Run&Tap: Investigation of On-Body Tapping for Runners

Nur Al-huda Hamdan, Ravi Kanth Kosuru, Christian Corsten, Jan Borchers
RWTH Aachen University
52056 Aachen, Germany
hamdan|corsten|borchers@cs.rwth-aachen.de ravi.kosuru@rwth-aachen.de

ABSTRACT
Devices like smartphones, smartwatches, and fitness trackers enable runners to control music, query fitness parameters such as heart rate and speed, or be guided by coaching apps. But while these devices are portable, interacting with them during running is difficult: they usually have small buttons or touchscreens which force the user to slow down to interact with them properly. On-body tapping is an interaction technique that allows users to trigger actions by tapping at different body locations eyes-free. This paper investigates on-body tapping as a potential input technique for runners.We conducted a user study to evaluate *where* and *how accurately* runners can tap on their body. We motion-captured participants while tapping locations on their body and running on a treadmill at different speeds. Results show that a uniform layout of five targets per arm and two targets on the abdomen achieved 96% accuracy rate. We present a set of design implications to inform the design of on-body interfaces for runners.

Author Keywords
On-body input technique; runners; empirical study

ACM Classification Keywords
H.5.2 User Interfaces: Input devices and strategies (e.g., mouse, touchscreen)

INTRODUCTION
In recent years, people have become more aware of the benefits of physical activity on their health and well-being [30]. To help runners track their physical performance and stay motivated, several fitness devices (e.g., Fitbit Charge, TomTom Touch, Apple Watch) have been developed. These devices provide runners with real-time measurements of distance, duration, speed, pace, and calories burned. Fitness apps like Runtastic [21] convert smartphones into fitness trackers and use voice coaching to help pace the user and build speed and endurance. But while fitness and mobile devices are designed to be portable during physical activity, their input space of small buttons or touchscreens has severe drawbacks on user experience: Studies have shown that even during a simple activity like walking, users are forced to slow down by 25%

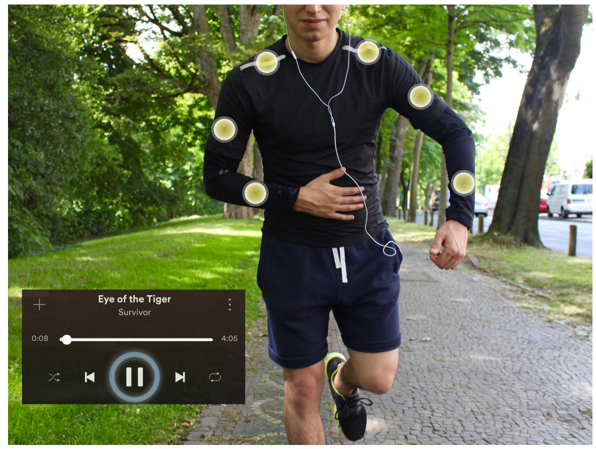

Figure 1. On-body tapping is an input technique that can potentially enable runners to trigger an action, e.g., pause the media player, by simply tapping on a designated body part eyes-free.

to interact with a mobile device properly [3]. And no matter how slow users walk, input performance will still suffer [22]. Oulasvirta et al. [19] demonstrated that interacting with mobile devices while walking fragments users' attention and puts them at risk. These drawbacks become more severe when users are engaged in a more physically and cognitively demanding activity such as running [19], with the hands and body constantly oscillating and fingers damp with sweat.

One way to overcome these limitations is appropriating the user's own body as an input surface [10]. The human body offers a large and always-available surface that can be accessed quickly and accurately without relying on visual feedback, due to proprioception [7]. It serves as a mnemonic frame of reference for associating meanings to different body parts [1] or kinesthetic cues [25]. While previous work, e.g., [8, 16, 32], propose on-body tapping as a promising technique for interacting with smart mobile devices, it remains unknown how users' motion, e.g., running, impacts this technique.

This paper presents an empirical investigation of the accuracy and perception of on-body tapping during running (Fig. 1). We conducted a user study to examine *where* and *how accurately* runners can tap on their body. Twelve participants were motion-captured while tapping locations on their upper body and running on a treadmill at different speeds. We evaluated the accuracy, layout, and size of on-body locations and the human factors that influence participants' tapping behavior. Subjective ratings of physical comfort, input confidence, and preference of these locations were collected. We summarize our findings in a set of design implications to guide the design of on-body interfaces for mobile users.

ISS'17, October 17–20, 2017, Brighton, United Kingdom.

ACM ISBN 978-1-4503-4691-7/17/10$15.00. https://doi.org/10.1145/3132272.3134140

RELATED WORK

Running is one of the most practiced sports worldwide[1]. So far, HCI research on running has been mainly focusing on socio-motivational technologies and gamification, e.g., [17, 18], rather than the user experience [26].

