Functional Workspace for One-Handed Tap and Swipe Microgestures

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ABSTRACT

Single-hand microgestures are a promising interaction concept for ubiquitous and mobile interaction. Due to the technical difficulty of accurately tracking small movements of fingers that are exploited in this type of interface, most research in this field is currently aimed at providing a good foundation for the future application in the real word. One interaction concept of microgestures is one-handed tap and swipe interaction that resembles one-handed interaction with handheld devices like smartphones. In this paper, we present a small study that explores the possible functional workspace of one-handed interaction which describes the area on the palmar surface where tap- and swipe-interaction is possible. Additionally to thumb-to-finger interaction which has been investigated more often, we also considered other fingers. The results show, that thumb interaction with index, ring and middle finger is the most appropriate form of input but other input combinations are under circumstances worth consideration. However, there is a high deviation on which locations can be reached depending on the individual hand anatomy.

CCS CONCEPTS

• **Human-centered computing** → *Interaction design theory, concepts and paradigms*; *Empirical studies in interaction design.*

KEYWORDS

Single-Hand Microgestures, SHMG, One-handed interaction, Functional Workspace

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1 INTRODUCTION

The human hand is one of our first tools for interacting with our surroundings. It is a multi-purpose tool that can perform manifold tasks, for example: physical manipulation of objects, gestural support of voice, symbolic actions and communication. It also is one of our primary tools for interacting with the digital world that was adapted in different ways according to changing forms of interaction: first, to type in commands in command line interfaces, later, to move a mouse in graphical user interfaces and lately, using touch and swipe on handheld devices and touch screens. However, all these interaction styles need to be designed ergonomically in accordance with the provided capabilities of our hands. One new form of interaction, that shows promising potential to operate within the progressively incrementing digitalization of our world is on-body interaction and specially single-hand microgestures (SHMGs).

SHMGs show high potential for enhancing interaction with our surroundings and can be applied in various ways, for example to enhance vehicle control [23] or as general purpose tool for everyday interaction like making phone calls or controlling a music player [10] in a subtle way. They can be combined with handheld object interaction [13, 20, 31] to provide additional features and might support the operation of new portable AR-devices like smart glasses in the future [15, 26] or make the abandonment of input-devices like controllers possible to allow hands-free interaction in virtual environments. A subset of possible microgestures is tap- and swiped-based interaction on specific locations on one hand to trigger specific commands, resembling interaction with smartphones and gamepad-type devices. This is often implemented as thumb-to-finger interaction, using the thumb as active element that activates opposed finger elements as buttons or slides across distinct areas. To further expand the number of possible interactions, we asked ourselves, if it is possible to adapt this form of interaction using other fingers as active element in respect to the human hand anatomy and comfort. During our research and designing one-handed microgestural interaction, we encountered the problem of inconsistent hand articulation. Developer design gestures in a distinct way that seems easy to use and comfortable. However, in later tests with other users the execution of some postures is sometimes anatomically not possible while others work just as intended. Furthermore, we observed a high level of disagreement which poses are comfortable. This led us to following question: "Which areas on the hand can be exploited for one-handed interaction so that most users are able to perform distinct tap- and swipe based-SHMGs in an easy and comfortable way?".

2 RELATED WORK

Designing Gestural Input

Gestural input is a new post-WIMP way of interacting with computer systems and a major topic of research in the last years. New devices like see-through glasses need a new way of interaction without using at least too obstructing hardware devices. Various forms of input are possible, for example symbolic, metaphorical or abstract gestures [30]. The design of SHMGs is stronlgy related to the design of mid-air gestures [27] which has been researched more intensely. One common way of desinging gestures is trying to maximize the guessability of gestures [29] by finding the best level of agreement to a set of defined gestures [4, 26]. While designing on-body user inputs, it is reasonable to exploit *body landmarks*[28] and trying to find comfortable poses [2, 10] by taking human anatomy into account. This is an important factor that should be considered during development of user interfaces to avoid fatigue when interacting with a system for a long time [3].

