Transferable Microgestures Across Hand Posture and Location Constraints: Leveraging the Middle, Ring, and Pinky Fingers

Nikhita Joshi[*]
nvjoshi@uwaterloo.ca
Reality Labs Research, Meta
Canada

Parastoo Abtahi
parastoo@princeton.edu
Reality Labs Research, Meta
Canada

Raj Sodhi
rsodhi@meta.com
Reality Labs Research, Meta
United States

Nitzan Bartov
nitzu@meta.com
Reality Labs Research, Meta
United States

Jackson Rushing
jacksonrushing@meta.com
Reality Labs Research, Meta
Canada

Christopher Collins
chriscollins@meta.com
Reality Labs Research, Meta
Canada

Daniel Vogel
dvogel@uwaterloo.ca
University of Waterloo
Canada

Michael Glueck
mglueck@meta.com
Reality Labs Research, Meta
Canada

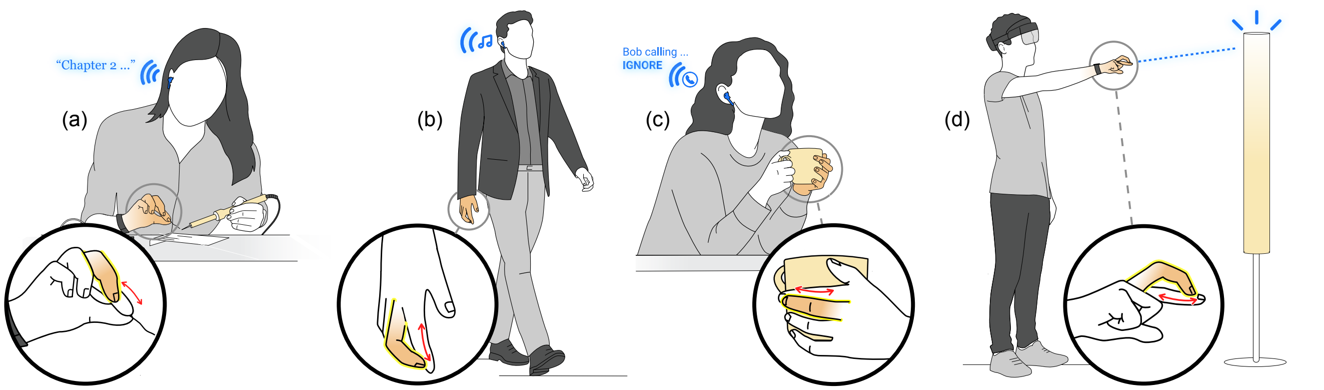

Figure 1: Examples of a 'middle finger swipe along index finger' microgesture that is transferable across hand location and posture constraints: (a) skipping ahead in an audio book while holding solder, (b) changing songs in a music player while walking with a relaxed hand, (c) ignoring a call while grasping a cup, and (d) dimming a smart lamp while pointing at it.

ABSTRACT

Microgestures can enable auxiliary input when the hands are occupied. Although prior work has evaluated the comfort of microgestures performed by the index finger and thumb, these gestures cannot be performed while the fingers are constrained by specific hand locations or postures. As the hand can be freely positioned with no primary posture, partially constrained while forming a pose, or highly constrained while grasping an object at a specific location, we leverage the middle, ring, and pinky fingers to provide additional opportunities for auxiliary input across varying levels of hand constraints. A design space and applications demonstrate how such microgestures can transfer across hand location and posture constraints. An online study evaluated their comfort and effort and a lab study evaluated their use for task-specific microinteractions. The results revealed that many middle finger microgestures were comfortable, and microgestures performed while forming a pose were preferred over baseline techniques.

[*]Also with University of Waterloo.

UIST '23, October 29-November 1, 2023, San Francisco, CA, USA

CCS CONCEPTS

• **Human-centered computing → Gestural input**.

KEYWORDS

interaction techniques, gestural input

ACM Reference Format:
Nikhita Joshi, Parastoo Abtahi, Raj Sodhi, Nitzan Bartov, Jackson Rushing, Christopher Collins, Daniel Vogel, and Michael Glueck. 2023. Transferable Microgestures Across Hand Posture and Location Constraints: Leveraging the Middle, Ring, and Pinky Fingers. In *The 36th Annual ACM Symposium on User Interface Software and Technology (UIST '23), October 29-November 1, 2023, San Francisco, CA, USA.* ACM, New York, NY, USA, 17 pages. https://doi.org/10.1145/3586183.3606713

1 INTRODUCTION

It can often be desirable to simultaneously perform a secondary or *auxiliary* task while engaged in a primary task. For example, adjusting music volume while writing [7] or examining a circuit diagram when soldering [17]. When the primary task requires use of the hand, such as holding an object or performing a mid-air gesture, performing auxiliary tasks can be difficult or impossible. This is especially true during highly constrained primary tasks, where the hand location and posture must be maintained to successfully complete the primary task. For example, while holding a camera to take a picture, the hand posture is constrained to the grasp needed to hold the camera and the hand location is constrained to a specific point in space to capture the desired subject. Voice input has been proposed as one way to perform auxiliary tasks; however, it is not ideal for every type of task (e.g., manipulating continuous values) [14] or context of use (e.g., public spaces) [11].

Microgestures, which are small, physically-constrained gestures performed by the fingers [41], can enable auxiliary input while the hands are occupied by performing gestures on the surface of a held object [29, 30], touching other fingers on the same hand [4, 5], or extending one or more fingers in the air [38]. Prior work has largely focused on using the index finger or thumb to perform microgestures. This focus is well-justified, as the index finger and thumb are known for being the most dexterous digits [10, 12, 26, 41]. However, because the index finger and thumb are crucial while grasping, performing microgestures using these digits may not always be feasible while holding an object. Many extended reality (XR) interactions, such as those implemented within the Hololens and Quest head-mounted displays (HMDs), rely primarily on a pinch gesture that uses the index finger and thumb to select and manipulate objects. Other mid-air gestures and postures rely on the index finger and thumb to establish semantic meaning: signs in American Sign Language, 'framing' a subject of interest [25], or 'pointing' for spatial deixis [3]. Thus, there is a conflict between the digits required for such primary tasks and those proposed for microgestures. One possibility is to offload thumb- or index finger-based microgestures to the free or non-dominant hand; however, this would not support primary tasks that are bi-manual and it would require user instrumentation to sense both primary and auxiliary tasks (e.g., wrist-worn sensors [19, 23] or gloves [36]).

There are, however, other fingers that could be employed for microgestures: the middle, ring, and pinky fingers. Although these digits are less dexterous, they are not as essential for many grasps and some have even been elicited from users in prior work [30]. Using the middle, ring, and pinky fingers would be advantageous in that they would be *transferable* across hand location and postural constraints. Transferability is an advantageous benefit of any gesture vocabulary as it would enable a user to learn a smaller set of gestures and use them broadly across a wide variety of situations. In other words, a user could learn a gesture once and apply it to other situations where the hand is freely positioned with no primary posture (Figure 1b), partially constrained by location while forming a pose mid-air (Figure 1d), or highly constrained while grasping an object (Figure 1c) at a specific location (Figure 1a). Furthermore, single-finger gestures that utilize the middle, ring, and pinky fingers would avoid false positives during gesture recognition as they are uncommon in everyday life [29].

We explore how microgestures employing the middle, ring, and pinky fingers can be used to perform auxiliary tasks. Our methodology was threefold to evaluate gesture transferability and ergonomics [42]. First, we created a design space to (i) characterize how hand locations and postures can be constrained and (ii) demonstrate the transferability of microgestures performed by the middle, ring, and pinky fingers within this design space through five proof-of-concept demonstration applications. Second, we evaluated the ergonomics of 77 microgestures performed using different hand postures through a large-scale online study. This study found that many of the microgestures performed by the middle finger were comfortable and did not require much effort. Third, we leveraged two proof-of-concept applications, which featured promising microgestures from the online study, in a small, in-lab study to gather additional feedback about their use for task-specific microinteractions when compared to traditional methods of auxiliary input. The results demonstrated that participants preferred performing microgestures alongside a hand pose, but performing microgestures while grasping an object required more effort and was least preferred. Overall, this research contributes:

- a design space for using the middle, ring, and pinky fingers for auxiliary input and five proof-of-concept applications to highlight their transferability across varying levels of hand location and posture constraints
- the first large-scale study (n=210) exploring the comfort of microgestures that demonstrated how the middle, ring, and pinky fingers are capable of comfortably performing different types of microgestures to a degree that is much more than we expect
- a lab study (n=10) that showed microgestures performed while forming a pose were preferred over baseline techniques.

2 BACKGROUND AND RELATED WORK

Ashbrook defined *microinteractions* as interactions with a device that take only a few seconds to initiate and complete [2]. Short, focused microinteractions can be used to accomplish auxiliary tasks while minimizing interruptions during a longer, primary task. Some examples of microinteractions include dismissing notifications or switching modes. Wolf et al. explored how *microgestures*, i.e., small, physically-constrained gestures involving the movement of fingers, can be used for microinteractions [41]. Subsequent research has focused on detecting microgestures through gesture recognizers [32] and novel input devices; for example, capacitive touch sensors worn on the nails [5, 17], wrist-worn sensors [19, 23, 31], gloves [36], and rings [21, 34, 37, 40]. Our work, however, is not focused on sensing, so we limit our discussion to prior work that focused on the physical factors that may impact microgestures that are performed by the middle, ring, and pinky fingers, and research on mid-air gestures and microgestures.

2.1 Hand Anatomy and Configurations

There are four sides of each digit along which microgestures can take place: the dorsal side refers to the back of the hand, the volar side refers to the palm (i.e., palmar side), the radial side is closest to the thumb, and the ulnar side is closest to the pinky [32].

Taxonomies have been proposed to classify the ways humans grasp different objects. Power grasps require holding objects using the palm, thumb, and one or more fingers, and are commonly used for heavier or larger objects. Precision grasps require holding objects between the tips of the thumb and one or more fingers, and are commonly used for manipulating smaller and lighter objects during tasks that require fine motor control [12, 20, 26]. Intermediate grasps combine elements of both power and precision grasps [16]. The GRASP taxonomy synthesized multiple taxonomies into 33 grasp types [12]. Within this taxonomy, the index finger is involved in the most grasps (29), followed by the middle finger (25), ring finger (19), and the pinky finger (14). However, for smaller objects, the middle, ring, and pinky fingers are often used in a supporting role as these fingers are "redundant" [26].

The structural and functional anatomy of the hand can impact the design of microgestures. Häger-Ross and Schieber measured how well each digit can move independently by calculating finger individuation scores and found that the thumb, index finger, and pinky finger are all able to move more independently as they each have their own muscles and connective tissues that allow for their stretching. However, the middle and ring fingers are physically connected by the same connective tissues, so they move together involuntarily [13]. Wolf et al.'s interviews with motor specialists revealed that for these reasons, the index finger is the ideal candidate for microgestures while the ring finger is the least feasible [41]. In addition, they note that middle finger and pinky finger microgestures are feasible, but may be less comfortable. However, Sridhar et al. suggested that fingers with poor finger independence can still be used by designing gestures that require simultaneous use of all dependent fingers [33].

2.2 Hand Input Techniques

Many mid-air gestures and poses involve the use of the index finger and thumb, making them inappropriate to use while performing microgestures. For example, deictic pointing with the index finger [3, 18, 45]; and semaphoric gestures that have semantic meaning, like extending the index fingers and thumbs into a 'framing' pose to take a picture [25], pushing the index and middle fingers together like scissors to perform a 'cut' operation [4], or using index finger and thumb movements to mimic clicking with a mouse [38]. Prior work suggests that pinching the index finger and thumb together and extending them are common interaction techniques [35], which can be seen in many in XR applications using the Hololens and Quest HMDs. The positions of specific fingers are important to establish meaning and for a system to accurately detect them, so microgestures performed by the middle, ring, and pinky fingers would be compatible with these common gestures and provide more options for auxiliary input.