Literature on mobile and wearable interaction has mainly focused on two input techniques to overcome the limitations of small device size: mid-air gestures [5] and voice input [14]. These techniques can potentially enable eyes- and device-free interaction, which is particularly convenient for users when they are engaged in a physical activity such as running. However, there is no clear evidence of the usability of such input techniques for users while running. New efforts [15, 32] have suggested using the human body as a physical extension to small devices, such as the smartwatch, to provide the user with a larger tactile surface for interaction.

Several design guidelines have been proposed for body-centric interaction with large displays [24], mobile devices [6], and for multi-surface interaction [29]. Body interactions are categorized into three themes based on proximal spaces—personal space (space occupied by the body), peripersonal space (space within hands reach), and extrapersonal space (space outside hands reach). The personal space hosts on-body interactions where actions are mapped to different parts of the user's body [6]. A number of techniques [1, 4, 6, 24] demonstrated how the human body, or parts of it, can be used to store and retrieve data, access shortcuts or menus items, and manipulate widgets mapped on the body via direct touch or a proxy, such as a mobile device.

The question of where to interact on the body was addressed by several investigations. Karrer et al. [13] conducted a study to determine the on-body locations that are physically and socially convenient for interaction. Participants preferred the arms, sternum, hip and pocket areas. Similar results were found by Profita et al. [20] who evaluated gender and cultural differences in social acceptance of on-body interaction. Wagner et al. [29] examined combining on-body tapping with mid-air pointing for multi-surface interaction. They showed that tapping on the body is a *Microinteraction* (requires <4 seconds to execute), which enables users to quickly return to their main task with minimal distraction [2]. They also found that users were faster and preferred tapping locations on the upper body (arms and torso) while tapping on the lower legs was slower and required additional balance.

Researchers have investigated the human factors that affect how users interact with the body. Lin et al. [16] investigated the number and distribution of locations that users can precisely tap on their forearms without visual feedback. They found that most users can distinguish six areas. They also noted that the distribution of locations was unique across users and more uniform near the joints (writs and elbow). Gustafson et al. [8] demonstrated that the landmarks on the palm of the hand (finger phalanges) provide users with haptic feedback that enables eyes-free interaction on skin to outperform interfaces on physical devices. Huang et al. [11] found that the anatomy of the hand affected the physical comfort and the precision of thumb-to-fingers interfaces. Vo et al. [27] showed how the abdomen area can be used to perform touch gestures, such as directional strokes, but for more complex gestures users' self-image reflected inconsistent behaviors.

So far, previous work has shown that users are able to tap on their body (palms, forearm, upper body) quickly and accurately without relaying on visual feedback. On-body tapping can be a socially acceptable technique if it avoids body areas that users feel uncomfortable tapping in public. This paper contributes to this body of literature by investigating the effect of users' motion, running, on on-body tapping. Our aim is to contribute to wearable interaction design for active users.

USER EXPERIMENT

In order to understand how running affects on-body tapping, we conducted a user experiment in which we motion-captured users performing tapping tasks on their body while running on a treadmill at different speeds. The goal was to examine where and how accurately users tap on their body and the effect of human factors (e.g., body anatomy, running movement pattern, speed, and fatigue) on users' performance.

Before the experiment, we ran a pilot study with three participants to determine the number and layout of locations that participants could access on their body during running. The study avoided locations that are socially unacceptable [20] or physically inaccessible e.g., the calf of the leg, which may effect users' balance [29]. Participants tapped locations on their upper body while standing still and while running. During the study we noticed that participants tapped on their body using their full hand or with four fingers (excluding the thumb). Based on our pilots, we defined 16 locations on the upper body—arms and abdomen. Locations that received the lowest physical comfort and tapping confidence ratings during standing and running conditions were excluded. Figure 2 shows the locations that were examined in the pilot study, and those that were selected for the experiment. The final location groups: ARM LOCATIONS: 5 targets on each arm (1 on shoulder, 2 on upper-arm, 2 on forearm) and ABDOMEN LOCATIONS: 6 targets (3 upper row, 3 lower row).

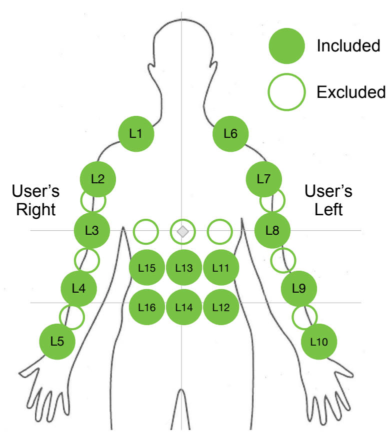

Figure 2. Twenty five on-body locations were tested in the pilot study: 16 locations were selected for the user experiment (filled circles), and 9 locations were excluded (empty circles).

