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µGlyph: a Microgesture Notation

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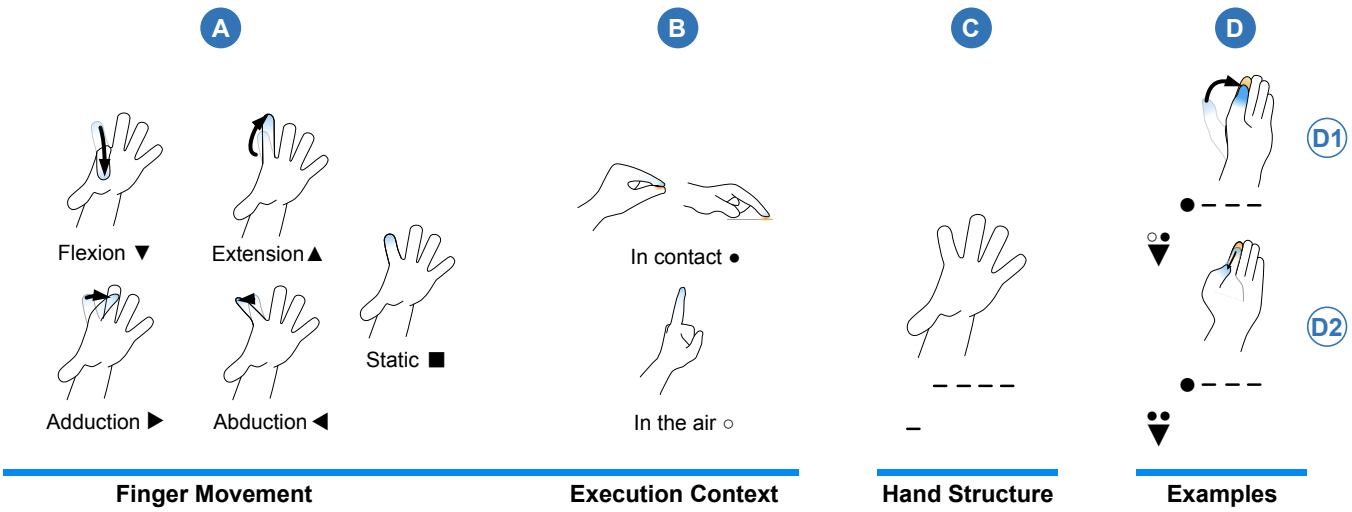

Figure 1: The µGlyph notation. Core elements: A) finger movements and B) execution contexts. C) Graphical structure based on a direct mapping with the hand. D) Two examples: D1) touch of the thumb on the index: a thumb flexion beginning in the air and ending in contact with the index, D2) downward drag of the thumb along the index: a thumb flexion beginning and ending at the contact of the index finger.

ABSTRACT

In the active field of hand microgestures, microgesture descriptions are typically expressed informally and are accompanied by images, leading to ambiguities and contradictions. An important step in moving the field forward is a rigorous basis for precisely describing, comparing, and analyzing microgestures. Towards this goal, we propose µGlyph, a hybrid notation based on a vocabulary of events inspired by finger biomechanics. First, we investigate the expressiveness of µGlyph by building a database of 118 microgestures extracted from the literature. Second, we experimentally explore the usability of µGlyph. Participants correctly read and wrote µGlyph descriptions 90% of the time, as compared to 46% for conventional descriptions. Third we present tools that promote µGlyph usage, including a visual editor with LaTeXexport. We finally describe how µGlyph can guide research on designing, developing, and evaluating microgesture interaction. Results demonstrate the strong potential of µGlyph to establish a common ground for microgesture research.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

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1 INTRODUCTION

Over the past decade, finger movements have been explored for interaction in a variety of contexts (e.g., augmented reality, cockpits, cars) to take advantage of their speed of execution, their potential to be performed without looking at the hand, and their immediate and permanent availability while holding or not an object. This interaction modality, initially designated as finger movement [40], is now more usually referred to as hand microgesture [7, 39, 44]. In this paper we consider hand microgestures as finger movements only, regardless of the forearm and wrist motion.

In the very active field of hand microgestures, a consensus has emerged to describe a microgesture as a quick and subtle movement of the fingers [7, 38], but no precise definition of a microgesture is provided. The absence of a precise definition and description of microgestures leads to ambiguities and even contradictions in the

papers of this field. First, ambiguity is an inherent phenomenon in natural language text+images descriptions [37, 47], which can lead to misunderstandings and inconsistencies amongst researchers. Second the current level of informality in the descriptions of microgestures leads to contradictions. For instance, the microgesture named `tap` can be considered as a mouse down event in [7] and as a mouse click event in [44]. Similarly, the microgesture named `press` can be considered as a mouse down event in [8] and as an increase of pressure in [39]. Moreover, the levels of detail in the description of microgestures is variable from one paper to another. For instance, one microgesture (e.g. `tap` [38]) can be decoupled into several microgestures by considering the finger that initiates the movement or the contact surface (e.g. `tap of the index finger on a specific phalanx` [35]). A notation to precisely define microgestures at multiple levels of granularity is required to be able to relate studies on similar microgestures and, more generally, to establish a common ground for microgesture research.

To this end, this paper proposes µGlyph (Figure 1), a hybrid (graphic-textual) notation of microgestures for HCI researchers and practitioners. The core elements of the notation are based on the biomechanics of the fingers to ensure the completeness of movements. A microgesture description is composed of:

- 1/ a movement (or absence of movement),
- 2/ a context of execution (i.e., movement performed in the air or on a surface) or a transition between two contexts (e.g., movement beginning in the air and ending in contact with a surface), and optionally,
- 3/ characteristics further detailing the movement (e.g., which finger performs the movement).

We investigate the expressiveness of the µGlyph notation by showing how the notation encompasses the features of existing microgesture taxonomies and by demonstrating how the notation solves ambiguities and contradictions identified in the literature. We further provide a database of 118 microgestures extracted from the literature that includes for each microgesture its provided description as well as its µGlyph description. Given the trade-off between expressiveness and ease of use, we also examined the ease of use of the µGlyph notation as compared to conventional text+images description. We conducted a user study with 18 participants who learned the notation, and then read and wrote µGlyph descriptions of microgestures. After a 9-minute course and a 10-minute training session, participants correctly interpreted µGlyph 89% of the time and correctly wrote µGlyph 91% of the time. In comparison, when the same participants read conventional descriptions (text+images) from the literature, they correctly interpreted the microgestures 46% of the time. To promote the usage of the µGlyph notation, we provide support tools available online: a UI with search features for the database, a visual editor with LaTeX export, and a proof-of-concept tool that generates an animated 3D model from µGlyph descriptions, with SVG export of the animation keyframes. Beyond an expressive and usable notation with support tools, µGlyph can also be used as a basis for engineering microgesture interaction, as has been done with movement/gesture notations: interaction design [23], development of recognizers and toolkits [26] and evaluation with a predictive model of performance [6].