Non-grasping microgestures can be leveraged to enable subtle and discreet input (e.g., [5, 21, 37]) or for multitasking (e.g., [23, 39]). However, prior work has mostly focused on eliciting and evaluating thumb-based interactions, where the thumb performs a gesture on the other fingers (e.g., [4, 15, 37]). Dewitz et al. explored the possibility of using the non-thumb fingers to perform microgestures [8]. They identified 26 interaction locations along the volar side of the hand and evaluated how comfortably all five digits could tap them. However, they only considered tapping on the volar side of the hand, which results in many inter-finger interactions being physically unreachable. Our work considers tapping and swiping along the radial and dorsal sides of all fingers, with a focus on using the middle, ring, and pinky fingers.

Microgestures can support the completion of auxiliary tasks while the hand is encumbered, such as while driving [1] or biking [36]. Wolf et al.'s research evaluated the feasibility of microgesturing while holding a steering wheel, credit card, or pen through interviews with hand ergonomics experts [41]. They found that many microgestures involving objects are feasible; however, feasibility depends on the nature of the primary task, the grasp, and the fingers involved. Sharma et al. built on these findings by considering a wider variety of objects during an elicitation study [30]. One motivating result was that for smaller objects held using lateral and tip grasps, most elicited gestures were performed by the middle, ring, and pinky fingers due to their availability. From a sensing perspective, Sharma et al. found that people do not naturally perform single-finger movements while holding and manipulating objects in everyday life, making such movements ideal to recognize explicit input [29]. Our work acknowledges other situations where the index finger and thumb are unavailable and systematically evaluating the comfort of middle, ring, and pinky finger microgestures that can be consistently applied to a wider range of situations.

Overall, the biomechanics of the hand suggest that middle, ring, and pinky finger microgestures may be less comfortable than those performed by the thumb or index finger, but these fingers are not used as frequently to grasp small objects and perform mid-air gestures and poses. Prior work has focused on thumb-based microgestures, but using other fingers has not been explored in depth.

3 DESIGN SPACE

Using the middle, ring, and pinky fingers for microgestures could enable a new auxiliary input interaction vocabulary, because the microgestures performed by each finger could transfer across the varying levels of hand constraints imposed by a primary task. This could support the use of global shortcuts or enable users to issue context-dependent commands based on their primary task. Prior work has created design spaces to categorize the type of microgestures that can be performed based on their regions of contact [32]; however, prior work has yet to create a design space that captures how microgestures can be used across varying levels of hand constraints. This is important to understand, as some microgestures may not work well across different levels of hand constraints, and interaction designers need to be aware of the limitations of microgestures that may be integrated into a future system. The presented design space consists of two hand constraints that vary depending on the primary task being performed: *hand location* and *hand posture* (Figure 2).

3.1 Hand Location Constraint

Hand location refers to the viable range of hand positions that can be used to perform a primary task. When the location is unconstrained, there are no limitations on where the hand must be positioned, making its location arbitrary. When someone is not performing any activities that require the use of their hands, or when

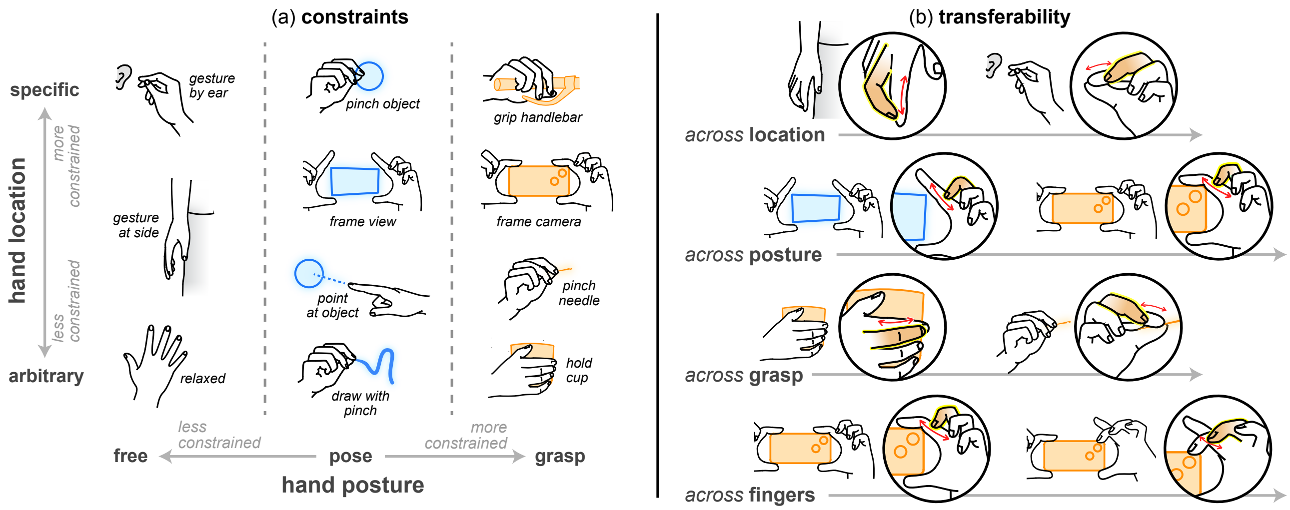

Figure 2: (a) The design space of constraint levels based on hand location and hand posture. The hand location constraint is the range of positions the hand must be placed to perform a primary task, and the hand posture constraint is how the fingers must be placed to perform a primary task. Primary tasks fall along a continuum, with some tasks being more constrained by location and posture than others. (b) Microgestures performed by the middle, ring, and pinky fingers can be transferred across hand location and posture constraints, grasps, and fingers, allowing someone to learn the same interactions once and transfer them to different situations.

there are no specific objects to interact with, the viable range of hand positions can be large. Although microgestures are generally more discreet due to their smaller movements, if additional social acceptability or subtlety is required or desired, the hand location can be partially constrained to be locations closer to the body. An even more constrained location would be when the hand needs to be close to something else to interact with it, for example, to perform gestures around the ear [6], or to grab objects at fixed relative positions (e.g., handlebars [36]).

3.2 Hand Posture Constraint

Hand posture refers to how the fingers are positioned relative to each other to perform a primary task. There are three levels of posture constraints: when the hand is free, when it is forming a pose, and when it is grasping an object. A free, unconstrained posture occurs when the fingers do not have to maintain any specific positions, meaning that the fingers are not overloaded with another task. In contrast, a pose posture constraint occurs when some fingers must be held in a specific way for meaning to be established. A grasp posture constraint would occur when some fingers must be positioned in a specific manner to hold a physical object.

3.2.1 Varying Grasp Constraints. Different object shapes and sizes require different grasps and constrain the fingers in different ways. For some object shapes, some fingers may be tucked away (e.g., when grasping a shopping bag). For larger and heavier objects, the middle, ring, and pinky fingers are needed for stabilization and have less freedom to move. But when holding smaller and lighter objects, these fingers are redundant [26]. Due to this limitation, we focus on the grasping of smaller objects.

3.3 Middle, Ring, and Pinky Microgestures

Prior design spaces for microgestures (e.g., [32]) characterized interaction types and contact regions (i.e., where the interaction will occur) for thumb-on-finger and finger-on-thumb microgestures. However, the additional hand posture constraint renders existing contact regions unfeasible. To narrow down the design space of microgestures that can be performed by the middle, ring, and pinky fingers specifically, we created an exhaustive list of over 250 different microgestures that made use of the dorsal, ulnar, and radial sides of each digit and the palm.[1] Microgestures that were impossible or very difficult to perform were filtered from this list. Difficult microgestures were defined as those that included reaching over multiple fingers or crossing one finger over another. We also filtered out microgestures that were not representative of, or transferable across, common grasps [12].

Through this filtering process, we identified four contact regions where the microgestures could occur (Figure 3). The first contact region was along the dorsal and ulnar side of the *adjacent finger*, i.e., the finger that is closest to the finger performing the microgesture. For the middle, ring, and pinky fingers, this was the finger on the radial side, but for the index finger, the adjacent finger was the middle finger. The second contact region was the radial side of the *thumb* and the third contact region was the base of the *palm*. The fourth contact region was *none*, which occurred when the finger was extended into the air.

We also considered three types of interactions: *tapping*, *swiping* in upward and downward directions (i.e., flexion and extension movements), and *extending* the finger in the air. Tapping and swiping can be performed along the adjacent finger, palm, and thumb, but extending can only be performed when there is no contact

[1]The full list of microgestures is included in the supplementary materials.

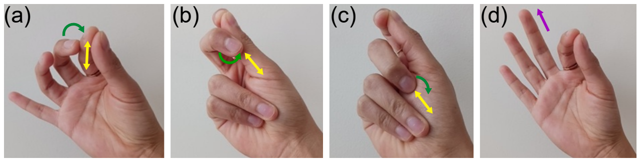

Figure 3: Three primary interactions illustrated using the middle finger on four contact regions while pinching: (a) tap (green) and swipe (yellow) on the adjacent finger, (b) tap and swipe on the thumb, (c) tap and swipe on the palm, (d) extend (purple) with no contact region.

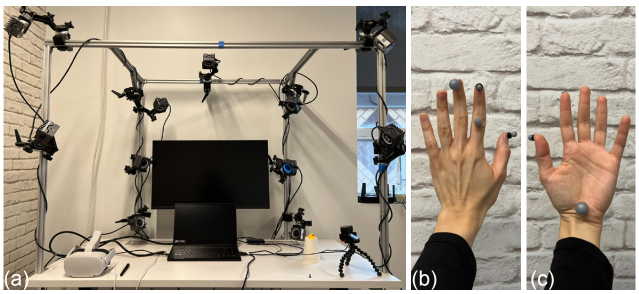

Figure 4: The OptiTrack setup and marker configuration.

region. These interaction types are common and have been highlighted in prior work [30]. We focused on using the dominant hand as it is advantageous for future sensing technologies that are worn on the dominant hand (e.g., [36]). We also focused on microgestures performed along the top two finger segments, as they have been shown to be the most comfortable [15, 37].

3.4 Transferability

Microgestures performed by the middle, ring, and pinky fingers can transfer across hand location constraints, hand posture constraints, and across fingers. They can be performed when the hand location is highly specific or when the hand location is arbitrary, allowing the same microgestures to be performed regardless of where the hand is positioned in space. Using these fingers for microgestures also transfers to other hand postures. When maintaining a pose that is similar to an object grasp, if the context switches to grasping the actual object, the same set of microgestures still work. Within a specific type of hand posture, there are many ways the hands can be constrained, like when grasping different types of objects. But since the middle, ring, and pinky fingers are not as essential, the same set of microgestures can transfer to different types of grasps. Even when some fingers are needed to grasp certain objects, characterizing microgestures by four contact regions and three interactions means the same interactions can be transferred to other, less important, fingers as needed.

Overall, this microgesture design space spans both hand location and posture constraints. Index finger- and thumb-based microgestures can also be applied across some of the constraint levels, such as when the hand posture is arbitrary. When the hand posture is in a pose or grasp, microgestures performed by the index finger and thumb can be difficult to use, given how often the index finger and thumb are used for mid-air gestures and postures, and how essential both digits are when grasping objects. Using the middle, ring, and pinky fingers for microgestures can enable input in contexts where input would have previously been impossible or very difficult, thereby improving transferability.

4 DEMONSTRATION APPLICATIONS

We created five applications to demonstrate how microgestures performed by the middle, ring, and pinky fingers could transfer to different levels of hand location and posture constraints, grasps, and fingers.

