Exploring Feedback and Instruction Modalities using Low Fidelity Prototypes for Running

Towards Designing a Wearable System

Jos Goudsmit*

Department of Industrial Design, Eindhoven University of Technology, Eindhoven, 5612AJ, The Netherlands; School of Sport studies, Fontys University of Applied Sciences, Eindhoven, 5644HZ, The Netherlands
j.goudsmit@fontys.nl

Steven Vos

Department of Industrial Design, Eindhoven University of Technology, Eindhoven, 5612AJ, The Netherlands; School of Sport studies, Fontys University of Applied Sciences, Eindhoven, 5644HZ, The Netherlands
s.vos@tue.nl

ABSTRACT

Running is a popular recreational sports activity, but it also has a discontinuation rate, primarily due to running-related injuries. Running injuries, and hence discontinuation can be reduced by providing feedback and instructions on running technique. This paper aims to explore three low fidelity feedback and instruction prototypes directed to design wearable-based systems for improving running technique. We explored feedback and instruction constructed with motor learning and running experts, consistent with motor learning principles. We constructed one prototype to assess the effects of feedback frequency another prototype to compare visual vs auditory feedback, and a prototype to investigate the effects of autonomy for their acute influence on stride frequency, self-efficacy and motivation. Results show that stride frequency changes were minor with all prototypes. Investigation of user experiences revealed an optimal feedback frequency at every one to two minutes and a preference for auditory instructions prior to running equally to real-time visual feedback. Providing autonomy had no improved motivation over no-choice. These results provide initial insights and suggestions to direct future design of wearable based feedback and instruction design for improving running technique.

CCS CONCEPTS

• Design methods, tools, and methodologies for designing physical and virtual interactive systems;

KEYWORDS

Running technique, feedback, instruction, wearable, low fidelity prototyping

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1 INTRODUCTION: RUNNING

Up to 50 million people in Europe participate in running with health or competitive goals [2, 17]. This running is largely performed individually or in small groups, outside sport clubs [3]. Running is also known to be an activity with high discontinuation rates due to injury and motivation loss [6, 10]. Wearable devices (e.g. smartphone and sports watches) have the potential to prevent discontinuation [23, 27]. Eight out of 10 event runners already use a wearable device for running, with most novice runners using their smartphone for tracking their runs and commonly measured variables are distance, time and route [10]. More experienced runners use sports watches with more data tracking possibilities such as heartrate, running speed and stride frequency [11, 13]. These wearable devices provide almost exclusively visual feedback. In general, the measured variables are represented in numbers and the user can self-determine when to look at this feedback. Some systems make additional use of visual cues such as colors or graphs [7]. This strategy causes an overload of information for the user and gives no direction to the user on how to improve running using the measured running variables [27].

One of the challenges in designing running-related wearables and interactions (i.e. feedback and instruction) is therefore the implementation of motor learning strategies [7, 27]. Running coaches use these motor learning strategies to provide easy to understand feedback and instruction, fitting the individual runner. In order to do so, coaches observe running technique, analyze the technique on-the-fly, and use their experience with the runner and a technical running model to provide personalized feedback and instruction [18]. Similarly, wearable running-related devices should therefore aim to provide feedback and instruction based on a real-time analysis of the running technique. It is however important that the wearable is practical in use, and provides feedback that is understandable for recreational runners' approach as well [7, 28].

Existing wearable systems mainly focus on measuring physiological factors of running while monitoring running technique and providing feedback are still uncommon [7, 28]. Only a few wearables are able to measure running technique, but providing directive, real-time feedback to the user is still challenging [27]. The present paper aims to explore three different low fidelity feedback and instruction prototypes as an initial step in the design process towards a wearable-based system for improving running technique. Based on the explorations we will provide possibilities

for designing specific feedback and instruction directions for designing interactive systems such as wearable running devices. The outline of the paper is first, to address the running technique and how this is measured using currently available wearable devices. Second, motor learning principles will be discussed followed by the introduction of three prototypes. Results of user tests will be presented next, followed by a discussion and concluding with design tools and requirements for designing interactive systems for running.

2 IMPROVING RUNNING TECHNIQUE

A screening of consumer-available wearables [7] and research-based devices [12, 16], revealed strengths with respect to measuring running variables and shortcomings with respect to feedback provided. Among others, the devices were found to be consistent in measuring running technique variables that are thought to be associated with injuries and/or running economy such as cadence and vertical oscillation [1], and foot strike pattern [12]. Other variables, such as trunk lean or knee angles, were not measured by most devices [7], even though they are sometimes also considered to be of relevance for preventing running injuries. Despite many devices measuring similar variables, a recent review found only weak evidence for the association of most variables with running injuries and/or running economy [27]. Furthermore, although the provided feedback and instructions by these wearables were found to improve the users' running technique, motor learning principles were not optimally implemented [7, 24].