The primary contributions described in this paper are:

- an expressive notation to describe microgestures at different levels of granularity;
- an evaluation that offers empirical insights into the usability of the notation;
- a database of 118 microgestures extracted from the literature and described using µGlyph, along with a set of support tools to promote the use of the notation.

2 RELATED WORK

Currently, there is no notation for microgesture interaction. Previous work has described microgestures with a name and a description, which is either a picture, a text or both, as in [7, 39]. Beyond punctual representations, as commonly used to represent specific gestures in different HCI fields, e.g. [16, 43] for touch gestures, we focus on notations that define rules for representing gesture features. After a review of movement/gesture notations, we review definitions and taxonomies of microgestures to highlight the variety of microgesture features. Finally, we point out the existing terminological problems due to the lack of notation.

2.1 Movement and gesture notations

The *cognitive dimensions of notations* introduced by Green [19] and further enriched by Green and Petre [18] define principles that can inform the design of a usable notation. The dimensions provide a framework for reasoning and analyzing features in notation. However, the dimensions are not independent: for a given notation a trade-off between the dimensions is achieved depending on the intended goals of the notation. Thus, a notation does not address all the dimensions and we give the short definitions of the dimensions used in the paper. **Abstraction gradient**: types and availability of abstraction mechanisms. **Closeness of mapping**: closeness of representation to domain. **Consistency**: similar semantics are expressed in similar syntactic forms. **Diffuseness / terseness**: verbosity of language.

While various notations exist for movements and gestures, we focus on notations that describe finger movements, in particular the multi-touch notations. We invite readers to read GestureCards [23] for a more detailed review of multi-touch notations. We provide a mere summary of existing notations organized into three types: textual, graphic and hybrid combining textual and graphic descriptions.

Textual notations rely on a set of letters, numbers, operators, and rules to define gestures. Choi et al propose a textual notation for 3D hand gestures that uses numerical coding to describe a hand pose [9]. For instance, a close hand with the index finger open is represented by 51666 ; 2422-233. It is therefore complex to read and write such a description without knowing the notation perfectly (low **closeness of mapping**). Krupka et al. also propose a XAML-based textual notation that allows developers to describe 3D hand gestures as hand pose sequences using natural language keywords

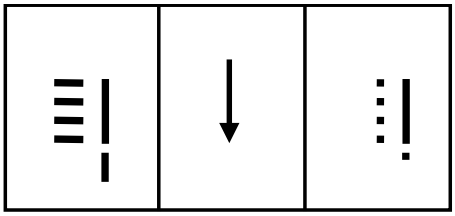


Figure 2: Example of a gesture description using the notation introduced in Charade [4]. The represented gesture is the arm moving down while closing all fingers.

such as "middle" "above" "index" [27]. However, both notations remain at finger level and it is not possible to describe a touch on a part of a finger, for instance a touch on a phalanx or on one side of a finger. Describing microgestures based on hand poses, will also lead to long and wordy descriptions of the sequence of intermediate finger poses (low **diffuseness / terseness**).

For multi-touch gestures, textual notations are often built to be computer readable in order to create gesture recognizers. To this end, Proton++ uses regular expressions and three atomic events, i.e. down (D), move (M), up (U), to define and recognize multi-touch gestures [26]. Those atomic events are represented by the structure $E_{T_{ID}}^{A1:A2:\cdots}$ where $E \in \{D, M, U\}$, T_{ID} is the identifier of the touch and A1:A2... are the properties of the touch, e.g. the trajectory direction with N (north), S (south), W (west), E (east), O (undetected direction). However, such precise textual descriptions can become complicated (low **closeness of mapping**). For instance $D_1^O M_1^O * M_1^S M_1^{O|S} * M_1^E M_1^{O|E} * U_1^{O|E}$ describes an L-shaped trajectory. GeForMt uses a set of higher-level events defining the basic gestures, e.g. line, circle. Events can be combined to create and recognize more complex gestures [25]. For instance CONNECT_START[LINE_SW;LINE_SE] describes two fingers touching and then separating, one towards south west and the other towards south east. By using words, the descriptions are easier to read than those of Proton++ but this results in long expressions (low **diffuseness / terseness**). The use of words as in GeForMt increases the human readability of the descriptions. However, when it comes to accurately describing a gesture, using words can lead to longer and more difficult to understand descriptions than graphical descriptions.

Graphic notations rely on a set of graphic symbols that are spatially arranged. Graphic notations are often built to be human readable. In multi-touch notations, these graphical elements are often arrows, for movements (high **closeness of mapping**), and icons, for additional features. For instance, Monox uses a set of different arrows, e.g. different arrowheads, to represent basic gestures, e.g. move, swipe and drag&drop [15]. Monox is a gesture notation for collaborative design and analysis of multi-touch interactions.

Baudel et al. created Charade, an application using 3D hand gestures. To describe the gestures, they propose a notation representing the movement of the arm with the initial and final pose of the hand [4]. Graphic symbols, e.g. dots and lines, are used to indicate whether a finger is closed or not. The symbols are spatially arranged according to a representation of a hand which offers high **closeness of mapping**, see Figure 2. However, the notation is based on the description of the wrist and the pose of each finger (low **Abstraction gradient**). Describing how these fingers interact with each other, i.e. contact, would also involve introducing new symbols and redesigning the graphical structure of the notation.

Labanotation is a movement notation to describe dance and choreographies [20]. Labanotation uses a set of graphical symbols to represent the part of the body that moves, the duration, the direction, and other features of the movement. A specific subset of the notation focuses on the hand and finger movements [21]. However, it takes intensive learning and training to read and use this notation for accurate descriptions: the complete list of Labanotation graphical symbols are described in 10 different books. Therefore, it is important for a graphic notation to have a high semantic transparency, i.e. "a novice can easily infer the meaning of a symbol from its appearance" [33], to shift the cognitive load from working memory to visual. Nonetheless, Labanotation summarizes the requirements for finger movement notations: "[the notation] defines [...] different [hand] parts as well as how these flex and extend or contact objects, another hand or indeed, itself" [21]. Benesh is another dance notation [5], which represents the body as a stave (high **closeness of mapping**). For movements, only the actuators (body and limb positions) are described within the five-line stave.

Hybrid notations use textual and graphic elements to describe each part of the movement with the most appropriate representations. Graphic elements can be used to abstract concepts that require complex and/or lengthy textual descriptions [34]. Moreover, graphic symbols can depict the perceptual content of the represented concept, i.e a high **closeness of mapping**. For instance, GestureCards [23] graphically represents the movement (high **closeness of mapping**) and uses additional textual elements to specify features including duration, direction, pressure, and speed (high **consistency**). Figure 3 presents a gesture card for a `swipe left` gesture.

