

# Effects of Moving Speed and Phone Location on Eyes-Free Gesture Input with Mobile Devices

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**Abstract.** Using smartphones while moving is challenging and can be dangerous. Eyes-free input gestures can provide a means to use smartphones without the need for visual attention from users. In this study, we investigated the effect of different moving speeds (standing, walking, or jogging) and different locations (phone held freely in the hand, or phone placed inside a shoulder bag) on eyes-free input gestures with smartphone. Our results from 12 male participants showed gesture's entering duration is not affected by moving speed or phone location, however, other features of gesture, such as length, height, width, area, and phone orientation, are mostly affected by moving speed or phone location. So, eyes-free gestures' features vary significantly as the user's environmental factors, such as moving speed or phone location, change and should be considered by designers.

**Keywords:** Eyes-free gestures · user's moving speed · phone's location · gesture features · phone movements · mobile device.

## 1 Introduction

Unlike desktop computers, which are typically used in a fixed and stable environment (*e.g.*, a typical setting would be the user seated), small screen devices like smartphones can be used in different environments, including indoors, outdoors, and so on [25]. Meanwhile, gesture input is mainstream on mobile device and a large majority of interaction with the touchscreen requires the visual attention of the user. However, a visual focus is not always possible or may be dangerous, *e.g.*, while walking or jogging. Gesture input can provide a modality to implement the interaction without the need to look at the smartphones [20]. In the literature, many empirical studies investigated the effect of different contextual factors on changes in user performance due to context, with varying findings.

In particular, interaction with touch surfaces in different mobility conditions is well studied in the literature, including note-taking when sitting [9], text entry when walking [6], wearable touch surfaces while standing [10], and web searching on a treadmill [14]. Different gestures based interaction techniques have been

also proposed. For example, Kubo et al. [16] introduced B2B-Swipe for eyes-free gesture from a bezel to a bezel on rectangular touchscreens, in particular for smartwatches. Negulescu et al. [17] studied the cognitive demands of an eyes-free tap, swipe, or move on a smartphone in distracted scenarios. Tinwala et al. [22] introduced an eyes-free text entry technique on touchscreens using graffiti strokes. However, to the best of our knowledge, no previous study have investigated the effect of mobility and smartphone location on eyes-free gesture production.

In this work, we investigate the effect of user’s moving speed and phone location on the articulation characteristics of gesture input. We run an experiment with 12 male participants to study the effect of three moving speeds (standing, walking and jogging) and two phone locations (the phone is hold freely alongside the body and in a shoulder bag) on gestures. Our findings indicate that the environmental factors (moving speed, and phone location) can significantly change gestures entered by participants. For example, the more is the user moving speed the more the gesture is bigger, faster and the more the phone move. while, holding the phone in a shoulder bag, have the inverse effect. Our findings also revealed that gesture production time was not affected by any of the variables.

## 2 Experiment

We conducted an experiment to evaluate the effect of the user’s moving speed and phone location on eyes-free gesture articulation on a mobile device.

### 2.1 Participants

Since the average walking and jogging speeds between genders are different and the same speed can cause different mental and physical loads for different genders [7], we only conducted experiments with twelve male participants to avoid increasing the number of independent variables in the analysis. Participants’ ages were between 20 and 34 years ( $mean = 26.8$ ,  $sd = 4.3$ ). All participants were right-handed, without any known mobility impairment, and had been using smartphones for several years.

### 2.2 Gesture set

The gesture set used in this study had 20 gestures in it. These gestures were selected from previous works(*e.g.*, [4, 2, 26]) and were composed of operands, letters, mark segments, rationally invariant and mnemonic gestures (see Figure 1).