2.1 Motor learning principles

Motor learning principles should be implemented to optimize the ability of wearables to change and improve running technique [5, 29]. In the present paper, the OPTIMAL theory [30] is adopted as a framework for constructing and providing feedback using low fidelity prototypes. The framework emphasizes the role of motivation and attention to improve the focus on the purpose of the task in question and thus the performance and motor learning of that task. Improving running technique (i.e. task at hand) is therefore dependent on (i) the autonomy of the user (the decisions the user can make during learning) [4, 30, 31], (ii) the enhanced expectancies of the user (self-efficacy, confidence in future performance and motivation) [30], and (iii) the external focus of attention during exercise (through feedback and instruction) [4, 20–22, 29–31]. Providing feedback and instruction can positively impact autonomy and enhanced expectancies if provided in an appropriate way. Therefore, the design of feedback and instruction is required to meet the addressed principles in the OPTIMAL framework. This can also help to improve the user experience [30].

2.2 Feedback and Instruction Content

For the explorations with the low fidelity feedback and instruction prototypes, we take the addressed principles in the OPTIMAL framework into consideration. The first principle is autonomy which is the possibility to influence decisions within the exercise by the user. Being able to choose when feedback is provided, for example, is related to learning improvements [4, 30, 31]. Almost any decision, how trivial it might be, helps improve autonomy and therefore

learning [9]. Another possibility to improve autonomy is to use supportive language. The second principle of enhanced expectancies refers to the way that users perceive their confidence in future performance. By enhancing their expectations for the performance, the self-efficacy and motivation can be improved as well [4, 30, 31]. Expectancies can be enhanced by using encouragement when the user is performing well or using social-comparative feedback in which the user is compared with less skilled performers. A different approach is decreasing the perceived performance difficulty [30]. The third principle of external focus refers to the focus of attention of the user. With an external focus, attention is focused on the effect of the movement, i.e. the result of the movement that the user aims to achieve. Providing knowledge of result can promote focus of the user to the effect of the movement. This principle stimulates the self-organization of the users' movements and improves learning and performance [4, 20–22, 29–31].

2.3 Feedback Modalities and Frequency

In addition to the principles regarding the content of the feedback and instruction, our explorations also take into account the different modalities and frequencies of the feedback and instruction [24]. Information can be provided to the user using different modalities with visual and auditory feedback being the most commonly used [24, 27]. Visual feedback refers to information that can be shown to the user by using lights, displays (both on the user or within the environment), video, etcetera. Caution should be exercised with real-time visual feedback as it can easily overload the visual perception that is also required to run safely [23]. Auditory feedback may, therefore, be safer to use in providing real-time feedback and instruction [23, 24]. Spoken feedback, alarms, beep signals or sonification are some examples that can be used as auditory feedback. Spoken feedback can be more detailed and, therefore, direct the focus of attention of the user.

The frequency at which feedback is provided can be influenced by several feedback strategies such as concurrent feedback, fading frequency, bandwidth-based, and self-determined feedback [5]. Concurrent feedback (during the performance) could interfere with the self-organization of the performance by the user [24]. Preventing this interference can be achieved using fading frequency feedback, it can be implemented by giving feedback less often when the user improves performance [5]. Self-determined feedback strategy lets the user decide when feedback is provided and therefore fits the autonomy principle [30].

The timing of providing feedback is another factor to take into consideration. Timing options are feedback provided before the performance (feed-up), during the performance (real-time), or after the performance, either directly following performance or a short while after [8, 14]. With the latter strategy, the user can process the intrinsic feedback first before the additional feedback is provided and processed. Feed-up before the performance can be seen as instruction based on past performance that can give direction to the users' next performance.

3 EXPLORING LOW FIDELITY FEEDBACK AND INSTRUCTION PROTOTYPES

Several scholars in the human-computer interaction community designed systems that provide feedback to runners on variables

related to the running technique. For example, Kiss and colleagues [12] created RunMerge, which could display ‘stance’ and ‘pronation’ patterns of the foot using a shoe pod. Users found that the visual representations were a positive aspect of the system. Nylander and colleagues [16] 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 find their solutions for improving their running technique. We argue that giving the runner direction and focus for technique changes is beneficial in finding the users’ optimal running technique.