[1] https://www.statista.com/topics/1743/running-and-jogging/

Participants

We recruited 12 participants (4 female). They ranged in age from 20 to 49 ($M = 25.91$, $SD = 8.12$). Eleven were right-handed and only one was left-handed. Eight participants ran on regular basis (at least once a week), while the others ran less regularly. Participants came wearing comfortable, non-restrictive clothing for the experiment.

Apparatus and Experimental Setup

Participants stood on a treadmill (HS-640A 9) facing an iPad3 mounted to the treadmill's control panel at 45° (Fig. 3). The treadmill was adjusted for 0° inclination. It had two side bars with buttons to control the running speed. Participants were asked to wear a fitted training shirt (92% Polyester, 8% Spandex) with long sleeves that was provided by the experimenter in three different sizes. Passive infra-red reflective markers were used to track the body movement. The markers were attached onto the shirts using instant glue to prevent them from falling or shifting while the user runs or sweats. They were placed on joints and landmarks (wrists, elbows, shoulders, collarbone, sternum, chest and hips) such that there was no major shift in position when the body parts move. Three additional markers were attached directly to the right hand and two to the left hand for tracking the hands' position while tapping. The markers were tracked in three dimensions by seven VICON cameras with sub-millimeter accuracy at a rate of up to 200 Hz. A GoPro 3 camera, mounted to the wall in front of the participant, was used to record the study.

Procedure and Task

Before the trials, participants stood still on the treadmill facing an iPad display. The experimenter explained how participants should map locations, which appeared on the displayed silhouette in front of them, to their own body. In each trial, a red dot with pulsating animation highlighted a location (randomly) on the silhouette indicating a tap should be performed. Participants were asked to use either hand to tap the corresponding location on their body as quickly and accurately as possible. This forced participants to react more promptly to the stimuli. During pilots, participants tried to increase their accuracy by reducing the speed at which they moved their arm and by keeping their hand longer over the location. Longer gestures are cognitively more demanding [2]. A trial ended and the next location appeared after the user had tapped the indicated location and the hand returned to the running position. Participants declared when tapping the wrong location and the trail was repeated. After tapping all locations, participants switched their running speed between low (3.7-4.4 mph) and high (5.6-6.2 mph) and started a new block of trials. The speed ranges where taken form a basic interval workout on the treadmill. Each participant performed 16 LOCATIONS × 2 running SPEEDS × 6 BLOCKS = 192 trials.

Following the trials, participants ranked each location on a 5-point Likert scale based on *physical comfort* (1—5: very uncomfortable—very comfortable) and *tapping confidence* (1—5: very unconfident—very confident). Participants rated on-body tapping based on cognitive demand (1—5: very undemanding—very demanding), likelihood of using the system in the future (1—5: very unlikely—very likely) and social acceptance. Participants performed an individualized action mapping task in which they mapped to their own body ten actions from the media and fitness apps (skip song forward and backward, increase and decrease volume, play and pause song; heart rate, speed, distance, elapsed time). The experiment lasted for about 60 minutes.

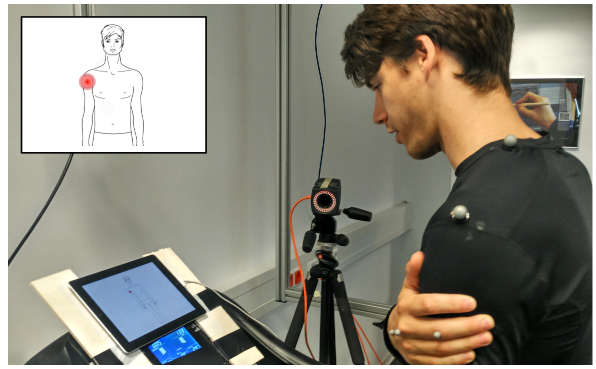

Figure 3. Participants ran on a treadmill and were motion-tracked. An iPad screen in front of them displayed a red dot with pulsating effect to signify the location that participants should tap on their body.

Data Processing

Following the procedure proposed by Lin et al. [16] to analyze the accuracy of on-body tapping locations, we first projected the data points (taps) collected from the Vicon system onto participants' arms (line connecting markers on the wrist-elbow-shoulder-collarbone) or abdomen (surface bounded by markers on the chest and sternum). We only analyzed taps on the arms in one dimension—along the vertical axis connecting the arm's joints. During the pilots, participants used the palm of their hands for tapping covering large areas of their arms in the horizontal dimension and making it hard to distinguish the point of contact. Secondly, we normalized the data points based on the arm's length or the abdomen's surface area of each participant. Thirdly, we removed 5.6% of the total points whose measured position was not within the two standard deviations from the centroid of location. The accuracy rate of a location was calculated as the ratio of taps that did not overlap with taps of neighboring locations, e.g., a 90% accuracy rate means that only 10% of the taps intended for a location overlapped with neighboring locations.