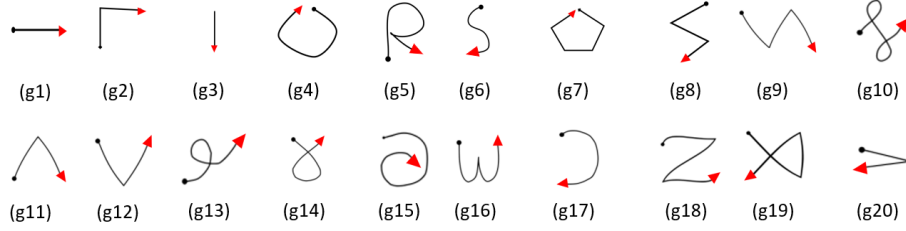


Fig. 1: Gesture set.

### 2.3 Apparatus

We collected stroke gestures using our custom software on a Samsung Galaxy S7 smartphone running Android 6.0.1. The smartphone was attached to a 1.5-meter cellphone lanyard to ensure it didn't fall. The smartphone's screen size is 5.65"×2.78" with a display resolution of 1440×2560 pixels and a pixel density of 227 pixels per cm. The smartphone's screen was mirrored onto a Samsung Galaxy Tab 7 tablet in front of participants while they were standing, walking, or jogging on a FreeMotion Reflex T11.8 treadmill. The dimensions of the shoulder bag used in the experiments were 20cm × 20cm × 5cm.

### 2.4 Design

The experiment used a  $3 \times 2$  within-subject design with two factors: *moving speed* and *smartphone location*. We followed [15] and chose to control the moving speed during the experiment. As in [15], the rationale for fixing the walking speed is that first, we assume that users will be unable to slow down or stop walking to use their mobile device, and second, by doing so, impaired walking effects are maximized as users can not slow down if the task becomes difficult. *Moving speed* covers three conditions: (1) standing at 0 km/h, (2) walking at 4.6 km/h, and (3) jogging at 8 km/h. The moving speed values are defined through preliminary experiments with two participants. We chose speeds that are different and fast enough that they have the potential to cause an effect while still being comfortable for participants to hold and use their smartphones. The participants in the preliminary experiment reported high frustration and difficulty conducting experiments at high speeds, such as 10 km/h. We therefore did not consider a running condition. *Phone location* describes how the phone is held by the dominant hand and covers two conditions: (1) free where the phone is held freely alongside the body (see Figure 2a) and (2) bag where the phone is held inside a shoulder bag (see Figure 2b).

### 2.5 Task & Procedure

During the experiment, participants stand on a treadmill in a gym. Participants were then asked to hold the phone with their dominant hand and use the thumb

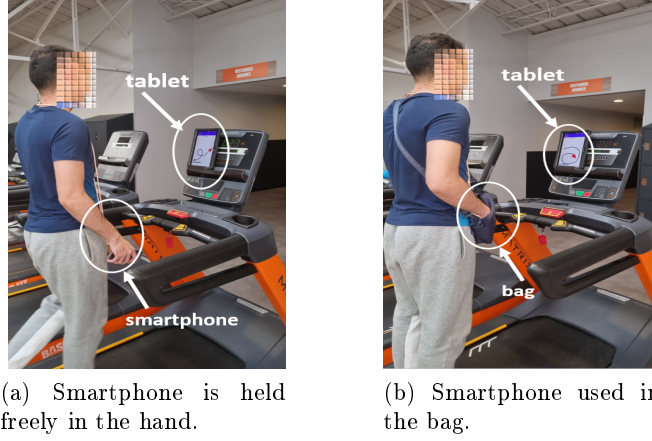


Fig. 2: Phone location during experiment: a) freely b) in the bag.

of their dominant hand to draw gestures on the screen without looking at the phone. In the free condition, participants were asked to hold the phone alongside their body (see Figure 2a). In the bag condition, participants were asked to hold the phone inside a shoulder bag (see Figure 2b). A preview of the gesture they had to draw was shown on a tablet placed in front of them on the treadmill. Since all the gestures in this experiment were single strokes, as soon as they lifted their finger from the touchscreen next gesture appeared. In case of any false entry, participants always had the option to use the back button of the phone to return to previous gestures.

