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The running & exercise mental break optimisation (REMBO) app

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Crossing Borders in Research on Sport and Physical Activity

Proceedings of the 4th Science Science & Engineering Conference on Sports Innovation

Eindhoven, The Netherlands, October 11, 2019

Edited by
Steven Vos,
Juan Restrepo Villamizar, and
Aarnout Brombacher.

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Fontys

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Proceedings of the 4th Science & Engineering Conference on Sports Innovation

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Organized by

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Fontys University of Applied Sciences

Edited by
prof.dr. Steven Vos
prof.dr. Aarnout Bombache
M.Sc. Juan Restrepo-Villamizar

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Wind tunnel facilities
Eindhoven University of Technology

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Introduction

Dear Reader,

On Friday 11 October 2019, the 4th edition of the Science and Engineering Conference on Sport Innovations (SECSI2019) took place in Eindhoven. The organization of SECSI2019 was this year in the hands of Eindhoven University of Technology, faculty Industrial Design, and Fontys University of Applied Sciences, School of Sport Studies. With the exchange of knowledge, this conference aims to stimulate sports research and innovation. Furthermore, its goal is to strengthen the partnerships between universities, research institutions, and universities of applied science in the Low Countries.

The participants of SECSI2019 got state-of-the-art insights in no less than 3 keynotes and 21 presentations in 7 parallel sessions. During these presentations, research results from disciplines such as human movement sciences, psychology, design, engineering, data science, etcetera. were shared. Extended abstracts of these presentations can be found in this proceedings.

Dr. Nicole Ummelen, vice president of the Executive Board of Eindhoven University of Technology, welcomed the participants and opened SECSI2019. Subsequently, the first keynote session entitled 'Technology and data in football: the missing link' was given by Professor Koen Lemmink (University of Groningen). His presentation focused on connecting sports sciences, data science and technology.

During lunch participants had the opportunity to a visit the wind tunnel facilities of Eindhoven University of Technology, led by Professor Bert Blocken. In his key note presentation 'Marginal gains… and more' Professor Blocken discussed the application of aerodynamics in cycling. Participants probably were not aware at that time, but he also gave a glimpse of the sub 2 hours marathon attempt that would take place one thought later was given. The third keynote was given by Harry van Dorenmalen, Chairman of the Dutch Top Team Sport. In his "Keep going, get better!" he went deeper into the SportInnovator ecosystem and the importance of cooperation.

We would like to thank all participants and presenters for their enthusiasm and contributions to crossing borders in research on sport and physical activity, as well to Marly Sluijsmans for her support on organizing the conference together with all the student volunteers involved.

Steven Vos, Juan Restrepo Villamizar, and Aarnout Brombacher
Editors

Keynotes SECSI 2019

Koen Lemmink

Professor University Medical Center Groningen, University of Groningen.

Bert Blocken

Professor Eindhoven University of Technology & KU Leuven

Harry van Dorenmalen

Chairman TopTeam sport SportInnovator

Technology and data in football: the missing link?

‘Marginal gains... and more’

“Keep going, get better!”

Improving & Optimizing **Sports Performance**

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Extended abstract

Fully Automated Dynamic Ultrasound Skeletal Muscle Analysis during Walking Exercise

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Submitted: 31/08/2019

Keywords: ultrasound imaging, voluntary contractions, walking exercise, automated algorithm, US probe fixation

1 Introduction

Ultrasound (US) Imaging is a fundamental procedure in the assessment of skeletal muscle architecture. Dynamic contraction implies muscle anatomical deformation, which depends on exercise type and intensity. Muscle Thickness (MT) and Fascicles Pennation Angle (FPA) reflect the potential to generate force and have therefore been investigated in adaptations occurring with training, injuries and pathological conditions [1],[2]. Although previous works have examined the muscle architecture change during dynamic exercise, the information on deformation in realistic long-lasting non-isometric dynamic conditions are insufficient and incomplete [3], [4]. No continuous MT and FPA measurements has been proposed in literature, due to the lack of US probe fixation systems and the substantial effort required for manual measurements, which results to be time-consuming and prone of errors.

2 Research Question

In this study, we investigated MT and FPA measurements during walking using US. Thanks to the recent introduction of US probe fixation systems, skeletal muscles can be imaged with US in dynamic conditions [5],[6]. Furthermore, we propose an automated algorithm for US muscle architecture analysis in dynamic conditions, starting from previous developed automated algorithms [7], [8].

3 Material and Methods

8 healthy subjects (age: 24.5 ± 1.9 y, BMI: 22.8 ± 3.0 kg/m2) are asked to walk at 4 km/h on a treadmill (LifeFitness, Illinois, USA) as in Figure 1 - A. US videos of the medial gastrocnemius muscle (Figure 1 - C) are recorded at 20 Hz with a MyLab70 ultrasound device equipped with a linear LA523 transducer (Esaote, Maastricht, The Netherlands) and fixated on the calf using a Probefix Dynamic (USONO, Eindhoven, The Netherlands) (Figure 1 - B). Dynamic US images are analysed with an automated algorithm for the continuous MT and FPA measurements. Results are compared with manual measurements performed by an expert operator (Figure 2, Panel A - B).

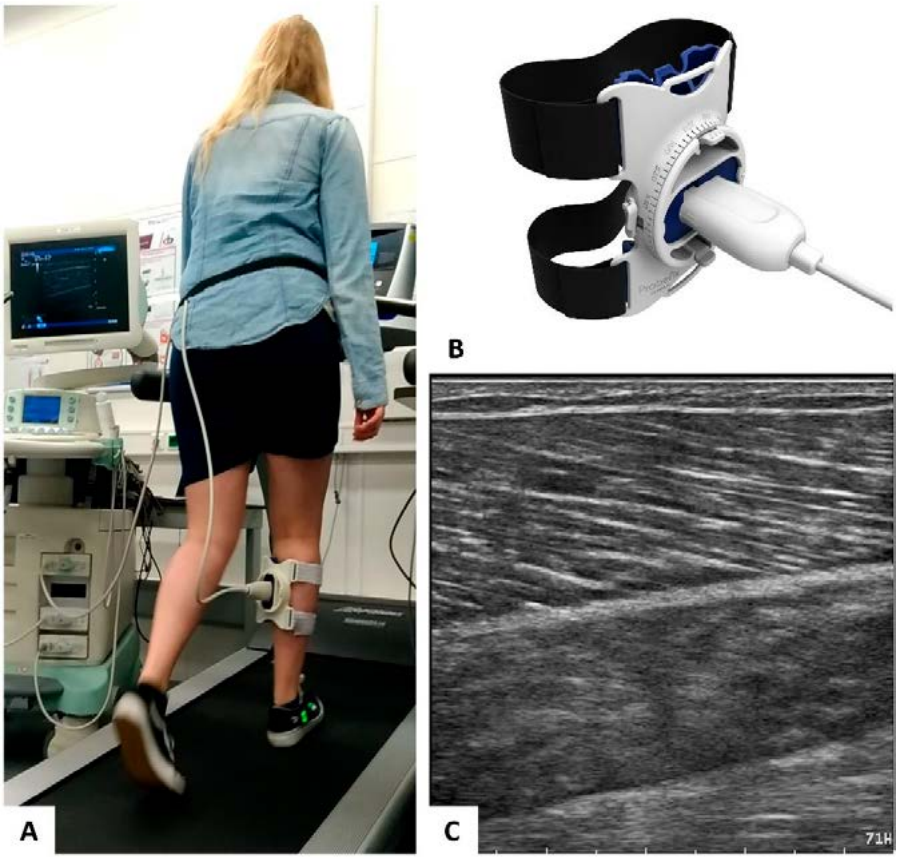

Figure 1. Example of continuous ultrasound acquisition during walking exercise.
(A) Subject walking on the treadmill;
(B) Probefix Dynamic (USONO, Eindhoven);
(C) Ultrasound image if the medial gastrocnemius acquired in dynamic condition.

4 Results

Experiments were successful in all subjects, providing US data and muscle parameters for sequences of 10 seconds. The percentage of incorrect automatic muscle segmentation is below 0.1%. The averaged MT is 15.4 ± 0.2 mm, ranging during gate between 9.6 - 21.5 mm. The averaged FPA is 13.1 ± 2.0^{o}, ranging between 4.6 - 18.2^{o}. Preliminary results of the manual validation show that the differences between the automatic and manual measurements are below 0.1 mm for MT and 2.5o for FPA respectively (Figure 2, Panel C). Automated analysis takes less than 0.8 second per image, compared to the 1.5 minutes of the manual annotation. The MT measurements presented a temporal pattern that can be qualitatively associated, for each subject, to a specific phase of the gait cycle (Figure 2, Panel D).

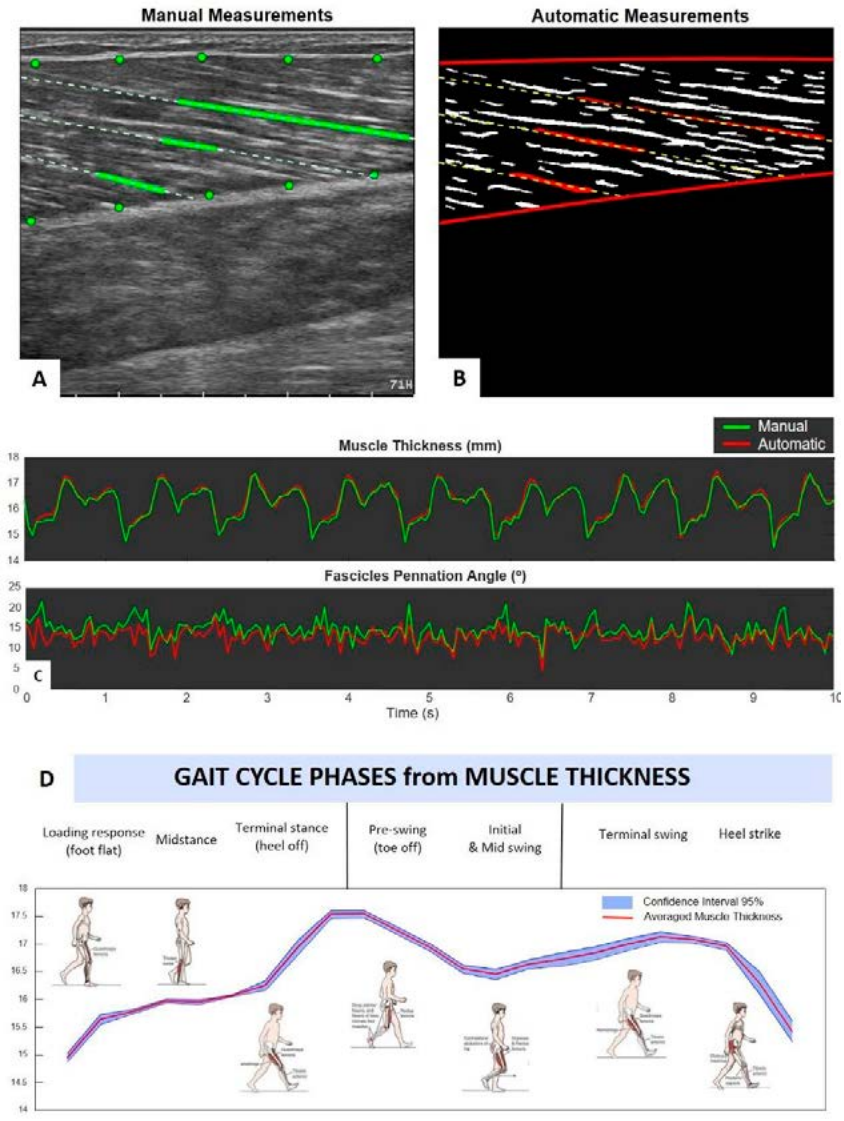

Figure 2. Output of the automated algorithm for skeletal muscle measurement.
(A) Example of manual muscle thickness measurements in five points and Pennation Angle along three representative fascicles of the Medial Gastrocnemius muscle.
(B) Example of automatic Muscle Thickness and Pennation angle on the corresponding three Fascicles.
(C) Manual vs Automatic Muscle Thickness and Pennation Angle in 10 seconds of acquisitions.
(D) Muscle Thickness changes associated with Gait Phases along 8 averaged cycles.

5 Conclusion

The proposed method shows that continuous automated US skeletal muscle architecture analysis during walking is feasible and has the potential of being robust and accurate, finding application in clinical practice and sports science.

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Extended abstract

The Running & Exercise Mental Break Optimisation (REMBO) App: Design Process and User Evaluation.

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Submitted: 11-09-2019

Keywords: running application; user experience evaluation; running-related injury; recovery; passion

1 Introduction

The popularity of running is steadily growing, which is great news considering its potential health benefits [1]. Less fortunate, however, is the associated injury rate in running. Recent research shows that no less than 52.2% of runners report a running-related injury (RRI) in the past 12 months [2]. These numbers suggests injury prevention in running is pivotal, but insufficiently practiced. The most common barriers for practicing injury prevention in running are "not knowing what to do" and "no history of RRI" [3] (p. 10). Therefore, we designed an application specifically for runners to prevent injuries and internalize a habitual preventative mindset concerning RRI in runners. We tested the application in a randomized controlled trial [4].

The application or app, which we aptly named the Running & Exercise Mental Break Optimisation (REMBO) app, contained various elements aimed at establishing the aforementioned goals, most importantly via a 'running check' questionnaire. The purpose of this short questionnaire was to determine ones' personal training capacity via a set of questions and to give a personalized advice accordingly relating to their planned training load for that day. In doing so, its goal was to help runners stay within healthy boundaries of training, thereby preventing overtraining and the associated risk of injury. Thereby the app stimulated them to ensure adequate recovery had taken place before they engaged in running again. The main proposed workings of our app revolved around mental aspects of injury prevention, which are likely to be very important in injury prevention [4]. These aspects include physical, cognitive and emotional recovery [5], and obsessive and harmonious passion [6], which are described more in-depth in our design paper [4].

In order to evaluate the ease of use and effectiveness of this app we set out to gage user experiences. Using a semi-structured interview format, we set out to qualitatively explore how users experienced usage of the app and points for improvement they recommended. Note that predicted relations with injuries and/or results from the trial are not part of the current abstract and will be reported elsewhere.

2 Methods

As a summary of the app design and workings: we compared several online app designing platforms, eventually selecting one which facilitated such design via a (near-)drag & drop experience with basic HTML support. The earlier mentioned 'running check' consisted of 12 items mainly related to mental aspects, such as mental fatigue, feelings of obligation, and focus. Some items related to physical indicators were also included (e.g., joint pain). All items were rated on a 7-point Likert scale. The feedback mechanism on planned trainings based on this

'running check' was implemented using traffic lights, a common and effective approach in interventions [7]; green for: safe running, orange for: risky running, and red for: no running recommended at all. Categories were determined via an algorithm based on 'running check' scores of users. Orange and red traffic lights were accompanied by advice on reduction of or alternatives for participants' planned training.

The REMBO app was first tested in a randomized controlled trial [4]. After this trial we requested 37 people from the intervention group (n = 214) (i.e., those who had access to the app) to partake in an interview. Of those invited, 14 accepted and were interviewed in a semi-structured fashion by phone. During this interview 18 questions (i.e., closed, open, and follow-up questions based on certain answers) were used to explore the following facets of user experience: general perception of the app and the 'run check'; outcomes resulting from app usage; anticipated future use; and possible improvements [8]. Results were analyzed according to Grounded Theory [9] using QDA Miner Lite (v2.0.6; Provalis Research, Montreal, Quebec, Canada).

3 Results

More positive than negative experiences were mentioned, with only a subset of these negative experiences pertaining to actual app content (c.f., app look). The 'running check' was nearly uniformly deemed a good indicator of their capacity, although some comments about its lack of physical questions and broadness of traffic light categories were mentioned.

A wide variety of ideas were offered when asking for improvements, including the ability to save data and link the app with other apps. Most interviewees said the app influenced their opinion of running injuries by increasing awareness of mental aspects (e.g., detaching from ones' sport), followed by a smaller share which said the app had not changed anything, following by a variety of yet smaller shares mentioning various positive outcomes other than awareness. Participants were nearly uniform (86%) in saying that the app would not require recurring usage but that its mechanism was internalized after a period of usage during the trial.

4 Conclusion

The goal of this study was to qualitatively evaluate the REMBO app among its users. Generally, the app was received well and achieved some of its intended effects, such as increased awareness of mental aspects (e.g., mentally detaching from ones' sport) of injury prevention. Multiple points for improvement were offered by users, including collaboration with or implementation in other apps and the option to save ones' data.

As the goal of our app was rather small in scope (i.e., to test proposed mechanisms relating to RRI) our design process was not as elaborate as some similar studies [10]. Combining solely the functional mechanism of our application with other apps which already possesses adequate design and a benefitting user base may avoid issues pertaining to our basic design.

The qualitative nature of this study can be considered both a strong and weak point, as the exploratory nature allows us to explore aspects otherwise missed, but the very nature (and sample size) of such studies generally complicate generalizability. Furthermore, some of our findings can also be considered ambiguous due to contrasting desires with comparable amounts of proponents on both sides of some issues.

In conclusion, this study shows that the design and implementation of the REMBO app were received favorably among the interviewed runners and app usage resulted in increased awareness of the mental aspects (e.g., mental recovery, passion) of RRI prevention.

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Extended abstract

COMPARING THE PERFORMANCE OF YOUTH FOOTBALLERS ON ANTICIPATORY CAPABILITY AND THEIR RESPECTIVE COACH RATINGS

Tom de Joode [1] and Saumya A. Mehta [1] and John van der Kamp [1] and Geert J. P. Savelsbergh [1]

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Submitted: 31-08-2019

Keywords: talent identification, decision-making, anticipation, actuarial judgment, perceptual-motor skill

1 Introduction

Recognizing athletes who will be successful in the future is the key of talent identification [1,2]. Selecting players is mainly done by scouts and coaches. While it is general accepted that they have an "eye" for talent, several studies show that their decision-making is affected by biases like individual experience [3] and relative age effect [4,5], even if coaches are made known of it [6]. Physiological and anthropometric characteristics of players cause unequal maturation within youth and cause performance differences between players [7]. Literature regarding talent identification suggest that perceptual skill is promising. Experts are found to be more efficient than novices in recognizing, analyzing and interpreting contextual information [8]. Moreover, more recent studies have emphasized how the perceptual capacity of experts focusses them more on important information of actions of opponents compared to novices. This higher anticipation capability lets experts gain better contextual information and act more efficiently by making more meaningful associations [9-11]. With the importance of anticipatory capability, the game-insight test (GIT) was developed and found to distinguish between skilled and less-skilled players [12]. This test might be an important tool to improve the talent identification. In current study the GIT is a tool for comparison between the coaches "eye" and the scorers for anticipation capability. Accordingly the GIT can be validated for clinical judgement and to gain knowledge whether a coach can differentiate players who can anticipate better or worse during a positional game situation. Thereby, it examines whether there is a correlation between coach ratings and the scores of players on the GIT.