Results

Subjective Ratings

Figure 4 (left) shows the average *physical comfort* ratings given by the participants for all locations. On average, participants rated the physical comfort of ARM LOCATIONS at 3.2 ($SD = 0.7$). Tapping the shoulders was physically the most challenging (L1, L6: $M = 2.0$). The wrists were found to be the most comfortable to tap (L5, L10: $M = 3.8$), followed by the upper-arms (L2, L3, L7, L8: $M = 3.6$). ABDOMEN LOCATIONS received the highest comfort ratings ($M = 3.9, SD = 0.36$).

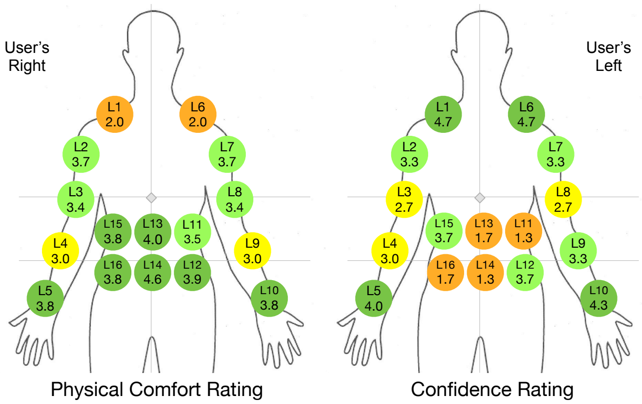

Figure 4. Average physical comfort ratings (left), average tapping confidence ratings (right). Green indicates higher (better) ratings and orange is for lower ratings on a 5-point likert scale.

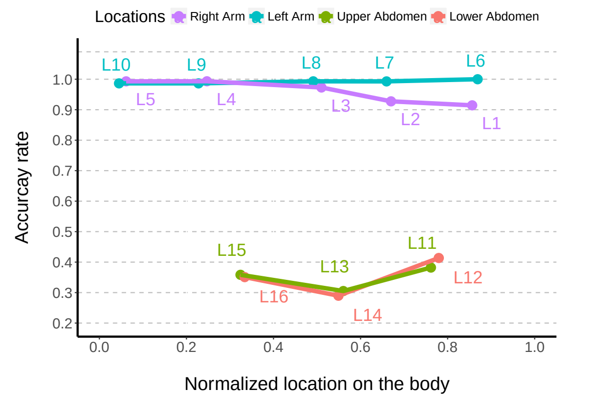

Figure 5. Broken-line graph that represents the accuracies of different on-body locations. The location of L1-L10 was normalized based on participants' arm length, and L11-L16 based on the width of the abdomen.

Figure 4 (right) shows the average *tapping confidence* ratings for all locations. In contrast to *physical comfort* ratings, ARM LOCATIONS received better and more consistent confidence ratings ($M = 3.8, SD = 0.8$) than ABDOMEN LOCATIONS ($M = 2.2, SD = 1.1$). Participants felt most confident tapping locations on the shoulders ($M = 4.7$), which is unsurprising, since one location was assigned to each shoulder. Locations on the wrists received high scores ($M = 4.1$). Locations around the elbow received lower scores ($M = 2.9$). Four abdomen locations received the lowest confidence scores (L11, L13, L14, L16: $M = 1.5$), while the two furthest locations on the abdomen received relatively higher ratings (L12, L15: $M = 3.7$).

As shown in Figure 4, the *physical comfort* and *tapping confidence* ratings were distributed similarly on the right and left sides of the body. But no conclusion can be derived from this since eleven of our twelve participants were right handed.

After running, participants rated the cognitive demand of on-body tapping at 2.6 (undemanding), and the likelihood of them using the system at 4.6 (high). All participants regarded on-body tapping as socially acceptable. Finally, when participants mapped ten actions to their own body, we did not find a uniform mapping amongst them. For example, some participants split the actions of the media player and fitness app cross the left and right sides of their body, while others mapped their most frequently accessed actions to the abdomen. And most participants mapped the pause and play actions to a single location. However, one consistent observation is that participants distributed the actions on their body surface such as to maximize the distance between any two input locations: each of the arms and the abdomen areas had at most three actions mapped to them.

Accuracy Ratings

A Kruskal Wallis test revealed a significant effect of LOCATION on *accuracy rate* ($\chi^2(15) = 162.6,\ p < 0.01$). A post-hoc test using Mann-Whitney tests with Bonferroni correction showed a significant difference between ABDOMEN LOCATIONS and ARM LOCATIONS ($p < 0.01$). The average *accuracy rate* of all locations was ($M = 0.75, SD = 0.31$).

Figure 5 shows the average *accuracy rate* of each location on the body. We found no significant effect or interaction effect of BLOCK or SPEED on *accuracy rate* ($p > 0.05$). We split the data of the arms and abdomen to perform further analysis.

