which adheres to the principles outlined by the World Medical Assembly Declaration of Helsinki. All participants were physically active for at least 5-hours per week and had to be free of neurological diseases and non-communicable chronic diseases.
Each participant performed 3 consecutive 20-seconds skipping with increasing intensities (slow, medium, fast). Intensities were chosen by each participant.
Each participant was equipped with uniaxial Dytran MEMS accelerometer positioned to acquire three-dimensional acceleration (range of +/- 16 g, Dytran Instruments Inc, California, USA) and a novel smart patch developed during a SINTEC project which has an integrated triaxial accelerometer. Both sensors were positioned in the lower lumbar region. The SINTEC smart patch consists of two parts: a module and a patch. Module (Figure 1a) consists of sensors board and battery connected via a Molex connector on a flexible circuit board with encapsulated materials. The passive patch (Figure 1b) consists of three materials: stretchable fabric sports tape (Kinesiology tape, Mueller), a thin polyurethane film (inspire® 2150, Transcontinental) placed in the centre of sports tape to form a non-adhesive interior, and two adhesive points made of adhesive silicone gel (Silbione 45, ELKEM) to hold the modules in place while handling.

(a) (b)

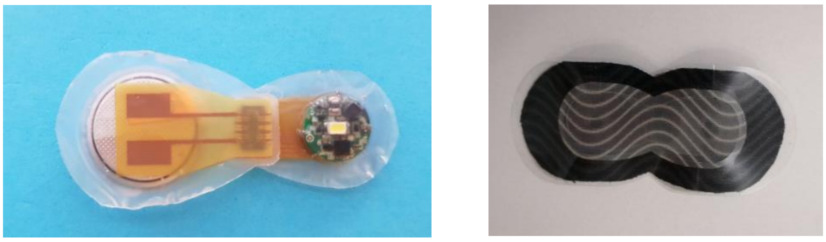

Figure 1. (a) Module containing sensor board, (b) SINTEC passive patch.

Skipping was performed on S2P bilateral force plates (S2P, Ljubljana, Slovenia). The Dytran accelerometers and S2P bilateral force plates were connected to Dewe 43 analogue to digital converters and DewesoftX data acquisition software (Dewesoft d.o.o., Trbovlje, Slovenia), while data from a SINTEC sensor with custom Windows application (Bio2BitWinApp, STMicroelectronics, Geneva, Switzerland).
Data were sorted and analysed in MATLAB (version R2020b, MathWorks, Natick, USA). The step frequency/cadence was derived from each of the devices. Figure 3a and b show the acceleration of the Dytran MEMS and SINTEC sensors at the pelvis, respectively. The cadence from accelerometers was determined from the location of the peaks in the acceleration graphs (Figure 3a, b) as:

$$Cadence\,[\mathrm{min}^{-1}] = \frac{1}{t_d[\mathrm{sec}]} \cdot 60,$$

where t_d is the time between two peaks in seconds. The cadence calculated from the data obtained from the force plates is shown in Figure 3c. Again, the cadence was calculated from the time difference between force peaks. Data were tested for normality by the Kolmogorov-Smirnov test as well as the differences between data. Because normality was rejected for all data ($p < 0.05$), statistical tests that do not assume normality were used. Concurrent validity, which evaluates the association between data from a new device (*i.e.* the ''SINTEC'' smart patch) and another device considered to be more valid (*i.e.* Dytran accelerometers, force plates), is reported. The Wilcoxon signed-rank test was used to assess systematic bias between trials, with the statistical significance set at $p < 0.05$. Limits of agreement (LoA) were calculated using a nonparametric approach, as proposed by Bland and Altman.

Figure 2. Laboratory set up.