2 Method

2.1 Participants

A total of 52 elite youth football players (mean age 11.6 years) participated in the study. Participants were playing in the squads of under 11, 12 and 13 of two major football academies at the highest level in the Netherlands. The questionnaire was answered by four head coaches of the respective teams.

2.2 Game-Insight Test

The GIT consisted of a 4 v 4 small sided game which were projected on a 2.4 x 2.4m screen. The videos were shot from the participant's point of view. Every video consisted of a positional game as well as a pass at the end of the video. Based on previous research there were three types of videos [8-11]:

- The film stopped 80 milliseconds after the passer made contact with the ball.
- The film stopped at the time when the passer made contact with the ball.
- The film stopped 80 milliseconds before the passer made contact with the ball.

Furthermore, two types of actions leading up to the final pass were also applied in the videos: a "solo" situation where an individual had the ball and then made the final pass, and a "duel" situation of uncertainty regarding possession and the final passer of the ball. 30 such films were used for each participant. The score of a participant performance was obtained by: the number of times the participant moved in the right direction (left, right or center of the starting position), the right zone and the right time (compared to answer videos). 1 point was awarded to the participant for each of these parameters, results in possible maximum of 3 points per trial.

2.3 Questionnaire

The questionnaire consisted of a 5-point Likert scale. The coaches were asked to rate each player for Creativity, Decision-Making and Anticipation.

3 Results

With use of the means and standard deviation high (N=13) and low (N=11) groups were created based on the scores of the coaches. Rating and the Game-Insight Test were conducted for both the groups on scores over all 30 trials, as well as 21 trials (excluding fake and indistinguishable trials). No significant correlations were found when Coach Rating was compared to the Score on Game-Insight Test on 30 trials (r=-.059; p= .679), while a weak yet statistically significant correlation was found between the Coach Ratings and Scores on Game-Insight Test over 21 trials (r=.290; p=.037). The scores on 21 trails were used for further analysis. Table 1 shows that the high scoring group was associated with a higher mean score on the game-insight test as compared to the low scoring group.

Table 1. Mean scores on GIT over 21 trials as a function of high & low scores on coach rating (CR)

	Group	N	Mean	Std. Deviation
GIT	High scorers CR	13	29.8462	4.45058
	Low scorers CR	11	25.1818	2.85721

In addition, the high- and low scoring groups created by CR, were also analyzed for easier and more difficult trials. The results of the t-test show that the mean difference in scores of high and low scoring groups on Duel trials (M=7.31, SD=1 for high scorers and M=7.36. SD=2 for low scorers) is not significant (as shown in table 2). There is, however, a significant (t(22)=2.653, p=.015) difference in the solo trials as a function of the high and low scoring groups (M=18, SD= 4.2 for high scorers and M=13.8, SD=3.3 for low scorers).

Table 2. Solo and duel trials as function of high and low scoring groups

Group	t	df	Sig. (2-tailed)
Duel	-.085	22	.933
Solo	2.65	22	.015

4 Conclusion

The study aim was to examine whether there is a relationship between an objective measure of anticipation and the coaches judgement. It was assessed to serve as a method of further validating the game-insight test – the objective measure, while also exploring the possible applications of this to coaches for selecting players. The analysis revealed a significant difference in performance of high and low scorers according to coach ratings on the game-insight test. It also revealed that this difference held significance when easier "solo" trials were considered, whereas no significant difference was found on the harder "duel" challenges. Indeed, what the coach "sees" is validated by the results on the game-insight test. It might be difficult to grade anticipatory capability correctly for each individual at this age, but coaches can certainly distinguish the best and worst within their group. Therefore, combining and comparing the opinion of coaches with objective perceptual skill measure (GIT) might increase the productivity of talent identification program.

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Extended abstract

Inspirun app: User Test of an Algorithm that Automatically adjusts Training Sessions for Runners

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Keywords: Running App, Personalization, Motivation, User tests, Alogrithm

1 Introduction

Research shows that approximately 50-75% of (event) runners use a running app, especially novice or less experienced runners [7]. This trend of using apps while exercising is consistent with trends like Quantified Self [9] and mHealth [5], which emphasize the potential of these monitoring devices to contribute to an active lifestyle by supporting behavior change [6]. Unfortunately, among runners there is still a high drop-out rate due to injuries [1,2] and decrease in motivation. The majority of these runners lack personalized guidance and support. (e-)Coaching and tailored advice could help these runners to avoid injuries, set goals and maintain good intentions [11]. In particular, apps have several advantages. Smartphones are widely used, they are embedded in daily life [3,11], and allow people to collect data anywhere and anytime [4]. Since most people already have a smartphone (up to 76% of all adults) [10] and apps are relatively cheap, apps became accessible for almost everyone. Unfortunately, available running apps primarily focus on monitoring performance and offer few or no features that support tailored guidance (e.g. personalized training schemes) [8].

Therefore, Vos et al. designed Inspirun, an e-coach app for runners [11]. Inspirun is an intelligent running app that provides automatic adjustment of training schemes based on heart rate data and GPS-data. (see Vos et al. [11] for a full description of the design). The present paper aims to give insight into how end-users experience the personalization of the algorithm that automatically adjusts the training scheme. We expected that if the end-user follows the app's instructions and completes the training as prescribed, the training will be consistent with the personal load capacity of the user and will be perceived by the user as personalized.

2 Study protocol

After ethical approval, 43 runners participated in our study between spring 2018 and autumn 2018. The participants used Inspirun until they completed 20 training sessions (i.e. scheme). We used online questionnaires (every two weeks), and data collected by the Inspirun to monitor the participants over time.

A total of 36 participants logged one or more training session those who did not register any run, stated that they underestimated the time investment needed. After the second questionnaire (3rd week), 28 participants remained. The main reason to quit was a bug that randomly caused disconnection with the Bluetooth heart rate sensor. These participants did not like the struggle of reconnecting with Bluetooth heart rate sensor while running.

More runners dropped out later in the study. Reasons mentioned for quitting were, being on holiday and hot temperatures since the study partly was conducted in the summer. Finally, 20 participants performed between 9 and 25 training sessions in the testing period. There is quite a variety in the number of questionnaires filled in, due to differences in running frequency per week.

3 Results

In the analysis, we included the results of the 20 participants who completed the full testing period. On average (including all questionnaires (n=95)) the experienced personalization scored a 3.81 (SD 0.76) on a 5-point Likert scale (see Table 1). Subsequently, we asked the runners to explain their scores. Those who were positive about the personalization (scoring 4 or 5) experienced the gradual increase of the intensity as pleasant. They felt that the sessions were challenging without being too hard. Runners who scored 2 or 3 (no 1 scores were given), indicated that they were not quite sure if the app accurately measured their heart rate or speed. Therefore, they doubted the accuracy of the personalization. We checked these claims by analyzing the data logged by Inspirun and indeed, for all runners who scored 2 or 3, on multiple runs pieces of the heart rate or GPS data were missing.

Table 1. Experience of the personalization of the training session on a 5-point Likert scale

	Two-weekly questionnaire							
	1	2	3	4	5	6	7	8
Mean score	3,85	3,65	3,90	4,11	3,63	3,17	4,00	4,00
SD	0,65	0,79	0,77	0,66	0,70	0,90	0,00	0,00
Number of runners	20	20	20	18	8	6	2	1

4 Discussion and conclusion

Inspirun was designed [11] to provide personalized training schemes based on biofeedback and GPS-data. The primary conclusion of our study is that the algorithm which automatically adapts training sessions to the runners' physical load (if provided with accurate data) is experienced as personalized.

Participants, whose data was complete and accurate, stated that the sessions matched with their training level. Building a PRP on both subjective (RPE) as objective (HR and Speed) aspects of intensity seems to be a good combination to develop an algorithm that is sensible for change.

Runners whose data was incomplete or inaccurate, doubted whether the sessions were accurate. In particular, gaps in heart rate data caused problems in the automatic calculation of the next session. For example, some runners had problems with the Bluetooth connection between the heart rate monitor and their smartphone while running. Therefore, the app not always collected heart rate data, but instead wrote zeros in the dataset. This caused a much lower average heart rate due to the inclusion of the zeros. Consequently, making the app think that the prescribed heart rates were too high. The same goes for inaccuracies in running speed. Runners experienced some problems when running in wooded and hilly areas, resulting in lower average speeds than expected, making the app think that the session was too hard to complete when this was actually due to the environment or signal strength of the GPS.

The algorithm of creating automatically and personalized training sessions seems to work when provided with complete and accurate data. Although the robustness of the algorithm, especially how it deals with flaws in the dataset is not reliable yet. In future work, first of all, the Bluetooth connection must be improved. Second, to make the algorithm more robust, the algorithm must be adjusted so that incomplete datasets (e.g. with too many zeros) are not used in the PRP. Third, additional parameters like elevation and running surface must be included when calculating the speed of a session.

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Extended abstract

Automatic extraction of performance metrics from football players with data mining

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Keywords: football; data mining; unsupervised; kids; sports

1 Introduction

Organized youth sport is seen as an important socializing context for children and adolescents. Sports, which are also known as the third pedagogical environment (next to home and school), contribute to a range of positive outcomes: self-esteem, social behavior and integration. There is recent evidence that there is a positive relationship between 'club culture and atmosphere' and 'organizational performance' (Schoot, 2016). This means that when a sport club focuses more on the elements of club culture, financial performance, member satisfaction and social sport performance can increase.

Based on the literature we can distinguish several conditions for a pedagogical sport climate (PSC) (Schipper-van Veldhoven, 2016). For example, the focus on sport pleasure, as it is the number one motivation to participate in sport and therefore an important determining factor of (continuous) sport participation. Fun is also an important educational tool. In other words, a bad pedagogical climate can interfere with the performance in the practice of sports. This can be assessed that by measuring how they are performing in comparison with their peers.

Typically, in high performance sports, the positional data comes with event data, which can support more detailed analysis of the performance of player. However, labelled football (soccer) data is hard to acquire and it usually needs humans to annotate the match events. This process makes it more expensive to be obtained by smaller clubs.

For this reason, we developed an Unsupervised Football Analytics Tool – UnFOOT. UnFOOT combines data mining techniques and basic statistics to measure the performance of players and teams only from positional data. The capabilities of the tool involve preprocessing the match data, extraction of features, visualization of player and team performance. It also has built-in data mining techniques, such as association rule mining, subgroup discovery and a proposed approach to look for frequent distributions.

Due to the lack of data from children playing, we tested the proposed approach in data from six professional football matches.

2 UnFOOT

There already exist tools that given the positional and event-labeled data can extract useful knowledge from the teams and players (Bialkowskiet al., Gud-mundssonet al.). However, these tools require event-labeled data, which can be more expensive to obtain than positional data.UnFOOT uses positional data from players in a football match and extracts different statistics as well as performance indicators of players and teams.

UnFOOT offers a simple and intuitive GUI for analyzing football matches only from spatiotemporal data of players. (A demonstration can be watched at https://youtu.be/x86tg48qEs4). The pipeline involves 3 stages: Processing of the data, Representation and Data Mining.

After loading the data, the tool makes one pass on the data and outputs a new dataset with extracted features. These features include the distance covered, the speed and the acceleration of the players. The dataset is divided into time windows of the same size. For each window, several internal modules extract different performance indicators and statistics from the positional data. One of the metrics, *pressure* uses a clustering technique (DBSCAN), from the python package *scikit-learn* (https://scikit-learn.org/stable/modules/clustering.html). With the clusters, we are able to identify moments of higher pressure of the players during the match. In the end of the analysis, the overall and detailed results are stored into a .csv file to enable further analysis outside of the tool.

From these performance indicators UnFOOT produces an overall player score which is the mean of the indicators. These player scores are also added together to obtain the score of each team.

The UnFOOT tool has an interface with several data mining techniques to explore the features extracted.

One module uses association rules mining to find relationships of performance indicators between consecutive time windows for a selected player. The last method uses subgroup discovery to find subgroups with unusual behaviour relatively to an user defined target. For the association rules mining module, we used *mlxtend* (http://rasbt.github.io/mlxtend/), and for the subgroup discovery module we used *pysubgroup* (https://pypi.org/project/pysubgroup/).

Besides, we also use a method to look for frequent distributions. These distributions can represent speed or distance covered by players. It is similar to frequent pattern mining, except that the items are distributions. For that, we use the Kolmogorov-Smirnov (KS) to verify if the distribution of one player is significantly different from the other players. Then, UnFOOT counts how many times each distinct distribution is observed during the match to obtain the support (frequency) per player.

2.1 Representation and Structure

The GUI is divided in 4 different tabs: *Player*, *Team*, *Data Analysis* and *Settings*. *Player*, evaluates and compares players according to their overall score or specific performance indicators. (Figure 1 a)); *Team*, displays and compares different team scores and shows the best players (Figure 1 b)); *Data Analysis*, allows the user to use an interface to execute data mining algorithms on the match data; and *Settings*, lets the user load the dataset and define some basic settings before starting the analysis.

3 Results

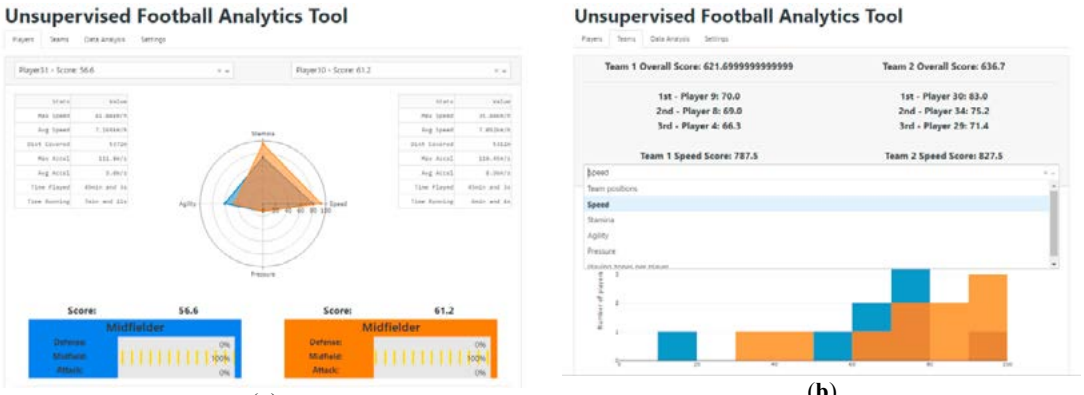
Six professional football games were analyzed with the tool. Due to privacy issues, we are not able to provide more details about the match, such as the name of the best player per match or the names of the teams. According to some metrics obtained (Table 1), the best players of the match are usually found on the tool's top three players of the winning team. In two cases, they even had the best score overall. Even though the overall score was not originally designed to predict the best player of the match, we use it to validate the scoring

function. However, this scoring function can only reasonably assess the quality of players, which are not goalkeepers. This is seen in Game 5, where the best player was actually a goalkeeper.

We can also observe that the sum of the team players' individual performance may not be enough to evaluate the performance of the team, since in only half of the cases the highest team score corresponds to the winning team.

Table 1. Results obtained with UnFOOT.

Match	Winner	Team A score	Team B score	Rank of the best player
1	A	758	778	3rd of Team A
2	A	814	811	1st overall
3	A	795	805	3rd of Team A
4	B	832	855	3rd of Team B
5	A	813	796	Last overall
6	A	816	819	1st overall



(**a**) (**b**)

Figure 1. This figure shows an example of the interface of UnFOOT for the (**a**) Individual Players; (**b**) Teams

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Stimulating **Physical Activity**

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Extended abstract

Grace: Designing for Exercise Motivation Through Social Support and Graceful Interactions

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Keywords: Constructive design research; graceful interaction; exercise intentions; wearable technology; social support

1 Introduction

Increasingly aware of the importance of active lifestyles, more and more people intend to be physically active [10]. Even though sport used to be an activity mainly practiced by men, we see an increasing development of women participating in sport, resulting in more gender equality in this area [11]. Despite their positive intentions, the main challenge for many people remains to maintain being physically active [10]. The average drop-out rate is around 50%, where women are less likely to continue their exercise regime compared to men [1, 5]. Studies indicate this is because women experience more unforeseen barriers and additionally attach greater importance to social support [5].
To support people in being more physically active, there has been an exponential increase in sport and physical activity-related wearable technology that enable body-monitoring and data tracking. Despite a general acceptance that people are different, many of these devices tend to take a "one-size-fits-all" approach through quantification of exercise behavior and stimulation of performance and competition [9]. Even though this type of motivation strategy speaks to a segment of people, there are also individuals who are not encouraged by being faster or stronger than others, but value social support more [5, 13]. Studies show that this type of "social thinking" seems to appeal to women in particular [5]. Additionally, studies have shown that not everyone feels comfortable wearing activity trackers due to the sporty and bulky appearances of the devices [12], preferring the ones that are more graceful [6, 7]. We therefore argue to incorporate gracefulness and social support as motivational strategies in sport-related wearable for women, and inform how to design for this.

2 Designing Graceful Interactions

Through an expert study involving industrial designers (n = 22), we have explored how to design for graceful interaction in product design. Using the Interaction Vocabulary Cards that consist of 11 seven-point semantic differential items [4], we asked the designers to describe how a graceful interaction with a physical product would feel/look like. We provided them with the following definition of gracefulness: "Gracefulness is characterized by elegance or beauty of form, manner, movement, or speech. It is elegant. Grace is the appearance of an easy presence (graceful movements appear as easy and effortless). And such presence involves a harmonious relatedness to one's context." [2, 3]. Based on this definition, the participants were asked to evaluate only the attributes considered relevant and leave the others blank. After the assessment of the 11 attributes, participants were asked to prioritize the 3 most relevant attributes.
The results of this study show that seven attributes are associated with designing for gracefulness: *slow*, *fluent*, *uniform*, *constant*, *precise*, *gentle* and *targeted* (Figure 1). Amongst these attributes, *fluency* (14), *gentleness* (12) and *slowness* (7) were selected as the most important attributes for a graceful aesthetic of interaction.