In the experiment phase, two phone location conditions were randomly presented to the participants. For each phone location, the three moving speed conditions were also randomly presented. Each participant in total performed 600 gestures ( $= 2 \text{ phone locations} \times 3 \text{ moving speeds} \times 20 \text{ gesture types} \times 5 \text{ repetitions}$ ). For each moving speed and phone location condition the gestures were presented to participant in a random order. The experiment took 30 minutes on average to complete.

### 3 Results

Our results include gesture features and smartphone directional movements. We also analyzed the qualitative observations. All analyses used a two-way ANOVA. Tukey post-hoc tests were used post-hoc when significant effects were found. Only significant effects and interactions are reported.

#### 3.1 Gesture Features

We selected six geometric features: (a) gesture length, (b) gesture height, (c) gesture width, (d) gesture area, (e) gesture duration, and (f) gesture speed. These

features have been employed in the gesture recognition and analysis literature [1, 21, 3, 23, 19] in order to characterize how stroke-gestures are produced by users.

**Gesture length.** Gesture length is the cumulative path distance from the first touch event registered to the last. We found significant main effects of *speed moving* ( $F_{2,22} = 27.232$ ,  $p < .0001$ ) and *phone location* ( $F_{1,11} = 10.659$ ,  $p = .008$ ) on *gesture length*. The jogging ( $mean = 10.63cm$ ,  $sd = 4.53cm$ ) led participants entering gestures with the longest lengths then walking ( $mean = 10.20cm$ ,  $sd = 4.63cm$ ) and standing ( $mean = 9.67cm$ ,  $sd = 4.55cm$ ). Post-hoc test confirms differences between all pairs ( $p < .05$ ). Holding phone freely ( $mean = 10.52cm$ ,  $sd = 4.53cm$ ) led also to gestures with significantly longer lengths than when holding it in a bag ( $mean = 9.85cm$ ,  $sd = 4.45cm$ ) ( $p < .05$ ).

**Gesture height.** Gesture height is the height of the bounding box that contains the gesture ( $max_{\mathbf{y}} - min_{\mathbf{y}}$ ). We found significant main effects of *moving speed* ( $F_{2,22} = 6.444$ ,  $p = .006$ ) and *phone location* ( $F_{1,11} = 23.963$ ,  $p = .0005$ ) on *gesture height*. Post-hoc tests show that standing ( $mean = 3.70cm$ ,  $sd = 1.77cm$ ) determined participants to produce gestures with significantly smaller heights than both walking ( $mean = 3.83cm$ ,  $sd = 1.74cm$ ) and jogging ( $mean = 3.87cm$ ,  $sd = 1.64cm$ ) ( $p < .05$ ). Holding phone freely ( $mean = 3.97cm$ ,  $sd = 1.64cm$ ) led to gestures with significantly higher heights than holding phone in a bag ( $mean = 3.65cm$ ,  $sd = 1.68cm$ ) ( $p < .05$ ).

**Gesture width.** Gesture width is the width of the bounding box that contains the gesture ( $max_{\mathbf{x}} - min_{\mathbf{x}}$ ). We found significant main effects of *moving speed* ( $F_{2,22} = 18.615$ ,  $p < .0001$ ) on *gesture width*. Larger widths than both walking ( $mean = 3.15cm$ ,  $sd = 1.16cm$ ) and standing ( $mean = 3.06cm$ ,  $sd = 1.20cm$ ) ( $p < .05$ ).

**Gesture area.** Gesture area is the surface area of the bounding box containing the gesture (height  $\times$  width). We found significant main effects of *moving speed* ( $F_{2,22} = 7.415$ ,  $p = .004$ ) and *phone location* ( $F_{1,11} = 11.823$ ,  $p = .006$ ) on *gesture area*. Post-hoc tests show that jogging ( $mean = 13.32cm^2$ ,  $sd = 8.86cm^2$ ) led to gestures with significantly larger area than both walking ( $mean = 12.99cm^2$ ,  $sd = 9.52cm^2$ ) and standing ( $mean = 12.33cm^2$ ,  $sd = 9.58cm^2$ ) ( $p < .05$ ). Holding phone freely ( $mean = 13.76cm^2$ ,  $sd = 8.86cm^2$ ) produced gestures with significantly larger area than when smartphone was in a bag ( $mean = 12.05cm^2$ ,  $sd = 8.89cm^2$ ) ( $p < .05$ ).