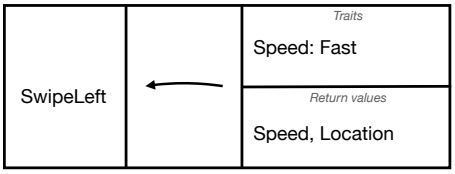


Figure 3: Example of a gesture card, reproduced from [23].

Drawing on existing notations, a hybrid notation of microgestures is promising: the notation should combine in a **consistent** way textual elements with graphic elements for a high **closeness of mapping**. Furthermore, the notation must enable the description of all possible finger movements and contacting surfaces, thus fulfilling the requirements defined for Labanotation. The following section highlights the variety of movements and contacting surfaces that need to be described by a microgesture notation.

2.2 Variety of microgestures

Soliman et al. define a design space for thumb-to-finger and finger-to-thumb microgestures [39]. This design space is organized along four axes: the type of actions (i.e., `tap`, `slide` and `draw`), the finger that initiates the action, the area of the finger on which the action is performed (e.g., a phalanx or the side of the finger) and the extension state of the other fingers [39]. For example, considering these four feature axes, we can differentiate a thumb `tap` on the bottom phalanx of the index finger from a thumb `tap` on the tip of the index finger. Moreover, these two microgestures can be distinguished according to the state of the other fingers of the hand, for example if the ring finger and/or the little finger are opened and/or closed during the movement. Those four axes, namely action, actuator, surface, and other properties, can be extended to all types of microgestures and give us a structure to review the features of microgestures.

Several studies on microgestures define additional actions to those defined by Soliman et al [39]. Way et al. define thumb-to-finger `touch`, `finger curl`, `finger extension`, and two-finger `opening/closure`. These actions were defined for microgestures that are recognizable by a wrist-worn camera [11]. Chan et al. define `tap`, `swipe`, `draw` and `circle`. These actions were identified from a user elicitation study with 16 participants [7]. Other actions have been studied but never defined: for instance `ream` [47], `tab` [47], `stretch` [38], `press` [38], `up` [14] or `flick` [12].

For actuators which perform the actions, while Soliman et al. only consider a single finger [39], other studies focus on microgestures performed by a group of fingers, e.g. `tap` thumb with index and middle fingers [7], or go into more detail by considering a specific joint of a finger, e.g. `finger lift` [11].

A microgesture can be further characterized according to the surface touched by the actuator. The literature on microgestures is divided into two families: free-hand microgesture and grasping microgesture. Free-hand microgestures are microgestures performed without holding an object. In this context, the touched surfaces are often parts of the hand itself. Soliman et al. define as a surface, a finger, a finger phalanx and a finger side [39]. Other studies introduce as a surface, a group of fingers, e.g. `swipe` on the index and middle fingers with thumb [7], and the palm, e.g. `tap` palm with the index, middle and ring fingers [7]. Grasping microgestures are microgestures performed while holding an object. In this context of holding an object, Sharma et al. define three surfaces: on body, on object, in the air [38]. On body, surfaces are similar to the ones defined for free-hand microgestures, e.g. a `tab` where the thumb goes around a driving wheel to touch a specific finger [47]. On object, surfaces can be any surface other than the hand, e.g. `external touch` [11], or specific object, e.g. up / down `drag` of the index or middle finger on stylus [47]. In the air, microgestures are performed without touching any surface, e.g. `stretch` [38] and `triangle` [14].

Finally, other features than the extension state of the fingers [39] have been introduced. For instance, the pressure is used to distinguish between a `tap` and a `force tap` [45].

2.3 Imprecise descriptions of microgestures

The variety of features of the microgestures already studied combined with the lack of precise descriptions of microgestures, leads to misunderstanding, ambiguities and even contradictions. A microgesture is generally described by a name and a description in the form of natural language text and/or images.

First, while some papers include a detailed textual description of each microgesture [7, 11, 39, 45], many papers describe a microgesture only by a name and an image [8, 12, 14, 24, 30, 31, 37, 38, 47]. This lack of precision can lead to misinterpreting a microgesture, for instance the microgesture named `ream` [47]. Furthermore, the same image can be used for describing different microgestures [47] leading to even more ambiguity.

Second, the description often lacks a precise definition of the initial and final states of a microgesture. For instance, does a tap [7, 44] end in contact or in the air? This issue with initial and final states consists of identifying which part of the movement is key to describing the microgesture. We illustrate this issue by making the analogy with a mouse down event and a click event which consists of a mouse down then up. Is the mouse down the key part of the movement or is it both mouse down and mouse up that define the key part of the movement? For instance, a `touch` [47], a `tab` [47], a `tap` [7] and a `press` [8] can be considered as a mouse down event while a `tap` [44] as a click event.

The absence of precise description leads to naming issues. Such issues are serious because they make it difficult to relate and compare pieces of research. Indeed, a same microgesture can be designated by several names, as illustrated by the following three examples (precisely described in Table 7):

- `close gap of index and middle` [11], `tap of index and middle` [7]
- `drag`[47] and `slide` [39]
- `multi finger snap` [12] and `swipe across all fingers` [7]

Moreover, the same name can designate different microgestures. In the following three examples, we quote names used for different microgestures and we provide their precise descriptions that highlight their differences in Table 7:

- `extend` [11] and `extension` [37]
- `tap` [7] and `tap` [44]
- `press` [8] and `press` [38]

The need for precise descriptions based on a notation is thus paramount in moving the field forward. Given the variety of features of the microgestures already studied, we conclude that a microgesture notation must:

- enable the unambiguous description of a large variety of microgestures, not covered by existing taxonomies;
- enable the description of microgestures at several levels of abstraction (**Abstraction gradient** dimension [18]), for example at a high level, by ignoring which finger is touched by another finger and at a low level by describing the finger that performs the action, the finger that is touched or other features such as the exerted pressure or the extension state of a finger;

		Choi et al. [9]	Krupka et al. [27]	Proton++ [26]	GeForMt [25]	Monox [15]	Charade [4]	Labanotation [21]	GestureCards [23]	Text/Images [7, 39]	**µGlyph**
Cognitive dimensions	**Abstraction gradient** description at different levels of abstraction	−	−	−	−	−	−	∼	∼	+	+
	Consistency specifically, robust to new features	−	∼	∼	∼	+	−	+	+	−	+
	Closeness of mapping clear mapping between representation and movement	∼	∼	−	+	+	+	−	+	+	+
	Diffuseness / terseness concise description of a movement	+	−	+	−	−	−	+	−	−	+
Movement features	Description of the initial and final states of the movement	+	+	+	∼	∼	+	+	−	∼	+
	Description of the fingers	+	+	−	−	−	+	+	−	+	+
	Description of other subparts of the hand (phalanxes, finger sides, palm, ...)	−	−	−	−	−	−	+	−	+	+
	Features of the movement other than its direction (pressure, amplitude, duration, ...)	−	−	−	−	∼	∼	∼	+	+	+

Table 1: Desired cognitive dimensions and movement features listed as requirements for a microgesture notation. Requirements and existing notations: '+': the notation fulfills the requirement, '∼': the notation partially fulfills the requirement, '–': the notation does not fulfill the requirement.