We found a significant effect of ARM LOCATIONS on *accuracy rate* ($\chi^2(9) = 33,\ p < 0.01$). A post-hoc test showed a significant difference in *accuracy rate* between locations L6 (left shoulder) and L2 (right upper-arm) ($p < 0.05,\ r = 0.68$). The average *accuracy rate* of ARM LOCATIONS was 0.98 ($SD = 0.05$). We found a significant effect of HANDINESS on *accuracy rate* ($\chi^2(1) = 11.24,\ p < 0.01,\ r = 0.31$). On average, *accuracy rate* of the left arm was 0.99 and for the right arm 0.96. Location on the left shoulder had the highest accuracy (L6: $M = 1.0$), and location on the right shoulder had the lowest accuracy (L1: $M = 0.91$).

We found a significant effect of ABDOMEN LOCATIONS on *accuracy rate* ($\chi^2(5) = 17.7,\ p < 0.01$). A post-hoc test showed a significant difference in accuracy between several ABDOMEN LOCATIONS. The average *accuracy rate* of ABDOMEN LOCATIONS was 0.35 ($SD = 0.09$). Location L12 in the lower row of the abdomen layout (left) had the highest accuracy ($M = 0.42$) and L14 in the lower row of the abdomen layout (center) had the lowest rate ($M = 0.29$).

Arms Layout

To examine the layout of arm locations for all participants, we compared the relative centers and size (spread) of each location. For each participant, location center was determined by calculating the mean distance of the participant's taps from the wrist joint, and normalized based on the arm length. Location size was calculated by multiplying the standard deviation of the data points by four (cf. [16]).

Figure 6 shows the projected tapping data on the line of the left and right arms for all twelve participants. The highest deviation in location centre across all users was in shoulder locations (L1: $SD = 28mm$, L6: $SD = 24.3mm$, 18% and 18.8% of location size, respectively). The centers of upper-arm locations were the most consistent across all users, especially locations above the elbow (L8: $SD = 14.3mm$, L3: $SD = 16.8mm$, 14% and 14.5% of location size, respectively). The tables in Fig. 6 summarize the average size of each location and the proportion which it occupies on the corresponding limb. Locations on the wrist (L5, L10) had the smallest absolute size while locations L3 and L8 on the upper-arms had the smallest proportionate size. Locations L2 and L7 on the upper-arms had the largest absolute size while L4 and L9 on the forearms had the largest proportionate size.

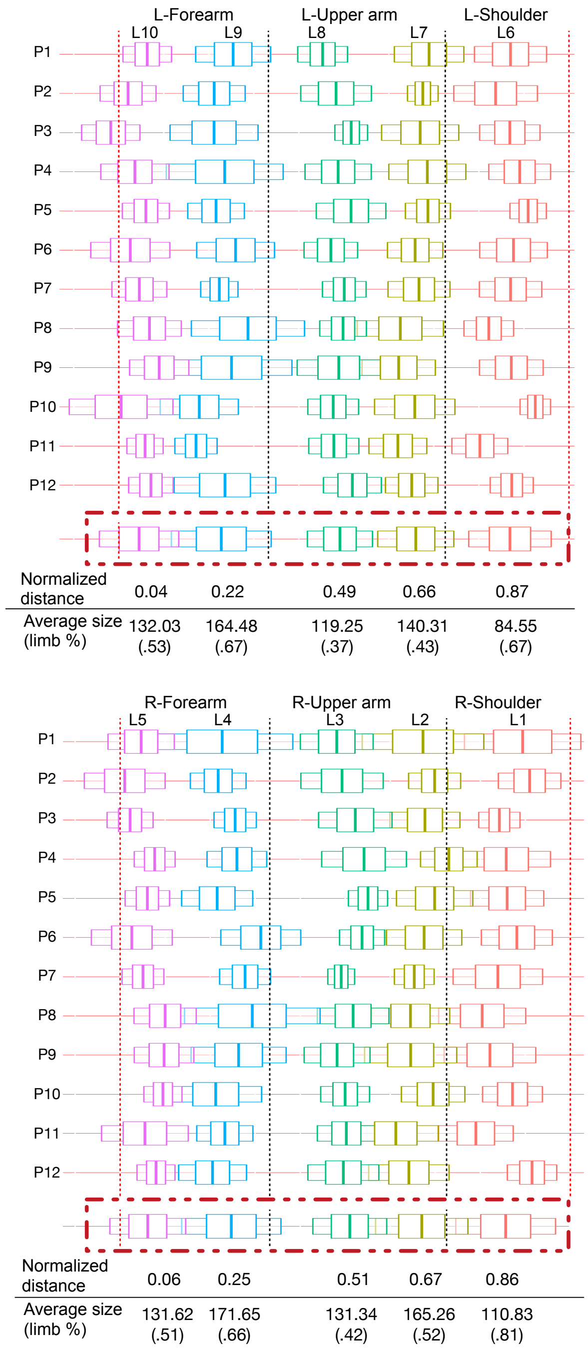

Figure 6. The projected tap distribution on the left arm (top) and right arm (bottom) for all participants. The thicker boxes represent taps within one standard deviation from location center, and the thinner represent two standard deviations. The vertical lines represent the landmarks—wrist, elbow, and shoulder joints and collarbone. The red dashed boxes highlight participants' mean values. The tables summarize the distance of each location center measured from the wrist joint relative to arm length; and absolute (in mm) and relative location sizes.