**Gesture duration.** Gesture duration is the time elapsed while entering the gesture, *i.e.*, the timestamp of the last touch event registered for the gesture minus the timestamp of the first touch event. We found no significant main effects on *gesture duration* nor interaction between moving and grasping ( $p > 0.057$ ).

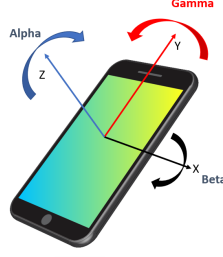


Fig. 3: Axes and orientations of the smartphone.

**Gesture speed.** Gesture speed is the average speed registered over all the touch events belonging to a gesture (length/duration). We found significant main effects of *moving speed* ( $F_{2,22} = 15.966$ ,  $p < .0001$ ) and *phone location* ( $F_{1,11} = 13.596$ ,  $p = 0.004$ ) on *gesture speed*. Post-hoc tests show that the jogging ( $mean = 12.40cm/s$ ,  $sd = 3.99cm/s$ ) determined participant to produce significantly faster gestures than both walking ( $mean = 10.84cm/s$ ,  $sd = 3.52cm/s$ ) and standing ( $mean = 10.81cm/s$ ,  $sd = 3.55cm/s$ ) ( $p < .05$ ). Holding phone freely ( $mean = 12.25cm/s$ ,  $sd = 3.99cm/s$ ) led to significantly faster gestures than holding phone in the bag ( $mean = 10.45cm/s$ ,  $sd = 3.63cm/s$ ) ( $p < .05$ ).

### 3.2 Mobile Directional Movement

Previous work showed that hand usage and body postures affect smartphone movement as users' perception of the smartphone device could be boosted [11]. It is therefore important to understand how eyes-free interaction may influence the tilt and rotation of the smartphone during gesture production. We then consider the same dependent variables than in [11] to characterise the phone's movement: Alpha (z-axis), Beta (x-axis) and Gamma (y-axis) using the inbuilt accelerometer and gyroscope (see Figure 3). For each of the directional axes, we captured the total deviation made around this axis, computed as the difference between the largest and the smallest value.

**Alpha deviation – deviation around z axis** There were significant main effects of *moving speed* ( $F_{2,22} = 107.146$ ,  $p < .0001$ ) and *phone location* ( $F_{1,11} = 7.038$ ,  $p = 0.023$ ) on *alpha*. Post-hoc test show that during jogging ( $mean = 14.34^\circ$ ,  $sd = 9.14^\circ$ ) participants held smartphone with significantly larger deviation around z axis than both during walking ( $mean = 9.19^\circ$ ,  $sd = 7.06^\circ$ ) and standing ( $mean = 4.91^\circ$ ,  $sd = 5.20^\circ$ ), and walking had larger deviation around z axis compared to standing. We also found that the deviation of the phone around the z axis while holding it freely ( $mean = 11.47^\circ$ ,  $sd = 9.14^\circ$ ) is significantly larger than when it is held in a bag ( $mean = 7.83^\circ$ ,  $sd = 7.39^\circ$ ) ( $p < .05$ ).

**Beta deviation – deviation around x axis** There was significant main effect of *moving speed* ( $F_{2,22} = 68.322$ ,  $p < .0001$ ) on *beta*. Post-hoc test show that during jogging ( $mean = 22.75^\circ$ ,  $sd = 11.59^\circ$ ) participants held smartphone with significantly higher deviation around x axis than during walking

( $mean = 16.32^\circ, sd = 9.90^\circ$ ) and standing ( $mean = 6.43^\circ, sd = 6.18^\circ$ ), and walking had larger deviation around x axis compared to standing ( $p < .05$ ).