To create each demonstration, we tracked individual fingers using the OptiTrack motion tracking system. Eleven cameras were mounted on a truss system around a tabletop (Figure 4a). Markers of varying sizes were placed on joints along the fingers and palm using hypoallergenic tape. Using markers of varying sizes allows OptiTrack to uniquely identify each marker without the use of rigid bodies. One marker was placed on the fingernail tip of the finger performing the microgesture, two markers were placed on the adjacent finger, one marker was placed on the fingernail tip of the thumb, and another marker was placed at the base of the palm (Figure 4b, c). The markers did not touch or interfere with each other while the microgestures were being performed. Marker data was streamed to Unity using the OptiTrack Motive software. We detect touch events in Unity using colliders placed between the two adjacent finger markers and between the thumb and palm markers. For applications that required a web page, the Unity application streamed touch events to client Node.js applications over a local WebSocket server. We describe each application below, highlighting different scenarios where microgestures could be used. All applications are shown in the accompanying video figure.

4.1 Transfer to Other Hand Locations

Ring finger microgestures can be used to answer a phone call. Swiping forward toward the tip of the middle finger rejects the call, but swiping backward toward the knuckle accepts the call. Tapping the middle finger ends the call. The same set of microgestures can be used in three different scenarios with varying hand location constraints (Figure 5). When drinking water, the hand location is the most arbitrary because the cup can be picked up and placed on the table, moved toward and away from the lips, or held in space. During a meeting, the hand location remains near the body. Writing in a notebook is the most constrained location since the hand holding the pen needs to be near a notebook.

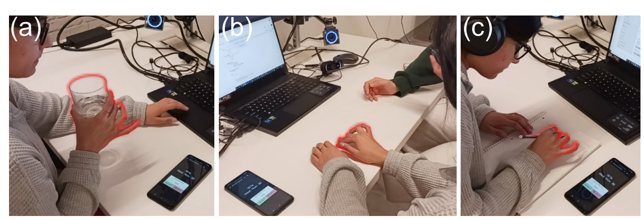

Figure 5: Transfer to other hand locations. Declining a call by swiping the ring finger on the middle finger while (a) drinking water, (b) in a meeting, and (c) writing in a notebook.

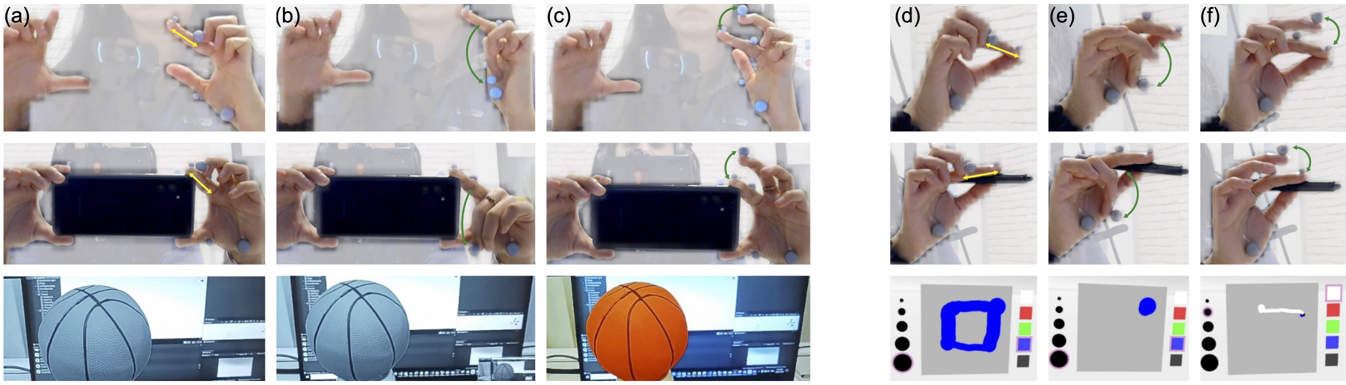

Figure 6: Transfer to other hand postures. Taking a photo: (a) swiping the middle finger along the index finger to zoom, (b) tapping the middle finger on the palm to capture a photo, and (c) tapping the middle finger on index finger to change filters. The same interactions while inking: (d) swiping the middle finger along the index finger to change stroke weight, (e) tapping the middle finger on the palm to clear the canvas, (f) tapping the middle finger on the index finger to change stroke colour.

4.2 Transfer to Other Hand Postures

We outline two applications: taking photos and inking. For each, we consider when the hand posture is both a pose and a grasp.

4.2.1 Taking Photos. A photo can be taken when grasping a smartphone in landscape mode or while maintaining a 'frame' pose in front of the body (Figure 6a-c). The latter could be a way for future AR glasses to initiate taking a photo (e.g., [25]) and is inspired by the American Sign Language sign for "take a picture." For both postures, the middle finger performs microgestures along the index finger: tapping cycles through different filters; swiping down and up zooms in and out, respectively. Tapping the middle finger on the palm takes the photo.

4.2.2 Inking. Inking can be done while grasping a stylus or while maintaining a pinch pose (Figure 6d-f), which is common in XR applications that leverage hand-tracking capabilities. For both postures, the middle finger performs microgestures along the index finger: tapping cycles through different stroke colours; swiping down and up increases and decreases stroke width, respectively. Tapping the palm clears the canvas.

4.3 Transfer to Other Grasps

To use middle, ring, and pinky finger microgestures as global shortcuts, the same microgestures should work while grasping different objects. Microgestures performed by the pinky can control a music player. Swiping forward and backward on the ring finger plays the next and previous songs, and tapping pauses and plays the music.

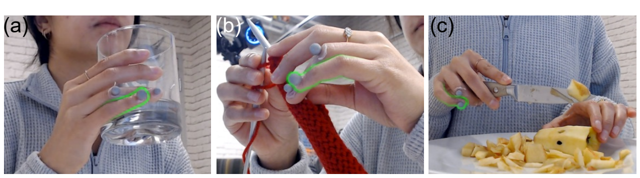

Figure 7: Transfer to other grasps. Controlling a music player using the pinky finger when (a) holding a cup, (b) holding knitting needles, and (c) holding a knife.

The same set of microgestures can invoke the same commands when holding a cup, knitting needles, or a knife (Figure 7).

4.4 Transfer to Other Fingers

Consistency across grasps is not always feasible, as some fingers can be more involved in some grasps. Microgestures performed by the ring finger can control a video tutorial while soldering: swiping forward and backward on the middle finger fast forwards and rewinds the video by 10 seconds, and tapping pauses and plays the video. But when holding a knife while cooking, the ring finger is tucked away and cannot easily move. The same interactions transfer to the pinky finger, allowing the user to tap and swipe their ring finger (Figure 8).

5 ONLINE STUDY

To gauge whether the trade-off of comfort for additional transferability is justified when performing microgestures using the middle, ring, and pinky fingers, and to understand which microgestures are most comfortable to perform, we administered two surveys that asked participants to try a set of microgestures while maintaining a pose (tip pinch or lateral pinch) or while grasping small objects (pen or phone) after watching short video demonstrations. After trying a single gesture for 10 seconds, participants were asked to provide numerical ratings about comfort and effort. Past evaluations of

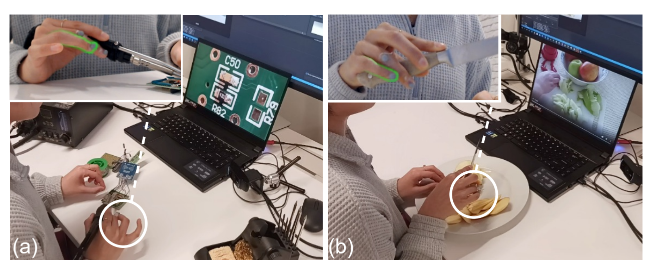

Figure 8: Transfer to other fingers. Controlling a video tutorial by: (a) using the ring finger while soldering and (b) using the pinky while holding a knife while cooking.

microgestures have all been performed in person, mainly at universities, thereby limiting the diversity of the participant pool and the number of participants that can be recruited. To gain additional diversity and evaluate the comfort and effort of microgestures at a large scale, we advertised the surveys on Amazon Mechanical Turk. Online, video-based studies are valid approaches to evaluating the ergonomics of gestural languages (e.g., [43]).

5.1 Participants

The inclusion criteria for each survey required that participants had completed at least 5000 MTurk tasks and had a HIT approval rating greater than 98%. As per our organization's requirements, we restricted the task to Canada and some states in the United States. Participants could only complete one of the two surveys. In total, 321 participants completed the surveys. Filtering out fraudulent responses resulted in 210 valid responses (see Appendix A.0.2 for details), of which 104 were for the pose survey and 106 responses were for the grasp survey (Appendix A, Table 3).

5.2 Evaluated Postures and Microgestures

For the pose survey, we evaluated two pinches that represent fundamental precision grasps: lateral pinches (thumb resting on the radial side of the index finger) and tip pinches (thumb resting on the volar side of the index fingertip). For both pinches, other fingers were stacked below the ulnar side of the index finger. For index finger microgestures, we used a modified version of a tip pinch where the thumb and middle finger were in contact.

For the survey that asked participants to grasp an object, we evaluated microgestures performed while grasping a pen or phone as they are common, readily-available objects that have relatively consistent weights. For the phone, participants held the phone in both landscape and portrait orientations.

For both surveys, we examined the effects of the finger performing the gesture on comfort and effort. We evaluated the index, middle, ring, and pinky fingers but omitted the thumb because prior work found that thumb-based microgestures are often rated highly [8], which also shortened the survey duration. The focus was on microgestures performed by the middle, ring, and pinky fingers, but the index finger was included as a baseline. In total, 43 microgestures were evaluated in the pose survey and 34 microgestures were evaluated in the grasping survey.[2] Twenty microgestures were common across both surveys, but with varying hand postures.

5.3 Design

Survey was a between-subjects factor, with POSTURE having two levels (POSE and GRASP). Each survey was within-subjects. Both surveys had four independent variables, of which three were the same: FINGER (levels: INDEX, MIDDLE, RING, PINKY), REGION (levels: ADJACENT, THUMB, PALM, NONE), and INTERACTION (levels: TAP, SWIPE, EXTEND). In addition, for the POSE condition, there was PINCH (levels: TIP, LATERAL) and for GRASP there was OBJECT (levels: PEN, PHONE-LANDSCAPE, PHONE-PORTRAIT). For both surveys, there was a secondary factor, GESTURE, that combined the PINCH or OBJECT, FINGER, REGION, and INTERACTION (i.e., 43 levels for POSE and 34 levels for GRASP).

[2]The full set of microgestures is included as videos in the supplementary materials. While holding a phone in landscape mode, we tested two additional "crossing" interactions. See A.0.3 for details.

There were three dependent variables: *Comfort*, *Effort*, and *Cannot Perform*. *Comfort* and *Effort* were numerical ratings participants assigned to each microgesture (1-7 range). *Comfort* encapsulates how physically comfortable a microgesture is to perform, while *Effort* encapsulates physical or mental effort required to simultaneously maintain the base posture and perform the microgesture. *Effort* was reverse scored (i.e., 8 - x) to align the valence and numeric scores for *Effort* and *Comfort*. We refer to this reversed score as *Ease*. *Cannot Perform* was a binary value indicating whether participants could perform the gesture.

5.4 Procedure

Both surveys were created and administered to participants using Qualtrics. Participants completed demographic information and were asked to try all the microgestures using their dominant hand. If they were ambidextrous, they were asked to pick a hand.

Participants first tried performing two baseline microgestures. One was objectively easy, requiring the participant to tap their index finger and thumb together. The other was more difficult, requiring the participant to cross their index finger over their pinky finger. These baselines taught participants how they would rate each microgesture and provided points of comparison.

