The Effects of Mobility, Encumbrance, and (Non-)Dominant Hand on Interaction with Smartwatches

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ABSTRACT
Smartwatches are designed for short interactions in varying mobile contexts. However little data is available on how present mobile conditions affect interaction with these devices. In this work, we investigate the effects of mobility (walking), encumbrance (by carrying items like shopping bags) and wearing the watch on the (non-) dominant hand on interaction techniques present with current devices: tapping targets, swiping, and flicking the wrist. The results showed that for tapping and swiping, the outfitted hand had the largest effect on selection time (9.41%, resp. 4.84% slower interaction when the watch was worn on the dominant hand), while for wrist flicking, encumbrance had the largest effect (11.94% slower when carrying bags). The walking condition had the largest effect on the error rate for all techniques. Swiping as an interaction technique was barely affected by any condition, both in terms of selection time and error rate, making it a robust mobile interaction technique for smartwatches.

Author Keywords
Smartwatch interaction; mobility; encumbrance; hand dominance; tapping; swiping; wrist-flicking

ACM Classification Keywords
H.5.2. User Interfaces: Input devices and strategies

INTRODUCTION
Smartwatches benefit from being quickly accessible at the user's wrist. This is especially beneficial in mobile context where access time for short interaction is important [1]. Mobile contexts, however, often have a negative effect on interactions when the user is on the move and potentially having their hands partly restricted by other physical activities.

Encumbrance and Walking
Users in mobile contexts are unlikely to focus all their attention on interaction with their mobile devices and often find their attention shared with other activities such as walking and carrying objects like shopping bags [7]. Ng. et al [6] observed that smartphone users that concurrently hold and carry objects while interacting with their devices are a frequent occurrence in public. In subsequent experiments, they found that users were significantly less accurate at targeting on a smartphone when being encumbered by carrying boxes or shopping bags.

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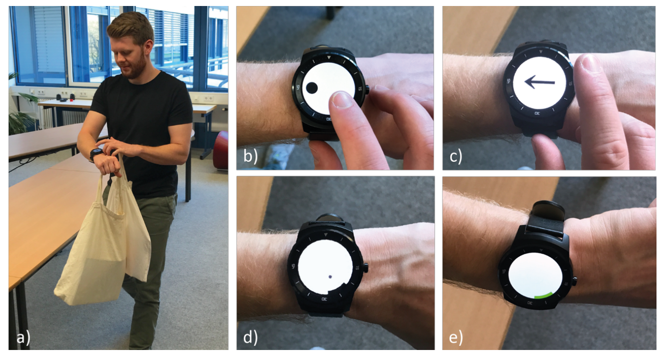

Figure 1. A user selecting targets while walking, being encumbered by carrying shopping bags, and wearing the watch on the non-dominant hand (a). We investigate the effects on tapping to select targets (b), swiping gestures (c), and flicking the wrist (d&e).

While most smartphones support one-handed interaction, many interactions with smartwatches involve and require both hands [8] by passively restricting the watch-outfitted hand in its movement and making use of the non-outfitted hand for touch interaction (notable exceptions are voice input, wrist-flicking and glancing at information). This could potentially make touch interaction with smartwatches even more prone to encumbrance as with devices that can be operated one-handed.

(Non-)dominant hand
Most research on touch performance implicitly imposes the use of a finger of the dominant hand [2]. Watches are traditionally worn on the left non-dominant hand, but differences in hand dominance (left-handed) and also personal liking lead to watches not always being worn on the left nor on the non-dominant hand. For smartwatches, the outfitted hand can often be chosen in the settings, for being relevant when it comes to tracking activities. For interaction, we hypothesize that the outfitted hand could have an impact: wearing the watch on the dominant instead of non-dominant hand could negatively affect touch interaction (then performed by the non-dominant hand), but on the other side could also have a positive effect on wrist-flicking interaction (then performed by the dominant hand).

Little data is available on how these conditions affect interaction with smartwatches, even though they span many mobile contexts. For this reason, we investigate the effects of mobility (walking), encumbrance (by carrying shopping bags) and outfitted hand (watch is worn on the dominant or non-dominant hand) for typical interaction techniques present with current smartwatches: tapping at targets (mainly used on Apple watchOS), swiping gestures (mainly used on Android Wear), and flicking the wrist (optional on Android Wear).

STUDY

We conducted a user study as a repeated measures factorial design with three independent variables:

Mobility

We used two conditions for *mobility*. For *walking*, participants would walk around an oval shaped table (5.3m long, 2.8m wide) in an empty seminar room (see Fig. 1) and reverse their direction at one end to balance the direction of movement. We allowed participants to find their own pace where they felt comfortable to move and interact at the same time. As a baseline, we used a *standing* condition.