- have a stable set of core elements that can be consistently (**Consistency** dimension [18]) extended with new features as the research area progresses (e.g., nail regions as new contacting surfaces [30]);
- be easy to read and write to be widely adopted by the community (**Closeness of mapping** and **Diffuseness / terseness** dimensions [18]).

Based on these requirements for a notation, Table 1 summarizes our review of existing notations. The following section describes µGlyph, the new notation we propose to fill the gaps by meeting all the requirements.

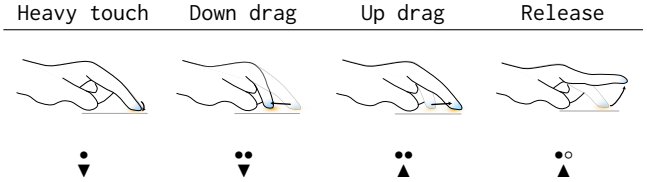


Table 2: Examples of microgestures described at a high level of abstraction with the movement and context glyphs of µGlyph.

3 µGLYPH NOTATION

µGlyph is a hybrid notation describing all possible finger movements and contacting surfaces. Referring to the *cognitive dimensions of notations* [18], the design of the µGlyph notation is as follows. µGlyph is based on a graphical representation of the hand (high **closeness of mapping**) where only the key elements of the microgesture are represented. To this end, the graphical symbols correspond to a finite set of low-level events that concisely (high **diffuseness / terseness**) describe any type of movements. A microgesture is a sequence of finger movements within an execution context. Graphical symbols represent the execution context that specifies if the movement is done in the air or in contact with a surface. The textual description is used in a consistent way (**consistency**) for finer features of the movement (**abstraction gradient**). The textual description also contributes to the extensibility of the notation, making it easier to add new movement features in the future.

Having introduced the main design principles of the µGlyph notation, we present it now step by step. Figure 4 at the end of the section summarizes all the steps.

3.1 Movements, Contexts and Graphical Structure

Based on the biomechanics of a finger, we use the finger movements described in Figure 1. A glyph is associated with each of these movements, derived from anatomical observations [42]. The following five movement glyphs are core elements of the µGlyph notation:

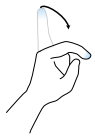
Hand structure	Index flexion	MCP (metacarpophalangeal) index flexion	PIP (proximal interphalangeal) index flexion	Base index touch
				
_ ----	_ $\overset{\circ\circ}{\blacktriangledown}$ ---	_ $\overset{\circ\circ}{\blacktriangledown}$ MCP ---	_ $\overset{\circ\circ}{\blacktriangledown}$ PIP ---	_ $\overset{\circ\bullet}{\blacktriangledown}$ b ---

Table 3: Examples of microgestures described at a low level of abstraction by specifying the features of the actuator as defined in µGlyph.

Extension (▲): movement of a finger away from the palm;
Flexion (▼): movement of a finger closer to the palm;
Abduction (◄): movement of a finger away from the sagittal plane;
Adduction (►): movement of a finger closer to the sagittal plane;
Static (■): absence of movement.

Movement glyphs are inspired from the representations commonly used for the concepts *play* (► movement metaphor) and *stop* (■ no movement metaphor). The triangle orientation represents the direction of the movement.

These finger movements are performed in an execution context that characterizes whether the movement is performed in the air or in contact with a surface. To represent the contact with a surface, we chose the glyph • (full circle), as in many representations of multi-touch gestures, e.g. guide iOS, wikipedia "Pointing device gesture". Contrastingly, a finger in the air is represented with the glyph ∘ (empty circle). We describe the contexts only at the beginning and at the end of the movement, which represents six possible cases divided into two groups.

(1) Single-glyph contexts
- ∘: the finger is in the air and stays in the air, in the same position. There is no movement possible.
- •: the finger stays at the same position on a surface. Some movements are possible, all subtle. For example, to exert pressure on a surface, the finger must be moved in the direction of the surface, but the contact position remains unchanged.

(2) Dual-glyph contexts
- ∘∘: the finger moves from one position in the air to another.
- ∘•: the finger moves from a position in the air to a position in contact with a surface.
- •∘: the finger moves from a position in contact with a surface to a position in the air.
- ••: the finger moves from one position in contact with a surface to another.

`Extension` (▲), `Flexion` (▼), `Abduction` (◄) and `Adduction` (►) are used with the contexts for which a movement is possible (∘∘, ∘•, •∘, •• or •). `Static` (■) is used only with the two contexts without changing position (∘ or •). Context glyphs are placed above a movement glyph. Two graphical structures co-exist: $\overset{-}{-}$ for single-glyph contexts and $\overset{--}{-}$ for dual-glyph contexts. The glyph – (dash) represents an unspecified slot, a wildcard for any glyph.
As letters form words, groups of glyphs form events. An event is a combination of movement and context glyphs (e.g. $\overset{\bullet\bullet}{\blacktriangledown}$). Such combinations of glyphs allow microgestures to be described at a high level of abstraction, as illustrated in Table 2 with elementary microgestures consisting of one event. By using unspecified slots for movements and/or contexts, microgestures can be described at an even higher level of abstraction. For instance, a drag can be described as the movement of a finger from one position in contact with a surface to another, without specifying the direction. The corresponding µGlyph description is: $\overset{\bullet\bullet}{-}$. This can be a drag up $\overset{\bullet\bullet}{\blacktriangle}$ or a drag down $\overset{\bullet\bullet}{\blacktriangledown}$, for example.

To obtain a more detailed description of a microgesture (low level of abstraction), µGlyph includes movement features, such as the actuator (the part of the hand that performs the movement), and context features, such as the receiver (part of the hand on which the movement is performed). Below we present these features of events and explain how to combine events to describe microgestures composed of several events.

3.2 Movement features: actuator

The actuator represents the part of the hand, i.e. the finger, which performs the movement [7, 11, 24, 36, 39, 45, 47]. To specify the finger actuator, we adopt a graphical structure representing a hand with the positions of the fingers: _---- (from left to right: thumb, index, middle, ring, pinky; see the representation on the left in Table 3). Just like the graphical structure of an event, a hand-based description can include unspecified slots (–). When specified, a slot defines an event. For instance, a flexion of the index finger which results in contact with a surface is described as follows: _ $\overset{\circ\bullet}{\blacktriangledown}$ --- .