Cadence is commonly measured in wearables and has been associated with running injuries [7, 27]. This variable was therefore used to analyze whether the feedback and instruction prototypes had an acute influence on the running technique. We used the motor learning principles to explore feedback and instruction low fidelity prototypes and explored these with runners in a real-life context. Low fidelity prototyping was used to gain quick and initial insights [25] in designing feedback and instruction for a wearable running system. During the development of the low fidelity prototypes, we consulted one motor learning and running expert and an experienced runner for pilot testing of the prototypes.

We developed three different low fidelity prototypes for exploration: (i) a feedback frequency prototype, (ii) a visual vs auditory feedback prototype, and (iii) an autonomy prototype. In each of the explorations, the runners used one prototype during running. Running intervals were set at a range of 5 to 10 minutes. In between and after the intervals the user experience, self-efficacy and/or motivation of the runner was measured. When relevant group comparison and related samples non-parametric statistical tests were performed using SPSS Statistics version 26 (IBM corp., New York, NY). All exploration protocols were approved by the research board of Fontys University of Applied Sciences.

3.1 Feedback frequency prototype

The feedback frequency prototype was developed to provide feed-up to the runner on the movement of the head, with the presumed effect that this would lead an increase in cadence [15, 32]. Runners, age ranged from 32 to 58, that participated were four experienced runners that were all member of a running club. The feedback prototype included the principles of focus on the effect of the movement, real-time feedback and visual feed-up (instruction). We used two systems to measure cadence: two runners used Wahoo TICKR (Wahoo Fitness, Atlanta, Georgia) wearable device connected to the Wahoo Fitness smartphone application, and (ii) the other two runners used Byteflies sensor dot system (Byteflies NV, Antwerp, Belgium). With the latter system we used 6 sensors placed on both feet, both shins, the pelvis and the chest. Custom-made algorithms were used to analyze cadence and variance in cadence. We measured the user experience and collected additional remarks from the runners.

Runners were shown laminated visual instruction cue cards (Figure 1) during running along with auditory feed-up at the start of every run. The focus of the feed-up for the runner was to “run with the head as high as possible in the sky”. Runners were instructed to

run four trials of 5 minutes at their own comfortable running speed on a concrete surfaced cycling road. The visual cue frequency was changed in every trial, all runners completed the trials in the same order. In the first running trial, only feed-up before running was provided, in the other running trials the visual cue (Figure 1) was presented one time (trial 2), two times (trial 3), or four times (trial 4). In between every trial the runners were asked to provide their user experience using one item “how did you experience this trial” and a 5-point Likert scale ranging from ‘very bad’ to ‘very good’.

3.2 Visual vs auditory feedback prototype

The visual and auditory feedback modality was used to explore visual vs auditory feedback. Both feedback modalities used focus on the effect of the movement. The timing of the visual information was real-time, see Figure 1 for an example. The auditory information was feed-up with real-time cues. We measured cadence and self-efficacy within this experiment. Seven runners (experienced runners and all member of a running club) age ranged from 43 to 72 wore a Wahoo TICKR (Wahoo Fitness, Atlanta, Georgia) connected to the Wahoo Fitness smartphone application to measure cadence. Following a 10-minute screening run to identify the preferred cadence of each runner, the runners were randomly divided into two groups. The first group, consisting of three runners, received verbal instruction to run at a 4% cadence increase target [15] for the second 10-minute run. During this session, runners were auditorily encouraged every minute to keep the cadence high with the cue “keep the cadence high”. The second group, four runners, also got the verbal instruction to run at a 4% increase in cadence. However, this group was provided visual feedback (Figure 1), every minute during the run on their real-time cadence, using a handheld smartphone. Both groups of runners ran two blocks of 10-minute running each. Before and after both blocks, the groups of runners answered the self-efficacy scale (4-point Likert scale, SRL-SRS questionnaire [26]).

3.3 Autonomy prototype

With the third prototype, we aimed to explore the principle of autonomy for the runner [9]. We designed four feed-up strategies using auditory and visual cues, and both internal focus and focus on the effect of the movement. We consulted one motor learning and running expert for the cue content and the prototypes were tested with one experienced runner. Autonomy prototypes addressed two running technique variables: cadence and vertical movement of the head. For cadence the focus on the effect of the movement was directed to a stride frequency of 80-85 strides per minute by hearing or seeing this frequency. The 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 focus on the effect of the movement 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”. Auditory feed-up was provided by listening to the cues, visual feed-up had the same readable cues with an additional video example (see Figure 1 for an example screenshot). General running motivation was measured before running with one item “to which

Figure 1: the visual cue prototype, real-time visual feedback display and visual feed-up with cue

Table 1: User Experience and cadence changes exploring feedback frequency prototype, N=4 runners.