Attribute 1	Frequency Attribute 1	No Response	Frequency Attribute 2	Attribute 2
Slow	**15**	6	1	Fast
Stepwise	2	1	**19**	**Fluent**
Instant	4	**15**	3	Delayed
Uniform	**14**	6	2	Diverging
Constant	**15**	7	0	Inconstant
Mediated	7	**8**	7	Direct
Spatial Separation	1	**13**	8	Spatial Proximity
Approximate	2	3	**17**	Precise
Gentle	**16**	6	0	Powerful
Incidental	1	7	**14**	Targeted
Apparant	4	**12**	6	Covered

Figure 1. Attributes rated by design experts (n = 22) to describe a graceful aesthetic of interaction, using the Interaction Vocabulary [4]

3 Design of Grace

Based on the notions that described a gracefulness interaction (slow, fluent and gentle), we designed Grace [8]: a piece of jewelry that encourages women to share and support exercise intentions with friends. Through Grace, users are able to see whether friends have the intention to go exercise that day and are able to cheer for them. This information is also shared about themselves.

Figure 2. Grace, a piece of interactive jewelry, enabling women to share their exercise intentions

3.1 Gracefulness Interactions embedded in Grace

To distinguish Grace from physical activity-related devices that focus on performance, which are usually designed as being fast, powerful and precise (by using numbers to provide users with feedback), we embedded the interaction qualities *slow, gentle* and *fluent*.
Slowness is expressed in the design of Grace and the way the feedback is provided throughout the day. This feedback cannot be seen on demand and is provided in the moment itself.
The attribute *Gentleness* is translated in all the interaction styles of Grace which entails several touch, motion, and mid-air gesture interactions. To plan an exercise, the hand is placed on the heart as to mimic the salutation of promise. The display, divided into slots for different friends, will now display skewed stripes. When the user

is done exercising, she taps herself three times on the chest, showing off a feeling of pride, and changing the stripes into mellow post-workout waves. Lastly, to cheer (regardless of their effort) for friends with a lively zig-zag pattern, you hold your hand on your heart for a feeling of connectedness.
The notion of *Fluency* is also embedded in the interaction styles of Grace as well as the smooth act of fidgeting, since these movements are 'easy or effortless'.

We set up an exploratory user study with three participants, to gain first insights into how the feedback given by Grace was experienced, and whether the different interactions with Grace were considered as graceful. Additionally, we assessed how the target women perceived the qualitative social support mechanism as a motivational strategy. The most important insights are that the participants indicated to value the cheering component of Grace, enabling social support and that the feedback was considered subtle yet graceful.

4 Conclusion

Through the design of Grace, we aim to extend the design space of sport-related wearables and inform how to design for exercise motivation through social support and graceful interactions. We believe the present study provides a different approach towards incorporating a more qualitative way by supporting women with their exercise intentions. This work thus provides a qualitative perspective and inspiring implications to designers of sports-related wearables. Additionally, by defining the notion of graceful interactions, designers can also use these attributes as a starting point for the design of interactive technologies in other application areas.

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"Keep going, get better"
Keynote by Harry van Dorenmalen

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Extended abstract

Virtual Community Building in Organized Sports in the Netherlands

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Submitted: September 9, 2019

Keywords: virtual community building; social network sites; voluntary sports club; identification; membership involvement

1. Aim and Research Questions

Virtual communities are online spaces with potential of integration of (member-generated) content and conversations [7,8]. In our research project we are interested in the adoption and building of virtual communities in organized sports, that is to say in the voluntary sports clubs (VSCs) in the Netherlands. Since these VSCs have massively transferred their communication with members from paper club magazines to online channels, these virtual communities arise from the use of a growing number of websites, e-mail and social network sites (SNSs). Although virtual communities are broadly investigated, such as social communities, brand communities, and public communities, there is little scholarly interest in virtual communities of member organizations that VSCs are an example of.

The study that is to be presented at SECSI2019 concerns the clubs' use of SNSs (ClubSNSs), such as Facebook and Twitter, within the virtual communities. These SNSs are increasingly used by the VSCs to facilitate organizational communication and to obtain a good internal climate [9]. However, academic understanding of the impact of ClubSNSs' content and conversations on the organizational performance of the VSC is in its infancy. In our study, we examined this impact of ClubSNSs use on the involvement among members and whether we can explain this by members' identification with the club. Furthermore, we have tried to categorize ClubSNSs by content types, such as informative, conversational or sociable ClubSNSs, and their role in stimulating the use of ClubSNSs. In this way we attempted to gain insight into the effect of types of ClubSNSs' content and conversations on membership involvement and the mediating role of identification with the club. This insight can help VSCs to develop effective ClubSNS channels that contribute to organizational goals such as supportive and loyal membership.

2. Background

As part of the virtual communities, social network sites are increasingly important for knowledge sharing, innovation and social interaction within organizations [2, 3]. In fact, SNSs facilitate working within companies by stimulating interconnections amongst employees [5]. In order to reach effective organizational communication, the identification of members with their organization is important [4], but we noticed that scholarly work about the role of SNSs to developing member identification in VSC is elusive. Moreover, we know that, as far as consumer brands are concerned, different motivations for the use of SNSs are distinguished (such as information, fun or empowerment) in order to explain the involvement of consumers in so-called online brand communities [6]. These motivations are used to elaborate content on these brand communities to engage and ultimately bind members [1]. In our research to VSCs, which are member organizations where members are the producers of the sports service themselves, we want to explore this motivational use of ClubSNSs, and the impact of content and identification with the VSCs.

3. Research Design, Methodology and Data Analysis

In a survey, students of the Fontys University of Applied Sciences, all members of voluntary sports clubs in the Netherlands (n = 129) were asked about their perceptions of their club's ClubSNSs uses, the content and conversations on ClubSNSs and the aspects of involvement and identification with their club, see figure 1. Since young adolescents are a risk group when it comes to retaining membership [9], it is important to gain more insight into their perceptions and ideas about SNSs as organizational channels of VCSs' virtual communities. Using factor analysis, we distinguished components, with which we conducted regression and meditation analyses in order to explore relationships.

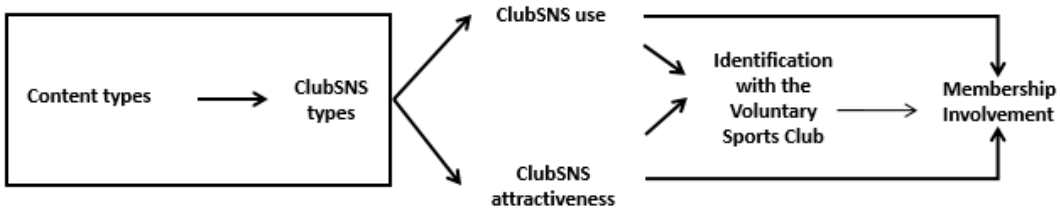

Figure 1. Conceptual model ClubSNSs and Membership Involvement.

4. Results / Findings and Discussion

Foremost, ClubSNSs are characterized as informational types of communication channels and less entertaining or interactional, which was underpinned by the strong relationships with informational content on ClubSNSs. Participants reported content about sports, members and clubs as favorite content, while other content types (e.g. polls, games) were less favorite. It

is important that this content is posted in messages, conversations, photos and video on the clubs' social network sites. Furthermore, participants motivated their use of ClubSNSs, because of its entertaining content and the opportunities to get in touch with other members. Ultimately, relationships were found between use of ClubSNS and membership involvement of members, which were explained by the identification of members with their sports club. Although we realize that the samples of students are quite specific, the results provide insights into aspects of use of ClubSNSs as virtual community channels and the potential of them for effective organizational performance of voluntary sports clubs.

5. Conclusion, Contribution and Implication

The main contributions of this study are the new insights into use of social network sites as part of virtual communities within member organizations in general. Moreover, our study extended our knowledge of use of ClubSNSs and the relationships with membership involvement and organizational identification within the context of member organizations, such as voluntary sports clubs, based on content, motivations and types of SNS channels.

Practical implications aimed at increasing effectiveness for engaging and binding members within the voluntary sport clubs are described, such as the introduction of a typology of ClubSNSs as a basis for management decisions.

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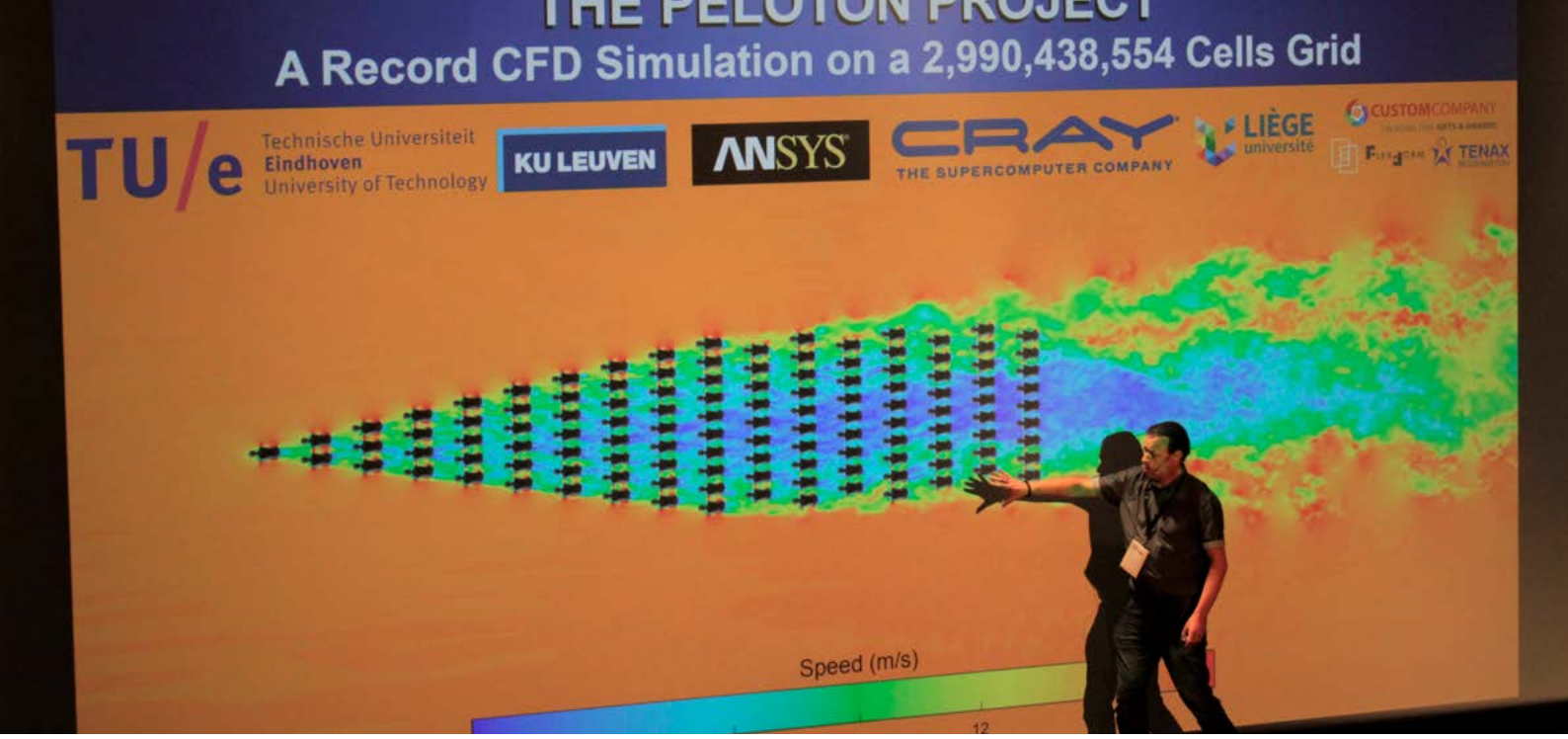

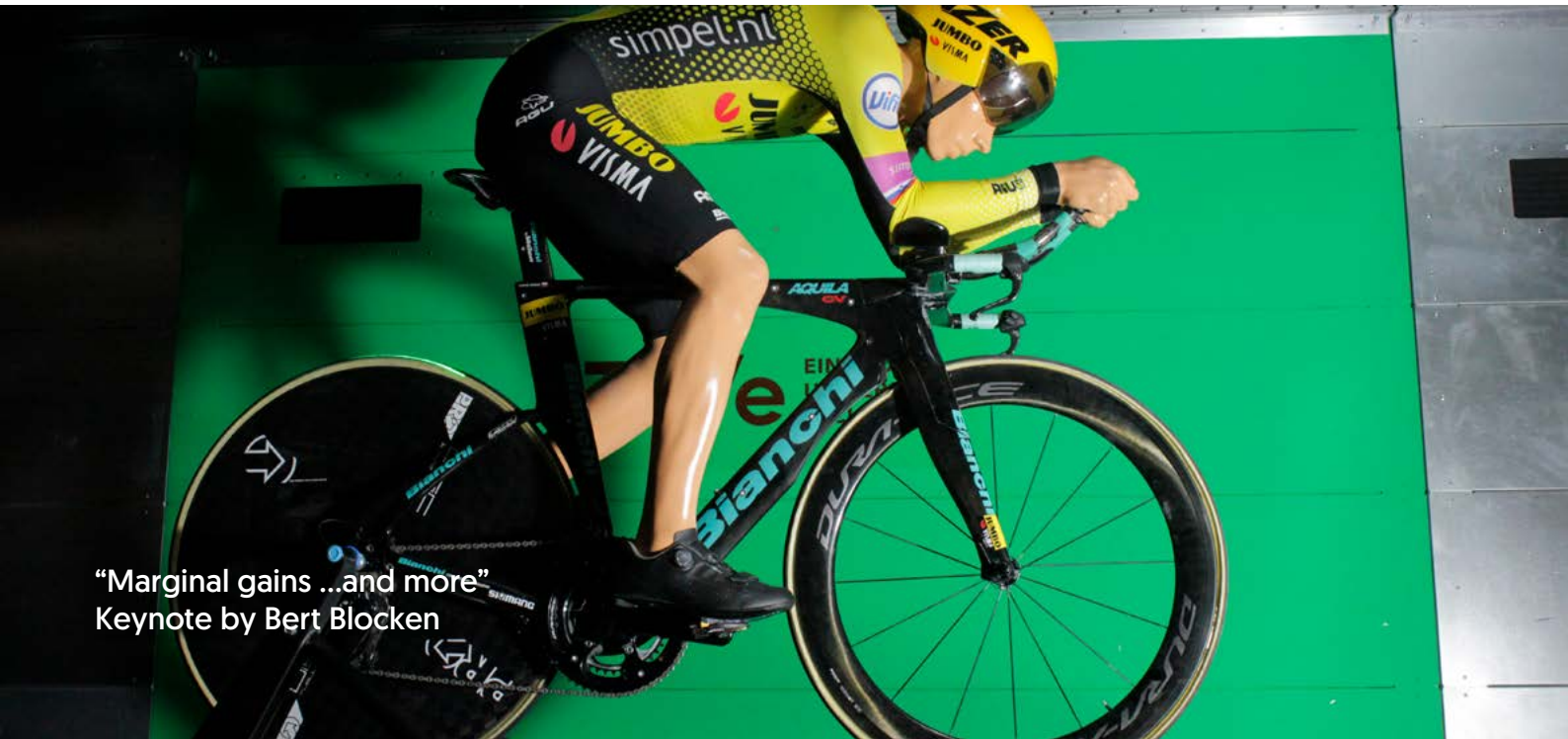

"Marginal gains ...and more"
Keynote by Bert Blocken

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Extended abstract

COMMONS: facilitating interdisciplinary collaboration in developing wearable technology for physical activity

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Submitted: 04 September 2019

Keywords: Interdisciplinary teams, technology, board games, physical activity

1 Introduction

The lack of physical activity and an increase in sedentary behavior poses far-reaching health risks in our society [1]. Technological developments can provide possibilities for increasing physical activity in the daily routine of individuals. However the impact of these wearables on physical activity is small. A personalized approach is absent in most consumer available wearables because limited non-technological expertise is consulted and the user is often not properly involved in the design process [2]. These wearables, which follow a "one size fits all" approach, are no longer used after a few months [3,4]. To provide this problem with a better answer, technological aspects will have to integrate with individual, social and environmental aspects [5]. Therefor an interdisciplinary approach could have an important role in the development of wearable technology in enhancing physical activity. Interdisciplinary collaboration seems straightforward but is not obvious and requires special attention [6]. Often members of interdisciplinary teams have different methods of research, have different definitions and might have a mental model in which they fully or partially disregard other disciplines. This leads to sub-optimal outcomes [6-8]. We developed a board game, as research prototype, named COMMONS [9], that logs data within the game, to gain insight into the dynamic process of collaboration.

Method

COMMONS is a research prototype with elements for logging data such as individual voting behavior, voting composition, card positioning, etc. This is done by voting boxes, RFID cards and readers and a microcontroller. COMMONS has two goals: (i) gain insights into gameplay with regards to choice, discussion and compromise between players and (ii) facilitating interdisciplinary collaboration in the design of wearable technology for stimulating physical activity. The game requires four players with different expertise. While playing, a user profile with context, goals, motivation and obstacles in relation to physical activity is leading. Players vote on features linked to the profile, wearable technology and physical activity. Features can be accepted, rejected or there is no consent in which case there is a discussion round. When a feature is accepted players must agree on the position of the card on the board. If there's a discussion round the overriding objections must be cleared and players discuss their arguments. At various moment players must resolve a 'Kairos' card, designed to disrupt and cause unpredictability. The only way players can deal with these cards is by working together. See figure 1 for an image of COMMONS.

Figure 1. COMMONS with four voting boxes, the board, set of features, Kairos cards and the profile.

In a first study the game has been played three times with a set of 52 features (cards) divided into four categories: hardware, software, user design experience and behavioral change techniques. Each round of the game players vote for a feature and whether it matches the profile that is central. In addition, a questionnaire was conducted with items about the background of the players, getting to know other players and their views, shifting individual mental models, interdisciplinary collaboration and overall game play.

With regard to the background of players questions have been asked such as gender, age and the expertise of participants. Questions related to getting to know other players and their views included: I got to know other areas of expertise and disciplines; I have gained insight into the arguments of other players; I understand why other players think other features are important.

According to Mathieu et al. (2000) mental models serve three crucial goals: they help people to describe, explain and predict events in their environment [10]. Questions regarding the shifting of the mental model included: I look at the features presented from a different angle; I have adjusted the importance of certain features; I have adjusted my vision on portable technology

As a definition for interdisciplinary working, we assume that disciplines need each other to solve a problem. The mutual influence determines the content. The insights that this creates transcend the boundaries of one's own profession. The questions related to this section included: I have more understanding of other people's views; I am better able to surrender in someone else's vision; that we have clarified concepts and definitions; that we have created a common language; that we as a team have improved our adaptability.

Results

Each game session has been analyzed separately and the data shows that with each feature other players agree or disagree. With four players who can each cast 3 different votes, there are 15 different voting compositions possible. All 15 different compositions are registered in the games. Features are immediately accepted in 35% of the rounds, 30% are immediately rejected and 35% end in a discussion round. Of these discussion features, 34% of them are accepted and 44% rejected. 22% remains without agreement.