For more detailed descriptions, other features of the actuator are specified as indices of the event. The parts of the finger that enter in contact with a surface are represented by the following textual symbols: b (*base*), m (*middle*), t (*tip*) and n (*nail*) as indices of the event. For instance, a `touch` performed by the base phalanx of an index finger is written as _ $\overset{\circ\bullet}{\blacktriangledown}$ b --- . Additional symbols denote the sides of a finger performing the movement: l (*left*), r (*right*), f (*front*)

Thumb touch on index	Thumb touch on middle finger nail	Thumb touch on middle finger base	Index touch on palm

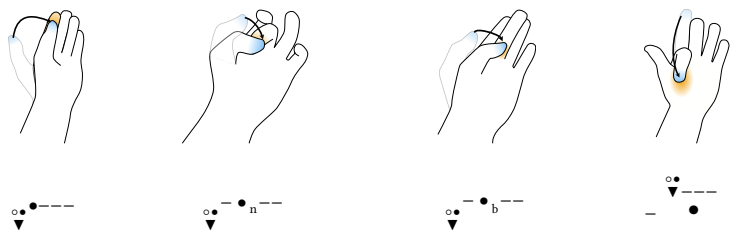


Table 4: Examples of microgestures described at a low level of abstraction by specifying the features of the receiver as defined in µGlyph.

and d (*dorsal*). For instance, a `touch` performed by the left side of an index finger is written as $\_\overset{\circ\bullet}{\blacktriangledown}{}_{\mathrm{l}}\!\!-\!\!-\!\!-$. Phalanxes and sides can be combined, for instance a `touch` performed by the left side middle phalanx of an index finger is written as $\_\overset{\circ\bullet}{\blacktriangledown}{}_{\mathrm{m,l}}\!\!-\!\!-\!\!-$. In addition to the finger parts, the finger joints performing the movement can be specified. For example, the `lift` microgesture, presented in EMGRIE [11], is performed by a specific finger joint. To describe the finger joint, we introduce two indices MCP (*Metacarpophalangeal*) used in EMGRIE, and PIP (*Proximal interphalangeal*) never used in the microgesture literature yet. MCP is the joint between the finger and the palm. PIP is the joint between the finger phalanxes. The `lift` microgesture [11] is written as $\overset{\circ\circ}{\blacktriangledown}{}_{\mathrm{MCP}}$.

Table 3 shows some of the examples presented above, including for each microgesture, its graphical representation and its µGlyph description.

3.3 Other movement features

Beyond the actuator of the movement, we introduce features of the movement itself.

First, when in contact with a surface, the actuator can exert pressure on the surface [11, 38, 44, 45, 48]. While in theory we can detect an infinite number of pressure levels, in practice, and without visual feedback, a user can only distinguish between a limited number [46]. In the microgesture literature, there are at most three pressure levels [45]. We represent those three pressure levels by Lo, Md and Hi, respectively for a *low*, *medium*, or *high* level of pressure. If only two levels are used, we then recommend using Lo and Hi. In the µGlyph notation, the level of pressure is specified below the movement glyph. For instance, a constant high pressure drag on a surface is written as $\overset{\bullet\bullet}{\blacktriangledown}{}_{\mathrm{Hi}}$. If the level of pressure changes between the beginning and the end of the movement, the change in pressure is specified with an arrow between the two pressure levels. For instance, the increase in pressure of a finger already in contact with a surface is written as $\overset{\bullet}{\blacktriangledown}{}_{\mathrm{Lo}\rightarrow\mathrm{Hi}}$. If required, new pressure levels can be defined and pressure values can be specified, e.g. an increase of pressure from 1 to 3 *Newton* $\overset{\bullet}{\blacktriangledown}{}_{1\mathrm{N}\rightarrow 3\mathrm{N}}$.

Second, microgestures are described as quick and subtle movements [7, 38, 39], corresponding to two additional movement features: duration and amplitude of the movement. Even though these two features are rarely used in the microgesture literature, they can be specified below the movement glyph. For instance, a maximum dwell time of 40 ms without movement is written as $\overset{\bullet}{\blacksquare}{}_{\mathrm{t}<40\mathrm{ms}}$. Similarly, amplitude can be used to specify a movement. From our literature review, three amplitudes of movement are identified: Cl (*Close*), Ha (*Half*) and Op (*Open*). For instance, a finger extension ending with a half-open finger is written as $\overset{\circ\circ}{\blacktriangle}{}_{\rightarrow\mathrm{Ha}}$ and a flexion from a fully open finger to a half-open finger as $\overset{\circ\circ}{\blacktriangledown}{}_{\mathrm{Op}\rightarrow\mathrm{Ha}}$. In addition, a finger pose (for example a half-open finger) is written as $\overset{\circ}{\blacksquare}{}_{\mathrm{Ha}}$. It is also possible to specify the opening percentage of the finger. A finger extension ending to a 25% open finger is written as $\overset{\circ\circ}{\blacktriangle}{}_{\rightarrow 25\%}$.

3.4 Context features: receiver

The receiver is the contact surface. The µGlyph features of a receiver are therefore only used in contexts where a contact surface is involved. Based on the literature, µGlyph enables us to describe two types of contact surfaces: a part of the hand, e.g. [39] and an object, e.g. [38].

When the contact surface is a part of the hand, it is described by the contact glyph • within the graphical representation of the hand. For instance, the thumb touching the index finger is written as follows: $\overset{\circ\bullet}{\blacktriangledown}\!\!-\!\!-\!\!-$. For more detailed descriptions, the features used for the actuator apply to the receiver. The textual symbols b (*base*), m (*middle*), t (*tip*) and n (*nail*) are therefore also used to describe the receiver. For instance, the thumb touching the base of the middle finger is written as $\overset{\circ\bullet}{\blacktriangledown}\!\!-\!\bullet_{\mathrm{b}}\!\!-\!\!-$ and the thumb touching the nail of the middle finger as $\overset{\circ\bullet}{\blacktriangledown}\!\!-\!\bullet_{\mathrm{n}}\!\!-\!\!-$. A contact on the palm of the hand is represented by the contact glyph (•) in the center of the graphical hand representation $\_\overset{\_\_\_\_}{\bullet}$. For instance, the index finger touching the palm of the hand is written as $\_\overset{\circ\bullet}{\blacktriangledown}\!\!-\!\!-\!\!-\!\!\bullet$. While

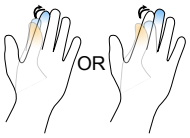
Tap	Thumb swipe on the index toward the palm	Index or middle finger tap on the thumb	Index and middle finger tap on the thumb
			
$\overset{\circ\bullet}{\blacktriangledown};\ \overset{\bullet\circ}{\blacktriangle}$	$\underset{\circ}{\bullet}{}^{\bullet}{}^{---};\ \underset{\bullet}{\bullet}{}^{\bullet}{}^{---};\ \underset{\bullet}{\circ}{}^{----}$	$\left(\bullet\overset{\circ\bullet}{\blacktriangledown}{}^{---};\ {}_{-}\overset{\bullet\circ}{\blacktriangle}{}^{---}\right)\Big\vert$ $\left(\bullet{}^{-}\overset{\circ\bullet}{\blacktriangledown}{}^{--};\ {}_{-}{}^{-}\overset{\bullet\circ}{\blacktriangle}{}^{--}\right)$	$(\bullet\overset{\circ\bullet}{\blacktriangledown}{}^{---}\ \vert\vert\ \bullet{}^{-}\overset{\circ\bullet}{\blacktriangledown}{}^{--});$ $({}_{-}\overset{\bullet\circ}{\blacktriangle}{}^{---}\ \vert\vert\ {}_{-}{}^{-}\overset{\bullet\circ}{\blacktriangle}{}^{--})$

Table 5: Sequence, choice and parallelism: Examples of µGlyph descriptions. On the left, the microgesture description is at a high level of abstraction. For the other three microgestures, the descriptions are more detailed, at a low level of abstraction.

the representation of all fingers is necessary to avoid any positional ambiguity, the palm is represented only if necessary.