**Gamma deviation – deviation around y axis** There was a significant main effects of *moving speed* ( $F_{2,22} = 93.213, p < .0001$ ) on *gamma* with *moving speed*  $\times$  *phone location* ( $F_{2,22} = 8.538, p < .002$ ) interaction. Post-hoc tests show, when standing (respectively, walking), holding the smartphone freely ( $mean = 5.60^\circ, sd = 4.36^\circ$ ) (respectively,  $mean = 9.39^\circ, sd = 6.65^\circ$ ) implies larger deviation around y axis than when holding the phone in a bag ( $mean = 2.65^\circ, sd = 3.07^\circ$ ) (respectively,  $mean = 6.442^\circ, sd = 4.728^\circ$ ) ( $p < .05$ ). However, when user runs the gamma deviation is significantly larger when the smartphone is placed in a bag ( $mean = 12.10^\circ, sd = 7.52^\circ$ ) compared to when it's hold freely ( $mean = 10.56^\circ, sd = 3.07^\circ$ ) ( $p < .05$ ).

### 3.3 Qualitative findings

During the experiments, some participants reported that when they were jogging they felt like they want to draw gestures faster. Some participant found some gestures were more complex and need more focus to draw which can be challenging to draw in a real time scenario, where they need to also remember the gesture shape. In particular, our participants found letter shaped gestures with curves and corners more complex to draw than the remainder gestures shapes. Jogging at 8 km/h was physically difficult for some participants and they had to take breaks in between.

## 4 Discussion and Future work

Our key finding is that the faster the moving speed, the longer, larger, and faster stroke gestures are produced. Inversely, when holding the phone in a bag, the produced gestures are slower, shorter, and smaller than when holding the phone freely. We also found no significant interaction ( $p > .05$ ), suggesting that these findings are consistent across respectively, different phone locations and moving speeds. Consequently, for walking and jogging, as well as for holding the phone in a bag, recognizers that rely on geometric and kinematic gesture descriptors, such as [21] (p. 335) should be used with precaution.

Importantly, it was interesting that our results showed that gesture production time was not affected by moving speed nor by phone location. In particular, moving faster or holding the phone freely led to faster gestures without requiring less time to draw the gesture but instead longer gestures which caused the gesture entering speed to increase. This result was expected due to findings from motor control theory that proved a dependency between writing speed and path length [24]. This finding advocates that long gestures as convenient shortcuts for different users moving speeds as people compensate the extra gesture length with increased gesture speed.

When it comes to the orientation of the smartphone a similar trend was observed. Generally, the higher moving speed participant had the more deviation

in the angles alpha and beta were observed. These findings can be explained by the fact that the more the user body moves, the more the phone will move. Consequently, designers should take into account this additional phone movement when considering motion gestures in their design for walking contexts [17].

However an opposite effect (*i.e.*, less phone movements) was observed when the phone is hold in a bag compared to holding the phone freely in particular for alpha deviation as well as when standing or walking for gamma deviation. These findings can be explained by the fact that when the phone is in a shoulder bag, there is less space to manipulate the phone which implies a phone more stable.

Our findings also indicate that gestures shapes (*e.g.*, letters) with complex geometries (*i.e.*, with a mixture of curves and lines) were more complex to draw. Thus, we recommend designers to avoid using such gesture shapes for moving contexts. And if needed they should be designed so that they are easy to articulate such that learning and memorization are facilitated.

Like any study, our study presents limitations. For example, in our study participants were younger than the population average, were right-handed, and all are men. Undoubtedly, elder people, children, left-handed or woman participants would behave differently. Participants were instructed to use a single-handed grip to generate the gestures on the touchscreen device. Additionally, as other phone locations exist with other dimensions like holding the phone in the pocket or inside other types/sizes of bags, and as the features of the produced gesture might change depending on the available space to hold the phone. These factors limits the overall generalizability of our findings for others interaction involving different hand grips [11] or body postures [12]. Also, only one phone was used in the experiments. Other phone sizes or form factors may produce different results or observations. These issues are worthy of investigation, but are beyond the scope of the current work. Moreover, the number of participants in our study was only 13 which is enough for a pilot study but more number of participants can be recruited in future.