Trial	Feedback frequency	Cadence ^a (SPM)	Cadence Variation	User Experience ^b
1	Feed-up alone	89,9 ($\pm 3,2$)	1,2 ($\pm 0,24$)	3,4 ($\pm 0,5$)
2	Feed-up and 1 visual cue	90,1 ($\pm 3,2$)	1,2 ($\pm 0,29$)	4,4 ($\pm 0,5$)
3	Feed-up and 2 visual cues	90,6 ($\pm 3,3$)	1,3 ($\pm 0,29$)	4,6 ($\pm 0,5$)
4	Feed-up and 4 visual cues	90,7 ($\pm 3,4$)	1,6 ($\pm 0,26$)	4,6 ($\pm 0,5$)

^a Cadence is displayed in strides per minute (SPM)

^b items are scored on 5-point scale (1-5); totally disagree, disagree, neutral, agree, totally agree.

extent are you motivated during running?” with a 5-point Likert scale ranging from ‘not at all motivated’ to ‘very much motivated’. After exploring the autonomy prototype runners were asked “did your motivation improve using the prototype compared to before?” to measure self-reported motivation change. This item was scored using a 5-point Likert scale ranging from ‘totally disagree’ to ‘totally agree’. Cadence was not measured in this exploration. Nineteen runners (average age of 47,6 ($\pm 7,8$) years), were randomly divided into two groups: (i) an autonomy group (n=10), that chose their preferred feedback modality and focus, and (ii) a no-choice group (n=9), who was appointed feedback modality and focus by the researcher.

4 RESULTS OF THE EXPLORATIONS

4.1 Feedback frequency prototype

Table 1 displays the results of the experiment with the feedback frequency prototype. Technique changes are displayed as cadence in strides per minute. A small upward trend was seen in cadence ($p=.308$) and variation in cadence ($p=.098$) when more visual cues are provided while running. The runners’ user experience changed over the trials ($p=.032$). Pairwise comparisons showed trial 1 to be lower than trial 3 ($p=.027$) and trial 4 ($p=.020$) and no differences between trial two, three and four. Additional remarks provided by the runners were (i) that the provided cues helped the running technique the most when they experienced fatigue, and (ii) that repeating the cue at unexpected timing helped them focus on their running technique.

4.2 Visual vs auditory feedback prototype

The results of the visual vs auditory feedback prototype (see Table 2) include measures of cadence in the two running trials and self-efficacy scores of both groups of runners before and after the running session. Acute changes for cadence were only measured for two runners in each group due to equipment failure. The visual group runners did run at their targeted cadence, non-parametric testing revealed no difference ($p=.200$) between both groups. Self-efficacy did not change after running with the prototypes in both groups ($p=.786$). User experience did not change as well ($p=.400$).

4.3 Autonomy prototype

No differences in motivation for running were found between the groups before the exploration of the autonomy prototype ($p=.549$). Both groups reported to be better motivated for running due to the feedback strategy of the group (see Table 3). There were no differences between both groups for self-reported motivation change ($p=.604$) after exploring the prototype.

5 DISCUSSION

Low fidelity prototyping for feedback and instruction on running technique performance was used to gain initial insight in user experience and acute technique changes. Exploration with the feedback frequency prototype showed that instruction and visual cues during running for stride frequency and user experience were beneficial. Due to the running time during the trials, ranging from four to five minutes, this frequency was an additional visual cue at least every two minutes following the instructional cue at the start of

Table 2: Cadence changes and self-efficacy scores for the visual vs auditory feedback prototype, N=7 runners.

Group	Trial	Cadence (SPM) ^a	Self-efficacy ^b	User Experience
Visual	1	88,5 ($\pm 0,5$)	3,1 ($\pm 0,3$)	2,3 ($\pm 0,3$)
	2	93 ($\pm 3,5$)	3,0 ($\pm 0,4$)	
Auditory	1	87,5 ($\pm 0,8$)	3,1 ($\pm 0,2$)	2,7 ($\pm 0,5$)
	2	88,5 ($\pm 3,5$)	3,1 ($\pm 0,2$)	

^aCadence results are based on only 2 runners in both groups.

^bitems are based on 4-point scale (1-4); totally disagree, disagree, agree, totally agree.

Table 3: Motivation changes for the autonomy prototype, N=19 runners.