If the contact surface is an object, then it is represented by a *gear* glyph ✹. Any additional information about this object is represented at the bottom left of the glyph. For example, a `touch` performed by the base phalanx of the index on an object, shown in Table 3, can be described more precisely as ${}_{-}\overset{\circ\bullet}{\blacktriangledown}{}_{b}{}^{---}{}_{mug}$✹.

Table 4 shows some of the examples presented above, including for each microgesture, its graphical representation and its µGlyph description.

3.5 Combining and factorizing events

The following symbols are inspired from other movement notations [9, 41].

3.5.1 Sequence. So far, we have presented the notation for describing a single event. But a microgesture is usually composed of more than one event. A sequence of events is represented with events separated by a semicolon " ; ".

For instance, a `downward swipe` of the thumb along the index is written as $\underset{\circ}{\bullet}{}^{\bullet}{}^{---};\ \underset{\bullet}{\bullet}{}^{\bullet}{}^{---};\ \underset{\bullet}{\circ}{}^{\circ}{}^{---}$ and a `tap` (i.e., pressing and releasing a finger) is written , at a high level of abstraction, as $\overset{\circ\bullet}{\blacktriangledown};\ \overset{\bullet\circ}{\blacktriangle}$. It is important to note that at a high level of abstraction, the actuator(s) of the first event remain(s) the same throughout the sequence. For instance, $\overset{\circ\bullet}{\blacktriangledown};\ \overset{\bullet\circ}{\blacktriangle}$ can represent ${}_{i}\overset{\circ\bullet}{\blacktriangledown};\ {}_{i}\overset{\bullet\circ}{\blacktriangle}$ or ${}_{m}\overset{\circ\bullet}{\blacktriangledown};\ {}_{m}\overset{\bullet\circ}{\blacktriangle}$ but cannot represent ${}_{i}\overset{\circ\bullet}{\blacktriangledown};\ {}_{m}\overset{\bullet\circ}{\blacktriangle}$.

3.5.2 Choice. A µGlyph description of a microgesture can include a choice between several values of a feature. The choice is represented by a pipe symbol " | ".

For instance, a `right swipe` of the thumb on the index base or middle phalanx is written as $\left(\underset{\circ}{\bullet}{}^{\bullet}{}_{b}{}^{---};\ \underset{\bullet}{\bullet}{}^{\bullet}{}_{b}{}^{---};\ \underset{\bullet}{\circ}{}^{\circ}{}^{---}\right)\Big\vert\left(\underset{\circ}{\bullet}{}^{\bullet}{}_{m}{}^{---};\ \underset{\bullet}{\bullet}{}^{\bullet}{}_{m}{}^{---};\ \underset{\bullet}{\circ}{}^{\circ}{}^{---}\right)$. Such a description is quite long and could be factored as follows: $\underset{\circ}{\bullet}{}^{\bullet}{}_{b|m}{}^{---};\ \underset{\bullet}{\bullet}{}^{\bullet}{}_{b|m}{}^{---};\ \underset{\bullet}{\circ}{}^{\circ}{}^{---}$. However, this introduces ambiguous possibilities such as: $\underset{\circ}{\bullet}{}^{\bullet}{}_{b}{}^{---};\ \underset{\bullet}{\bullet}{}^{\bullet}{}_{m}{}^{---};\ \underset{\bullet}{\circ}{}^{\circ}{}^{---}$. To specify that the choice described in the first event should be applied to the second event, a variable should be added as follows: $x \in \{b|m\}$, $\underset{\circ}{\bullet}{}^{\bullet}{}_{x}{}^{---};\ \underset{\bullet}{\bullet}{}^{\bullet}{}_{x}{}^{---};\ \underset{\bullet}{\circ}{}^{\circ}{}^{---}$.

3.5.3 Parallelism. A µGlyph description can include events in parallel, represented by the parallel symbol " || ". For instance, the index and middle fingers touching the thumb is written as $\left(\bullet\overset{\circ\bullet}{\blacktriangledown}{}^{---}\ \Big\vert\vert\ \bullet{}^{-}\overset{\circ\bullet}{\blacktriangledown}{}^{--}\right)$. Again, the description is quite tedious and can be factored. For this purpose, the events are combined, resulting in the following description: $\bullet\overset{\circ\bullet}{\blacktriangledown}\ \overset{\circ\bullet}{\blacktriangledown}{}^{--}$. Beyond events performed in parallel, multiple values of a feature at a given time are described using the parallel symbol. For instance, a touch of the index on the tip of the thumb and on the middle phalanx: $\bullet_{t||m}\overset{\circ\bullet}{\blacktriangledown}{}^{---}$.

Table 5 shows some of the examples presented above, for each microgesture, its graphical representation and its µGlyph description.

3.6 Encapsulation

Some microgestures can be described by a long sequence of different µGlyph events, which can make the description difficult to read and understand. This is particularly the case for the microgestures based on the drawing of shapes [7, 14, 37, 38, 47] (usually a circle). Those microgestures are systematically performed on a 2D plane in the air or on a surface. Even if each drawing could theoretically be represented by a succession of events (for example $\overset{\circ\circ}{\blacktriangledown};\ \overset{\circ\circ}{\blacktriangleright};\ \overset{\circ\circ}{\blacktriangle};\ \overset{\circ\circ}{\blacktriangleleft}$ for a rectangle), it seems much simpler and more intelligible to define a new symbol representing the drawing to be made, for example the symbol ⍈ to represent a square. By using this symbol, the notation is simplified but remains consistent. For instance, a square-shaped movement performed by the index finger in the air is written as ${}_{-}\overset{\circ\circ}{⍈}{}^{---}$. For consistency, events can be encapsulated if and only if they share the same context (∘∘ or ∙∙), the same actuator(s), and represent a monotonic progression of other movement features (for instance $\underset{1N\to 2N}{\overset{\bullet\bullet}{\blacktriangledown}};\ \underset{2N\to 2N}{\overset{\bullet\bullet}{\blacktriangleright}};\ \underset{2N\to 3N}{\overset{\bullet\bullet}{\blacktriangle}};\ \underset{3N\to 4N}{\overset{\bullet\bullet}{\blacktriangleleft}}$ encapsulated into $\underset{1N\to 4N}{\overset{\bullet\bullet}{⍈}}$).