Functional Workspace for One-Handed Tap- and Swipe-based Interaction

The *functional workspace* of the human hand which describes the area where interaction is generally possible has been investigated in the past. The interaction with virtual buttons and sliders on one hand is a subset of the catalogue of possible gestures that utilizes the palmar surface as specific workspace. The mainly focused form of interaction is thumb-to-finger interaction where the thumb is moved to a specific location on a specific finger and used as tap or slide input [4, 6, 7, 10, 24, 25, 32]. Using the tips of other fingers to interact with points on the palmar surface, however, has only been investigated rarely [18] and, to our knowledge, not for single-hand interaction. Some studies exist that analyze 3D-*functional workspace* of thumb and fingers in a clinical context [14, 16]. But these studies constrained the movement of other joints which is not practical for designing tap- or swipe input on the surface of the palm as the thumb can by itself mainly move within a volume above the palm. Overall, a complete description of the complete *functional workspace* has not been described, yet.

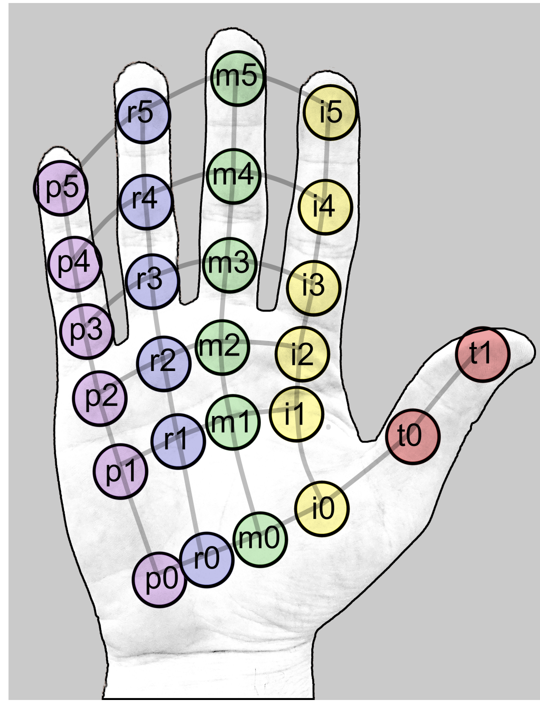

Figure 1: Grid-like pattern of interaction locations used in our study.

Tracking systems for Single-Hand Microgestures

The tracking of hand and finger motion is still a matter of research and a universal solution has not been found, yet. One approach to designing a system with some degree of mobility is to attach a RGB or depth camera to some body part to capture movement from an external perspective [1, 8, 18, 19, 21]. In other cases the camera system is mounted to the wrist or hand [5, 13, 22]. Other approaches involve the utilization of various sensors for example on-skin electronics [12, 28], ultrasonic sensors [11], magnetic sensors [6, 10], bioacoustics [9] or radar [17]. One popular choice for a subtle wearable device is the use of a ring on one finger [5, 24, 32] or a watch or armband on the wrist [9, 13, 22]. It is noticeable that systems are often designed to accomplish a specific task and in most cases are not suited to fully track the human hand.

3 SINGLE HAND FUNCTIONAL WORKSPACE

In the following, we present the results of a small study that was conducted to further explore the possibilities of single-handed tap- and swipe-interaction. We were especially interested in how taps of other fingers compare to the thumb-to-finger opposition, which has been researched more often [4, 6, 7, 10, 24, 25, 32].

Participants

We recruited 23 participants (16 male, 7 female) with a background in human computer interaction design from our university department. The average age was 26,1 years (SD=3.6). They were not involved in the development or conduction of the study. The hands of participants were all healthy and did not suffer from any diseases like athrosis that would heavily impact the flexibility of joints.