Group	Feedback strategy	Motivation before ^a	Self-reported Motivation change ^b
Autonomy (n=10)	By choice of the runner	4,3 ($\pm 0,6$)	3,4 ($\pm 0,9$)
no-choice (n=9)	Assigned by the researcher	4,1 ($\pm 0,6$)	3,6 ($\pm 0,9$)

^a items are scored on a 5-point Likert scale (1-5); not at all motivated, not motivated, neutral, motivated, very much motivated

^b items are scored on 5-point scale (1-5); totally disagree, disagree, neutral, agree, totally agree.

each trial. We executed this experiment with experienced runners that already had a higher stride frequency [19]. This could explain the small change during the trials. The combination of the user experience and the stride frequency results led us to conclude that at least a two-minute interval of feedback is optimal.

The visual vs auditory feedback prototype was not only different in feedback modality but in feedback timing as well between the groups. User experience for the visual feedback and auditory feedback was found to be the same in this study which contradicts with other findings where visual feedback is found to be preferred [24]. A possible explanation could be that the visual feedback was presented on the smartphone display. Runners had to carry the smartphone in their hand during running which was reported inconvenient. To cope with this inconvenience, experienced runners, compared to novice runners, often use more specific running related wearables such as sports watches [10, 11, 13]. The group of runners in this exploration were experienced runners, so they may be used to wrist-worn solutions. The development of wrist-worn sports watches or smartwatches is promising and might improve user experience with visual feedback during running for novice runners as well [23]. Stride frequency results show that the visual feedback influenced the running cadence in the targeted direction for one runner. Real-time timing of the visual feedback enabled the runner to see the cadence during running. This feedback strategy is beneficial when targeting acute changes. For motor learning and long-term performance changes this strategy is found to be detrimental according to the guidance hypothesis [24]. The auditory feed-up prototype in this exploration showed no acute changes in cadence in one runner but had higher user experience compared to the visual prototype. The use of the two prototypes did not influence the runners' self-efficacy. Altogether, we suggest that using auditory feed-up is preferred for running and might help with motivation because of the specific target provided.

Giving runners autonomy with our prototype did not result in improved motivation in our exploration. We explored this prototype in a single session and asked the runners how likely the used prototype would improve their motivation for future running. Therefore, these prospective and subjective results should be interpreted with care. Literature learns that providing autonomy improves learning and running efficiency [9, 30].

Based on the results of our exploration we can conclude that minor or trivial acute cadence changes occurred during running using the prototypes. The results regarding the user experience provide some insights and direction for implementing feedback strategies. The feedback frequency tends to have an optimal at providing feedback at least every two minutes of running as found with the exploration with the first prototype. Auditory feed-up is equally preferred as visual feedback as found in the experiment with the visual vs auditory prototype. Giving autonomy to the runner seems to improve motivation however, this was only small and not more than the no-choice group.

Explorations with low fidelity prototypes show directions to design running related wearables. Results suggests providing feed-up before running to give the runner focus for the run. During running, visual or auditory feedback can be provided at least every two minutes. Giving the runner a choice in either one of these steps might promote the user experience and motivation.

6 FUTURE DIRECTIONS

The results learned that acute technique effects are not seen in these experiments. The user experience of the provided feedback gives directions for future experiments and design tools. With the low fidelity prototypes, we provided examples to use within running related wearables aimed at improving running technique.

Suggestions for design tools and requirements identified within the results of the explorations. The frequency of providing feedback could be timed at least every two minutes during running. More

frequent feedback had no additional benefits for cadence changes and user experience. Auditory feedback and visual feedback are equally preferred, which also has advantages for technique changes. However, acute changes in the running may increase the risk of injury [23]. Caution is therefore required. Visual feedback should be given with care and should be easy to perceive while running. Smartwatches and sports watches show promising developments in this direction [23]. Results with regarding to autonomy are inconclusive, theoretically giving users a choice will encourage learning and is therefore proposed [27, 30].

The aim of this paper was directed to explore feedback and instruction as one of the factors that influence discontinuation. We used three different low fidelity feedback and instruction prototypes to gain insight in this initial step in the design process towards a wearable-based system for improving running technique. Workload and motives should be taken into account as well in designing real-time feedback [27]. Future work should address these factors as well as long-term influences (e.g. Motor learning and performance) of feedback on running technique. More specific on designing and validating feedback strategies taken the suggestions made in this paper as a starting point. This will be the focus of the future steps that will be taken to design a user-friendly, wearable, running technique feedback system.

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