Encumbrance

For *encumbrance*, participants would carry two shopping bags, one in each hand, each weighing 900g. As a baseline, participant would not be encumbered.

Outfitted Hand

For the *outfitted hand*, participants wore the watch either on the *dominant*, or as a baseline on the *non-dominant* hand.

This resulted in 8 combinations (2 *mobilities* x 2 *encumbrances* x 2 *outfitted hand* conditions) counterbalanced with a 8x8 latin square. Each participant undertook these 8 conditions for each of the three interaction techniques (*tapping*, *swiping*, and *wrist-flicking*), completing all conditions of an *interaction technique* before moving to the next one. The order of *interaction techniques* was counterbalanced, leading to overall 24 orders of conditions. Each condition started with a random training set of 8 trials, followed by 36 recorded trials. Participants kept their hand close to the watch during each condition to allow measuring *selection* rather than *access* time.

The dependent variables were *selection time* and *error rate*.

Participants and Procedure

We randomly recruited 24 participants (3 left-handed, none both-handed, 7 female) from our institution with an average age of 24.8 (range: 21 to 44). 11 participants regularly wear watches, of whom 1 left-handed participant stated to wear his watches on the dominant rather on the non-dominant hand. 2 participants stated to have a high level of experience with smartwatches, another 4 participants had experience due to previous studies using smartwatches. For the study, we used a LG G Watch R running Android Wear 1.5. The study took 60 minutes on average and each participant received €10 and a chocolate bar as compensation.

Tapping

For tapping, we used a target selection task with round targets having a diameter of 48dp (~7mm). This corresponds to the minimal button size as suggested by the Android Wear guidelines and is slightly larger than homescreen icons on Apple watchOS (~6.1mm). Targets were selected successively in random order. If a participant failed to successfully select a target, the trial was repeated at a later point in time. We used 9 pre-defined target locations and each location had to be selected 4 times. With 8 conditions and 24 participants this resulted in 6912 selections.

Selection time

For the selection time, a 2x2x2 (*encumbrance* x *mobility* x *outfitted hand*) repeated measures ANOVA (sphericity was met) showed significant effects for *encumbrance* ($F(1,23) = 10424$, $p<.01$, $\eta^2=.312$), *mobility* ($F(1,23) = 21557$, $p<.001$, $\eta^2=.484$) and *outfitted hand* ($F(1,23) = 67513$, $p<.001$, $\eta^2=.746$). There was no significant interaction between the effects. Being encumbered, and walking made selections 2.66%, resp. 4.22% slower, while wearing the watch on the dominant hand had the largest effect (9.41% slower).

Error Rate

For the error rate, a repeated measures ANOVA (sphericity was met) showed significant effects for *encumbrance* ($F(1,23) = 9598$, $p<.01$, $\eta^2=.294$), *mobility* ($F(1,23) = 50221$, $p<.001$, $\eta^2=.686$) and *outfitted hand* ($F(1,23) = 8763$, $p<.01$, $\eta^2=.276$). There was a significant interaction between the effects of *encumbrance* and *mobility* ($F(1,23) = 11385$, $p<.01$, $\eta^2=.331$)

Mobility had by far the largest effect on the error rate, increasing the chance of missing a target from 2.87% for *standing* to 9.67% for *walking*. The *outfitted hand* had the lowest effect increasing the error rate only by 30.3% (in contrast to 226.8% for *mobility* when *walking*)(see Fig. 2).

Swiping

For swiping, participants would perform directional touch gestures (up, down, left, and right). Swiping gestures are frequently used in Android Wear to navigate through applications and notifications and also used in Apple watchOS to navigate within applications or to open and close the notification- or command center.