Future work will also consider more challenging scenarios where participants are encumbered (*e.g.*, holding objects such as shopping bags [18]) or had to focus their attention on some other primary task that could be cognitively or/and visually demanding (*e.g.*, writing a text [5, 13], performing a saturation attention task [13] or driving [8]). Finally, future work will investigate the effect of adding haptic feedback during eyes-free gesture production.

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## References

1. Anthony, L., Brown, Q., Nias, J., Tate, B.: Examining the need for visual feedback during gesture interaction on mobile touchscreen devices for kids. In: Proceedings of the 12th International Conference on Interaction Design and Children. p. 157–164. IDC '13, Association for Computing Machinery, New York, NY, USA (2013). <https://doi.org/10.1145/2485760.2485775>
2. Appert, C., Zhai, S.: Using strokes as command shortcuts: Cognitive benefits and toolkit support. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. p. 2289–2298. CHI '09, ACM, New York, NY, USA (2009). <https://doi.org/10.1145/1518701.1519052>
3. Blagojevic, R., Chang, S.H.H., Plimmer, B.: The power of automatic feature selection: Rubine on steroids. In: Proceedings of the Seventh Sketch-Based Interfaces and Modeling Symposium. p. 79–86. Eurographics Association, Goslar, DEU (2010)
4. Bragdon, A., Nelson, E., Li, Y., Hinckley, K.: Experimental analysis of touchscreen gesture designs in mobile environments. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. pp. 403–412 (2011). <https://doi.org/10.1145/1978942.1979000>
5. Chen, Q., Perrault, S.T., Roy, Q., Wyse, L.: Effect of temporality, physical activity and cognitive load on spatiotemporal vibrotactile pattern recognition. In: Proceedings of the 2018 International Conference on Advanced Visual Interfaces. AVI '18, Association for Computing Machinery, New York, NY, USA (2018). <https://doi.org/10.1145/3206505.3206511>
6. Clawson, J., Starner, T., Kohlsdorf, D., Quigley, D.P., Gilliland, S.: Texting while walking: an evaluation of mini-qwerty text input while on-the-go. In: Proceedings of the 16th international conference on Human-computer interaction with mobile devices & services. pp. 339–348 (2014). <https://doi.org/10.1145/2628363.2628408>
7. Coast, J.R., Blevins, J.S., Wilson, B.A.: Do gender differences in running performance disappear with distance? *Canadian Journal of Applied Physiology* **29**(2), 139–145 (2004)
8. Cockburn, A., Woolley, D., Thai, K.T.P., Clucas, D., Hoermann, S., Gutwin, C.: Reducing the attentional demands of in-vehicle touchscreens with stencil overlays. In: Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '18. pp. 33–42. ACM Press (2018)
9. Dai, L., Sears, A., Goldman, R.: Shifting the focus from accuracy to recallability: A study of informal note-taking on mobile information technologies. *ACM Transactions on Computer-Human Interaction (TOCHI)* **16**(1), 1–46 (2009)
10. Dobbstein, D., Winkler, C., Haas, G., Rukzio, E.: Pocketthumb: A wearable dual-sided touch interface for cursor-based control of smart-eyewear. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* **1**(2), 1–17 (2017)
11. Eardley, R., Roudaut, A., Gill, S., Thompson, S.J.: Understanding Grip Shifts: How Form Factors Impact Hand Movements on Mobile Phones, p. 4680–4691. ACM, New York, NY, USA (2017)
12. Eardley, R., Roudaut, A., Gill, S., Thompson, S.J.: Investigating How Smartphone Movement is Affected by Body Posture, p. 1–8. ACM, New York, NY, USA (2018)
13. Guettaf, A., Rekik, Y., Grisoni, L.: Effect of attention saturating and cognitive load on tactile texture recognition for mobile surface. In: *Human-Computer Interaction*