Procedure

The participants were introduced to the study by presenting the concept and intention of tap- and swipe-based single-hand interaction. From a small previous prestudy we identified interaction pairs (active finger tip and passive location on the hand, see figure 1) that were randomly presetend as graphic to all participants to be rated considering difficulty by recreating the shown action using their dominant hand. We utilized the identification of the tap interaction between the tip of the thumb and tip of the index finger (t1-i5-tap) as baseline as it was identified to be the most comfortable position [10]. Participants rated the difficulty using a 5-point likert-type scale with following ranks: (4) just as difficult as baseline tap, (3) slightly more difficult than baseline tap, (2) much more difficult than baseline tap, (1) almost not possible to perform, (0) not possible. It was emphasized, that we wanted to capture the individual impression of difficulty and not the estimated difficulty for possible users. Users were allowed to move the passive part to make contact with an active part, for example by moving the index finger tip (i5) towards the thumb (t1), even though the tap was described the other way around. However, a tap should be clearly distinguishable, so that other fingers apart from the active part should not be touching the surface. The side of the active part (palmar, dorsal, ulnar or radial) was not specified during the study, as we only focused on a contact between active and passive part.

Results

The ratings of comfort for each combination of active part and passive target location are displayed as individual table for each active part. As we capture ordinal data, we display the frequency of answers 0 to 4, the first quartile Q1 and median Q2 for a single tap to a specified location (L). Standard deviation was not considered appropriate as some records were not normally distributed. To describe the dispersion, we instead calculated MSE as the mean squared distance to the median value.

It can be seen that the thumb has the most distinguishable tap locations with a Q1-rating of at least 3 and a small MSE-value of less than 0.5 (11, see table 1), which can be interpreted as location that is presumably comfortable to most users. Thumb tap locations in the palm area below the fingers produces much smaller rating with more dispersion and are only easy to reach to some users while others cannot perform a tap effortlessly. In a similar way, other fingers can reach the surface of the palm but produce usually a high MSE-value respectively both, high and low ratings (see tables 2, 3, 4), which implies that interactive elements at these locations cannot be reached reliably. However, locating interactive elements on the thumb and thenar region seems to be possible for index, middle and ring finger. The little finger should only be used to interact with thumb (t1) as all other ratings are rather dispersed and Q1-ratings are very low (see table 5).

From the ratings of our participants we created heatmaps that display possible location for interactive elements for single-hand tap-interaction 2. We used the Q1-rating as basis because it can be interpreted as a rating where most (75%) of participants can perform actions without much effort, which implies that developing an interface based on these ratings is adequate for the majority of users.

Additional observations

Some participants stated that using two or more fingers fingers instead of one to tap on specific points on the palmar area was a lot easier than just using a single finger due to the dependencies of finger movements. It many cases it is not possible to distinguish between the active and the passive part of a tap, as both involved parts are moved, in some cases the passive part is even moving more than active part (e.g. moving the thumb tip to index tip from a resting position).

4 DISCUSSION

Implications for System Design

Using the collected data from our study, different systems can be designed that are probably comfortable to most users. It seems reasonable to distribute interactions over the whole interaction space to make them distinguishable from each other. For example, a singe tap from t1 to i5 should be easily distinguishable from a tap from t1 to p5, whereas a tap from t1 to i4 might be perceived as very similar. This can be utilized to group similar actions close to each other and separate different actions which might help in creating the mental model of the user interface. Frequently used actions should utilize comfortable positions. Rarely used actions can utilize less comfortable interactions which can still be performed by most users. We presume that swipe comfort correlates strongly with tap comfort and results should be transferable but this has to be further investigated as Huang et al. [10] found that swipes are generally perceived as less comfortable.

L	0	1	2	3	4	Q1	Q2	MSE
i1	22%	26%	26%	26%	-	1	2	1.39
i2	-	9%	35%	48%	9%	2	3	0.78
i3	-	-	17%	39%	43%	3	3	0.61
i4	-	-	-	17%	83%	4	4	0.18
i5	-	-	-	-	100%	4	4	0.00
m1	87%	13%	-	-	-	0	0	0.13
m2	17%	13%	39%	26%	4%	1	2	1.26
m3	-	-	9%	43%	48%	3	3	0.57
m4	-	-	-	9%	91%	4	4	0.09
m5	-	-	-	-	100%	4	4	0.00
r1	43%	17%	30%	4%	4%	0	1	1.30
r2	4%	4%	35%	30%	26%	2	3	1.17
r3	-	-	9%	39%	52%	3	4	0.74
r4	-	-	4%	17%	78%	4	4	0.35
r5	-	-	-	30%	70%	4	4	0.00
p1	48%	26%	22%	4%	-	0	1	0,87
p2	-	9%	35%	30%	26%	2	3	0.96
p3	-	4%	22%	22%	42%	2	4	1.48
p4	-	-	4%	26%	70%	3	4	0.43
p5	-	-	-	30%	70%	3	4	0.30