We evaluated whether there is a common layout of locations on the right and left arms that works for all users. In Fig. 6 the layouts highlighted in red dashed boxes represent the means of users' data points on each arm. These layouts capture 97.7% of data. This suggests that a uniform interface layout on the arms is possible. This layout includes slight overlaps. Nevertheless, the accuracy rate of this layout is 98%.

Abdomen Layout

Figure 7 illustrates the distribution of users' taps on the abdomen. Ellipses represent the spread of taps around the center of each location. The navel represented the centroid of abdomen locations. We explored whether reducing the number of locations can increase the accuracy of the abdomen area: removing locations from the center of the abdomen (L13, L14) or an entire row of locations (e.g., L11, L13, L15) increases the average accuracy rate of the remaining locations by 60%. Reducing the number of locations to two with maximum distance between them, e.g., L12 and L16, increases the abdomen's accuracy rate from 35% to 96%.

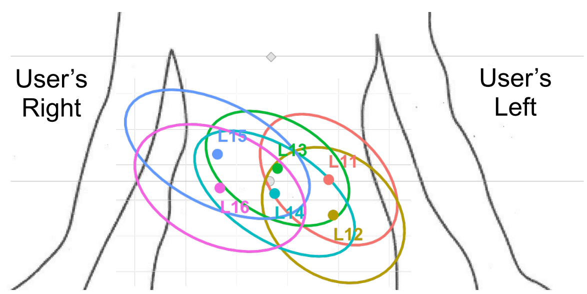

Figure 7. The projected tap distribution on the abdomen for all participants. The Ellipses are centered around each location's centroid and cover taps within two standard deviations from the center. The horizontal gray lines mark the level of the sternum (top) and the navel (below).

DISCUSSION AND DESIGN IMPLICATIONS

Based on the experimental results and observations of the user experiment, we present the following design implications:

Locations that are passive or closer to the hands are physically more comfortable to tap. Several participants noted that tapping at the elbow while it rapidly swings backwards and forwards required them to disturb their running pattern in order to synchronize the movements of their arms. In response, they attempted to hit away from the elbow, on a less active limb such as the forearm or the upper-arm (see L3, L4, L8, L9 Fig. 6). The abdomen, a more passive (stable) part, received participants' highest comfort ratings. In addition, the abdomen and the wrists were favored due to their proximity from the hands while in running form. These areas require small amplitude movements to make contact. In contrast, locations on higher body parts, e.g., shoulders, were found physically more demanding. Voelker et al. [28] described how lifting the arm upwards in mid-air leads to fatigue even when users are seated. *Designers should avoid placing targets on the elbow area. We recommend excluding the shoulder locations as they scored below 3.0 on the physical com-*

fort scale. Alternatively, less frequently accessed actions can mapped to the shoulders.

Users are more confident interacting near body landmarks. Participants' tapping confidence scores were higher for locations that were associated with a body landmark (e.g., wrist joint, elbow joint, shoulder, navel). When two locations share a single landmark, e.g., L6 and L7 share the shoulder joint, data shows that the participants associated one location with the landmark (e.g., L6 with the shoulder joint) and deliberately tapped further away from the landmark to signify the second location (e.g., L7). Lin et al. found that participants' taps were less spread near the wrist and elbow joints while tapping on the forearm. On the abdomen, participants reported that the navel helped guide their interactions. But as data shows that beyond acting as a pseudo-centroid for the abdomen area, the navel, a single landmark, was not enough to distinguish six locations accurately. Ängeslevä [1] showed that mapping actions to body landmarks improved participants' recall. *Designers should attempt to associate targets with body landmarks and void overloading a single landmark with several targets.*

Users prefer spreading input locations over the body rather than concentrating them. During the individualized action mapping task, participants chose to spread input locations over their body, maximizing the distance between any two locations instead of concentrating them in the most accessible areas (abdomen) or the most accurate areas (arms). Some participants described their layouts as 'easy to remember' and 'less likely to get confused'. This follows from the previous design implication. *Spreading actions over the body enables users to create clearer associations between targets and body landmarks and increases tapping confidence.*

The size of input areas on the body is not necessarily proportionate to limb size. Participants' taps were spread disproportionately on the arm (forearm, upper-arm, and shoulder) but similarly on both arms. Locations on the right arm were on average 10% larger than on the left arm.