- INTERACT 2021: 18th IFIP TC 13 International Conference, Bari, Italy, August 30 – September 3, 2021, Proceedings, Part IV. p. 557–579. Springer-Verlag, Berlin, Heidelberg (2021)
- 14. Harvey, M., Pointon, M.: Searching on the go: the effects of fragmented attention on mobile web search tasks. In: Proceedings of the 40th International ACM SIGIR Conference on Research and Development in Information Retrieval. pp. 155–164 (2017)
- 15. Kane, S.K., Wobbrock, J.O., Smith, I.E.: Getting off the treadmill: Evaluating walking user interfaces for mobile devices in public spaces. In: Proceedings of the 10th International Conference on Human Computer Interaction with Mobile Devices and Services. p. 109–118. ACM, New York, NY, USA (2008)
- 16. Kubo, Y., Shizuki, B., Tanaka, J.: B2b-swipe: Swipe gesture for rectangular smart-watches from a bezel to a bezel. In: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems. pp. 3852–3856 (2016)
- 17. Negulescu, M., Ruiz, J., Li, Y., Lank, E.: Tap, swipe, or move: Attentional demands for distracted smartphone input. In: Proceedings of the International Working Conference on Advanced Visual Interfaces. p. 173–180. AVI '12, ACM, New York, NY, USA (2012)
- 18. Ng, A., Williamson, J., Brewster, S.: The effects of encumbrance and mobility on touch-based gesture interactions for mobile phones. In: Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services. p. 536–546. MobileHCI '15, Association for Computing Machinery, New York, NY, USA (2015). <https://doi.org/10.1145/2785830.2785853>
- 19. Rekik, Y., Vatavu, R.D., Grisoni, L.: Understanding users' perceived difficulty of multi-touch gesture articulation. In: Proceedings of the 16th International Conference on Multimodal Interaction. p. 232–239. ACM, New York, NY, USA (2014)
- 20. Roudaut, A., Rau, A., Sterz, C., Plauth, M., Lopes, P., Baudisch, P.: Gesture Output: Eyes-Free Output Using a Force Feedback Touch Surface, p. 2547–2556. ACM, New York, NY, USA (2013)
- 21. Rubine, D.: Specifying gestures by example. In: Proceedings of the 18th Annual Conference on Computer Graphics and Interactive Techniques. p. 329–337. SIGGRAPH '91, ACM, New York, NY, USA (1991)
- 22. Tinwala, H., MacKenzie, I.S.: Eyes-free text entry on a touchscreen phone. In: 2009 IEEE Toronto International Conference Science and Technology for Humanity (TIC-STH). pp. 83–88 (2009)
- 23. Vatavu, R.D., Vogel, D., Casiez, G., Grisoni, L.: Estimating the perceived difficulty of pen gestures. In: Campos, P., Graham, N., Jorge, J., Nunes, N., Palanque, P., Winckler, M. (eds.) Human-Computer Interaction – INTERACT 2011. pp. 89–106. Springer Berlin Heidelberg, Berlin, Heidelberg (2011)
- 24. Viviani, P., Terzuolo, C.: 32 space-time invariance in learned motor skills. In: Stelmach, G.E., Requin, J. (eds.) *Tutorials in Motor Behavior, Advances in Psychology*, vol. 1, pp. 525–533. North-Holland (1980)
- 25. Wobbrock, J.O.: Situationally aware mobile devices for overcoming situational impairments. In: Proceedings of the ACM SIGCHI Symposium on Engineering Interactive Computing Systems. EICS '19, ACM, New York, NY, USA (2019)
- 26. Wobbrock, J.O., Wilson, A.D., Li, Y.: Gestures without libraries, toolkits or training: A \$1 recognizer for user interface prototypes. In: Proceedings of the 20th Annual ACM Symposium on User Interface Software and Technology. p. 159–168. UIST '07, ACM, New York, NY, USA (2007)