In each game all of the players indicated that they could share their point of view, that they were actively involved in the process and that they had better insight into the arguments of the other players. Only 18% of players indicate that they have adapted their vision on wearable technology and physical activity and 27% indicate that they have adjusted the images of other expertise.

In questions about interdisciplinary collaboration 55% of the players agree that they created a commons language. 18% and 27% respectively are neutral or not agree on this. 91% of the players indicate that they had fun during the game.

Conclusion and discussion

Working with RFID cards and scanners, voting boxes and a micro-controller provides enough data to gain insight into voting behavior and the course of the game. We can carefully conclude that interdisciplinary collaboration, within the development of wearable technology related to physical activity, is not straightforward. Players have different point of views and find different features important to each other. With each feature, other players agree or disagree and some players put their stamp on a feature to a greater or lesser extent. Players indicate that they understand each other's points of view better and have better insight in each other's arguments. On the other hand, they have hardly changed their view of wearable technology in relation to physical activity and have not adjusted their view of other areas of expertise.

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Sensing

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Extended abstract

The introduction and concurrent validation of an inertial magnetic measurement-based motion tracking system in soccer

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Submitted: 30-08-2019

Keywords: Inertial Measurement system; Inertial magnetic measurement units; Kinematics; Soccer; Biomechanics

1 Introduction

This contribution concerns the introduction of a new inertial measurement-based motion analysis system (IMS) and its concurrent validity with an optoelectronic motion analysis system (MAS) during various soccer-specific movements. Movement kinematics have traditionally been obtained using MAS. However, these systems are restricted to a laboratory-based setting, require an experienced operator, and involve extensive start-up procedures [1]. In order to measure movement kinematics in a field setting throughout training sessions and matches on a day to day basis, the system must be quick to set up, easy to use, not be restricted to a limited measurement volume, and provide continuous measurements. Measuring movement kinematics using IMS may be the solution. Due to the recent miniaturisation of inertial magnetic measurement units (IMMU's), their low cost, and low power usage, these sensors are wearable and unobtrusive. IMMU's measure acceleration, angular velocity, and the earth magnetic field in three orthogonal axes respectively. When attached to body segments, these data can be used to derive segmental and joint kinematics using a sensor fusion algorithm and a biomechanical model [2].

2 Methods

2.1 Inertial Measurement-Based Motion Analysis System

The IMS consists of five IMMU's (Invensense MPU-9150, Invensense San Jose, California), which are attached to the shanks, thighs, and lower back (figure 1). The orientation of each sensor is obtained throughout a measurement period using a Madgwick orientation filter. A two-step calibration procedure is used to determine the relative orientation of each sensor with respect to the body segment it is attached to. The calibration procedure consists of a static and a functional calibration. During the static calibration, the longitudinal axis of each sensor is aligned with the direction of gravity, while in the functional calibration step the frontal axis of

each sensor is aligned with the frontal axis of its corresponding segment. Once the orientations of each segment are known, relative orientations are obtained and knee and hip joint angles and angular velocities are calculated.

2.2 Experimental Validation

Eleven healthy amateur soccer players (N = 11, mean ± sd, age; 22 ± 3, height; 181 ± 6 cm, weight 76 ± 11 kg) with at least one training session and match per week and no recent history of lower limb injury were recruited. The participants were equipped with the IMS and twenty reflective markers placed at anatomical bony landmarks. The markers were placed on the medial and lateral malleoli, medial and lateral femoral epicondyles, the anterior and posterior superior iliac spines, the lateral and posterior side of the thighs, and the lateral side of the shanks. The participants performed seven soccer-specific movements at three different intensities as the validity may be task and speed specific: jog (50-60%), sub maximal (75-80%) and maximal (100%). The movements included an acceleration run, a rapid deceleration, a 180° turn, a 60-75° angle cut, a kick, and a jump. Root-mean square differences (RMSD) between the two systems were calculated for knee and hip flexion/extension angles and flexion/extension angular velocities.

Figure 1. This figure illustrates where the IMMU's are placed, as well as the calibrated segment coordinate frames.

3 Results

Overall, RMSD's were 5.0 ± 4.4° (4.3 ± 3.9% maximum range of motion (maxROM)) for the knee joint angle, 8.2 ± 4.8° (8.4 ± 4.7% maxROM) for the hip joint angle, 185 ± 82°/s (15.9 ± 7.3 % maximum angular velocity (MAV)) for the knee angular velocity, and 84 ± 34°/s (11.4 ± 4.7% MAV) for the hip angular velocity.

4 Discussion

Relatively low absolute and relative RMSD's between joint angles and angular velocities measured by the IMS and MAS were observed. These results concur with values previously reported by others using different

IMS's. However, those results were obtained with lower intensity movements, such as walking, running, and manual labor[3-7]. Differences between the IMS and MAS can be explained by inaccuracies in the orientation estimation of each individual sensor, soft tissue artifacts, and differences in biomechanical model. In a MAS, segment-fixed coordinate frames are obtained using the markers placed at anatomical landmarks, whilst in an IMS the segment coordinate frames are obtained using calibration postures and movements. As a result, these segment coordinate frames are not the same. Despite small discrepancies between the two systems, knee and hip angles could be obtained reliably by an IMS in soccer-specific movements performed at a high intensity.

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System Calibration

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Extended abstract

Cadence modulation: pacing steps or strides?

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Submitted: Sep 06 2019

Keywords: Cadence; step length; sensorimotor synchronization; phase shift; phase difference

1 Introduction

For a variety of reasons, like gait rehabilitation in stroke patients [1-3] or injury prevention in athletes [4,5], a change in step frequency might be indicated during walking or running. Auditory pacing is often used to prescribe a particular frequency in cyclic motor tasks, including human locomotion [6-9]. In general, the stronger the cyclic movements are coupled to the pacing signal, the stronger the effect of that signal on the overall movement pattern [3,10].

In the literature, several measures are used to examine how strongly cyclic movements are coupled to the pacing cues. When this coupling is stronger, movements can be synchronized to a range of prescribed frequencies, the variability of the relative timing between cues and movement events is lower [8], and perturbations in the pacing rhythm are corrected faster [3,7,11,12]. Coupling strength varies with different pacing types [7]. In both tapping and walking, for example, coupling was stronger for a cue per tap/step (1:1 ratio) than for a cue for every other tap/step (1:2 ratio) [3,7]. Furthermore, coupling strength varies with pacing frequency, with a stronger coupling for pacing frequencies at or around one's self-selected frequency [8].

The aim of our study was to compare the coupling strength of step-based and stride-based pacing for both walking and running, at pacing frequencies slower than, equal to, and faster than the self-selected step frequency. Based on the literature, we expected stronger coupling in the self-selected step frequency condition than in the other two conditions. In addition, we expected stronger coupling for step-based pacing than stride-based pacing for both walking and running.

2 Methods

Sixteen healthy runners (7 male/9 female; Aged 29±5.8 years; mean±standard deviation) walked and ran on an instrumented treadmill (Dualbelt; Motek, Amsterdam), equipped with two force platforms that measured force vector data. Auditory cues were played by the computer through speakers. Step-based pacing (one cue per step) and stride-based pacing (one cue per stride) were compared in a repeated-measures design. All conditions were completed at three pacing frequencies: the self-selected step frequency multiplied by 0.9 (slow), 1.0 (self), and 1.1 (fast). For each of these 12 conditions, participants completed a synchronization-perturbation task. During the first minute of this task the pacing rhythm was constant. Then, phase perturbations (±60°) occurred every 30 to 40 steps. Participants were instructed to synchronize their footfalls with the cues, and to correct synchronization after perturbations.

Foot strikes were determined from the collected force and center of pressure data. A virtual cue was added to the data from stride-based pacing conditions, allowing for step-based calculations for these conditions as well. Time series of the point-estimate of relative phase ϕ were calculated for all conditions according to:

$$\phi = 360° \cdot \frac{(\text{cue onset} - \text{foot strike})}{\text{interval ipsilateral cues}}. \qquad \text{equation 1 [11]}$$

For the synchronization period, the variability (within subject circular standard deviation) in ϕ was calculated. For each perturbation, the type of response was classified as a typical response (±60° correction), atypical response (±120° or ±300° correction) or invalid response. For the typical responses, the percentage correction per step after perturbation was calculated per condition.

3 Results

There was a main effect of frequency on the variability in ϕ ($F(2,18)=4.24$, $p<0.05$, $\eta^2=0.32$). Variability in ϕ was lower for the self-selected frequency compared to the other two frequencies (Figure 1a). A significant locomotion by pacing interaction ($F(1,9)=5.68$, $p<0.05$, $\eta^2=0.39$) represented a higher variability in ϕ for stride-based pacing than for step-based pacing, but only for running (Figure 1b).

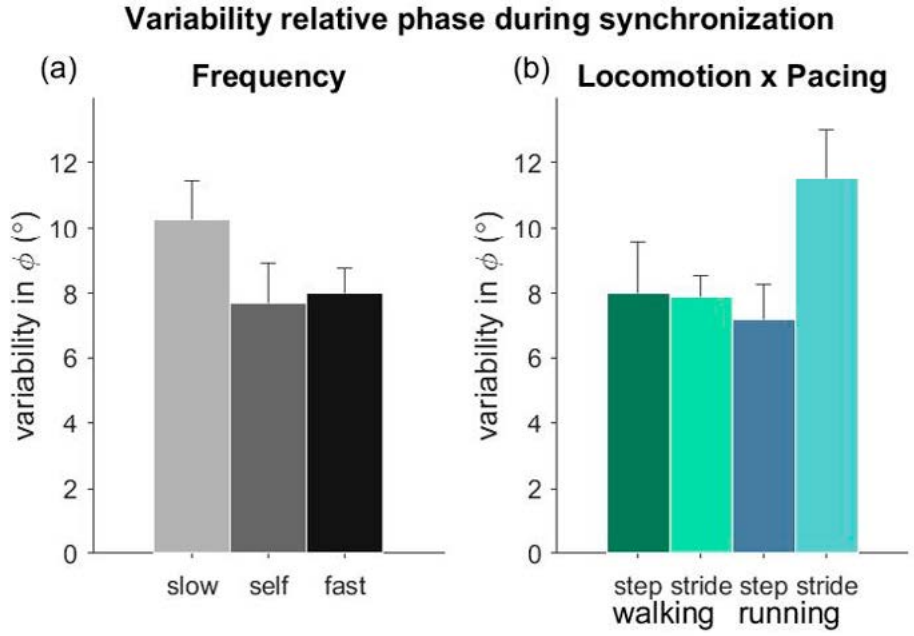

Figure 1 The mean within subject variability of the relative phase during synchronization for the different frequency conditions **(a)** and the different locomotion and pacing types **(b)**. The error bars represent the standard error of the mean.

The various response types were not evenly distributed over the conditions (Figure 2a). There was a large number of invalid responses in the fast and slow frequency conditions in running, mainly due to an inability to synchronize with the cues, which led to a large number of excluded participants in the overall analysis. Therefore, we chose to examine the effects of pacing type and frequency for walking only, and the effects of locomotion and pacing type for the self-selected frequency only. For walking, there were significant main effects of steps ($F(2,24)=187.89$, $p<0.001$, $\eta^2=0.94$) and frequency ($F(2,24)=8.59$, $p<0.01$, $\eta^2=0.42$) on the percentage correction, as well as a frequency by step interaction ($F(38,456)=5.52$, $p<0.001$, $\eta^2=0.32$; Figure 2b; slower initial corrections for slow pacing compared to self-selected and fast pacing). For the self-selected frequency, significant main effects of locomotion ($F(1,14)=31.89$, $p<0.001$, $\eta^2=0.70$), pacing ($F(1,14)=5.80$, $p<0.05$, $\eta^2=0.29$), and steps ($F(19,266)=213.06$, $p<0.001$, $\eta^2=0.94$) on the percentage correction were found, as well as a locomotion by step interaction ($F(19,266)=15.23$, $p<0.001$, $\eta^2=0.52$; Figure 2c)

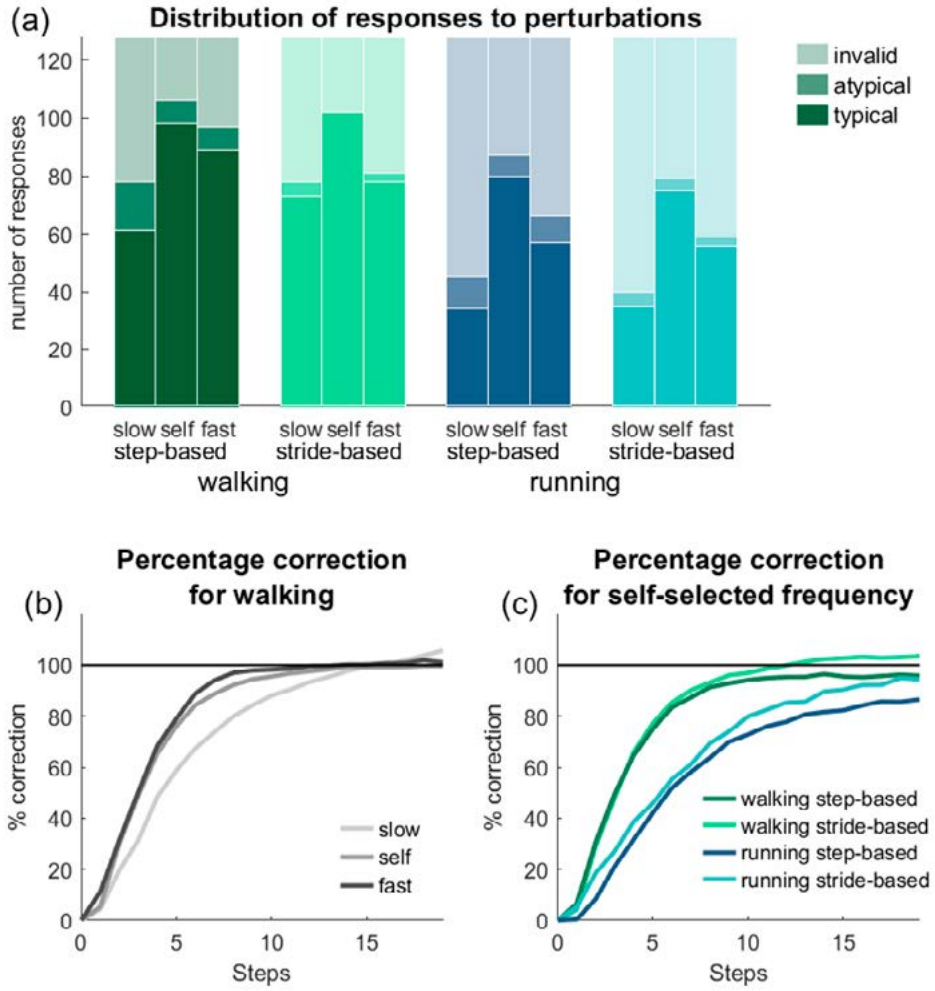

Figure 2 (**a**) Distribution of responses to perturbations. Bottom bars represent typical responses of +60°, middle bars represent atypical responses of ±120°/±300°, and top bars represent invalid responses. (**b**) Percentage correction for the steps after perturbation for the different frequency conditions in walking. (**c**) Percentage correction for the steps after perturbation for the different locomotion and pacing types in the self-selected frequency conditions.

4 Discussion

We expected a stronger coupling for pacing frequencies corresponding to self-selected cadence than for slower or faster frequencies. We found a lower variability in ϕ for the self-selected than for the slower pacing frequency accompanied by a lower proportion of invalid responses to perturbations. Furthermore, corrections after perturbations were faster for the self-selected pacing frequency compared to slow frequency. However, no significant differences were found between the fast frequency and self-selected frequency conditions, suggesting that the coupling was strong enough to increase step frequency.

In line with the expectation of stronger coupling for the step-based compared to the stride-based pacing, we found a significantly higher variability in ϕ with stride-based pacing, but only in running. There was a small main effect of pacing type on the corrections after perturbation, with overall a slightly quicker response for stride-based pacing.

In conclusion, both step-based and stride-based auditory pacing could be used to increase step frequency in walking. In running, although the response to perturbations may be slightly faster with stride-based pacing, step-based pacing seems preferable due to the stronger coupling during synchronization.

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Extended abstract

Smart Sensor Shorts: a novel IMU based method to continuously assess the biomechanical training- and match load in team sports.

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Keywords: Load monitoring; Inertial measurement units; Biomechanical load; Injury prevention; Performance enhancement

1 Introduction

In soccer, muscle strain injuries constitute more than a third of all time loss injuries, with the hamstrings being the most frequently involved [1]. Although multiple prevention programs have been introduced to prevent players from hamstring strain injury [2-4], the number of hamstring strain injuries still rises each year [5, 6]. A possible explanation of these injuries could be the high muscle load around the hip involved during actions in modern game play like sprinting, directional change, jumping and kicking.

Players constantly train hard to improve their physical capacities to withstand the physical demands of the game. The proper dose and variation of training intensity, duration, frequency and type in combination with sufficient recovery lead to adaptation improving fitness and performance [7]. However, an imbalance between load and recovery can lead to prolonged fatigue and maladaptation [8], which increases the risk of sustaining an injury.

Current available systems to monitor load are mainly focussed on monitoring physiological load (e.g. distance covered or running velocity), and do not take biomechanical load into account. IMUs may be a potential method to monitor biomechanical load. Therefore, the main purpose of this study is to present an inertial measurement unit-based sensor set up, combined with results of a 30-meter linear sprint test to provide a proper baseline for consequent measurement of biomechanical load in the field.

2 Method

2.1 Participants

Three amateur soccer players (male, age 22,3 ± 2,5 years, body mass 78,7 ± 5,1 kg, height 186,3 ± 6,4 cm, training experience 17,3 ± 3,8 years) were included in the study. Inclusion

criteria were having over one-year soccer experience and not having a history of musculoskeletal injury in the lower extremity within 6 months before the test. The study has been approved by the ethical committee of the Center for Human Movement Sciences of the University of Groningen (Register number: 201800904) and all subjects provided informed consent.

2.2 Experimental protocol

Inertial measurement units (IMUs) were attached to the pelvis, to thigh and shank bilaterally (Figure 1). For sensor calibration, subjects were asked to flex their hip and knee to a 90° angle in the sagittal plane, followed by extending the hip to a standstill position. Subjects were asked to perform a soccer specific warming-up [4]. Thereafter, subjects performed three 30 meter linear sprints as fast as possible. Between the tests, subjects had sufficient rest. Kinematic data of the fastest linear sprint was used for data analysis.