Next, they began the main task, where they were presented with a random hand posture to maintain (pinch or object to hold). While maintaining this posture, they were asked to use a randomly selected finger to tap or swipe a randomly selected region of their hand for 10 seconds after watching a short, looping video of the gesture. Tapping was always performed before swiping to reduce mental load. Other non-pinching or non-grasping fingers could be placed anywhere. After, participants provided numerical ratings, ranging from 1 (very low) to 7 (very high) on a semantic differential scale. If a participant could not complete the microgesture, they could indicate this in the ratings and optionally describe what prevented them from performing it (Appendix A, Figure 17). Once they tapped and swiped all regions of their hand using the selected finger, participants were asked to extend their finger for 10 seconds. This was repeated for all fingers and hand postures. After completing all microgestures, participants answered open-ended questions. Each survey took roughly 30 minutes to complete and participants received $7.50 USD upon completing the survey.

6 RESULTS

We first present results for POSE, followed by GRASP, and the microgestures that were included in both surveys. For *Comfort* and *Ease*, we present the average scores of participants who could perform the microgesture, which is appropriate for the 1-7 scale interval data on a semantic differential scale.[3] We discuss differences using the confidence intervals depicted in the figures. Estimation is increasingly being recommended by HCI researchers and scientists more broadly [9], and allows researchers to make inferences even when they have an unbalanced experimental design. All confidence intervals show 95% confidence, and were created using the bootstrapping method

[3]We also examined median scores but did not observe any major differences when compared to the means.

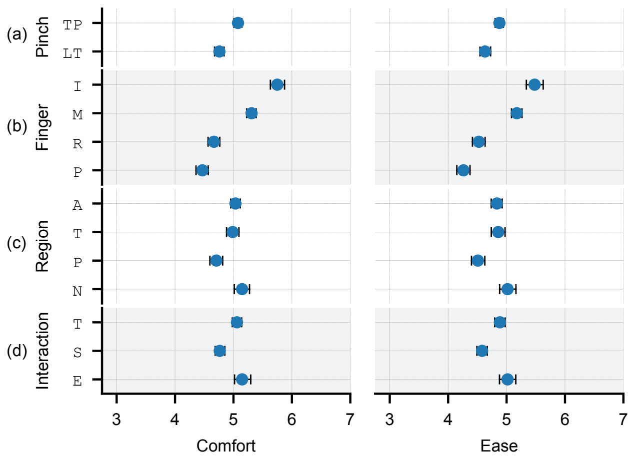

Figure 9: The average *Comfort* and *Ease* ratings for the POSE posture, grouped by (a) PINCH, (b) FINGER, (c) REGION, and (d) INTERACTION (higher is better).

with 10,000 resamples. **For brevity, we refer to the four independent variables in the figures using abbreviations, separated by dashes: PINCH/OBJECT–FINGER–REGION–INTERACTION.** For PINCH, TP and LT refer to TIP and LATERAL; for OBJECT, PN, PP, and PL refer to PEN, PHONE-PORTRAIT, and PHONE-LANDSCAPE. For FINGER, REGION, and INTERACTION, all abbreviations are the first letter of each level (Appendix A, Tables 1 and 2).

6.1 Pose Posture

The data revealed several trends across PINCH, FINGER, REGION, and INTERACTION. TIP was more comfortable than LATERAL (Figure 9a). INDEX was the most comfortable and easiest, followed by MIDDLE, and RING and PINKY (Figure 9b). SWIPE was less comfortable than and not as easy to perform as other INTERACTIONS (Figure 9d). Out of the 4472 data points that were collected,[4] there were 72 responses (1.6%) that indicated that participants could not perform a GESTURE (Figure 10c).

6.1.1 Comfort and Ease. To examine the effect of GESTURE, we sorted the microgestures by average *Comfort* in descending order (Figure 10), and discuss the properties those that have confidence interval ranges greater than or less than 5 (higher end of the 1-7 numerical scale). Microgestures with entire confidence intervals greater than 5 are generally comfortable and easy to perform.

Twelve microgestures had confidence intervals with entire ranges greater than 5 for *Comfort* (Figure 10a, green shaded region). Most used a TIP pinch, the INDEX (4) or MIDDLE (7) fingers and a TAP INTERACTION (6). There were fourteen microgestures with confidence interval ranges less than 5 (Figure 10b, red shaded region). All but one used the RING (5) or PINKY (8), and most used a SWIPE INTERACTION (8). Generally, microgestures with high *Comfort* scores had high *Ease* scores. However, there were fewer microgestures with higher *Ease* scores (8 with entire confidence intervals greater

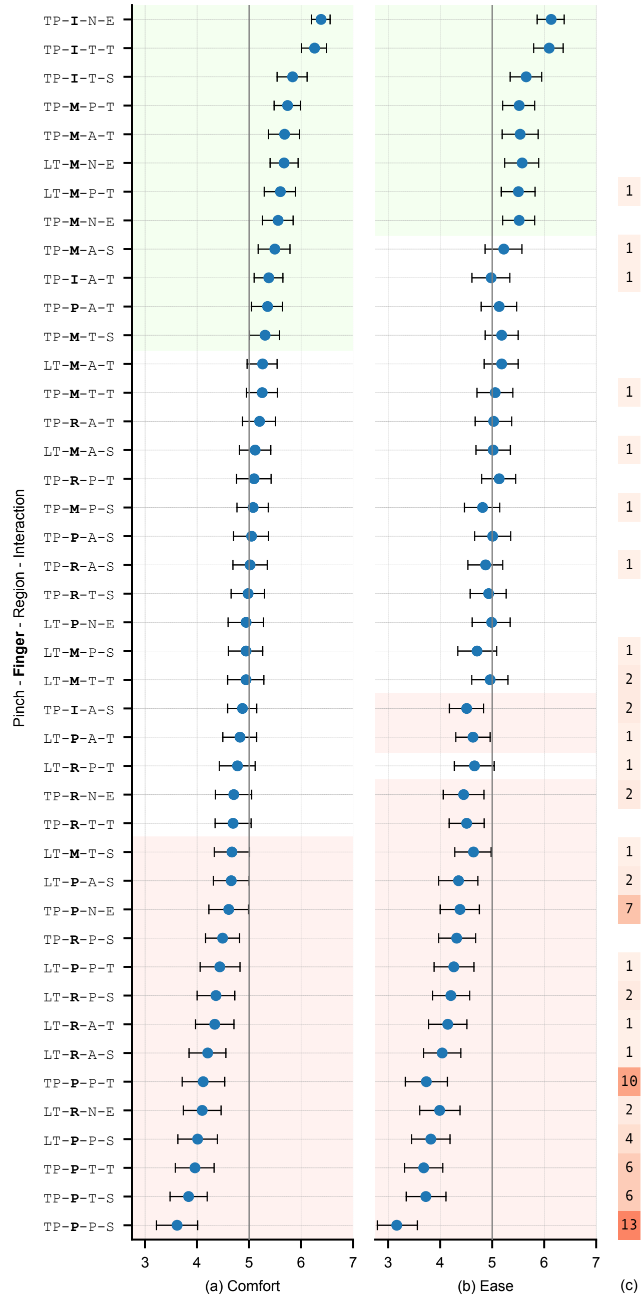

Figure 10: (a) Average *Comfort*, (b) average *Ease*, and (c) number of *Cannot Perform* responses that were collected for all POSE microgestures. GESTURE is sorted by average *Comfort*, in descending order. Higher scores are better. Green regions indicate microgestures whose confidence intervals were greater than 5 and the red regions indicate those less than 5.

than 5), suggesting that some microgestures could be performed comfortably but with less ease.

[4]For POSE: 104 participants × 43 GESTURES = 4472

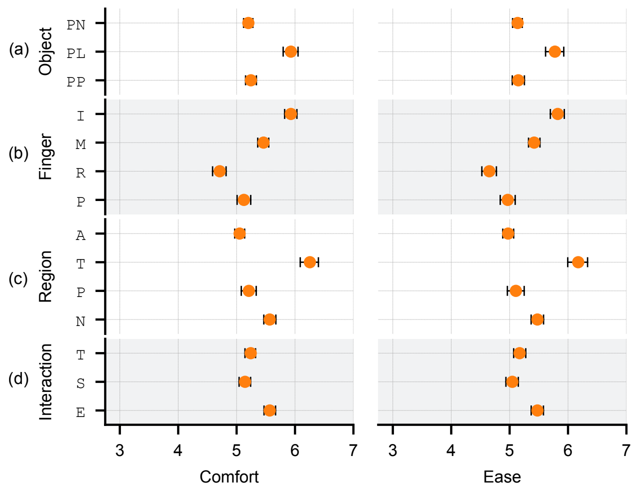

Figure 11: Average *Comfort* and *Ease* ratings for the GRASP posture, grouped by (a) OBJECT, (b) FINGER, (c) REGION, and (d) INTERACTION (higher is better).

6.2 Grasp Posture

PHONE-LANDSCAPE was the most comfortable and easiest OBJECT to grasp (Figure 11a). For FINGER, INDEX was the most comfortable and easiest, followed by MIDDLE, PINKY, and RING (Figure 11b). THUMB was the most comfortable REGION and was the easiest, followed by NONE. No differences were observed between ADJACENT and PALM. EXTEND was more comfortable and easier than TAP and SWIPE. Out of the 3604 data points that were collected,[5] there were 50 responses (1.4%) that indicated that participants could not perform a GESTURE.

6.2.1 Comfort and Ease. The results showed that thirteen microgestures had entire confidence interval ranges greater than 5 for *Comfort* (Figure 12a, green shaded region). Most used the INDEX (5) and MIDDLE (7) FINGER and almost half (6) used an EXTEND INTERACTION. Five microgestures had entire confidence intervals less than 5 (Figure 12a, red shaded region); all used the RING FINGER (5). Two additional microgestures had confidence interval ranges less than 5 for *Ease* (Figure 12b, red shaded region).

6.3 Comparing Pose and Grasp

To get a general sense of the effect grasping an object had on the ratings, we compared the responses for the 20 microgestures that were common across surveys. In the subsequent analysis, the PINCH and OBJECT measurements were aggregated, and the GESTURE property included the FINGER, REGION, and INTERACTION. When aggregating across FINGER, REGION, and INTERACTION, there were some cases where GRASP was more comfortable and easier than POSE. These included when the FINGER was the PINKY (Figure 13a), when the REGION was the PALM or when it was NONE (Figure 13b), and when the INTERACTION was SWIPE or EXTEND (Figure 13c). Out of 7244 data points,[6] 106 responses (1.5%) indicated that a participant could not perform a microgesture.