A uniform interface layout on the upper body is possible. A general layout of five input locations per arm is possible. While the the layouts of locations on the right and left arms are not identical, they are very similar. On the abdomen, however, only by reducing the number of locations from six to two can we reach a uniform interface layout of 96% accuracy rate,

Tapping with the palm of the hand stabilizes users and eases cognitive load. In the pilot and the main experiment, participants consistently used the palm of their hands to tap on the body. Several participants reported that tapping with the palm of the hand on a moving body part (e.g., forearm) helped them maintain their balance. Many found it faster and easier to tap with the hands open rather than with a single finger. Hudson at al.'s [12] describes how inexact or inattentive input gestures require less cognitive resources from the users. In addition, most participants felt more confident that they were tapping the 'right' location on the body using their full hand.

LIMITATIONS AND FUTURE WORK

A main limitation of this study is that most participants were right handed. A follow-up study will be necessary to examine the influence of handiness on body tapping and for the implementation of future interfaces. In the study, participants ran at a jogging speed range (4.4-6.2 mph). We found no significant effect of speed on user performance. The effect of higher running speeds remains unexplored. Furthermore, the social acceptance issue should be considered beyond the lab setting. Moreover, we only investigate the tapping behaviors on the upper body, we recommend examining other accessible body areas (e.g., thighs) as well as other acceptable gestures on the body. Another important aspect to investigate is how users map functions to their own body space.

Technical Implementation

Although this work has derived the design implications and demonstrated the feasibility of on-body tapping for runners, a user study with a working system may be necessary to verify the design guidelines and assess learning effects. Wearable technologies for detecting tapping on the body include acoustic sensors [10], infrared proximity sensors [15], ultrasonic sensors [16], skin electronics [31], electricity [32], and interactive textiles [9, 13] . However, we have no evidence on how they perform when users are running. Schneegass et al. [23] revealed a first demonstrator of a textile sensor that can detect user input during walking and suggested several improvements to increase reliability. Smart textile technology is particularly interesting for interacting on large parts of the body as it can be embedded seamlessly into the user's clothes and scales well to a wide range of sensor sizes. In addition, an interactive training shirt, for example, can be designed to provide runners with tactile cues at interactive locations. We are in the process of developing a sensor that builds on [23]'s work to help us study users' tapping behavior.

CONCLUSION AND FUTURE WORK

This paper serves as the preliminarily foundation of body-centric interaction for runners. It explores the potential of on-body tapping as an eyes-free input technique for triggering actions in smart devices while the user is running. We present first insights on the distribution, accuracy, and perception of different tapping locations on the upper body. Based on the study, we propose on-body tapping as a feasible input modality for runners: Results show that a uniform interface layout of five input locations per arm and two locations on the abdomen is possible with 96% accuracy rate. Although this paper focused on runners, the design implications can contribute to efforts of designers and researchers investigating eyes-free input techniques for users during locomotion.

Acknowledgments

We thank Simon Voelker and Krishna Subramanian for valuable discussions during the progress of this project.

REFERENCES

1. Ängeslevä, J., Oakley, I., Hughes, S., and O'Modhrain, S. Body Mnemonics Portable Device Interaction Design Concept. In *UIST '03*, ACM, 2–5.