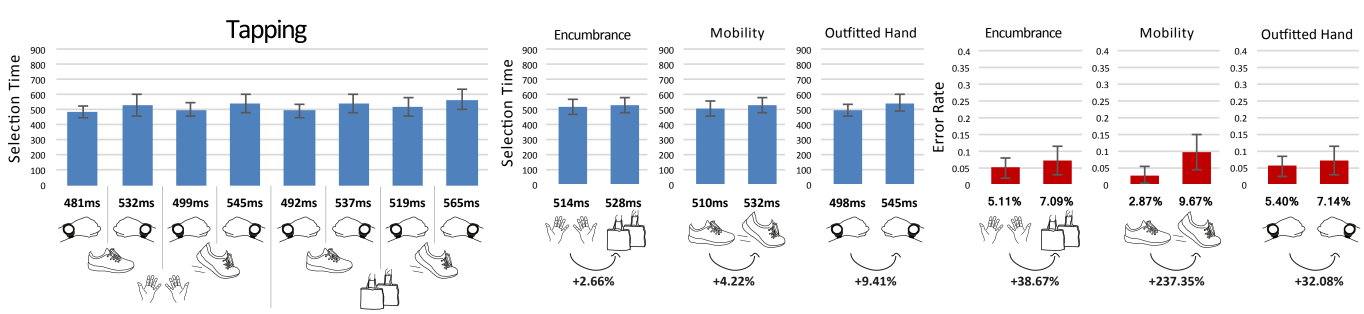

Figure 2. Selection time and error rate for tapping selections. The *outfitted hand* had the largest effect on the selection time (9.41%), while *encumbrance* and *mobility* had comparatively low effects (2.66%, resp. 4.22%). The error rate was significantly increased by all conditions. *Walking* had the largest effect (237.35%), followed by being *encumbered* by carrying shopping bags (38.67%) and wearing the watch on the *dominant* hand (32.08%). We depict the *non-dominant* hand as a left-hand icon and the *dominant* hand as a right-hand icon, albeit the handedness was reversed for left-handed participants.

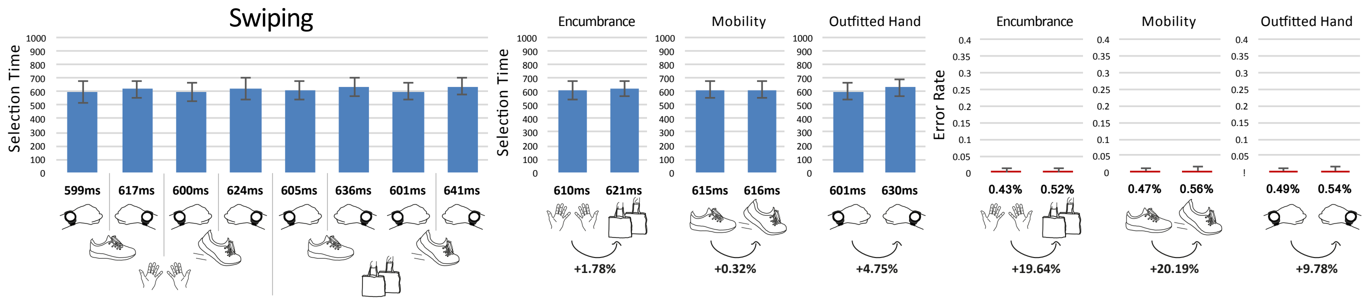

Figure 3. Selection time and error rate for swiping gestures. Swiping was in general barely effected by any condition. The *outfitted* hand had a significant effect on the selection time, but this was only a slight increase (4.75%).

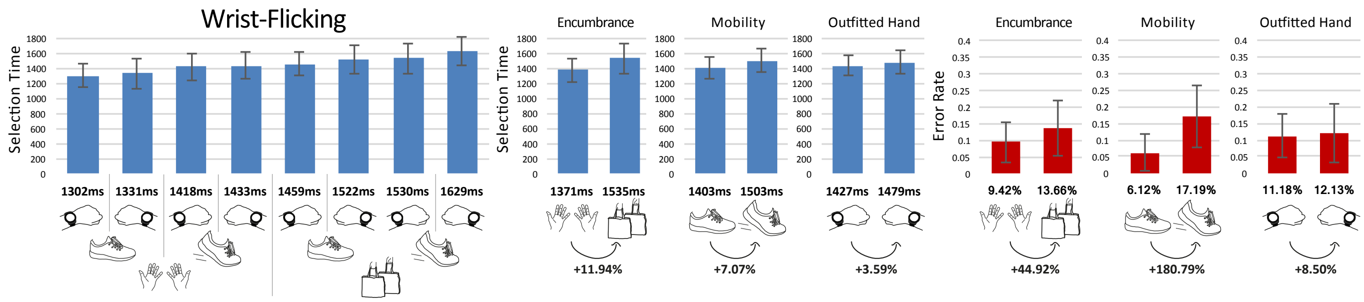

Figure 4. Selection time and error rate for wrist-flicking gestures. *Encumbrance* had the largest effect on the selection time (11.94%), while *walking* had the largest effect on the error rate (180.79%).

The respective swiping direction was displayed for each task with a large arrow on the display (see Fig. 1). As with tapping, trials were conducted successively in random order. We used 4 directions and each directional gesture had to be performed 9 times, resulting in 6912 gestures.