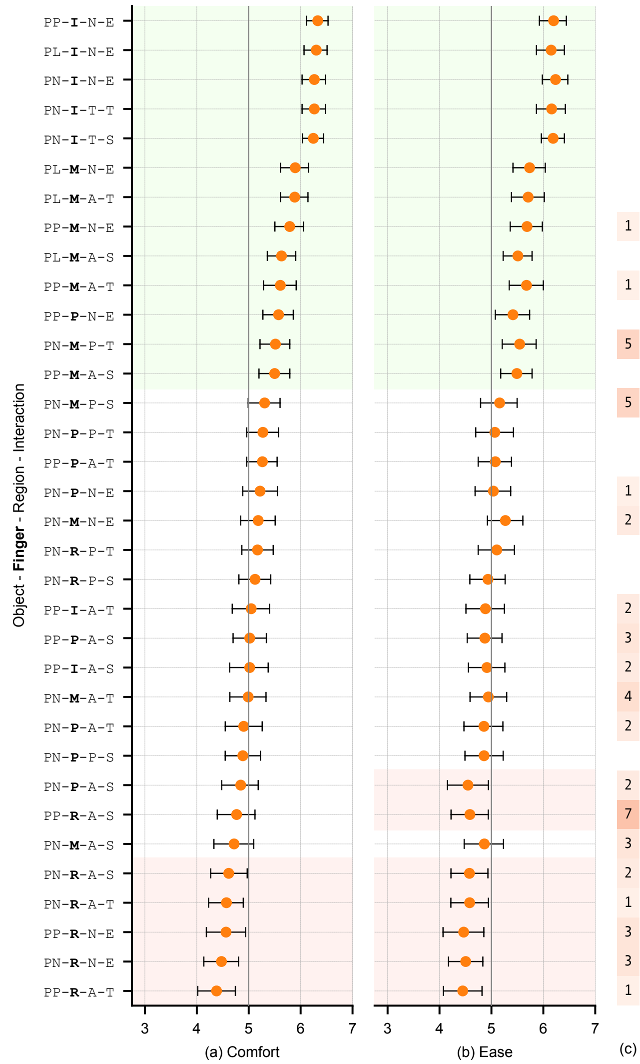

Figure 12: (a) Average *Comfort*, (b) average *Ease*, and (c) number of *Cannot Perform* ratings for all GRASP microgestures. GESTURE is sorted by average *Comfort*, in descending order. Higher scores are better. Green regions indicate microgestures whose confidence intervals were greater than 5 and the red regions indicate those less than 5.

6.3.1 Comfort and Ease. There were seven microgestures that had confidence intervals greater than 5 for *Comfort* (Figure 14a; green shaded region); three used the INDEX finger and four used the MIDDLE finger. Excluding one GESTURE (M-P-S), all microgestures that used the MIDDLE had confidence intervals greater than 5. Only two microgestures had confidence interval ranges less than 5. For *Ease*, the microgestures with confidence interval ranges above and below 5 were the same, save two (R-A-T and M-A-S). For almost all microgestures save two (P-P-T and P-P-S), there was no difference between POSE and GRASP.

[5]For GRASP: 106 participants × 34 GESTURE = 3604

[6]Not all microgestures were tested equally across POSE and OBJECT. For TIP, all 20 were included, but for LATERAL, only 15 were included; for POSE there are 104 participants × 35 GESTURE = 3640 responses. For PEN, 18 microgestures were included, for PHONE-LANDSCAPE 4 were featured, and for PHONE-PORTRAIT 12 were featured; for GRASP there are 106 participants × 34 GESTURE = 3604 responses. Overall, 3640 + 3604 = 7244

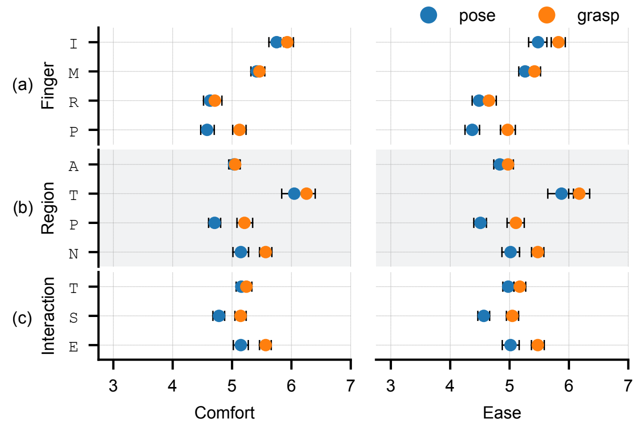

Figure 13: Average *Comfort* and *Ease* for POSE and GRASP, grouped by (a) FINGER, (b) REGION, and (c) INTERACTION (higher is better).

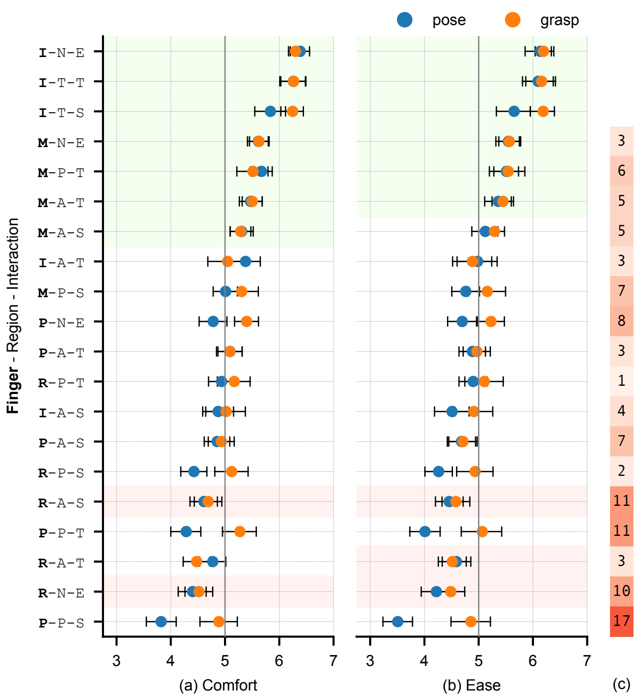

Figure 14: (a) Average *Comfort*, (b) average *Ease*, and (c) number of *Cannot Perform* ratings, split by POSTURE. GESTURE is sorted by average *Comfort*, in descending order. Higher scores are better. Green regions indicate microgestures whose confidence intervals were greater than 5 and the red regions indicate those less than 5.

6.4 Qualitative Feedback

The free-form responses found at the end of the two surveys provided insights into the factors that might have impacted microgesture comfort and ease. The first two authors created a broad set of topics and categorized all responses to ensure nothing was missed. The topics included call-outs to specific postures, fingers, regions, or interactions, and the physical or mental side effects of performing the microgestures. We did not calculate an inter-rater reliability score as the data was straightforward and the codes were not the outcome of interest [24].

Overall, several participants (46) noted how the index and middle fingers were easier or more comfortable than the ring and pinky fingers. This generally aligned with the ratings, where the index and middle fingers were reported to be higher in comfort and ease. Microgestures involving these two fingers frequently had confidence intervals greater than 5, whereas the ring and pinky fingers frequently had confidence intervals less than 5.

Participants had ideas about why some fingers were harder or less comfortable than others, many of which were related to finger individuation and independence [13]: finger strength and dexterity (5), frequency of use for tasks (3), a lack of finger independence (3), and physical "locks" or "pops" that restricted movements (3). Other reasons included finger length (4) and coordination issues (7), e.g., *"my fingers didn't want to respond to what I wanted them to do"* (P33).

The base posture made moving specific fingers harder or uncomfortable (8). When grasping an object, the object could sometimes get in the way (3). Participants noted how the same microgestures could feel very different across postures (2), or grasps (11), e.g., *"it was like the difficulty changed in some of the [microgestures] that were otherwise the same. I would have just thought my finger had the same dexterity and strength regardless of how they were configured"* (P118). Conversely, some participants commented on the impacts the microgestures had on their posture, specifically how it impacted their grip on the phone or pen (2) and stability (2).

Few participants noted differences between interactions, e.g., *"I was occasionally surprised when rubbing or tapping the same area could feel quite different from each other in action"* (P9). Extending certain fingers, such as the middle finger, may be socially inappropriate and look like *"a bad gesture"* (P89), echoing prior work [44]. Six participants noted how swiping was the most challenging, of which two noted it resulted in tension in the wrist.

Although a microgesture may be comfortable to perform, it may require additional cognitive effort to figure out how to correctly position the hand or move each finger, and we observed that *Ease* was lower than *Comfort* 23% of the time. A few participants (4) commented to this effect, e.g., *"It took a lot of focus to make it work, though once I figured it out it was easier to complete"* (P113).

6.5 Summary

Overall, the index finger was the most comfortable and easiest to perform microgestures with when the hand was maintaining a pose and when it was grasping an object. Many index finger-based microgestures had comfort and ease ratings that were greater than 5, and some microgestures could be performed by all 210 participants (I-N-E, I-T-T, I-T-S). Many of the microgestures performed using the middle finger also had high comfort and ease ratings, consistently appearing within the highest-rated microgestures while pinching and grasping an object (Figures 10 and 12; green shaded region). Furthermore, across postures, comfort and ease appeared to be fairly consistent, suggesting that they could transfer well across different levels of hand constraints (Figure 13).

The ring finger and pinky finger were consistently ranked lowest (Figures 10 and 12; red shaded region). Many pinky finger-based microgestures received different scores across postures, suggesting that their transferability would be less feasible or come at a greater cost. Several participants commented how using their ring and pinky fingers was challenging. There were many microgestures in the middle with scores around 5, which suggests that they may be feasible to use after additional practice. The percentages of responses where participants could not perform a microgesture were quite low (< 2% for both surveys), indicating that microgestures involving the middle, ring, and pinky fingers are feasible options.

7 LAB-BASED STUDY

To better understand the impact microgestures performed by the middle finger have on task-specific microinteractions, we conducted a follow-up lab-based study. We invited participants to try the inking and camera demonstration applications described previously (Figure 6). These two applications were selected as they both feature the same set of middle finger microgestures which were among the most comfortable set from the online study (Figure 14a, M-P-T, M-A-T, M-A-S). Both applications can be performed while holding an object or while performing a mid-air gesture. We compared three variations of these microgestures for each application: while holding a stylus or phone, while performing a pinch or 'frame' mid-air gesture, and baseline techniques that involved selecting UI elements. During the experiment, participants were asked to re-create a drawing or a picture by manipulating the inking or camera options. We recruited 10 participants (Appendix A, Table 4) and used the same OptiTrack setup described in Section 4 (Figure 4).

7.1 Task

While performing a mid-air gesture and holding an object, participants used the same set of microgestures to change properties related to the stroke or photo. For the inking application, the baseline was performed with hand posture, where the colours and stroke weights were selected from a UI by pinching the index finger and thumb together. For the camera application, the baseline was selecting filters and zooming in/out by pressing a button or dragging a slider on a smartphone within a custom camera interface. These two baselines encapsulate current methods of inking in VR with hand tracking and taking a photo with a smartphone.

For each microgesture variation, participants re-created drawings or photos (Appendix A, Figure 18). For the inking application, the re-creation was a rectangle, where each side had a different stroke weight and colour. For the camera application, the re-creation was a picture of a rubber duck. The re-creations were designed so that participants would have to make large or small adjustments. Small adjustments involved tapping once to change the stroke filter or colour and performing smaller swipes to change the stroke width or zoom. Large adjustments involved tapping three times or performing larger swipes. Combining large and small adjustments for both adjustable properties resulted in four levels of adjustments. Since each inking re-creation involved four adjustments, participants completed four re-creations using each technique for the inking application and sixteen for the camera application.

7.2 Design

This within-subject methodology had two independent variables: the APPLICATION (levels: INKING and CAMERA) and the TECHNIQUE (levels: POSE, GRASP, BASELINE). The order of TECHNIQUE was counterbalanced using a Latin square and the order of APPLICATION was swapped between participants. Each survey that was completed after trying a single TECHNIQUE consisted of five questions from the NASA-TLX (all scored from 1-7). Due to occasional tracking issues caused by occlusion from the participant's body or objects being held, the "frustration" question was omitted. One optional free-form response was included to collect additional comments.

The surveys that were completed after trying all the TECHNIQUES for a single APPLICATION consisted of two questions. One question asked participants to rank all techniques from best to worst (1 = best, 3 = worst), with ties being allowed, one free-form response question asked participants to explain their ranking.