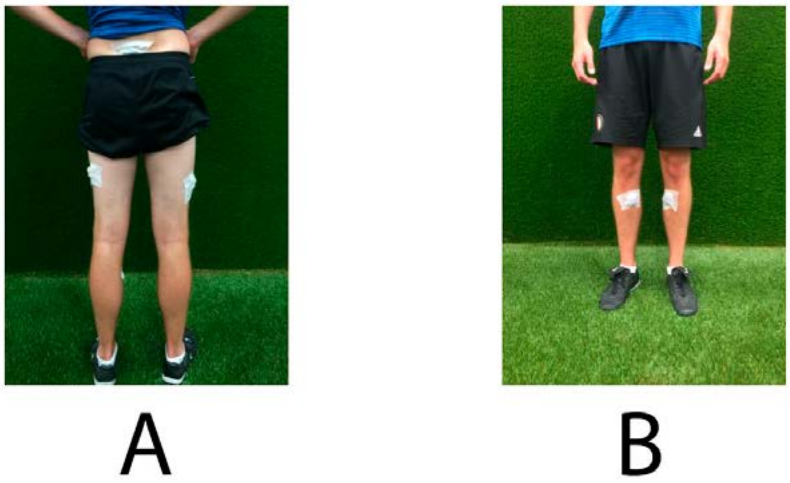

Figure 1. Representation of sensor set-up. (a) Sensor placement on the pelvis, and right and left thigh (b) sensor placement on the right and left shank.

2.3 Data analysis

Data was analysed in Matlab. Orientation of each IMU was obtained by integrating the angular velocity measured by the gyroscopes and optimized through sensor fusion using a Madgwick filter [9]. Hip and knee joint angle, and range of motion on the sagittal plane were calculated, using the orientation of each IMU. The gyroscope signal was used for calculating joint angular velocities and step identification.

3 Results

Hip angles ranged between 80,2° (± 9) maximal flexion and 14,2° (± 8) maximal extension during acceleration, 58,2° (± 11) maximal flexion and 15,1° (± 8) maximal extension during

top speed, and 47,4° (± 5) maximal flexion and 26,7° (± 3) minimal flexion during deceleration. Hip angular velocities ranged between 821,8 °·s^{-1} (± 117) and –665,8 °·s^{-1} (± 67) during acceleration, 652,4 °·s^{-1} (± 115) and -620,0 °·s^{-1} (± 82) during top speed, and 340,7 °·s^{-1} (± 129) and -336,7 °·s^{-1} (± 61) during deceleration.

Furthermore, knee angles ranged between 120,1° (± 6) maximal flexion and 17,1° (± 8) minimal flexion during acceleration, 116,3° (± 10) maximal flexion and 10,9° (± 11) minimal flexion during top speed, and 96,7° (± 8) maximal flexion and 22,8° (± 6) minimal flexion during deceleration. Knee angular velocity varied between 1228,8 °·s^{-1} (± 116) and -1174,5 °·s^{-1} (± 119) during acceleration, between 1133,3 °·s^{-1} (± 203) and -1231,8 °·s^{-1} (± 129) during top speed, and 1060,4 °·s^{-1} (± 159) and -870,7 °·s^{-1} (± 136). Figure 2 illustrates continuous kinematic data of one linear 30-meter sprint test.

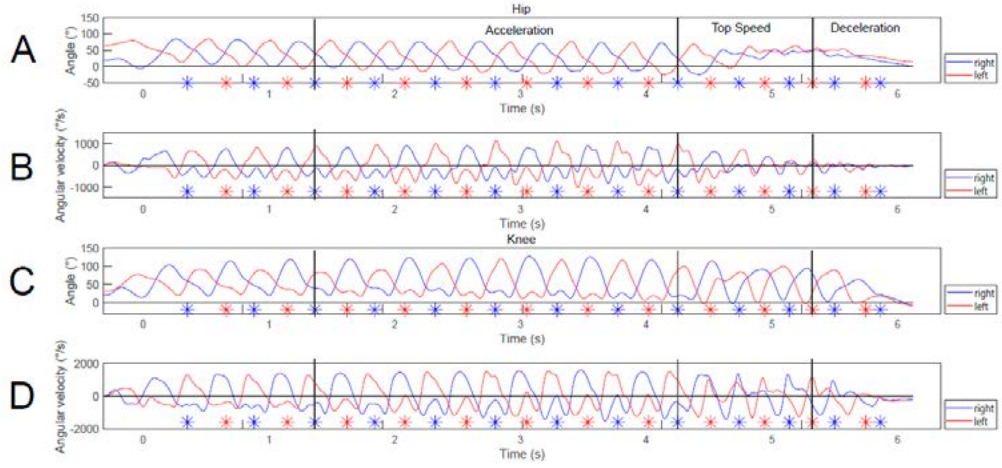

Figure 2. Visualization of sprint kinematics during a 30 meter sprint. An asterix indicates when a step has been detected. (A) Left and right hip flexion and extension angles over time. (B) Left and right hip angular velocities over time. (C) Left and right knee angles over time. (D) Left and right knee angular velocities over time.

4 Discussion and conclusion

The hip and knee joint angles and angular velocities presented in this study concur with previous research examining lower extremity kinematics during sprinting [10-14]. Maximal hip and knee flexion angles were higher during the acceleration phase of the sprint when compared to the top speed phase of sprint, which was also observed in a study examining lower extremity kinematics and hamstring muscle activity [15]. The fact that different kinematics and muscular activity are observed during several sprint phases implies that biomechanical loading changes within in a single sprint, which should be considered when monitoring biomechanical load of a sprint.

The kinematic variables obtained by the sensor setup can be used in a model in order to monitor biomechanical load of the lower extremity in the field. The model enables to estimate

biomechanical loading variables acting on the musculoskeletal system such as muscle length, joint forces or joint moments. Besides biomechanical loads acting on the musculoskeletal system, forces acting on the body as a whole can be estimated as well. Ground reaction forces (GRF) describe the biomechanical loading experienced by the total musculoskeletal system, and can be estimated using Newton's second law of motion (i.e. $F = m \cdot a$). The possibility to monitor these variables during measurements on the field provides new information to optimize performance, or to prevent injuries. However, it should be noted that the relevance of the biomechanical load-response pathway remains to be determined despite new technology enables to estimate biomechanical load in the field [16]. Thus, validation studies are needed to establish the relationship between biomechanical load metrics and adaptive or injury mechanisms.

To conclude, the sensor setup presented in this study will be integrated in the Smart Sensor Short which is currently under development. The Smart Sensor Short is a tool that enables to continuously monitor biomechanical training- and match load. The information provided by the Smart Sensor Shorts can be used by professionals in a daily sports setting to evaluate their training programs and optimize them, aiming to reduce injury and optimize performance.

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Feedback

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Extended abstract

Designing Motor Learning Based Instruction and Feedback for Running Technique Changes

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Keywords: Running technique, feedback, instruction, motor learning

1 Introduction

Running is popular and to a great extent performed individually or in small groups, outside sport clubs [1]. Running is also known to be an activity with high drop-out rates due to motivation loss and high injury risk [2,3]. One of the interventions that affect motivation and injury risk is developing a proper running technique [4]. A challenge in designing instructions and feedback is the implementation of motor learning principles [4].

Several researchers in the human-computer interaction community designed systems that provide feedback to the runner on variables related to running technique. For example, Nylander and colleagues [5] provided visualizations of accelerations in horizontal and vertical directions and audio feedback on cadence with their RunRight system. User experience results showed that the visualizations were easy to understand. Feedback provided by these systems were open to interpretations of the user which helps the user finding their own solutions for improving their running technique. From the motor learning theory [6] and coaching perspective [7], we argue that giving the runner direction in their technique changes is beneficial in finding their optimal solution. The aim for the present paper is therefore to design and test instruction and feedback prototypes that provide this focus to the runner.

2 Feedback Prototype design and tests

Two prototypes were developed applying the autonomy and external focus principles as proposed with the OPTIMAL model [6]. (i) an external focus feedback prototype, and (ii) an autonomy prototype. In each of the experiments the runners used one prototype during running.

2.1 External focus feedback prototype

The external focus feedback prototype focused the attention of the runner outside of the body using visual or auditory feedback. The timing of the visual feedback was real-time, the auditory information was feed-up (instruction beforehand). Seven runners ran a 10-minute screening run to identify the individual preferred cadence. The runners were then divided into two groups, (i) an auditory feed-up group and (ii) visual feedback group. Before and after running the user experience (5-point Likert scale) and self-efficacy (4-point Likert scale using the SRL-SRS questionnaire [8]) was collected.

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2.2 Autonomy prototype

The autonomy prototype was designed to experiment with the principle of autonomy for the runner [9]. We designed four different feed-up strategies using auditory and visual form, and both internal and external focus. For cadence the external focus was directed to a step frequency of 160-170 by hearing or seeing this frequency. Internal focus was directed to a short arm action and elbow angle using the cue 'run with the elbows in 45-degree angles'. For vertical oscillation the external focus was 'keep the head as still as possible' with the cue 'run with your head kept still'. The internal focus was directed to soft feet contact with the ground and quickly picking up the feet, the used cue was 'run with soft contact and short contact time'. The influence on the self-reported motivation of the runners was measured using a custom developed questionnaire using a 5-point Likert scale. 19 runners were divided in two groups, (i) an autonomy group, that chose their preferred feedback form and focus, and (ii) a no-choice group, who were appointed feedback form and focus by the researcher.

3 Results

3.1 External focus feedback prototype

Self-efficacy did not change after running with the prototypes in both groups (Table 1). User experience was higher with the runners that were provided auditory feedback compared with the runners that used the visual feedback. Acute influences on cadence were only measured for 2 runners in each group due to equipment failure.

Table 1. Technique changes and self-efficacy scores for the external focus feedback prototype, all items are based on 4-point scale (1-4); totally disagree, disagree, agree, totally agree. N=7 runners.

Group	Trial	Cadence (spm) n=2	Cadence (%)	Self-efficacy (SD)	User experience (SD)
Visual	1	88,5	100%	3,1 (0,28)	
	2	93	105%	3,0 (0,35)	2,3 (0,28)
Auditory	1	87,5	100%	3,1 (0,23)	
	2	88,5	101%	3,1 (0,24)	2,7 (0,47)

3.2 Autonomy prototype

Small differences were found between the groups for motivation before using the prototype (Table 2). Both groups claimed to be better motivated for running due to the feedback strategy of the group. The No-choice groups motivation change was a little higher compared to the autonomy group.

Table 2. Motivation scores for the autonomy prototype, all items are based on 5-point scale (1-5), N=19 runners.

Group	Feedback strategy	Motivation before (SD)	Motivation change using the prototype (SD)
Autonomy	By choice of the runner	4,3 (0,64)	3,4 (0,92)
No-choice	Assigned by the researcher	4,1 (0,57)	3,6 (0,94)

3.3 Conclusion from the experiments

Based on the results of our experiments we can conclude that minor or trivial acute technique changes, as measured in cadence, occurred during running using the prototypes. Auditory feed-up is preferred over visual feedback as found in the experiment with the visual vs auditory prototype. This finding contradicts with other findings [10]. A possible explanation could be that the visual feedback was presented on the smartphone display

carried during running which was inconvenient to see for the runners. Giving autonomy to the runner seems to improve motivation however, this improvement is a bit lower compared to the motivation improvement as reported by the no-choice group.

4 Future directions and design requirements

Feedback design principles that can be derived from the results in this paper are the type of feedback preferred by runners is auditory feedback which also has its benefits for technique changes as well. However, caution must be taken in acute technique changes for possible injury risks [11]. Visual feedback should be provided with care and should be easy to perceive while running. Wrist-worn LCD or smartwatches show promising developments in this direction [11].

Future experiments will address long-term influences of feedback on running technique. Feedback strategies that enable the runner to choose their preferred way to change their running technique will be the focus of the future design steps that will be taken in our aim to design a user-friendly, wearable, running technique feedback system.

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Design of the study
Coupling strength
Step-based
Stride-based
Walking
Running
Slow
Self-selected
Fast

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Extended abstract

Who is active at Work? Expressing Social Feedback on Physical Activity in the Office Environment

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Submitted: 5-9-2019

Keywords: Social feedback; Physical Activity; Office environment; Design intervention; Office workers;

1 Introduction

Society is facing a noticeable increase of individuals who are living an inactive lifestyle. The office environment is identified as a/the place where a substantial part of this inactive behaviour happens [2, 12]. Several design interventions are developed often focussing on apps and trackers [5]. These platforms could improve the activity pattern of individuals, but are often individually focused, limiting the option of social support in an open office environment. Social support is consistently identified to support the improvement of the physical activity (PA) level of individuals [7,8]. This social support could however be presented in multiple ways (e.g. cooperation, competition [5]). The office environment is diverse, with individuals with different personalities and levels of competitiveness [4]. Social support should therefore target an heterogenous group of individuals. Within this work, we focus on the visualizing social feedback via a tangible design. The tangible design gives the possibility to display physical activity data in an open office environment. The social feedback visualizes the PA-level in a non-ranked way to target an heterogenous audience.

Figure 1. Stimulight: a tangible design visualizing social feedback on PA

2 Method

2.1 Stimulight

Stimulight (Figure 1) was developed to gain an understanding of the effect on social feedback in the office environment. An earlier version of the design was developed for a similar, quantitative focused research [1].

The same three research setups of: individual awareness (IA), social awareness on an individual level (SAIL) and social awareness on a social level (SASS, Figure 2) were used to gain a deeper, qualitative, understanding.

2.2 Participants and Research setup

Stimulight was tested by civil servants working for the City of Eindhoven. In total, 8 where selected (4 male, 4 female) to participate in the study. Participants were instructed about the study purpose and consent was obtained. They received a Fitbit and Stimulight. The intervention interval to visualize the feedback was set at 500 steps every 2-hours. This was based on the Fitbit challenge [3]. Participants were randomly assigned to one of the intervention designs and were divided over 3-test periods (Figure 2).

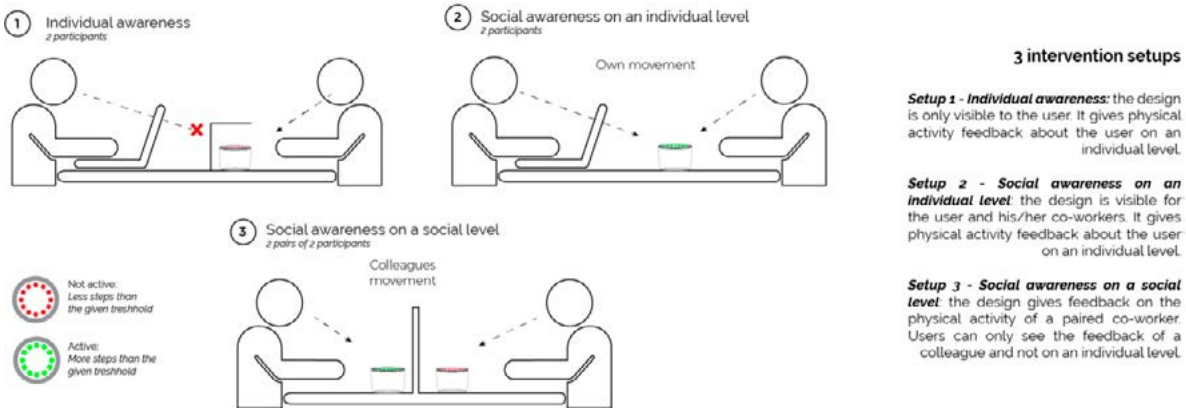

Figure 2. interventions setups to research the effect of social feedback

3 Results

3.1 Social awareness on an individual level

Participants experienced the feedback as a motivational factor to be active, due to the gained awareness, and the possibility to be motivated by colleagues. This did however add pressure/stress due to the open, visual feedback. From an office environment aspect, social feedback was seen as a way to create an overview to see who is active or not, creating an incentive to activate others to be active. A participant did indicate that: "*The primary purpose of being present at the workplace is to work and not to be physically active",* which is seen as a common factor of people not being active throughout their workday [6].

3.2 Social awareness on a social level

The participants experienced, due to the social feedback, a social control/stimulation on the work floor (between participants) where they could compare, control, motivate others and confirm their activity pattern. Participants explained that they discussed the intervention feedback and motivated each other to be active: "*You do have a kind of social control..... Yes, it did lead to interaction".* With regard to the feedback: "*I think it adds something to have an interaction. It triggers you, you say something about it, it has a social aspect, for sure.".*

Participants did however experience a lack of individuals feedback/awareness due to the expressing of only collegial feedback.

3.3 Individual awareness

The individual awareness intervention was not really seen as motivational to become active on a personal level. Participants received the feedback but this did not instigate them in becoming active. They did however express that they compared their feedback with each other: "*of course we have done it individually but, I have secretly been looking at the other person to see what he has."* and *"Yes, we have compared a little bit to see how much we had*". By doing this, participants added a form of social feedback themselves where they are able to compare their activity pattern.

4 Discussion and future work

The goal of this research was to learn how different forms of social feedback could influence the PA-level of individuals in the office environment. Both social interventions (SAIL and SASS) were experienced as more motivational. This is in line with previous research which shows that social factors play an important role in increasing engagement of individuals to become physically active [11]. This social component was not implemented within our individual intervention and could have therefore limited the motivational impact of the intervention.

Although the SAIL intervention was experienced by the participants as motivator, it was at the same time seen as stressful. This could be explained due to the source of the feedback. The feedback of the design was visible for everyone. This includes friends and well-known colleagues, but also less-known people. Individuals are more likely to be active when they are supported by friends or family [13]. Support or feedback from non-familiar people could therefore have led to a more stressful experience.

The intervention of SASS was seen as creating the least amount of awareness on being active. This was indicated by the participants due to the missing individual feedback. Research by Stragier [10] shows that higher levels of engagement due to the combination of both individual and social affordance. Only giving feedback on a social/collegial level could have limited the needs of the user.

4.1 Future and design implications

Social feedback had a motivational effect, created awareness and opened an opportunity to be active in a social, work-related way. A balance should however be found were both individual and social feedback are shown, without creating a negative form of stress. We want to encourage future work to further elaborate on the effect of social feedback on PA within tangible design interventions while establishing an environment where a social overview is created where individuals can motivate each other to improve their activity pattern, throughout their workday.

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Extended abstract

Synchronizing steps in running: pros and cons

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1 Introduction

Synchronizing to rhythmic stimuli (e.g., auditory or visual metronome), either deliberately or unintentionally, can benefit cyclical (e.g. locomotor) behavior in healthy and pathological contexts [1,2]. Such entrainment has also been demonstrated to enhance the efficiency and hence performance of strenuous cyclical movement tasks [3-5] such as running [6,7]. There are also some anecdotal examples of such entrainment benefits in world-class sporting events [see, e.g., 6]. Next to deliberate synchronizing, runners appear to be prone to spontaneously adapting to rhythms that deviate from their own cadence [8]. However, such mismatching rhythms may disturb performance in case people unintentionally entrain to these [3]. Here we therefore briefly outline pros and cons of entrainment in running alongside some preliminary results of a recent experiment at our lab.