(a) (b) (c)

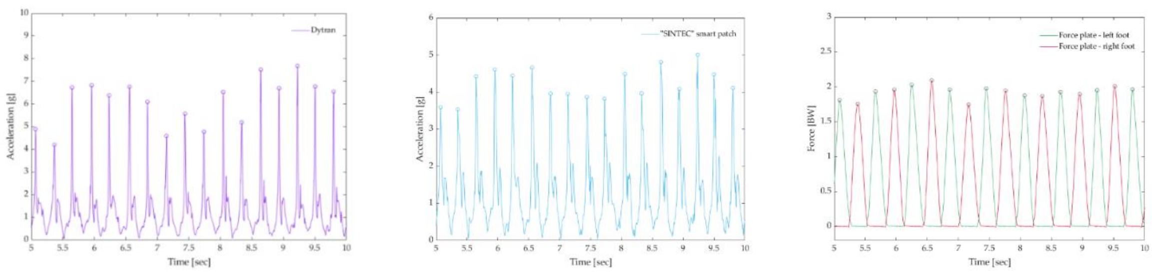

Figure 3. An example of signals as acquired from (a) Dytran MEMS accelerometer, (b) "SINTEC" smart patch, and (c) force plates.

RESULTS: Bland Altman plots are shown in Figure 4. The LoA for the comparison between Dytran and "SINTEC" smart patch are -14 and 15 min^{-1}, and between force plates and "SINTEC" smart patch -17 and 16 min^{-1} for all skipping intensities combined. The Wilcoxon signed-rank test showed that there was no statistically significant difference between the mean cadence determined with the Dytran accelerometers (0.08 min^{-1}, $p = 0.82$), or the force plates (-0.17 min^{-1}, $p = 0.88$), compared to the "SINTEC" sensor.

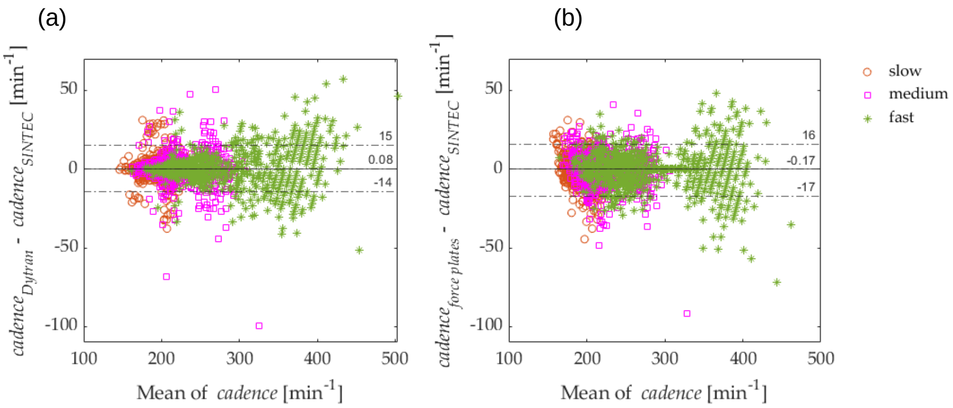

Figure 4. Bland-Altman plot of the skipping cadence as assessed with (a) Dytran accelerometers and "SINTEC" smart patch, (b) force plates and "SINTEC" smart patch.

DISCUSSION: In this study, we determined skipping cadence from a novel SINTEC smart patch, Dytran MEMS accelerometers, and a force plate. Concurrent validity was assessed by determining the agreement of cadence between each method. We found very good agreement for cadence determined at different intensities of skipping. The limits of agreement when comparing Dytran and "SINTEC" smart patch were the lowest (-14 and 15 min^{-1}). The Wilcoxon signed-rank test shows no statistically significant difference between the mean cadence determined with different sensors/devices. The study by Adams *et al*., 2016 compared running cadence obtained with a motion-capture system and a watch with a heart rate strap. The mean bias between cadence was 1.2 steps/min which is higher compared to our study. The limitation of our study is that the skipping cadence (slow, medium and fast) was self-selected by the participants. Since the skipping cadence was self-selected, participants could achieve their highest cadence. However, we could not perform a reliability study because it was not possible to achieve the exact same skipping cadence for two repetitions. In the future, skipping cadence for different intensities will be compared as well as state of the art device (Garmin Running Pod) will be added for comparison.

CONCLUSION: A novel "SINTEC" smart patch is a valid tool for assessing skipping cadence.

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