Microgesture name	Standard µGlyph	Concise µGlyph
Index base touch	$\_\overset{\circ\bullet}{\blacktriangledown}{}_{b}\text{---}$	$\overset{\circ\bullet}{{}_{i}\blacktriangledown}{}_{b}$
Thumb touch on the nail of the middle finger	$\overset{\circ\bullet}{\blacktriangledown}\text{-}\bullet_{n}\text{--}$	$\overset{\circ\bullet}{{}_{t}\blacktriangledown}({}_{m}\bullet_{n})$
Index touch on the palm	$\_\overset{\circ\bullet}{\blacktriangledown}\text{---}\bullet$	$\overset{\circ\bullet}{{}_{i}\blacktriangledown}(\bullet_{p})$
Index base touch on a cup	$\_\overset{\circ\bullet}{\blacktriangledown}{}_{b}\text{---}\ {}_{cup}\text{✿}$	$\overset{\circ\bullet}{{}_{i}\blacktriangledown}{}_{b}({}_{cup}\text{✿})$
Left swipe of the thumb on the index base or middle phalanx	$x \in \{b\|m\}, \underline{\circ\bullet}\bullet_{x}\text{---}\ ;\ \underset{\blacktriangleright}{\bullet\bullet}\bullet_{x}\text{---}\ ;\ \underline{\bullet\circ}\circ\text{---}$	$x \in \{b\|m\}, {}_{t}\overset{\circ\bullet}{\text{—}}({}_{i}\bullet_{x});\ {}_{t}\overset{\bullet\bullet}{\blacktriangleright}({}_{i}\bullet_{x});\ {}_{t}\overset{\bullet\circ}{\text{—}}$
Index and middle touch on the thumb	$\bullet\overset{\circ\bullet}{\blacktriangledown}\overset{\circ\bullet}{\blacktriangledown}\text{--}$	$\overset{\circ\bullet}{{}_{i\|\|m}\blacktriangledown}({}_{t}\bullet)$
Square made by the index finger in the air	$\_\overset{\circ\circ}{\square}\text{---}$	$\overset{\circ\circ}{{}_{i}\square}$

Table 6: Microgestures described using the standard µGlyph hand-based representation and using the concise µGlyph representation.

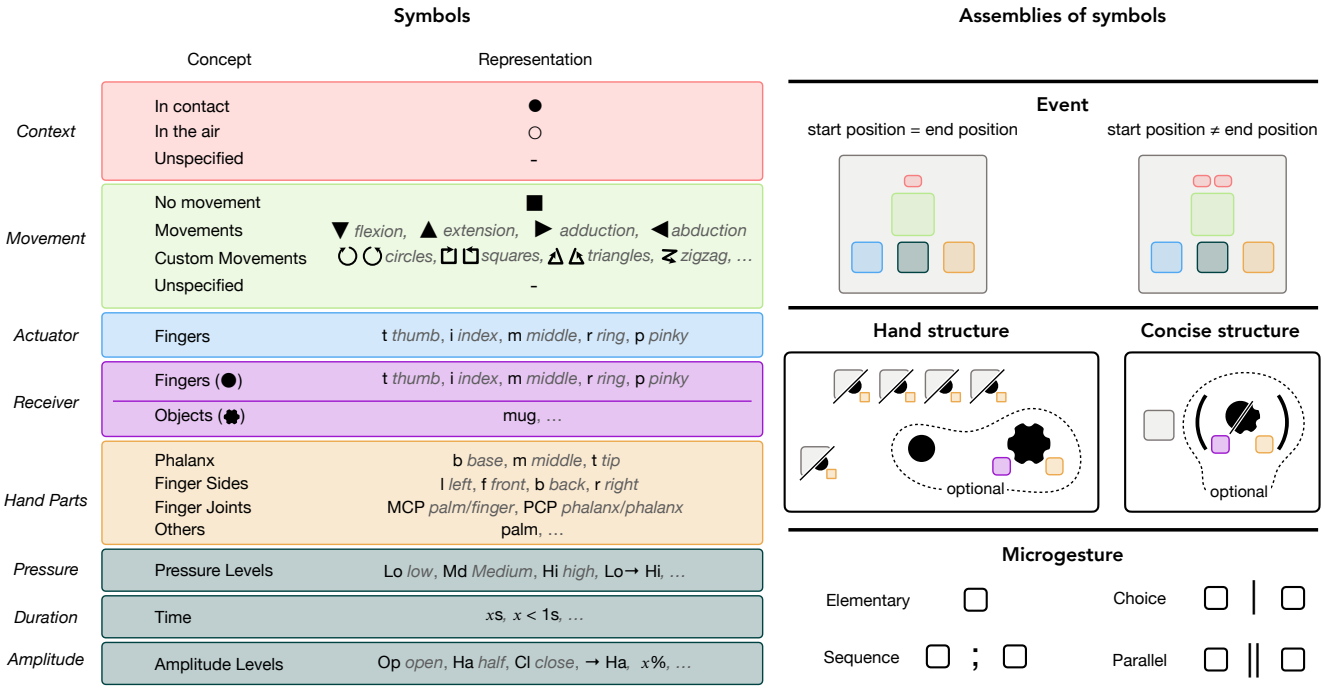


Figure 4: Global summary of the µGlyph notation.

3.7 Concise notation

So far, we have described a microgesture using a graphical representation of the hand to make the description more intelligible. However, this notation can take a lot of space to describe a simple microgesture, such as an extension of the index finger: $\_\overset{\circ\circ}{\blacktriangle}\text{---}$. For a more concise and advanced way of describing a microgesture, the fingers are specified by their first letter at the bottom left of the event glyph. For instance, an extension of the index finger is written as $\overset{\circ\circ}{{}_{i}\blacktriangle}$. Receivers can also be specified in a more concise way. They are represented as a function of the event. For instance, a touch of the middle finger on the base phalanx of the thumb is written as $\overset{\circ\bullet}{{}_{m}\blacktriangledown}({}_{t}\bullet_{b})$. The rest of the notation is unchanged.

Table 6 includes microgestures and their two descriptions: the hand-based description and the concise description.