Table 1: Comfort rating for thumb (t1) as active part.

L	0	1	2	3	4	Q1	Q2	MSE
t0	-	-	-	30%	70%	3	4	0.30
t1	-	-	-	-	100%	4	4	0.00
i0	-	-	17%	39%	43%	3	3	0.61
i1	-	13%	26%	35%	26%	2	3	1.04
i2	13%	30%	17%	30%	9%	1	2	1.48
m5	-	-	-	22%	78%	4	4	0.22
r5	13%	13%	39%	13%	22%	1	2	1.65
p5	48%	39%	-	9%	4%	0	1	1.22

Table 2: Comfort rating for index finger (i5) as active part.

L	0	1	2	3	4	Q1	Q2	MSE
t0	-	-	4%	43%	52%	3	4	0.61
t1	-	-	-	-	100%	4	4	0.00
i0	-	-	-	39%	61%	3	4	0.39
m0	-	9%	26%	43%	22%	2	3	0.83
m1	-	4%	30%	43%	22%	2	3	0.70
m2	30%	35%	22%	13%	-	0	1	1.04

Table 3: Comfort rating for middle finger (m5) as active part.

L	0	1	2	3	4	Q1	Q2	MSE
t0	-	-	17%	52%	30%	3	3	0.48
t1	-	-	-	-	100%	4	4	0.00
i0	-	-	4%	48%	48%	3	3	0.52
m0	-	-	17%	39%	43%	3	3	0.61
r0	13%	26%	13%	26%	22%	1	2	1.91
r1	-	13%	43%	22%	22%	2	2	1.22
r2	26%	35%	30%	4%	4%	0	1	1.13

Table 4: Comfort rating for ring finger (r5) as active part.

L	0	1	2	3	4	Q1	Q2	MSE
t0	39%	13%	17%	30%	0%	0	1	1.78
t1	-	-	-	26%	74%	3	4	0.26
i0	22%	13%	30%	22%	13%	1	2	1.74
m0	22%	13%	35%	22%	9%	1	2	1.57
r0	17%	13%	30%	22%	17%	1	2	1.74
p0	57%	22%	4%	9%	9%	0	0	2.57
p1	35%	13%	13%	30%	9%	0	2	2.17
p2	13%	17%	17%	26%	26%	1	3	2.30

Table 5: Comfort rating for little finger (p5) as active part.

From our findings, we suggest following considerations when designing SHMGs for palmar tap- and swipe-based UIs:

The thumb has the greatest articulation space and can be used for tap interaction on index, middle and ring finger. This confirms the findings considering interaction space of Huang et al. [10]. The little finger and the area just beneath the fingers (palmar side of the metacarpophalangeal joints) can additionally be considered for thumb interaction, but should only be implemented for rarely used actions.

Additionally to the thumb, the remaining fingers can be used as active part during interaction, too. The index finger can perform a tap on the last segment of the middle finger and a swipe on the thumb. For middle and ring finger, this swipe can even be extended to the thenar region. The palmar side of the metacrpophalangeal joints, the area around the proximal palmar crease and around the Hypothenar are not easy to reach for all users and should not be used for finger interaction.

It is important for developers to regard the functional workspace of the hand during development of microgestures and check if assumptions that apply to their own hands also pertain to the intended users. As seen by big MSE-values for some records, the movement of joints makes reaching for certain locations very easy to some people while it might be impossible to others. This can be a pitfall, when only the developer's hands are regarded during development.