2 Synchronizing with convenient rhythms

Extensive theoretical and empirical research from a coupled oscillator perspective [9,10] indicates that stronger coupling enhances the stability of a coordination pattern as well as the stability of each of the rhythmically moving components. For sensorimotor coordination this implies that the stability (and hence energetic economy [11]) of the runner's rhythm could be enhanced by entrainment to external rhythms. In line, results in human locomotion indicate enhanced locomotor coordination [6], lower physical strain on the body [12] and lower oxygen consumption [3,4] associated to such entrainment.

External rhythms can be of any nature: from a beat in music, to flashing lights, to rhythmic movements of someone else. Provided that it can be perceived, any rhythm offers the possibility and incentive of pacing and synchronization of movements [13]. For instance, when the tempo of an auditory rhythm is nicely aligned to the cadence of the runner, such pacing results in a less variable running pattern [6], which is thought to imply higher running efficiency [6,7,11,12]. Given that humans walking side-by-side often unintentionally fall into step with each other [14], even more so when holding hands [15], visual and haptic/physical rhythms can also entrain. For strenuous locomotion, visual entrainment effects are however rather understudied and (thereby) somewhat more disputable [16-18], hence deserving more empirical attention [16]. Also, in this context, the stringency of haptic/physical entrainment provides an exciting endeavor that has recently been taken on [e.g., 19,20].

Now, how could such entrainment effects be employed to the benefit of running performance? One could for instance think of synchronizing steps to an opponent or pacemaker. However, such a strategy would only be feasible if the pacemaker's cadence is similar, or at least sufficiently close to that of the runner [21], which is delineated next.

3 Cons of sensorimotor entrainment

When one oscillator is forced by another one with a differing eigenfrequency this leads to phase-locking, provided that the eigenfrequencies are not too far apart [9]. Accordingly, runners indeed adapt to the tempo of a sensory rhythm when it deviates 1-3% from the runner's natural cadence for a given running speed [8, 21].

Although beyond a certain tempo-difference the phase-locking effect disappears [8,21], some entrainment effects may maintain. That is, the individual component(s) keep their own movement frequency with an intermittent tendency toward synchronizing, which would yield fluctuations around the average component frequency [9]. Accordingly, coupling oscillators of mismatching frequencies entails poorer between-oscillator coordination as well as less stable component rhythms [9,10]. In strenuous tasks other that running it has been shown that entrainment to deviating rhythms indeed disturbed performance [3]. Thus, entraining to such mismatching rhythms slightly in/decreases running cadence [8] and would theoretically be at the expense of the stability and variability of the running pattern (and hence energetic efficiency and performance).

Table 1. Gait parameters (means ± SE) for each auditory condition, and according RM ANOVA results.

Variable	Condition			Statistics	
	CTRL	IN	ANTI	$F(2,26)$	p
Mean step frequency (steps/min)	163.9 ± 2.2	162.8 ± 2.1	165.5 ± 2.4	7.89	< .05
SD of step frequency (steps/min)	6.19 ± 0.36	5.49 ± 0.49	6.55 ± 0.41	3.57	< .05
SD of between-leg phase relation (°)	3.39 ± 0.2	3.04 ± 0.3	3.58 ± 0.2	4.25	< .05

4 Preliminary experimental results

Tests and reports regarding to how such 'less convenient' external rhythms affect running pattern variability and stability are lacking. In a simple lab-experiment we therefore aimed to address this issue. Fifteen experienced distance runners ran on an instrumented treadmill (Motekforce Link, Amsterdam, The Netherlands) at a self-selected endurance speed in three different counterbalanced conditions of 7 min each: a control condition without auditory stimuli (CTRL), a condition in which footfalls (determined using the force plate) instantly triggered a sound of a footfall, hence presented in-phase with the actual footfall (IN), and a condition in which the sound was presented exactly half a step duration later than the registered footfall, yielding each sound to be presented in antiphase with respect to the steps (ANTI). Thus, while the auditory rhythmic sequence was *per definition* of similar tempo as the step cadence, the intermittent antiphase stimuli were expected to induce a more variable running pattern [9,10]. Preliminary analysis indeed showed that compared to CTRL the step variability increased in ANTI, while it decreased for IN (Table 1), which supports the idea that running with an convenient external rhythm may enhance performance, while (unintentional) entrainment to an inconvenient external rhythm may lead to poorer performance.

5 Next steps

While these preliminary averaged outcomes are in line with the entrainment hypothesis, inter-individual differences existed that may be related to each runner's susceptibility to auditory entrainment [13]. Notably though, these entrainment effects were already observed despite the fact that treadmills impose substantial limits on running maneuverability and movement adaptations (e.g., due to size and set constant speed [22,23]). Together with the observation that even Usain Bolt showed surprisingly large fluctuations in step frequency in his 100m world record race [16], we therefore deem it is imperative to run experimental tests 'off the treadmill' (Blikslager & De Poel, in progress).

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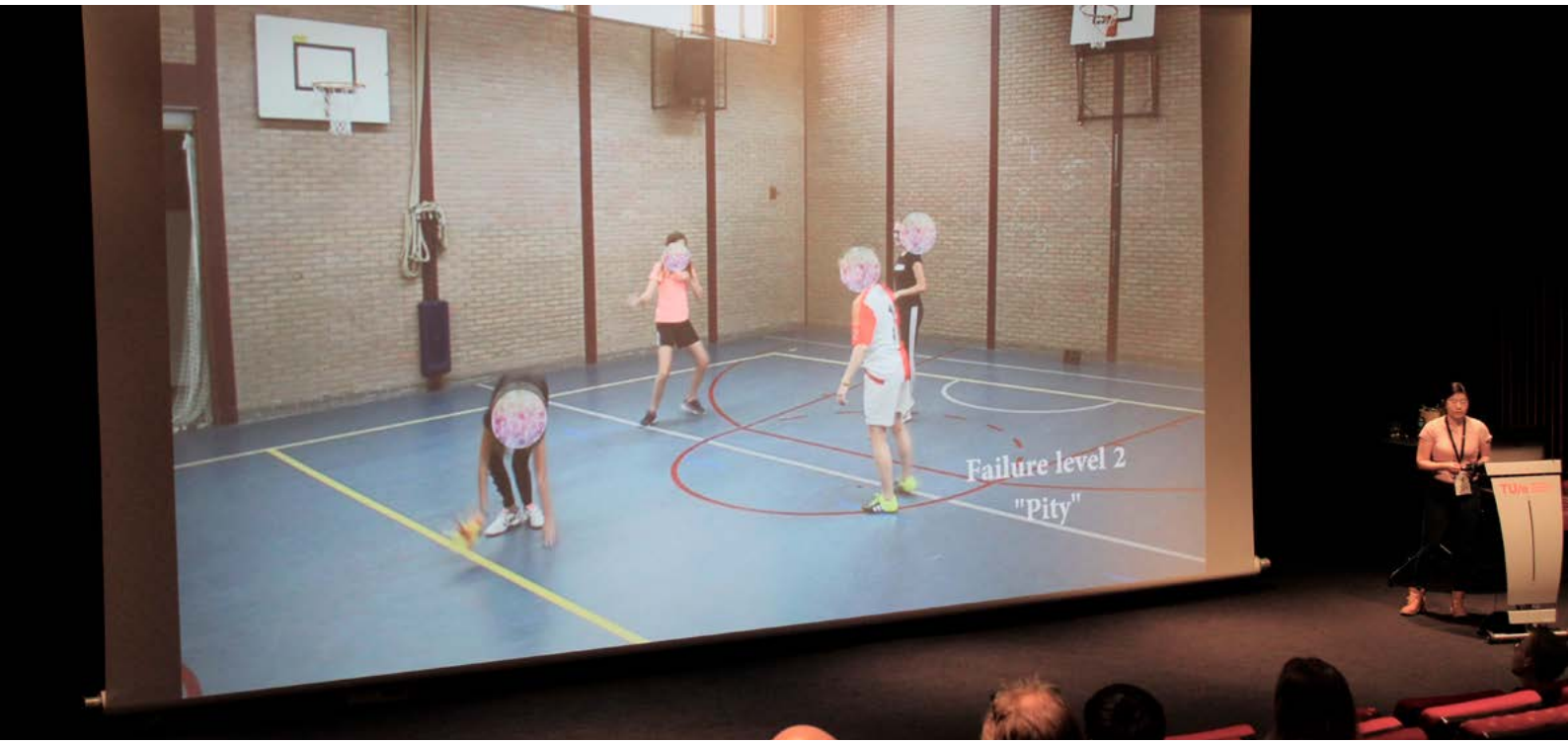
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Extended abstract

Designing Digitally-Augmented Feedback for Physical Education

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Keywords: adolescents; Physical Education; augmented feedback; playfulness; social engagement.

1 Introduction

Active participation in physical activity (PA) is beneficial for teenagers' physical and mental development [1]. Moreover, it can also prevent childhood obesity and cardiovascular diseases [2]. However, extensive studies have shown that most adolescents (12-15 years) tend to drop out from regular PA [3,4], partly due to lack of interests [4].

Physical Education (PE) is an essential setting for adolescents to participate, learn skills [5], and develop interests towards PA [6]. Previous studies have suggested fun, enjoyment [7] and social relationship [8] as the primary motivational factors for teenagers' PA participation [9,10]. In PE, playfulness and social interaction are also seen as meaningful experiences [11] and thus become educational goals that go beyond teaching students' motor skills [12]. Thus, our research investigates the design of playful and social experiences in PE context to enhance the motivation of adolescents to be physically active.

In the field of human-computer interaction (HCI), many researchers have explored designing digitally augmented feedback (DAF) to promote adolescents' PA playfully and socially. For instance, Hitron et al. [13] developed tangible Scratch Nodes which provides a pair of players real-time LED light feedback during outdoor play. Delden et al. [14] augmented several virtual effects on a physical play space in the traditional group tag game. These researches have shown that using DAF could stimulate multisensory experiences and improving the performance of players. However, to our knowledge, few studies have explored the design approach and evaluated the effects of DAF on adolescents' PA in PE context.

In our research, we follow the approach of research-through-design [15] where the theoretical analyses, design practices, and evaluations are performed iteratively. Our research questions are: 1) How to design DAF to enrich and enhance adolescents' playful and social experiences in PE context? 2) To what extent could the playful and social experiences from DAF facilitate PE?

2 Previous Work and Findings

2.1 Explore the Effects of Audio-augmented Feedback

In our first explorative study, we designed and evaluated *Shuttlezap* [16,17], a cooperative tangible play object that provides real-time playful audio feedback based on user's performance and behaviors (see Figure 1). By following the research through design approach, the design of *Shuttlezap* was iterated with behavior pattern observation, video-based mock-up, and expert interviews. The final design was evaluated in a within-subject field study with 20 teenagers (Heerbeeck College, Best, the Netherlands) to investigate the effects of augmented audio feedback. Results showed the playful audio feedback could increase playfulness in terms of perceived *relaxation* and *expression*. We also summarized qualitative findings such as teenagers enjoying playful audio feedback because it is enjoyable and immersive; interactive and explorative. They felt more socially engaged due to it breaking the silence and providing a joyful atmosphere; stimulating interactions and promoting team climate. Their perceived competence is enhanced for it motivating active participation and competitiveness, providing guidance and feedback.

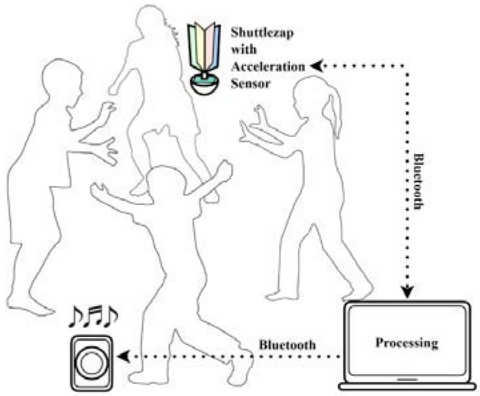

Figure 1. System structure of *Shuttlezap* [16].

2.2 Identify a Design Approach of DAF for Teenagers' PA

In the first explorative study, we saw the potential of audio-augmented feedback in enhancing teenagers' motivation for PA. To further explore the design approaches about DAF for teenagers' PA, we conducted a systematic literature review [18], which analyzed 25 studies about the design and evaluation of technology-supported interventions for promoting adolescents' PA. This review 1) illustrates a design diagram with four design phases to give an overview of the design knowledge through the process. 2) provides a theoretical framework with seven design requirements (see Figure 2) to inform future designs in the field. 3) makes recommendations that can support design decision making for future design research in the HCI domain.

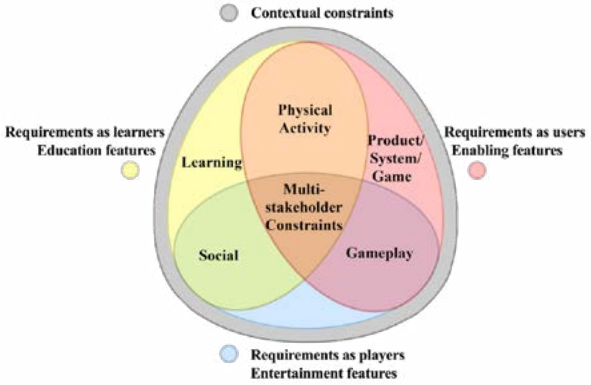

Figure 2. Framework of design requirements from adolescents' triple roles [18].

3 Current Status and Future Work

3.1 Understanding Users' Experiences and Identify the Design Opportunities for DAF

The framework from our review study suggests investigating design requirements from multiple perspectives and in a specific context. Therefore currently, we are carrying out one-on-one semi-structured interviews with 16 adolescents and 4 PE teachers (Heerbeeck College, Best, the Netherlands) in their real context of PE class. This user-context study is focused on 1) gaining a better understanding of adolescents' experiences, special needs, and PE teachers' requirements on giving and receiving feedback in PE context. 2) investigating users' acceptance of PA related technology. 3) identifying design opportunities and recommendations on introducing DAF into PE. Two coders are analyzing the qualitative data through a thematic analysis approach [19], and the results will be published later.

3.2 Future Work

In the future, we plan to organize three co-design workshops to generate, optimize, and refine a DAF design concept which focuses on the feedback of PA related physiology data in a PE context. The first workshop

focuses on eliciting adolescents' playful and social requirements on DAF and creating design concepts. In the second workshop, the designers will discuss the generated concepts with PE teachers and PE experts to position their educational requirements. The last workshop will focus on synthesizing and balancing stakeholders' requirements based on the previous requirements framework (see Figure 2). Designers from multidiscipline will be invited, such as backgrounds in child development, education, vitality, and data visualization.

The final concept from these co-design workshops will be developed and evaluated in two field studies. The first comparative study aims to examine the short-term effects of DAF on users' playful and social experiences. Moreover, the second longitudinal evaluation aims to investigate the long-term effect of DAF on users' motivation and engagement with PA.

4 Conclusions

This design research explores the design of DAF for motivating adolescents' PA participation in PE context through enriched and enhanced playful and social experiences. In the literature review, we investigated the design approach for DAF in teenagers' PA and provided theoretical knowledge on the design practice. Then we contextually interviewed adolescents, PE teachers, and PE experts to clarify design requirements and conducted three co-design workshops to generate the design concepts on the feedback of PA related physiology data. In future research, the co-created design concept will be developed and evaluated in the in-situ field study to investigate the short-term and long-term effects of DAF on user experiences and engagement with PE.

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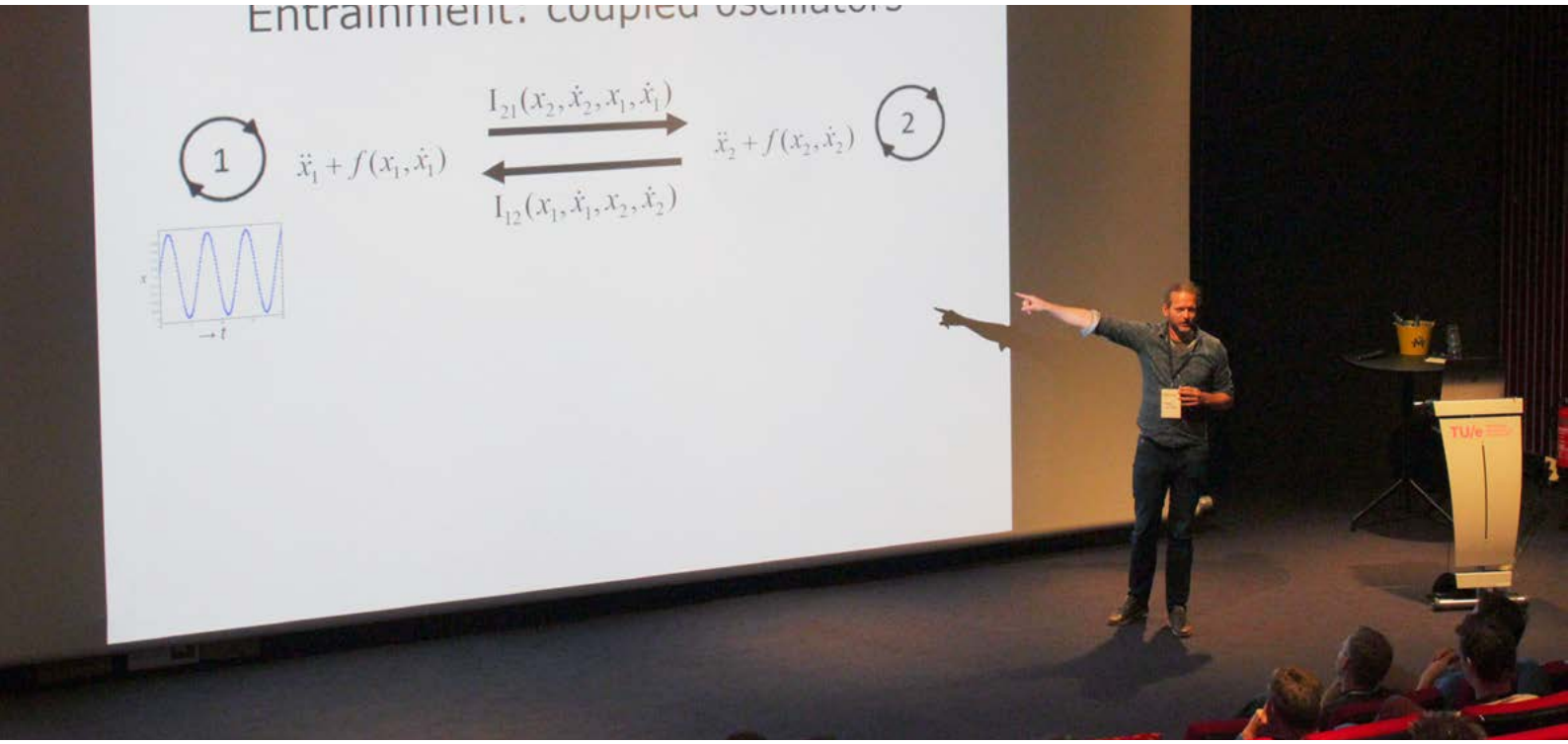
Study
In total, 49 participants (21 females, 28 males between 21 to 55 years old) were recruited to evaluate the two interfaces. 37 (75,5%) of the participants had previous running experience and had used any fitness or running-related app, while the other 12 (24,5%) participants had not had any previous experience with running, and with any running or a fitness-related mobile app.
Heuristics evaluation
Visibility,
Consistency,
Aesthetics
Simplicity
Reason(s) to like and dislike the interfaces where formulated


Entrainment: coupled oscillators
1
$\ddot{x}_1 + f(x_1, \dot{x}_1)$
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$I_{12}(x_1, \dot{x}_1, x_2, \dot{x}_2)$
$\ddot{x}_2 + f(x_2, \dot{x}_2)$
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Extended abstract

Perception of Vibrotactile Feedback in Cycling: Development of an Indoor Training Bike System for Correcting the Aerodynamic Position

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Submitted: 9/9/2019

Keywords: Vibrotactile feedback; Indoor training system; Aerodynamics; Cycling; Frontal area

1 Introduction

To achieve excellent cycling performances, an optimal aerodynamic and biomechanical position is required [1, 2]. However, it is difficult to maintain the most efficient position during physical effort, especially when fatigue increases. This study investigates the opportunities to use vibrotactile feedback as an indicator of the optimal cycling position [3]. Therefore, the aim of this study was 1) to investigate the perception of vibrotactile signals during different levels of physical exercise on the thighs and spine and 2) to develop an indoor training system to guide cyclists to their most efficient and aerodynamic posture.