2. Ashbrook, D. L. *Enabling mobile microinteractions*. Georgia Institute of Technology, 2010.
3. Bergstrom-Lehtovirta, J., Oulasvirta, A., and Brewster, S. The Effects of Walking Speed on Target Acquisition on a Touchscreen Interface. In *MobileHCI '11*, ACM, 143–146.
4. Bossavit, B., Marzo, A., Ardaiz, O., and Pina, A. Hierarchical Menu Selection with a Body-Centered Remote Interface. *IwC '13*.
5. Brewster, S., Lumsden, J., Bell, M., Hall, M., and Tasker, S. Multimodal 'Eyes-free' Interaction Techniques for Wearable Devices. In *CHI '03*, ACM, 473–480.
6. Chen, X. A., Marquardt, N., Tang, A., Boring, S., and Greenberg, S. Extending a Mobile Device's Interaction Space Through Body-centric Interaction. In *MobileHCI '12*, ACM, 151–160.
7. Darling, W. G., and Miller, G. F. Transformations Between Visual and Kinesthetic Coordinate Systems in Reaches to Remembered Object Locations and Orientations. *Exp. Brain Res. 93*, 3, 534–547.
8. Gustafson, S. G., Rabe, B., and Baudisch, P. M. Understanding Palm-based Imaginary Interfaces: the role of Visual and Tactile Cues when Browsing. In *CHI '13*, ACM, 889–898.
9. Hamdan, N. A.-h., Blum, J. R., Heller, F., Kosuru, R. K., and Borchers, J. Grabbing at an Angle: Menu Selection for Fabric Interfaces. In *ISWC '16*, ACM, 1–7.
10. Harrison, C., Tan, D., and Morris, D. Skinput: Appropriating the Body as an Input Surface. In *CHI '10*, ACM, 453–462.
11. Huang, D.-Y., Chan, L., Yang, S., Wang, F., Liang, R.-H., Yang, D.-N., Hung, Y.-P., and Chen, B.-Y. DigitSpace: Designing Thumb-to-Fingers Touch Interfaces for One-Handed and Eyes-Free Interactions. In *CHI '16*, ACM, 1526–1537.
12. Hudson, S. E., Harrison, C., Harrison, B. L., and LaMarca, A. Whack Gestures: Inexact and Inattentive Interaction with Mobile Devices. In *TEI '10*, ACM, 109–112.
13. Karrer, T., Wittenhagen, M., Lichtschlag, L., Heller, F., and Borchers, J. Pinstripe: Eyes-Free Continuous Input on Interactive clothing. In *CHI '11*, ACM, 1313–1322.
14. Lakshmipathy, V., Schmandt, C., and Marmasse, N. TalkBack: A Conversational Answering Machine. In *UIST '03*, ACM, 41–50.
15. Laput, G., Xiao, R., Chen, X. A., Hudson, S. E., and Harrison, C. Skin Buttons: Cheap, Small, Low-powered and Clickable Fixed-icon Laser Projectors. In *UIST '14*, ACM, 389–394.
16. Lin, S.-Y., Su, C.-H., Cheng, K.-Y., Liang, R.-H., Kuo, T.-H., and Chen, B.-Y. Pub-Point Upon Body: Exploring Eyes-Free Interaction and Methods on an Arm. In *UIST '11*, ACM, 481–488.
17. Mauriello, M., Gubbels, M., and Froehlich, J. E. Social Fabric Fitness: The Design and Evaluation of Wearable E-Textile Displays to Support Group Running. In *CHI '14*, ACM, 2833–2842.
18. Mueller, F., Vetere, F., Gibbs, M. R., Edge, D., Agamanolis, S., and Sheridan, J. G. Jogging over a Distance Between Europe and Australia. In *UIST '10*, ACM, 189–198.
19. Oulasvirta, A., Tamminen, S., Roto, V., and Kuorelahti, J. Interaction in 4-second Bursts: The Fragmented Nature of Attentional Resources in Mobile HCI. In *CHI '05*, ACM, 919–928.
20. Profita, H. P., Clawson, J., Gilliland, S., Zeagler, C., Starner, T., Budd, J., and Do, E. Y.-L. Don't Mind me Touching my Wrist: A Case Study of Interacting with On-Body Technology in Public. In *ISWC '13*, ACM, 89–96.
21. Runtastic GmbH. Mobile Fitness App. 25-08-2017. `https://www.runtastic.com/en/apps/runtastic`.
22. Schildbach, B., and Rukzio, E. Investigating Selection and Reading Performance on a Mobile Phone while Walking. In *MobileHCI '10*, ACM, 93–102.
23. Schneegass, S., and Voit, A. GestureSleeve: Using Touch Sensitive Fabrics for Gestural Input on the Forearm for Controlling Smartwatches. In *ISWC '16*, ACM, 108–115.
24. Shoemaker, G., Tsukitani, T., Kitamura, Y., and Booth, K. S. Body-Centric Interaction Techniques for very Large Wall Displays. In *NordiCHI '10*, ACM, 463–472.
25. Tan, D. S., Pausch, R., Stefanucci, J. K., and Proffitt, D. R. Kinesthetic Cues Aid Spatial Memory. In *CHI EA '02*, ACM, 806–807.
26. Tholander, J., and Nylander, S. Snot, Sweat, Pain, Mud, and Snow: Performance and Experience in the Use of Sports Watches. In *CHI '15*, ACM, 2913–2922.
27. Vo, D.-B., Lecolinet, E., and Guiard, Y. Belly gestures: body centric gestures on the abdomen. In *NordiCHI '14*, ACM, 687–696.
28. Voelker, S., Sutter, C., Wang, L., and Borchers, J. Understanding Flicking on Curved Surfaces. In *CHI '12*, ACM, 189–198.
29. Wagner, J., Nancel, M., Gustafson, S. G., Huot, S., and Mackay, W. E. Body-Centric Design Space for Multi-Surface Interaction. In *CHI '13*, ACM, 1299–1308.
30. Warburton, D. E., Nicol, C. W., and Bredin, S. S. Health Benefits of Physical Activity: the Evidence. *CMAJ 174*, 6 (2006), 801–809.
31. Weigel, M., Nittala, A. S., Olwal, A., and Steimle, J. SkinMarks: Enabling Interactions on Body Landmarks Using Conformal Skin Electronics. ACM, 3095–3105.
32. Zhang, C., Bedri, A., Reyes, G., Bercik, B., Inan, O. T., Starner, T. E., and Abowd, G. D. TapSkin: Recognizing On-Skin Input for Smartwatches. In *ISS '16*, ACM, 13–22.