7.3 Procedure

Markers were placed on the participant's dominant hand and they performed a short calibration sequence in Unity to fine-tune properties related to touch detection with the OptiTrack system. Next, participants were assigned an application and technique. For each technique, they completed re-creations using all four levels of adjustments. After they finished their re-creation, they completed a short survey about their experience using the technique before trying the next technique. Once the participant tried and completed surveys for all techniques, they completed another survey asking them to rank the different techniques. This was repeated for the next application. Due to the aforementioned tracking issues, we instructed participants to focus on the concept of using middle finger microgestures to accomplish their task while completing surveys rather than the usability of the current tracking and implementation. The entire experiment took roughly 90 minutes and participants received a $75 USD gift card upon completing the experiment.

7.4 Results

Similar to the online study, we focused on visually examining confidence intervals (Figure 15) and reporting the average scores for each APPLICATION. In the free-form responses, participants provided comments similar to responses in the online study. Instead of reiterating these comments, we focus on factors more specific to each APPLICATION.

7.4.1 Camera. We observed that GRASP had the highest score for physical demand (Figure 15a). Participants believed they were less successful at the task with GRASP than BASELINE, and BASELINE required less effort than POSE and GRASP. For the overall rankings (Figure 16a), the majority of participants ranked POSE as the best, followed by BASELINE, and then GRASP.

P3 noted that POSE was nice for taking photos because they could focus their attention on the image preview, but with BASELINE their focus was split between the image preview and the UI, i.e., *"[with pose] I can focus on the viewfinder on the screen and make small adjustments. [For baseline] the UI for adjusting the saturation/zoom is on the same surface as the viewfinder. Therefore I would have to shift my attention back and forth."* P5 noted how the type of photography

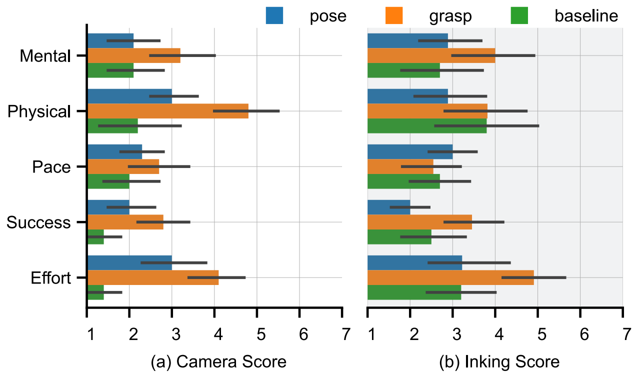

Figure 15: Average scores for each APPLICATION and TECHNIQUE. Confidence intervals are 95% confidence, created using the bootstrapping method with 10,000 resamples. Lower scores are better.

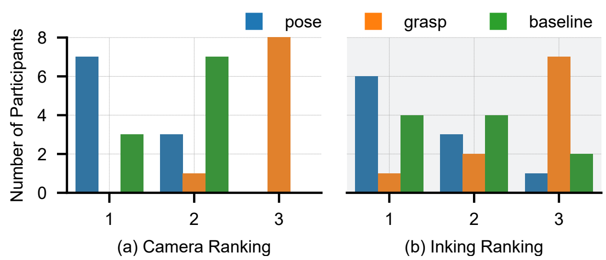

Figure 16: The overall rankings for each APPLICATION and TECHNIQUE, where ties were allowed.

could impact their preferences, i.e., *"in the context of taking photos, speed, reliability, and ease of functionality that takes less fine-tuned movements is preferable. Especially in social situations or trying to capture a 'moment'."* P10 noted how for GRASP, moving their fingers caused the phone to move as well, i.e., *"gestures with an object was my least favorite, because the gestures themselves caused the frame of the photo to change."*

7.4.2 Inking. For TECHNIQUE (Figure 15b), participants believed they were less successful at the task with GRASP than POSE. GRASP also required more effort than BASELINE. For the rankings (Figure 16b), the majority of participants ranked POSE as the best and GRASP as the worst. Five participants commented on how microgestures were helpful while inking as they did not have to move their entire arm to select new colours and strokes, e.g., *"selecting UI elements on screen is tiring because you need to use your whole arm to make changes constantly. The gestures made it easier to edit the drawing mode without moving my pen/cursor."* (P1)

7.4.3 Summary. Overall, POSE was preferred by participants and, with the exception of effort for CAMERA, appears to be as good as BASELINE. In contrast, GRASP was least preferred and required more effort than BASELINE for both applications.

8 DISCUSSION

The design space and the applications demonstrate how microgestures performed by the middle, ring, and pinky fingers can be used for auxiliary input that transfers across hand location, hand posture, grasps, and fingers. The online study revealed that many microgestures performed by the middle finger are comfortable and easy to perform when pinching and holding a pen and phone. The lab study revealed that performing microgestures while maintaining a hand pose is as comfortable as baseline techniques and is preferable over performing microgestures while grasping an object.

Overall, our work has two main takeaways: (i) **it is possible to use the middle, ring, and pinky fingers for auxiliary input**, and (ii) some microgestures **transfer well across varying levels of hand constraint**. Together, our threefold methodology revealed additional factors that are important to consider when designing microgestures for the middle, ring, and pinky fingers.

First, **transferring microgestures to different hand locations and posture constraints has effects**. A key part of gesture transferability is how performance is impacted in other contexts [27, 42], and we observed effects when transferring microgestures to different fingers during the online study and when transferring them to different postures during the lab study. Although microgestures performed by the middle, ring, and pinky fingers can enable auxiliary input in situations where it otherwise would have been very difficult or impossible to do so, this does not mean the experience is identical across hand location and posture constraints.

Second, **the nature of the primary task impacts usability**. The design space is defined by the impact the primary task has on hand location and posture. As such, the primary task should place constraints on the auxiliary task, not the other way around. As shown by the qualitative feedback from both studies, if microgestures impact the ability to perform the primary task, either by changing the hand location or by impacting the ability to maintain a specific hand posture, they are not as suitable to use.

Third, in addition to physical factors like hand location and posture, **there are other ways the hands can be constrained during a primary task**. Middle finger movements may be inappropriate in social settings [44], but adjusting the hand location to be closer to the body or performing such movements with even smaller movements may increase social acceptability. Some primary tasks are time-sensitive. Based on current technologies, there are technological constraints: physical sensors on the fingers [5, 17] may get in the way, and tracking the hands with a head- or body-mounted camera [22, 32] means the hand location must be in the camera's field of view. As sensing technologies improve, this will become less of an issue.

8.1 Design Recommendations

When the index finger and thumb cannot be used for microgestures, **the middle finger is the next best finger to use**. Many middle finger microgestures are as comfortable and as easy to perform as microgestures performed by the index finger. The middle finger can comfortably perform microgestures along the adjacent finger and palm, and when extending. When using the middle finger, **the adjacent finger is the best contact region** as it can comfortably support both tapping and swiping. As shown by the inking and camera applications, middle finger microgestures can also transfer across hand postures. But the middle finger is more essential when grasping some objects, so **middle finger microgestures may be even more advantageous when forming a pose than when**

grasping an object. When the middle finger is not available to use when grasping, using the ring or pinky finger is possible, but will likely be less comfortable. Due to their more limited dexterity and risks of "locking" or "popping," **the ring and pinky fingers should be used for discrete operations**, like directional swiping and tapping, rather than for continuous operations that require more fine motor skills.

8.2 Limitations and Future Work

We discuss limitations and possibilities for future work.

8.2.1 Additional Postures and Hands. There are other poses and grasps that could have been evaluated. Participants were instructed to use their dominant hand, but it may not always be the most dexterous [13]. Future work should expand upon our exploration by comparing the same microgestures across a wider range of poses and grasps, with both hands.

8.2.2 Validity. Although participants from the online study were told other fingers could be placed anywhere, the free-form responses suggested that some believed only one finger should move, which may have caused poorer scores. Participants tried all microgestures for 10 seconds, but this is not realistic of actual usage [2], so comfort and effort would likely be better in practice. Microgestures performed with larger or more controlled movements would likely be less comfortable than those performed with smaller or more relaxed movements. However, given the nature of the online study, we could not control for or examine this, but we believe it would be interesting to examine in future work. The online study had a diverse set of participants, but the lab study was less representative of the general population. Future work should examine microgestures performed by the middle, ring, and pinky fingers across a more diverse population.

8.2.3 Technical Feasibility. Markerless tracking is ideal, and we observed that popular libraries like Google's MediaPipe Hands and the Quest 2 HMD could not accurately recognize single-finger movements because such movements are uncommon [29]. Important directions for future work include (i) creating training sets of microgestures performed by the middle, ring, and pinky fingers across varying levels of hand location and posture constraints; and (ii) accurately detecting such microgestures through a wrist-worn device (e.g., [19, 23, 31]) or using computer vision (e.g., [32]).

8.2.4 Gesture Mappings. When the hand location is arbitrary, swipes have directional associations in different locations. Varying hand locations may impact how well users can remember command mappings, and future work should investigate how they transfer to different hand locations in more depth.

8.2.5 Familiarity. In the lab study, most participants had experience with XR, so they would be more familiar with maintaining pinches for a primary task. This could have been why performing microgestures while maintaining a pose was preferred and less physically demanding. With additional practice, performing microgestures while grasping an object may become more comfortable. Exploring long-term practice of grasping microgestures is an important avenue for future work.

9 CONCLUSION

Overall, we contribute a design space focused on how the middle, ring, and pinky fingers can be used to perform microgestures across varying levels of hand location and hand posture constraints. Through five applications, we demonstrated how such microgestures could transfer across hand locations, hand postures, applications, grasps, and fingers. An online study with 210 participants showed that many microgestures were thought to be comfortable, and many middle finger gestures were not much more uncomfortable than those performed by the index finger. A lab study utilized the most comfortable middle finger microgestures in inking and photography tasks and found that microgestures performed while maintaining a pose were preferred to microgestures performed when grasping. Microgestures performed by the middle, ring, and pinky fingers give users more options and opportunities for auxiliary input, providing them with the flexibility needed to interact with their devices in more contexts.