2 Perception of vibrotactile cues during cycling

2.1 Method

Nine well-trained amateur cyclists participated in the experiment, which started with a systematic step test to determine the maximal power. During the experiments, vibrating elements were attached at three locations on the thighs and three locations on the spine. The vibrating signals were activated individually or in combinations in random order when the subjects were cycling at 0, 50, 70 or 90% of their maximal effort. Subjects had to indicate the location of the perceived signal on a touchscreen. The percentages of right recognition as well as the reaction time were calculated for both the thighs and spine for the four levels of physical exercise.

2.2 Results

Table 1 shows the differences in the percentage of correct answers and reaction times between the different levels of physical effort and between the thighs and spine. For both the thighs and the spine, the number of correct answers is similar for physical exercise at 50, 70 and 90% of the maximal effort compared to stationary position ($p > 0.1$). Furthermore, there is a decrease in reaction time at 70 and 90% of the maximal effort compared to 0 and 50% ($p < 0.001$). There is a higher perception accuracy (spine 59.4%, thighs 53.0%) and quicker reaction time (spine 889 ± 537 ms, thighs 1342 ± 1248 ms) for the spine compared to the thighs ($p < 0.01$).

Table 1. Overview of the percentages of correct answers and average reaction times for the four levels of physical effort for both the thighs and the spine.

	Thighs		Spine	
Exercise (%)	**Correct answers (%)**	**Reaction time (ms)**	**Correct answers (%)**	**Reaction time (ms)**
0	56.7	1622 ± 158	59.9	1076 ± 590
50	48.3	1529 ± 91	58.5	998 ± 575
70	55.2	1124 ± 56	59.2	806 ± 478
90	51.0	983 ± 40	58.5	691 ± 406

2.3 Discussion

The results show that vibrotactile cues are well perceived during all levels of physical effort for both the thighs and the spine. However, to guide cyclists to the most aerodynamic position, vibrotactile feedback on the spine is preferred due to a higher perception of the signals. The decrease in reaction time for 70 and 90% levels of physical effort proves the opportunities of vibrotactile feedback in cycling and can be explained by the increase of adrenaline at higher intensities [4].

3 Development indoor aerodynamic training bike system

3.1 Test set up

Using previous outcomes, an indoor training bike system to provide vibrotactile feedback on the aerodynamic position during cycling is developed. Figure 1 shows the setup, consisting of a vibration motor attached to the processus spinosus C7 [5] which can be activated wirelessly (Figure 1a) to provide feedback on the optimal position (Figure 1b). The most optimal aerodynamic position is determined and captured using the frontal area calculation with a camera. Furthermore, a certain bandwidth above the reference position is added to allow a margin of error. When participants exceed this margin, vibrotactile feedback is applied to remind subjects for their optimal position. The aim is to provide accurate and comfortable corrections for wrong positions, without annoying subjects by continuous correcting their posture.

3.2 Protocol

To optimize the indoor training bike system, a study is initiated 1) to investigate the effectiveness of vibrotactile feedback in training the aerodynamic position and 2) to define an optimal margin above the aerodynamic reference position wherein no feedback is provided.

Therefore, the most aerodynamic position is determined for each participant individually using the frontal area calculation, while subjects are wearing a cycling suit and helmet. This position is captured as the reference position during the protocol, which consists of periods where the subjects must maintain their reference posture at 70 and 80% of their maximal heart rate. In between the reference periods, they are asked to alter their positions two times: 1) sitting upright and 2) come out of the saddle. Subsequently, they should recapture their ideal position using three different feedback conditions in random order: 1) without vibrotactile feedback, 2) with vibrotactile feedback with a margin of 1,5% and 3) with vibrotactile feedback with a margin of 3%. Afterwards, the difference in attaining the reference position between the three conditions is compared as how quick, accurate and long subjects attain the optimal position. This knowledge is used to optimize the training bike system to guide cyclists to their most efficient and aerodynamic position.

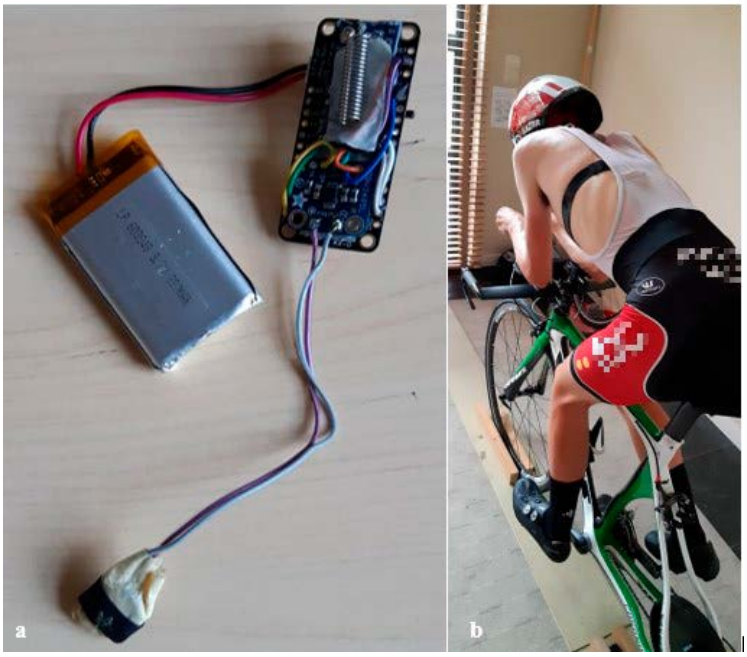

Figure 1. The indoor training system consisting of (**a**) the vibrating motor with wireless module and battery; (**b**) the bike and cyclist with vibration motor attached to C7.

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- Recreational running popular activity among unorganized individuals
- Technique, feedback and know-how missing

- 24/7 tracking devices and activity data
- Data-heavy, “more is better”* or post-event

Fig 1. State of the art consumer tracking device: Garmin Fenix 6X

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Extended abstract

Haptic Feedback in Running: Can we use muscle stimulation for information transfer?

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Submitted: 11/09/2019

Keywords: Haptic feedback; muscle stimulation; information transfer; running; gait analysis.

1 Abstract

A new haptic feedback mechanism is explored for personalized data interaction on the body. Our goal is to use electrical muscle stimulation under the level of full contraction to transfer basic information about running metrics. In this research, it was concluded that (i.) muscle stimulation under the level of contraction can be noticed in the form of a vibrating/beating type of feedback on the skin, (ii.) feedback is noticeable while running and (iii.) it does not negatively impact running performance or comfort. his is on-going research and future work is already in progress.

2 Introduction

The notion to regularly exercise to promote healthy aging has spread among society. Recreational running has become a popular activity for the unorganized and individual practitioners because of the low threshold to enter the sport [1, 2]. On another side, the technological progress developed in such rapid pace where consumers have access to more and more tools for personal data tracking, such as sports trackers, smartwatches and smartphone applications [3, 4]. As a result, the recreational runner has easier access to (semi) professional sport and coaching equipment and data [5]. However, the current user interface and data visualization of these tools are data-heavy and incomprehensible for the average runner.

In this extended abstract, we look at new methods for personalized data interaction. This work introduces a new haptic feedback mechanism to transfer information using muscle stimulation. Our goal is to create tangible feedback close to the body about personal running metrics. This direct, on-the-body interaction is used to give coaching and injury prevention while running.

2.1 Electrical muscle stimulation as feedback

Electrical muscle stimulation (EMS) can be used as a feedback mechanism [6]. Lopes et al. [7, 8] are forcefully activating the muscle to create awareness around everyday interactions. In this work, we are looking to provide tangible feedback using EMS under the level of full contraction. We provide small impulses on the skin to cause vibration around the electrode for basic information transfer.

2.2 Data visualization in sport data

In spite of many tools to actively monitor personal health, the consumer data analyzations and data visualizations are designed for and around professionals. The goal is often performance-related and associated with “More is better" [9] methodology and this is not suitable for recreational use. A more personalized

approach is needed to address the recreational sector. We look at personal coaching using EMS based on gait analysis of personal running data.

3 Methods

In the academic fields, there is no published literature about muscle stimulation under full contraction. In this research, we defined the basic requirement and setup procedure to apply muscle stimulation while in motion.

3.1 Device hardware and electrode placement

The hardware in this research is a CE approved TENS muscle stimulation device and CE approved electrodes. The TENS muscle stimulation device is modified for wireless control. The output of the device is a biphasic wave with a frequency between 15 and 60 Hz and a variable amplitude between 0 and 76 volt. The device used to track running metrics and gait analysis is the Arion running wearable [10].

Two pair of two electrodes are placed on each leg in the area around the outer side of the shins. A pressure sock is fitted around the electrodes to prevent the electrodes from falling off while running. This muscle area does not impact running and is suitable for running feedback based on gait analysis.

3.2 Experiment setup

The experiment is designed to explore the basics of muscle stimulation under full contraction. In this work the focus is to validate if muscle stimulation can be used as a feedback mechanism (i.) under the level of full contraction, (ii.) while running and (iii.) without impact on running comfort. All experiments are conducted on a treadmill in a controlled environment. Chosen participants (n=5) had no prior experience with muscle stimulation.

The experiment is divided into three parts, (i.) calibration and warming up, (ii.) EMS perception, and (iii.) feedback while running. For each participant, the EMS intensity is calibrated twice for each leg. Before warming up in passive state, and directly after warming up in active state. During the experiment, data about running metrics were collected using Arion wearables.

4 Results

Table 1 shows the EMS calibration settings for each participant, measured in volt. Muscles in active state require less EMS intensity to reach similar stimulation levels. EMS intensity varies per participant and main variables are muscle size, body type, and skin sensitivity.

Table 1. EMS calibration for passive state, active state and final intensity in volt. EMS feedback perception, out of 20. Final adjustment in volt.

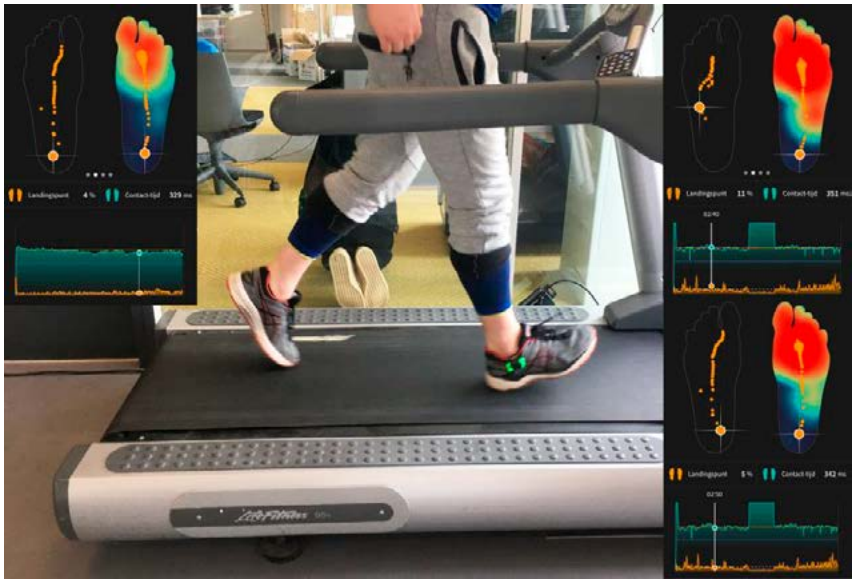
Participant	Passive (L/R)	Active (L/R)	Final (L/R)	Perception	Adjustment
P1	33/30	30/30	30/30	95%	-
P2	27/24	24/24	27/24	100%	+3L
P3	21/21	21/21	24/24	90%	+3L/3R
P4	27/27	18/21	24/21	95%	+6L
P5	30/27	27/27	30/30	95%	+3L/3R

EMS intensity was calibrated manually, to the level where a vibrating/(heart) beat feedback was perceived. In between experiments, adjustments were made to EMS intensity if needed. According to the participants, the

feedback is not considered as obtrusive nor uncomfortable. It does provide a new type of sensation around the skin but does not have a direct impact on running performance.

In the last part of the experiment direct feedback was given to the participant based on live running data. Haptic feedback was applied when foot strike deviates from measured running metrics, shown in figure 1. Principles are noted, but bigger sample size is needed to draw a final conclusion.

Figure 1. Foot strike: Calibrated base line (top left), Deviation (top right), Own correction (bottom right). Data from Arion Wearable running application.



5 Conclusion

In this work, we introduced haptic feedback using muscle stimulation under full contraction. The purpose of this research is to explore the possibilities and applicability of muscle stimulation in sport and data transfer. From this research, it is concluded that: (i.) muscle stimulation under the level of contraction can be noticed in the form of a vibrating/beating type of feedback on the skin, (ii.) feedback is noticeable while running (iii.) and it does not negatively impact running performance or comfort.

6 Future work

With the conclusion of the basic principles of haptic feedback using muscle stimulation, we want to continue this research and address future work. (i.) Variable EMS intensity and smart calibration process. We already concluded that haptic EMS feedback has many variables and therefore require a more advanced setup procedure (with A.I.?) (ii.) Research the long-term effects of haptic EMS feedback. The effect of EMS on body performance is measured based on short experiments. What effects does it have for people actively using it for a longer period of time (i.e. half a marathon run), runner's high [11]? (iii.) Redesign EMS, electrodes, and integration of tracking hardware/software.

7 Acknowledgement

We would like to thank Atogear for giving us the possibility to actively measure personalized running metrics in a well visualized and clear context. We hope to collaborate together for future research and design new possibilities for personalized running feedback.

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Extended abstract

Towards translating the effect of music into motor using deep learning

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Keywords: sonification; deep learning; gait analysis; adaptive music; platform

1 Introduction to music, emotion and human motion

For centuries music composers have indicated 120 beats per minute (BPM) as the performance tempo for their marching music compositions. Recent studies [1] confirm that the preferred step frequency for walking is indeed 2Hz (= 120 per minute). The study also shows that runners prefer a step frequency of ~3Hz while listening to music with a tempo of a little less than 3Hz (2.6-2.9Hz or 156BPM to 174BPM). Furthermore, during running brainwaves (EEG Delta waves) of 3Hz were registered.

The relationship between motion and musical rhythm relies on the close connection between their neurological networks, suggesting that musical rhythm might have evolved from rhythmic movement [2]. Moreover, musical rhythm evokes movement because it activates areas in the brainstem and areas of the cerebral cortex [3] which send out signals that make arms and legs move. Next to the relationship between motor and musical rhythm, other neurological studies describe the relationship between music and emotion, revealing the different neurological networks that are activated as a result of an emotional state [4].

Studies applying Russel's [5] two-dimensional Valence-Arousal model for parametric emotion description show how musical composition elements relate to emotion perception [6]. Other studies [7] suggest how emotion can be regarded as one of several subcomponents of musical expression. This means that music holds both a relationship with motor through its rhythmic (tempo) characteristics and a relationship with (perceived) emotion which can be extended through musical expression from music to emotion into movement.

Artificial neural networks can be used to detect emotion from gait [8]. This study also shows that music can act as an agent to influence gait. While the impact of specific musical composition elements may be highly personal (every person has their own preferred running playlist), we hypothesize that using deep learning, it becomes possible to steer individual running technique into a controlled direction by exposing the runner to music with the appropriate musical parameters. To test our hypothesis, we designed a versatile sensing and sonification platform described in Section 2. We describe our experimental approach in Section 3.

2 Real-time sensor, analysis, and sonification platform

We designed a platform that works both in a field and lab setting and is able to provide real-time audio feedback based on (machine learned) sensor data analysis. At the same time, the platform is designed as an experimentation sandbox and should be flexible in its use of sensors, feedback and analysis. Figure 1a depicts an overview of the platform.

2.1 Platform

At the core of the sonification platform are a smartphone (iPhone) and a web server. The mobile device runs a native app that acts as a hub for all sensor data and provides audio feedback through connected headphones. All supported external sensors use the BlueTooth Low Energy (BLE) protocol to connect directly to the iPhone that subsequently transfers the data over WebSockets to a server. To provide flexibility in experiments, the iPhone app contains a view that exposes web-based applications, allowing for rapid prototyping without rebuilding and

deploying the main iPhone app. Due to the limited resources of smartphones, the server performs most sensor processing. It comprises of several independent modules in Docker containers with at its core the WebSockets server that handles all communications, making it easily extendable.