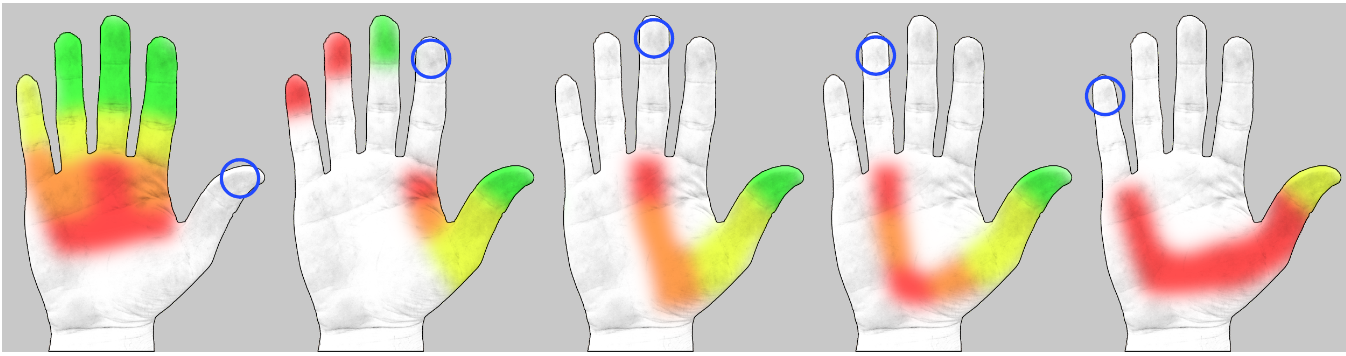

Figure 2: Heatmaps generated from Q1 ratings of comfort for different active parts (blue circle). Green (4): very easy to reach, yellow (3): slightly less comfortable, orange (2): major difficulties, red (0,1): not reliably reachable, white: not considered.

Trackability Using Consumer Hardware

Besides the user-centered perspective, the hand tracking capabilities are an important factor for further research. During development of hand-based interaction techniques, we experienced difficulties tracking all movements accurately using consumer hardware. Usually, tracking devices seem to be specialized in tracking distinct movements, for example in-air gestures with one hand, while they fail at tracking other unintended poses. Sometimes, certain movements such as abduction and adduction of fingers or crossing of fingers are not supported. This makes development of new interaction techniques difficult since a developer is limited to certain movements that a supported by available hardware.

5 LIMITATIONS AND FUTURE WORK

In our study we only focused on tap-interaction on the palmar side of the hand. Additionally, it is possible to utilize the lateral and dorsal parts of the fingers [21] to further expand the expressiveness. It would be interesting to see how these input locations perform compared to the input pairs explored in this paper. Also, as some participants stated that using two fingers to tap onto a location on the palm is easier due to the dependent movements, this form of interaction could be researched and compared to the t1-i5-tap, too. Furthermore, slides seem to produce slightly lower comfort ratings [10] so these should be explored for different locations separately, too.

For our study, we recruited participants from our university for pragmatical reasons so our findings are probably only transferable to young adults. We suppose a decline in joint flexibility with age so a broader study with more heterogenous users is a reasonable next step to improve generalization and allow designing interfaces for various user groups. Generally, the number of participants should be increased to further support the findings.

One addition to the research field of SHMGs might be the development of a metric that quantifies the tracking capabilities of tracking systems for this purpose. From our experience, most available systems are not able to perform this task out-of-the-box. Aligning the development of tracking devices to a standardized metric, that describes which aspects of tracking have to be improved, might guide the process to a sufficient and affordable system. Individual solutions are currently the usual way to avoid this obstacle but are unfortunately not available to all researchers and developers.

6 CONCLUSION

Our study shows that locating interactive elements on the palmar surface is not limited to the fingers and can be extended successfully to some locations to thumb and thenar region as well. Interactive elements on the inner surface of the palm should be avoided as not all users are able to reach these locations. The generated heatmaps in this work can be used as reference for positioning interactive tap-locations in developing one-handed tap-interaction UIs.

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