REFERENCES

[1] Leonardo Angelini, Francesco Carrino, Stefano Carrino, Maurizio Caon, Omar Abou Khaled, Jürgen Baumgartner, Andreas Sonderegger, Denis Lalanne, and Elena Mugellini. 2014. Gesturing on the steering wheel: A user-elicited taxonomy. In *Proc. Int. Conf on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '14)*. ACM, New York, NY, USA, 1–8. https://doi.org/10.1145/2667317.2667414
[2] Daniel L Ashbrook. 2010. *Enabling Mobile Microinteractions.* Georgia Institute of Technology.
[3] Richard A Bolt. 1980. "Put-that-there" Voice and gesture at the graphics interface. In *Proc. Conf on Computer Graphics and Interactive Techniques.* 262–270.
[4] Edwin Chan, Teddy Seyed, Wolfgang Stuerzlinger, Xing-Dong Yang, and Frank Maurer. 2016. User elicitation on single-hand microgestures. In *Proc. SIGCHI Conf. on Human Factors in Computing Systems.* ACM, New York, NY, USA, 3403–3414. https://doi.org/10.1145/2858036.2858589
[5] Liwei Chan, Rong-Hao Liang, Ming-Chang Tsai, Kai-Yin Cheng, Chao-Huai Su, Mike Y. Chen, Wen-Huang Cheng, and Bing-Yu Chen. 2013. FingerPad: Private and subtle interaction using fingertips. In *Proc. ACM Symposium on User Interface Software and Technology.* ACM, New York, NY, USA, 255–260. https://doi.org/10.1145/2501988.2502016
[6] Yu-Chun Chen, Chia-Ying Liao, Shuo-wen Hsu, Da-Yuan Huang, and Bing-Yu Chen. 2020. Exploring user defined gestures for ear-based interactions. *Proc. ACM Hum.-Comput. Interact.* 4, ISS, Article 186 (Nov. 2020), 20 pages. https://doi.org/10.1145/3427314
[7] Nalin Chhibber, Hemant Bhaskar Surale, Fabrice Matulic, and Daniel Vogel. 2021. Typealike: Near-keyboard hand postures for expanded laptop interaction. *Proc. ACM Hum.-Comput. Interact.* 5, ISS, Article 486 (nov 2021), 20 pages. https://doi.org/10.1145/3486952
[8] Bastian Dewitz, Frank Steinicke, and Christian Geiger. 2019. Functional workspace for one-handed tap and swipe microgestures. In *Mensch und Computer 2019 - Workshopband.* Gesellschaft für Informatik e.V., Bonn. https://doi.org/10.18420/muc2019-ws-440
[9] Pierre Dragicevic. 2015. *HCI Statistics without p-values.* Ph. D. Dissertation. Inria.
[10] Scott FM Duncan, Caitlin E Saracevic, and Ryosuke Kakinoki. 2013. Biomechanics of the hand. *Hand Clinics* 29, 4 (2013), 483–492.
[11] Aarthi Easwara Moorthy and Kim-Phuong L Vu. 2015. Privacy concerns for use of voice activated personal assistant in the public space. *Int. J. of Human-Computer Interaction* 31, 4 (2015), 307–335.
[12] Thomas Feix, Javier Romero, Heinz-Bodo Schmiedmayer, Aaron M Dollar, and Danica Kragic. 2015. The GRASP taxonomy of human grasp types. *IEEE Trans. on Human-Machine Systems* 46, 1 (2015), 66–77.
[13] Charlotte Häger-Ross and Marc H Schieber. 2000. Quantifying the independence of human finger movements: comparisons of digits, hands, and movement frequencies. *J. Neuroscience* 20, 22 (2000), 8542–8550.
[14] Benjamin Hatscher and Christian Hansen. 2018. Hand, foot or voice: Alternative input modalities for touchless interaction in the medical domain. In *Proc. ACM Int. Conf. Multimodal Interaction.* ACM, New York, NY, USA, 145–153.
[15] Da-Yuan Huang, Liwei Chan, Shuo Yang, Fan Wang, Rong-Hao Liang, De-Nian Yang, Yi-Ping Hung, and Bing-Yu Chen. 2016. DigitSpace: Designing thumb-to-fingers touch interfaces for one-handed and eyes-free interactions. In *Proc. SIGCHI Conf. on Human Factors in Computing Systems (CHI '16).* ACM, New York, NY, USA, 1526–1537. https://doi.org/10.1145/2858036.2858483

[16] Noriko Kamakura, Michiko Matsuo, Harumi Ishii, Fumiko Mitsuboshi, and Yoriko Miura. 1980. Patterns of static prehension in normal hands. *Am. J. Occupational Therapy* 34, 7 (1980), 437–445.

[17] Hsin-Liu (Cindy) Kao, Artem Dementyev, Joseph A. Paradiso, and Chris Schmandt. 2015. NailO: Fingernails as an input surface. In *Proc. SIGCHI Conf. on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 3015–3018. https://doi.org/10.1145/2702123.2702572

[18] Maria Karam and schraefel m.c. 2005. A taxonomy of gestures in human computer interactions. (2005).

[19] David Kim, Otmar Hilliges, Shahram Izadi, Alex D. Butler, Jiawen Chen, Iason Oikonomidis, and Patrick Olivier. 2012. Digits: Freehand 3D interactions anywhere using a wrist-worn gloveless sensor. In *Proc. ACM Symposium on User Interface Software and Technology (UIST '12)*. ACM, New York, NY, USA, 167–176. https://doi.org/10.1145/2380116.2380139

[20] JMF Landsmeer. 1962. Power grip and precision handling. *Annals of the Rheumatic Diseases* 21, 2 (1962), 164.

[21] Chen Liang, Chun Yu, Yue Qin, Yuntao Wang, and Yuanchun Shi. 2021. DualRing: Enabling subtle and expressive hand interaction with dual IMU rings. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 5, 3, Article 115 (Sept. 2021), 27 pages. https://doi.org/10.1145/3478114

[22] Mingyu Liu, Mathieu Nancel, and Daniel Vogel. 2015. Gunslinger: Subtle arms-down mid-Air interaction. In *Proc. ACM Symposium on User Interface Software and Technology (UIST '15)*. ACM, New York, NY, USA, 63–71. https://doi.org/10.1145/2807442.2807489

[23] Christian Loclair, Sean Gustafson, and Patrick Baudisch. 2010. PinchWatch: A wearable device for one-handed microinteractions. In *Proc. MobileHCI*, Vol. 10. ACM.

[24] Nora McDonald, Sarita Schoenebeck, and Andrea Forte. 2019. Reliability and inter-rater reliability in qualitative research: Norms and guidelines for CSCW and HCI practice. *Proc. ACM Human-Computer Interaction* 3, CSCW (2019), 1–23.

[25] Pranav Mistry, Pattie Maes, and Liyan Chang. 2009. WUW-wear Ur world: A wearable gestural interface. In *Proc. CHI'09 Extended Abstracts on Human Factors in Computing Systems*. ACM, New York, NY, USA, 4111–4116.

[26] John R Napier. 1956. The prehensile movements of the human hand. *J. Bone and Joint Surgery. British volume* 38, 4 (1956), 902–913.

[27] David N Perkins and Gavriel Salomon. 1992. Transfer of learning. *Int. Encyclopedia of Education* 2 (1992), 6452–6457.

[28] Timothy Ryan. 2020. Fraudulent responses on Amazon Mechanical Turk: A Fresh Cautionary Tale. https://timryan.web.unc.edu/2020/12/22/fraudulent-responses-on-amazon-mechanical-turk-a-fresh-cautionary-tale/

[29] Adwait Sharma, Michael A. Hedderich, Divyanshu Bhardwaj, Bruno Fruchard, Jess McIntosh, Aditya Shekhar Nittala, Dietrich Klakow, Daniel Ashbrook, and Jürgen Steimle. 2021. SoloFinger: Robust microgestures while grasping everyday objects. In *Proc. SIGCHI Conf. on Human Factors in Computing Systems (CHI '21)*. ACM, New York, NY, USA, Article 744, 15 pages. https://doi.org/10.1145/3411764.3445197

[30] Adwait Sharma, Joan Sol Roo, and Jürgen Steimle. 2019. Grasping Microgestures: Eliciting Single-Hand Microgestures for Handheld Objects. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300632

[31] Adwait Sharma, Christina Salchow-Hömmen, Vimal Suresh Mollyn, Aditya Shekhar Nittala, Michael A. Hedderich, Marion Koelle, Thomas Seel, and Jürgen Steimle. 2022. SparseIMU: Computational design of sparse IMU layouts for sensing fine-grained finger microgestures. *ACM Trans. Comput.-Hum. Interact.* (Oct. 2022). https://doi.org/10.1145/3569894

[32] Mohamed Soliman, Franziska Mueller, Lena Hegemann, Joan Sol Roo, Christian Theobalt, and Jürgen Steimle. 2018. FingerInput: Capturing expressive single-hand thumb-to-finger microgestures. In *Proc. International Conference on Interactive Surfaces and Spaces (ISS '18)*. ACM, New York, NY, USA, 177–187. https://doi.org/10.1145/3279778.3279799

[33] Srinath Sridhar, Anna Maria Feit, Christian Theobalt, and Antti Oulasvirta. 2015. Investigating the dexterity of multi-finger input for mid-air text entry *(CHI '15)*. ACM, New York, NY, USA, 3643–3652. https://doi.org/10.1145/2702123.2702136

[34] Wei Sun, Franklin Mingzhe Li, Congshu Huang, Zhenyu Lei, Benjamin Steeper, Songyun Tao, Feng Tian, and Cheng Zhang. 2021. ThumbTrak: Recognizing micro-finger poses using a ring with proximity sensing. In *Proc. Int. Conf. Mobile Human-Computer Interaction* (Toulouse & Virtual, France) *(MobileHCI '21)*. ACM, New York, NY, USA, Article 2, 9 pages. https://doi.org/10.1145/3447526.3472060

[35] Hemant Bhaskar Surale, Fabrice Matulic, and Daniel Vogel. 2019. Experimental analysis of barehand mid-air mode-switching techniques in virtual reality. In *Proc. SIGCHI Conf. on Human Factors in Computing Systems (CHI '19)*. ACM, New York, NY, USA, 14 pages. https://doi.org/10.1145/3290605.3300426

[36] Yanke Tan, Sang Ho Yoon, and Karthik Ramani. 2017. BikeGesture: User elicitation and performance of micro hand gesture as input for cycling. In *Proc. CHI Conf. Extended Abstracts on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI EA '17)*. ACM, New York, NY, USA, 2147–2154. https://doi.org/10.1145/3027063.3053075

[37] Hsin-Ruey Tsai, Cheng-Yuan Wu, Lee-Ting Huang, and Yi-Ping Hung. 2016. ThumbRing: Private interactions using one-handed thumb motion input on finger segments. In *Proc. Int. Conf. on Human-Computer Interaction with Mobile Devices and Services Adjunct* (Florence, Italy) *(MobileHCI '16)*. ACM, New York, NY, USA, 791–798. https://doi.org/10.1145/2957265.2961859

[38] Daniel Vogel and Ravin Balakrishnan. 2005. Distant freehand pointing and clicking on very large, high resolution displays. In *Proc. ACM Symposium on User Interface Software and Technology (UIST '05)*. ACM, New York, NY, USA, 33–42.

[39] Jérémy Wambecke, Alix Goguey, Laurence Nigay, Lauren Dargent, Daniel Hauret, Stéphanie Lafon, and Jean-Samuel Louis de Visme. 2021. M[Eye]Cro: Eye-Gaze+microgestures for multitasking and interruptions. *Proc. ACM Hum.-Comput. Interact.* 5, EICS, Article 210 (May 2021), 22 pages. https://doi.org/10.1145/3461732

[40] Katrin Wolf, Sven Mayer, and Stephan Meyer. 2016. Microgesture detection for remote interaction with mobile devices. In *Proc. Int. Conf. on Human-Computer Interaction with Mobile Devices and Services Adjunct (MobileHCI '16)*. ACM, New York, NY, USA, 783–790. https://doi.org/10.1145/2957265.2961865

[41] Katrin Wolf, Anja Naumann, Michael Rohs, and Jörg Müller. 2011. A taxonomy of microinteractions: Defining microgestures based on ergonomic and scenario-Dependent requirements. In *IFIP Conf. on Human-Computer Interaction*. Springer, 559–575.

[42] Haijun Xia, Michael Glueck, Michelle Annett, Michael Wang, and Daniel Wigdor. 2022. Iteratively designing gesture vocabularies: A survey and analysis of best practices in the HCI literature. *ACM Trans. Comput.-Hum. Interact.* 29, 4, Article 37 (May 2022), 54 pages. https://doi.org/10.1145/3503537

[43] Yen-Ting Yeh, Fabrice Matulic, and Daniel Vogel. 2023. Phone sleight of hand: Finger-based dexterous gestures for physical interaction with mobile phones. In *Proc. SIGCHI Conf. on Human Factors in Computing Systems*. ACM, New York, NY, USA, 19 pages.

[44] Jingjie Zheng and Daniel Vogel. 2016. Finger-aware shortcuts. In *Proc. SIGCHI Conf. on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 4274–4285. https://doi.org/10.1145/2858036.2858355

[45] Thomas G Zimmerman, Joshua R Smith, Joseph A Paradiso, David Allport, and Neil Gershenfeld. 1995. Applying electric field sensing to human-computer interfaces. In *Proc. SIGCHI Conf. on Human Factors in Computing Systems*. 280–287.