Selection Time

For the selection time, a repeated measures ANOVA (sphericity was met) showed significant effects for the *outfitted hand* ($F(1,23) = 24855$, $p<.001$, $\eta^2=.519$), being 4.75% slower. *Mobility* and *encumbrance* had no significant effects on the selection time (1.9%, resp. 0.3% slower).

Error Rate

A repeated measures ANOVA (sphericity was met) showed no significant effect on the *error rate* for any of the conditions. The error rate remained below 0.6% under any condition (see Fig. 3).

Wrist Flicking

Wrist flicking can be used on Android Wear to navigate through notifications by quickly flicking the wrist inwards or outwards and then back into the starting position. This has the advantage that unlike with touch-gestures on the watch, only one hand is required for interaction. Guo et al. [3] argue that flicking or tilting on a watch could be used for more pronounced interaction. Flicking the watch inwards or outwards can also be regarded as flicking a virtual on-screen cursor to the 12 or 6 o'clock position and back into the middle of the screen. For a more profound flicking interaction we utilize all 12 clock positions with different target sizes (30°, 45°, 90°) (see Fig. 5). Participants would move a virtual on-screen cursor towards a clock position by flicking the wrist in the respective direction (see Fig. 1) and then back into a flat reference position. Each position was selected for three different target sizes by each participant, resulting in 6912 flicking gestures.

Selection Time

For the selection time, a repeated measures ANOVA (sphericity was met) showed significant effects for *encumbrance* ($F(1,23) = 123750$, $p<.001$, $\eta^2=.843$), *mobility* ($F(1,23) = 24341$, $p<.001$, $\eta^2=.514$), and the *outfitted hand* ($F(1,23) = 8780$, $p<.01$, $\eta^2=.276$). There was no significant interaction between the effects. Being *encumbered* had the largest effect and made wrist-flicking 11.94% slower, followed by *mobility* (7.07%) and *outfitted hand* (3.59%). Contrary to the hypothesis, using the *non-dominant* hand was slightly faster than using the *dominant* hand.

Error Rate

For the error rate, a repeated measures ANOVA (sphericity was met) showed significant effects for *encumbrance* ($F(1,23) = 21028$, $p<.001$, $\eta^2=.478$) and *mobility* ($F(1,23) = 88254$, $p<.001$, $\eta^2=.793$). There was no significant interaction between the effects. The *outfitted hand* had no significant effect.

Target Position and Size

We furthermore looked at the different target positions and target sizes (see Fig. 5). Participants were fastest when flicking to the 6 and 12 o'clock position. These could be selected by solely rotating the wrist. Other positions involved movement of the arm (e.g. moving the hand down or up for the 3 and 9 o'clock position). Interestingly the error rate was lowest for the 3, 6, 9 and 12 o'clock positions, which could be due to the remaining clock positions requiring both: movement of the arm (hand up or down) and rotation of the wrist (inwards or outwards). The error rate for 90° targets was quite low (2.20%), while for 30° it was very high (16.25%), suggesting that 90° targets at the 3, 6, 9 and 12 o'clock position could extend current wrist-flicking gestures (which only use 6 and 12 o'clock positions).

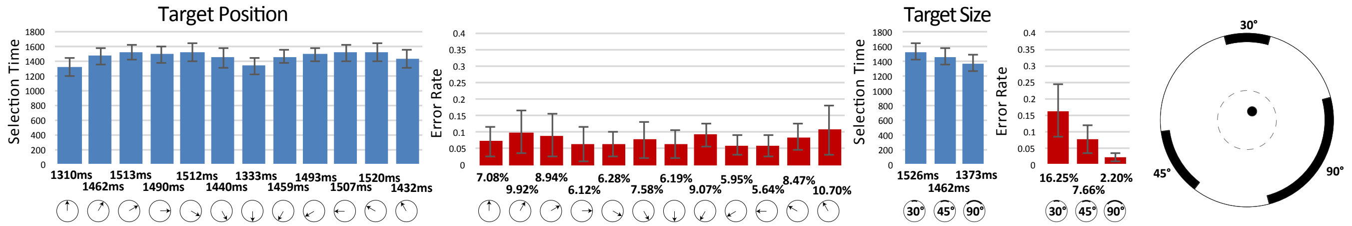

Figure 5. Wrist-flicking gestures segmented into target positions and target sizes. Participants had to flick a cursor (small black dot) from within the center of the display (dashed circle) into the boundaries of an angular target at the edge of the display and back into the center. The 12 clock positions served for target positions. Targets were either 30°, 45°, or 90° in size. Participants were fastest when flicking to the 6 and 12 o'clock position. The target size had a very large effect on the error rate, which was quite low for 90° targets (2.20%), but high for 30° targets (16.25%).