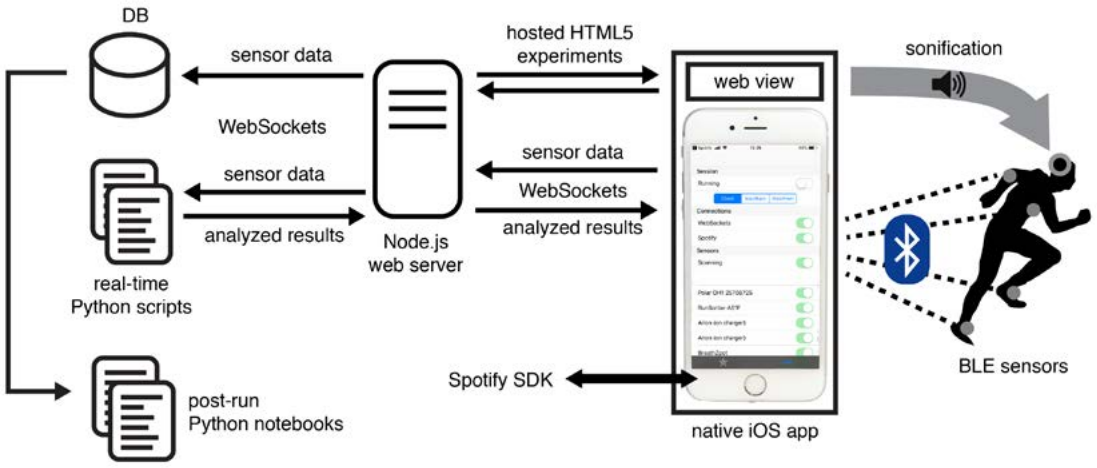

Figure 1. Diagram of the developed sensor, analysis, and sonification platform.

2.2 Sensors

The supported sensors are a combination of the IMU data of the iPhone with a sampling rate of 100Hz, and several smart sensors. These are: heart rate sensors (HR GATT protocol), speed and cadence (RSC GATT protocol), RunScribe Plus foot pods for per-stride impact, braking, contact time, and more, BreathZpot for ribcage volume, and Arion insoles. A proper 4G connection can transmit all sensor data effortlessly.

2.3 Analysis

On the server, Python scripts buffer and process the data in real time to compute for instance foot strike timings, cadence and the outcome of a Human Activity Recognition (HAR) model from accelerometer data. The analyzed results are sent back to the smartphone. All data is stored in MongoDB and as csv-files so that post-run data analysis is also possible.

2.4 Sonification

We distinguish two forms of personalized audio feedback. First, audio can follow the runner by direct sonification of the sensor data on the mobile device, e.g. engineered step sounds for every foot strike. Second, audio can lead the runner by playing (engineered) music based on server-side data analysis.

The iPhone app also connects to the Spotify music streaming app to store current song information and control programmatically the music being played. In addition, Spotify specifies a range of musical parameters (including valence and arousal) of the music it hosts, allowing analysis of a runner's response to music using their personal playlist.

3 Translating music to motor and running quality

We propose to treat the interaction between music and running technique as a translation problem, tackling it with (deep) machine learning. First, a gallery of gait patterns is extracted for each runner from either the accelerometer data as Angle Enhanced Gait Dynamic Images [9], or from the RunScribe Plus stride data. Second, a deep Convolutional Neural Network (CNN) is trained for feature extraction to detect the runner from the gallery, similar to [10]. When exited, the last hidden layer of the CNN now contains a vector representing the features of the input. Third, a Self-Organizing Map (SOM) can be created based on the feature space, as in [8]. Individual runs can be plotted on this map.

Changes in running technique during exposure to music shows up as shifts on the map. Consequently, a relation can be learned between an individual runner and certain musical parameters, and this relation can be exploited to steer the runner in (certain) controlled directions. In the future, experts can label proper running technique and relate this to the same abstract map. With this data-centric approach we develop a system that may steer recreational runners subconsciously towards better running technique with personalized musical feedback.

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Extended abstract

Exploring the value of user-generated app data to design and improve urban running environments

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Keywords: Big Data; User-Generated Data; Physical Activity; Data Visualization; Healthy Environments

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Sedentary behavior, physical inactivity and the concomitant health concerns have made increasing physical activity one of the grand societal challenges in most of the western world [1, 2]. Promoting healthy and active lifestyles is therefore a contemporary topic in both government practice as across multiple disciplines in research (e.g. in the fields of sports studies, urban design, geography, sociology and psychology) [3].

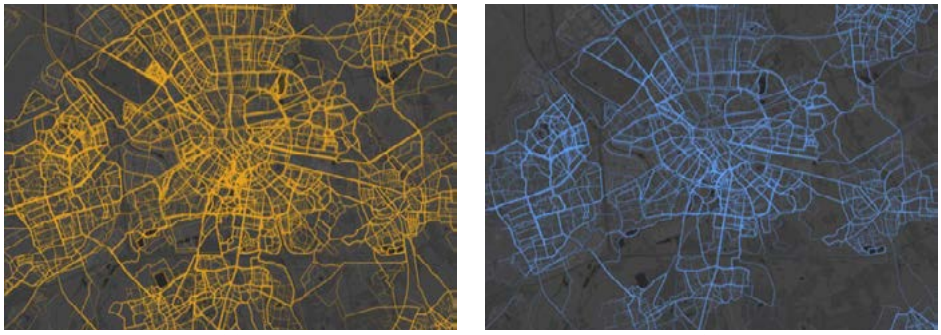
There is ample evidence that for people, physical activity is influenced by individual, social and environmental factors [4–7]. In this study, we focus on the environmental influence and how this can contribute to a healthier and more active society. Focusing on convenience, transport and 'practical' matters, larger cities and metropoles have not necessarily developed with this in mind [3], even though a pleasant, 'healthy' environment stimulates the health, happiness and welfare of the people using it. Since the design and layout of urban areas have the potential to contribute to a more active and therefore improved lifestyle [7], local and national governments can provide focus on health values through their urban planning. We write this paper from a perspective of sports and urban planning and reflect on the value that large-scale GPS running datasets can have in this field.

In Europe, running is by far the most practiced sport [8–10]. Where, how and why people run is notably influenced by urban layouts [7, 11]. In this paper we aim to create an insight in the extents of this influence, using GPS trail data collected from the *Start2Run* [12] (Belgium) and *Hardlopen met Evy* [13] (Netherlands) running apps from Energy Lab. These apps together have collected data of almost 2.1 million runs, ran by approximately 230.000 users between 2012 and 2016. The apps intend to motivate (novice) runners to run by providing training schedules and feedback and offer them insight into their running patterns. Next to full GPS trails of each run, the dataset contained accompanying metadata for each run, including a run- and user-id, timestamp, the distance, duration, average speed and effective time (running time minus stopping time) of the run and a training-id if a specific training program of the app was followed.

In this study, we explored how this type of user-generated data could help to define what makes an ideal running environment and how this could contribute to creating public spaces for a better running climate [14]. We used a mixed-data source approach to collect data for this research. We first used the large-scale dataset of GPS trails to find running *'hotspots'*, and *'coldspots'*. To do this, we used interactive data visualizations as a tool to quickly explore and recognize possibly interesting locations patterns for research. We created maps showing the running locations, first on a large scale, showing general spread in a large area with only the starting point of each run. These maps showed several hotspots, that coincided perfectly with the most populated areas; the largest cities in the Netherlands and Belgium. When zooming in on these cities, the full GPS trails were added, showing exact running locations. This way we could quickly locate and evaluate different places in different cities. The hotspots and coldspots on these maps showed the exact locations that are preferred or avoided by runners. This showed that in general most hotspots coincide with green or water (parks in urban areas).

Subsequently, we computed extra attributes to enrich the running data, including derivatives of the timestamp (time of the day, day of the week and month of the run), but also whether the run took place during the day or at nighttime (merged with sunrise and sunset times), in what kind of weather (merged with meteorological data) or in what type of neighborhood (indicated by real estate value in area of the run).

When visualizing the GPS trails while coloring or hiding all runs with specific characteristics, different patterns emerge for different times or different circumstances. By comparing these maps, we see that preferred running routes can differ notably from one map to the next, indicating that running patterns change over time or with circumstances. A clear example can be seen in the daylight and nighttime maps (Figure 1), some popular spots during the day are completely avoided after dark. Visiting some of these spots showed that the presence or absence of streetlights is probably an important factor in these changes, together with places being more or less remote or inhabited. Another example is shown when comparing the rain runs and dry runs. Not only do we see a noticeable decrease in runs during rain in general, we also again see differences in where the most popular running spots are. In the Hague, for example, the coastline is a much-used running track when it is dry, but hardly used when it rains. From analysis and comparisons of these maps we can not only derive strong indications of which environmental factors appeal to runners, we can also see the influence of changing circumstances on running behavior and how this varies over time. This provide new and valuable insights in running patterns and behavior.



(**a**) (**b**)

Figure 1. Visualization of GPS running trails in Eindhoven of runs: (**a**) during daylight hours; and (**b**) after nightfall.

With these findings we show that this previously unavailable user-generated data can give clear insight into how current urban spaces are used and in how the actual users respond to the urban areas they inhabit. These we can use to understand better which environmental qualities contribute to an appealing running climate so that we can create healthy and active urban spaces that accommodate, encourage and attract urban runners.

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Extended abstract

Psycho-physical Implications of On-Skin Computing Interfaces for Sports and Physical Activity

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1 Introduction

1.1 Human Body and Wearable Technology

Nowadays, computing devices are no longer used exclusively as extensions of the human body, but as part of the body itself [1, 2,10]. As the integration of computing devices into the human body emerges and matures as an important and appealing field within the HCI community [1, 2, 4, 5, 9], Wearable Computing explores opportunities of merging computational and sensory devices into the body in a way that re-shapes the relationship between human and computer [2]. A growing interest within this field explores the human skin and its properties as a substrate for wearable computing. The explorations and advances on this area range from creating skin-like electronics that act as removable tattoos for health monitoring [2, 3] to biosensors inject-ed on the skin to measure different body internal composition [4].

This paper discusses the potential association of OSI with higher bodily self-consciousness, to gain insights into the implications of OSI for HCI. We believe this will allow us to start defining how to design meaningful bodily interfaces taking into account their psycho-physical qualities as a core factor within the design process.

On-stratum Interfaces (OSI): The Human Skin as Interactive Substrate. As the outer-most layer of our body, the human skin offers possibilities to develop novel interactive systems and modalities never explored before [2, 5, 6]. Due to the intrinsic properties of the human skin and the progress of wearable technology and into the human augmentation, the skin has become increasingly important in the field of HCI [6]. OSI tend to endow new abilities to the human body or to overcome its limitations [5]. Unlike “conventional” wearable devices, which focus on improving external systems, OSI focus on making the human body intelligent and augmented [2, 5, 6].

Despite the increasing interest of using the skin as a substrate of interaction, most of the explorations focus on technical challenges [4, 7, 8, 9]. Thus, the current knowledge to support, guide and conduct design processes of user interfaces on the human skin is rather limited.

OSI Implications for design. Using the human skin as a mean of interaction differs significantly from Screen-Based Interfaces (SBI) [2, 5, 6], not only in terms of its geometry but also in its primary function and possible interaction modalities [5]. Existing design principles for user interfaces cannot simply be transferred to the skin, as this does not account for its unique physical and psychological characteristics [2, 6, 10].

Due to the integration of OSI into the human body, one direction to explore their intrinsic advantages and differences over other interfaces (SBI primarily), is to address their potential association with a higher Feeling of Body Ownership and bodily self-consciousness. Such association might be possible by exploring the OSI's capability of eliciting the feeling of body ownership, through on-skin feedback as an illusory body continuity mechanism [11], as shown in Figure 1. Consequently, questions and opportunities arise that can be investigated

with-in OSI occur, such as: How do people perceive their self-generated data? How do they integrate it into their life? and How does it transform health-related habits?

1.2 Related work

Feeling of body ownership or Feeling of Ownership (FO) as concept, has its roots in psychology as a fundamental mechanism of self-consciousness [14, 15, 16, 17, 18]. More recently the FO has been explored within the HCI community [11, 12, 19] reflecting the importance of a person's experience of self-consciousness when interacting with technology. Tieri et al., (2015) suggests that the conscious embodiment of a body extremity requires a natural (continuous) looking visual body appearance. Jun et al., (2018) suggest that synchrony between a digital avatar and a VR user elicits the FO and modulates participants' emotions.

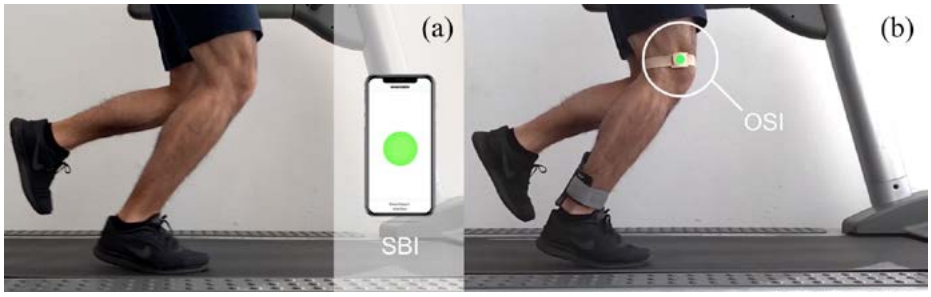
Regarding OSI, Bergstrom-Lehtovirta et al., (2018) explored the sense of agency with touchpad, keyboard, and on-skin interaction. They replicated the findings that skin input increases the sense of agency, originally reported by Coyle et al., (2012). Eschler, Bhattacharya & Pratt, (2018) found that these tattoos, considered as OSI, facilitated three post-traumatic growth processes: (i) changed self-perception; (ii) changed the sense of relationships with others; and (iii) changed the philosophy of life. In another study, Pohl & Hornbæk, (2018) suggest that on-skin interfaces have the potential to increase the inwards attention due to their closeness to the body combined with their feedback possibilities.

2 Method

2.1 Design Exploration

In our study, we used a running training as a real-case scenario to explore and obtain insights on the characteristics of OSI and SBI as real-time feedback interfaces for runners.

KneeMPACT. It is a research through design prototype we designed to measure running technique using foot-strike as a single parameter. The prototype consists of a shoe insole equipped with force sensitive resistors to measure runner's foot strike. According to different studies [26, 27, 28, 29], landing on the front part of the foot represents less knee impact than landing on the midfoot, and the latter represents less knee impact than landing on the heel. The objective of KneeMPACT is not to validate such affirmation but to use it as research exploration scenario. According to the foot strike type, the system delivers feedback through two separate interfaces (see Fig. 1): an SBI (a) and an OSI (b).



The study. In total, 49 participants (21 females, 28 males between 21 to 55 years old) were recruited to evaluate the two interfaces. The foot-strike OSI and the foot-strike SBI were presented to the participants in the form of video. The first part of the study was a blind user test. Four questions based on 4 heuristics (visibility, consistency, aesthetics, and simplicity, matching with the real world) principles [30], plus two open questions regarding the reason(s) to like and dislike the interfaces where formulated (see Table 1). The participants evaluated both interfaces separately by answering these 6 questions. In the second part of the study, we explained both interfaces, their purpose, and functionality. Subsequently, participants were asked to compare the two interfaces by answering 6 questions regarding the same evaluation criteria used in the blind user test (see Table 2).

3 Results

Blind user test. Gender and age did not represent a significant difference in the results of the study. A statistically significant difference ($P \leq .001$) was found regarding the difficulty to associate the actions of the runner and the information delivered by both interfaces. Using a seven-point scale (Likert scale score: 1=very easy; 7=very difficult) the scores for both interfaces were: foot-strike OSI = 3,86; foot-strike screen-based interface = 2,83. Furthermore, when participants were asked to infer the purpose of each interface, their answers were very similar and close to their actual purpose. Despite the extra information displayed in SBI ("Knee impact"), participants associated the OSI with similar concepts such as biomechanics of the knee, running technique, muscle stress, effects of foot-strike on knee impact, or knee injury prevention. These findings suggest that the location, bodily augmentation, the intrinsic feedback and body continuity characteristics of OSI have the potential to be equally effective to deliver bodily-related information without using the inherent cues and advantages of SBI.

Regarding the clarity of the interfaces, 53,1% of the participants perceived the information delivered by the OSI as insufficient, compared with the 36,7% regarding the SBI. Furthermore, 14,3% of the participants perceived the information deliver by the SBI as "more than enough", compared with the 2% regarding the OSI. 69,4% of participants found a clear relation between the action performed by the runner and the information delivered by the SBI, contrasted with the 36,7% for the OSI. When participants were asked to provide reasons why they liked each of both interfaces, they considered the OSI appealing and simple to represent bodily-related data, while the SBI as a convenient, and easy to use system due to the use of a smartphone. The main reasons why participants liked the SBI are mostly related to its usability and convenience. The usability factor was the main reason why participants disliked the OSI. Participants disliked the SBI, primarily because looking at the phone while running is very inconvenient and dangerous.

Comparison test. The results were rather similar to the blind user test results. The substantial insights and information on this section of the study come from the last three comparative questions, which were not presented in the blind user test (see Table 2). The 20,4% of the participants considered the OSI as the best alternative to support runners to understand their running technique, while the 79,6% chose the SBI as the better alternative. The high preference for the SBI as better interfaces to understand running technique has two reasons: first, participants find them familiar, accessible and relatively easy to understand at first glance. Second, SBI rely on the cognitive skills of the user. Therefore, when asking "which interface is better to understand…" implies a cognitive process inherent of these inter-faces. Yet, 42,9% of them chose the OSI and 57,1% chose the SBI. Although the majority of participants still preferred the SBI over the OSI, the latter increased its preferability by more than 20%. This increase can be explained by the potential of these interfaces to augment the body and to elicit the FO associated with bodily-related information delivered by the interface.

4 Discussion and conclusion

Smartphones and mobile apps have become the default and standard user interface for mobile computing. As SBI, their advantages to display high-resolution, dynamic and complex information, represent a major challenge for the development of successful and meaningful OSI. Moreover, the novelty and unconventionality of OSI are still reasons for people to prefer SBI. Despite this preference, in our exploration, we obtained interesting insights on the potential and advantages of OSI over SBI to deliver feedback focused on eliciting bodily self-consciousness and self-awareness. Aligned with the findings regarding the sense of agency and self-attribution originally reported by Coyle et al., (2012) and replicated by Bergstrom-Lehtovirta et al., (2018), OSI offer possibilities to develop bodily interactive experiences through illusory body continuity design interventions. Yet, even though the location of OSI helps for recognition and bodily association of the information delivered by the interface, it represents difficulties for visibility, ease of understanding and user interaction. More exploration in this area is needed to find stronger evidence to support our preliminary findings regarding OSI and their intrinsic capabilities to elicit higher self-consciousness.

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