A APPENDIX

A.0.1 Survey Interface. For each microgesture, participants were shown (a) an image of the base POSTURE and text explanations, (b) looping videos and text that described the FINGER, REGION and INTERACTION (with the hand shown in the video matching the hand used by participant), (c) a semantic differential scale for *Comfort*, and (d) a semantic differential scale for *Effort* (all seen in Figure 17). At the end of the survey, participants were asked the following: *"In 2 or 3 sentences, what was your experience trying these different gestures? For example, were you surprised by which gestures you could and could not perform comfortably, or were there some gestures that required more or less effort than expected?"*

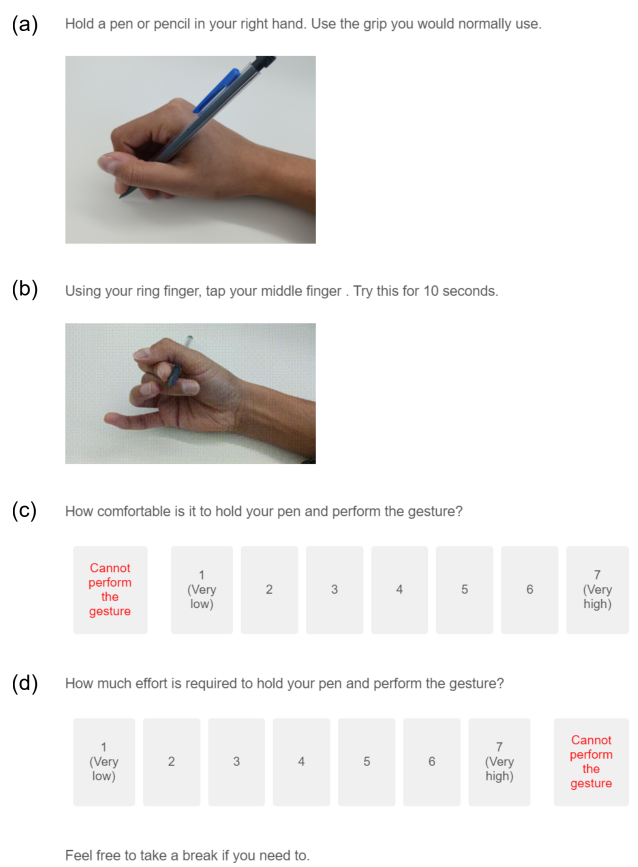

Figure 17: Interface for the online study.

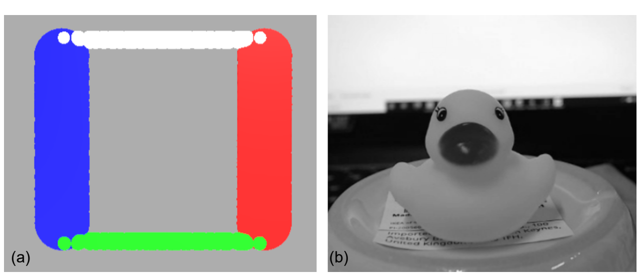

Figure 18: Example drawing and photo participants recreated during the (a) inking and (b) photography tasks.

Table 1: Microgesture abbreviations for the POSE condition.

gesture	PINCH	FINGER	REGION	INTERACTION
TP-I-A-T	TIP	INDEX	ADJACENT	TAP
TP-I-A-S	TIP	INDEX	ADJACENT	SWIPE
TP-I-T-T	TIP	INDEX	THUMB	TAP
TP-I-T-S	TIP	INDEX	THUMB	SWIPE
TP-I-N-E	TIP	INDEX	NONE	EXTEND
TP-M-A-T	TIP	MIDDLE	ADJACENT	TAP
TP-M-A-S	TIP	MIDDLE	ADJACENT	SWIPE
TP-M-T-T	TIP	MIDDLE	THUMB	TAP
TP-M-T-S	TIP	MIDDLE	THUMB	SWIPE
TP-M-P-T	TIP	MIDDLE	PALM	TAP
TP-M-P-S	TIP	MIDDLE	PALM	SWIPE
TP-M-N-E	TIP	MIDDLE	NONE	EXTEND
TP-R-A-T	TIP	RING	ADJACENT	TAP
TP-R-A-S	TIP	RING	ADJACENT	SWIPE
TP-R-T-T	TIP	RING	THUMB	TAP
TP-R-T-S	TIP	RING	THUMB	SWIPE
TP-R-P-T	TIP	RING	PALM	TAP
TP-R-P-S	TIP	RING	PALM	SWIPE
TP-R-N-E	TIP	RING	NONE	EXTEND
TP-P-A-T	TIP	PINKY	ADJACENT	TAP
TP-P-A-S	TIP	PINKY	ADJACENT	SWIPE
TP-P-T-T	TIP	PINKY	THUMB	TAP
TP-P-T-S	TIP	PINKY	THUMB	SWIPE
TP-P-P-T	TIP	PINKY	PALM	TAP
TP-P-P-S	TIP	PINKY	PALM	SWIPE
TP-P-N-E	TIP	PINKY	NONE	EXTEND
LT-M-A-T	LATERAL	MIDDLE	ADJACENT	TAP
LT-M-A-S	LATERAL	MIDDLE	ADJACENT	SWIPE
LT-M-T-T	LATERAL	MIDDLE	THUMB	TAP
LT-M-T-S	LATERAL	MIDDLE	THUMB	SWIPE
LT-M-P-T	LATERAL	MIDDLE	PALM	TAP
LT-M-P-S	LATERAL	MIDDLE	PALM	SWIPE
LT-M-N-E	LATERAL	MIDDLE	NONE	EXTEND
LT-R-A-T	LATERAL	RING	ADJACENT	TAP
LT-R-A-S	LATERAL	RING	ADJACENT	SWIPE
LT-R-P-T	LATERAL	RING	PALM	TAP
LT-R-P-S	LATERAL	RING	PALM	SWIPE
LT-R-N-E	LATERAL	RING	NONE	EXTEND
LT-P-A-T	LATERAL	PINKY	ADJACENT	TAP
LT-P-A-S	LATERAL	PINKY	ADJACENT	SWIPE
LT-P-P-T	LATERAL	PINKY	PALM	TAP
LT-P-P-S	LATERAL	PINKY	PALM	SWIPE
LT-P-N-E	LATERAL	PINKY	NONE	EXTEND

A.0.2 Participant Filtering. As crowdsourced surveys have a high risk of fraudulent responses, we only analyzed surveys from participants who (1) passed basic attention checks (e.g., identifying colours, shapes, or answering basic math questions), (2) did not answer questions too quickly (i.e., rejected < 1 second), and (3) provided reasonable responses for open-ended questions asked at the end of the surveys. The filtering of open-ended responses was performed by the first author and fraudulent responses were quite easy to identify (e.g., short one-word responses such as "nice" or "good" or dictionary definition-like responses that were repeated across participants). This process resulted in 210 valid surveys being analyzed (i.e., 34.6% of surveys were omitted, which aligns with findings from Ryan [28]). To further confirm response validity, we

Table 2: Microgesture abbreviations for the OBJECT condition.

gesture	OBJECT	FINGER	REGION	INTERACTION
PN-I-T-T	PEN	INDEX	THUMB	TAP
PN-I-T-S	PEN	INDEX	THUMB	SWIPE
PN-I-N-E	PEN	INDEX	NONE	EXTEND
PN-M-A-T	PEN	MIDDLE	ADJACENT	TAP
PN-M-A-S	PEN	MIDDLE	ADJACENT	SWIPE
PN-M-P-T	PEN	MIDDLE	PALM	TAP
PN-M-P-S	PEN	MIDDLE	PALM	SWIPE
PN-M-N-E	PEN	MIDDLE	NONE	EXTEND
PN-R-A-T	PEN	RING	ADJACENT	TAP
PN-R-A-S	PEN	RING	ADJACENT	SWIPE
PN-R-P-T	PEN	RING	PALM	TAP
PN-R-P-S	PEN	RING	PALM	SWIPE
PN-R-N-E	PEN	RING	NONE	EXTEND
PN-P-A-T	PEN	PINKY	ADJACENT	TAP
PN-P-A-S	PEN	PINKY	ADJACENT	SWIPE
PN-P-P-T	PEN	PINKY	PALM	TAP
PN-P-P-S	PEN	PINKY	PALM	SWIPE
PN-P-N-E	PEN	PINKY	NONE	EXTEND
PL-I-N-E	PHONE-LANDSCAPE	INDEX	NONE	EXTEND
PL-M-A-T	PHONE-LANDSCAPE	MIDDLE	ADJACENT	TAP
PL-M-A-S	PHONE-LANDSCAPE	MIDDLE	ADJACENT	SWIPE
PL-M-N-E	PHONE-LANDSCAPE	MIDDLE	NONE	EXTEND
PP-I-A-T	PHONE-PORTRAIT	INDEX	ADJACENT	TAP
PP-I-A-S	PHONE-PORTRAIT	INDEX	ADJACENT	SWIPE
PP-I-N-E	PHONE-PORTRAIT	INDEX	NONE	EXTEND
PP-M-A-T	PHONE-PORTRAIT	MIDDLE	ADJACENT	TAP
PP-M-A-S	PHONE-PORTRAIT	MIDDLE	ADJACENT	SWIPE
PP-M-N-E	PHONE-PORTRAIT	MIDDLE	NONE	EXTEND
PP-R-A-T	PHONE-PORTRAIT	RING	ADJACENT	TAP
PP-R-A-S	PHONE-PORTRAIT	RING	ADJACENT	SWIPE
PP-R-N-E	PHONE-PORTRAIT	RING	NONE	EXTEND
PP-P-A-T	PHONE-PORTRAIT	PINKY	ADJACENT	TAP
PP-P-A-S	PHONE-PORTRAIT	PINKY	ADJACENT	SWIPE
PP-P-N-E	PHONE-PORTRAIT	PINKY	NONE	EXTEND

also ran a small pilot study within our organization (n=10) and observed that larger trends align, albeit with less confidence.

A.0.3 Additional Cross and Cross-Swipe Microgestures. While grasping the phone in landscape mode, we evaluated two additional microgestures: crossing the middle finger over the index finger, and simultaneously crossing and swiping along the radial side of the index finger with the middle finger. Both microgestures were rated low for *Comfort* and *Ease* (means below 5). Crossing had average scores of 4.1 and 3.7 for *Comfort* and *Effort*, while crossing while swiping had average scores of 3.7 and 3.6. These two microgestures were mentioned by 12 participants as being the most challenging or least comfortable.

Table 3: Demographic information about the participants who completed each survey.

POSTURE	Gender		Age		Handedness		Reduced Dexterity		Experience	
POSE	Men	54	18-24	5	Right	95	No	102	Typing	88
	Women	50	25-34	37	Left	6	Yes	2	Playing an Instrument	30
			35-44	42	Ambidextrous	3			Playing a Sport	21
			45-54	11					Creative Activities	25
			55-64	7					Sign Language	3
			65+	2					Other	3
									None	11
GRASP	Men	54	18-24	3	Right	96	No	104	Typing	94
	Women	52	25-34	37	Left	8	Yes	2	Playing an Instrument	35
			35-44	38	Ambidextrous	2			Playing a Sport	29
			45-54	13					Creative Activities	36
			55-64	9					Sign Language	5
			65+	5					Other	3
			Unknown	1					None	9

Table 4: Demographic information about the participants from the lab study.

Gender		Age		Handedness		Reduced Dexterity		Experience		AR/VR Experience	
Men	7	18-24	1	Right	9	No	9	Typing	10	Significant	6
Women	3	25-34	9	Left	1	Yes	1	Playing an Instrument	2	Limited	4
								Playing a Sport	4		
								Creative Activities	3		
								Other	1		