DISCUSSION

The results from the experiment show that mobility, encumbrance, and the outfitted hand have significant effects on interaction with smartwatches which however highly depends and differs for the investigated interaction techniques. Swiping gestures were barely affected by any condition, while tapping was notably affected by the outfitted hand and wrist-flicking by carrying shopping bags.

Generally, users found coping mechanism that made the effects smaller than initially expected, e.g. for tapping and swiping, users could rest their interacting hand on the watch hand to increase hand stabilization. In previous studies on smartphones and encumbrance, Ng et al. [7] found that using two hands for interaction increased the accuracy. In this regard, the cost of requiring both hands for touch interaction with smartwatches can be beneficial for hand stabilization.

Lyons [5] argued that during smartwatch interaction, the watch hand is only partly restricted since it is still free to hold objects. The same however is true for the interacting hand. Since only one finger is required for touch interaction with the watch, the remaining hand is able to grasp objects (e.g. the handle of a shopping bag), so that being encumbered by a graspable object that does not restrain the whole hand only has a small effect. For wrist-flicking however, which requires more active movement of the arm (resp. the wrist), the effect is larger.

The outfitted hand had a large effect on tapping interaction, while it only had a small effect on swiping gestures. Kabbash et al. [4] found that for rough pointing or motion, the non-dominant hand is as good as the dominant hand, while for precise pointing the hands significantly differ. In this regard, directional swiping on a watch can be seen as a rough motion, while tapping requires more precision and hence is more affected. For wrist-flicking, we expected the watch worn on the dominant hand to have a positive effect on interaction. Contrary to this, participants were slightly faster using the non-dominant hand. This might be explained by participants being generally more familiar with a watch worn on the non-dominant hand and having experience in rotating the wrist to glance at the time.

CONCLUSION

Touch interaction with smartwatches involves two hands, but both only partly. In contrast to smartphones that actively need to be held in hand, a watch is attached to the wrist, leaving the watch-hand free to hold objects, but also only partly restraining the interacting hand (requiring only one finger for touch input). The term *two*-handed interaction can thus be misleading. Since both hands can support and stabilize each other, interaction is quite robust to mobility and encumbrance effects.

The more precision an interaction required, the more it was affected by mobile conditions, making directional swiping gestures that only require rough pointing, a very robust interaction technique for smartwatches.

The study results showed that each of the interaction techniques was differently affected by different conditions, so that interaction designers that want to extend the interaction capabilities of smartwatches [9] need to be aware of the varying conditions in mobile contexts. Swiping was least affected by any condition, which indicates that designers can utilize swipe gestures when the smartwatch application is expected to be primarily used when being mobile.

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REFERENCES

1. Ashbrook, D. L. *Enabling mobile microinteractions*. PhD thesis, Georgia Institute of Technology, 2010.
2. Goguey, A., Nancel, M., Casiez, G., and Vogel, D. The performance and preference of different fingers and chords for pointing, dragging, and object transformation. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, ACM (2016), 4250–4261.
3. Guo, A., and Paek, T. Exploring tilt for no-touch, wrist-only interactions on smartwatches. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services*, ACM (2016), 17–28.
4. Kabbash, P., MacKenzie, I. S., and Buxton, W. Human performance using computer input devices in the preferred and non-preferred hands. In *Proceedings of the INTERACT'93 and CHI'93 Conference on Human Factors in Computing Systems*, ACM (1993), 474–481.
5. Lyons, K., and Profita, H. The multiple dispositions of on-body and wearable devices. *IEEE Pervasive Computing 13*, 4 (2014), 24–31.
6. Ng, A., Brewster, S. A., and Williamson, J. The impact of encumbrance on mobile interactions. In *IFIP Conference on Human-Computer Interaction*, Springer (2013), 92–109.
7. Ng, A., Brewster, S. A., and Williamson, J. H. Investigating the effects of encumbrance on one-and two-handed interactions with mobile devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2014), 1981–1990.
8. Wagner, J., Nancel, M., Gustafson, S. G., Huot, S., and Mackay, W. E. Body-centric design space for multi-surface interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2013), 1299–1308.
9. Zhang, C., Yang, J., Southern, C., Starner, T. E., and Abowd, G. D. Watchout: Extending interactions on a smartwatch with inertial sensing. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers*, ACM (2016), 136–143.