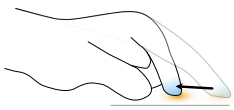
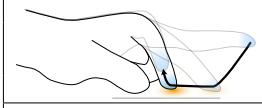
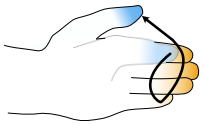
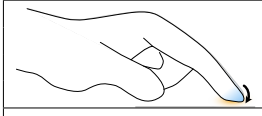
Picture	Paper	µGlyph	Additional characteristics
	Press [8] **Tap** [7] Finger touches [11] Finger taps [39]	$\overset{\circ\bullet}{\blacktriangledown}(\bullet)$ $\overset{\circ\bullet}{\blacktriangledown}$ $(x,y) \in A, {}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{x}\bullet_{y})$	 $A = \{i\|m\|r\\|p\} \times \{b\|m\|f\}$ $A = \{i\|m\|r\} \times \{b\|m\|f\}$
	Tap [38] **Tap** [37] **Tap** [44] Pinch [36]	$\overset{\circ\bullet}{\blacktriangledown}; \overset{\bullet\circ}{\blacktriangle}$ $(x,y) \in A, {}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{x}\bullet_{y}); {}_{t}\overset{\bullet\circ}{\blacktriangle}$	 $A = \{i\|m\} \times \{b\|m\|f\} \cup \{i, tl\} \cup \{r, n\}$ $A = \{i\|m\|r\|p\}$
	**Swipe Left or Right** [37] **Extension** [37] **Drag** [47] **Slide** [39] Slide thumb on finger [11] linear thumb-to-finger slides [39]	$\overset{\bullet\bullet}{\blacktriangleleft} \Big\| \overset{\bullet\bullet}{\blacktriangleright}$ $\overset{\bullet\bullet}{\blacktriangle}$ $\overset{\bullet\bullet}{\blacktriangledown} \Big\| \overset{\bullet\bullet}{\blacktriangle} \Big\| \overset{\bullet\bullet}{\blacktriangleleft} \Big\| \overset{\bullet\bullet}{\blacktriangleright}$ $x \in A, {}_{t}\overset{\bullet\bullet}{\blacktriangledown}({}_{x}\bullet) \Big\| {}_{t}\overset{\bullet\bullet}{\blacktriangle}({}_{x}\bullet)$	 $A = \{i\|m\|r\|p\}^{n}$, with $n >= 1$ $A = \{i\|m\|r\|p\}$
	**Swipe** [7] Drag&Drop thumb on index-side [47]	$x \in A, {}_{t}\overset{\circ\bullet}{-}({}_{x}\bullet); \left({}_{t}\overset{\bullet\bullet}{\blacktriangledown}({}_{x}\bullet) \Big\| {}_{t}\overset{\bullet\bullet}{\blacktriangle}\right); {}_{t}\overset{\bullet\circ}{-}$	$A = \{i\|(i\|\|m)\|(m\|\|r)\}$ $A = i\text{-}l$
	Swipe across all fingers with thumb [7] Multi-finger snap [12]	${}_{t}\overset{\circ\bullet}{-}({}_{p}\bullet); {}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{r}\bullet); {}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{m}\bullet); {}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{i}\bullet); {}_{t}\overset{\bullet\circ}{-}$	
	Squeeze/Pull up [36] **Press** [38]	$x \in A, \underset{\text{Lo} \to \text{Hi}}{{}_{x}\overset{\bullet}{\blacktriangledown}} (\bullet); \underset{\text{Hi} \to \text{Lo}}{{}_{x}\overset{\bullet}{\blacktriangle}}$	$A = \{i\|m\|r\|p\}$
	Strech [38] Extend [11] Up [14] Thumb up [47]	$\overset{\circ\circ}{\blacktriangle}$ $\overset{\circ\circ}{\blacktriangle}_{\text{MCP}}$ $x \in A, {}_{x}\overset{\circ\circ}{\blacktriangle}$	 $A = \{i\|m\|(r\|\|p)\}$ $A = t$

Table 7: Theoretical expressiveness of µGlyph: descriptions of microgestures at two levels of abstraction and highlighting (in bold) of terminological problems existing in the literature.

4 THEORETICAL EXPRESSIVENESS: DESCRIPTIVE POWER OF µGLYPH

Theoretical expressiveness refers to the ability of µGlyph to unambiguously describe existing microgestures, regardless of the usability of µGlyph. Indeed, the ease of use, reading and writing of µGlyph descriptions, i.e. the practical expressiveness of µGlyph, is the focus of the next section.

First, we motivate the µGlyph notation by showing that it encompasses and extends the axes of Soliman et al.'s characterization scheme [39]. The four axes, namely *Action*, *Actuator*, *Touch Location* and *Finger flexion*, are described in the related work section. The first three axes correspond in µGlyph respectively to *the movements and contexts*, *the movement features: actuator* and *the context features: receiver*. In addition, the µGlyph *movement features: actuator* extend Soliman et al.'s *Actuator* axis by considering the parts of the finger (phalanxes, sides) and the finger joints. The fourth axis, *Finger flexion*, describes the extension state of the fingers that are not the actuator and corresponds to the µGlyph *other movement features*. As presented by Soliman et al., there are two ways to describe a *finger flexion*, by specifying either the flexion movement or the finger pose. Using µGlyph, on the one hand, a flexion movement is described using `Extension` (▲) and `Flexion` (▼), for instance a

finger extension ending with a x% open finger $\overset{\circ\circ}{\underset{\rightarrow x\%}{\blacktriangledown}}$. On the other hand, a finger pose is described with `Static` (■), for instance a x% open finger $\overset{\circ}{\underset{x\%}{\blacksquare}}$. More generally, this example shows that µGlyph supports the two common ways of describing a microgesture: the description of a sequence of movements or a sequence of positions.

Second, we translated into µGlyph all the microgestures described in a precise and textual way in the literature [7, 11, 39, 45]. The purpose of this translation exercise was to test the ability of the notation to allow the specification of subtle differences described in the text. Table 7 includes a subset of these microgestures. Using µGlyph, we described several other microgestures of the literature. The tables in the Appendix B contain the complete list of microgestures described in µGlyph. In total, we described 118 microgestures from 17 papers. Of the papers considered, some provide precise definitions and characterization schemes of microgestures [7, 11, 39, 45], others are seminal papers in the field of microgesture e.g. [38, 47]. In addition, the papers cover various contexts of use, e.g. airplanes [44], cars [14, 22, 47], microgestures on a pen [40], free-hand microgestures [8, 12, 24] and propose various recognition mechanisms, e.g. cameras [8], gloves [44], bioacoustics [12] and electromyography [36]. Some papers also provided us edge cases to describe using µGlyph, e.g. [30].

Finally, we have pointed out some terminological problems existing in the literature. It is worth examining whether the µGlyph notation, by allowing a precise and unambiguous description of the microgestures, solves these problems. Based on the description in µGlyph, we can identify similar microgestures that are referred to by different names in the literature. For instance, a `close gap index and middle` [11] and a `tap of index and middle` [7] are both described by $\left({}_{i}\overset{\circ\bullet}{\blacktriangleright}({}_{m}\bullet)\ \middle\|\ {}_{m}\overset{\circ\bullet}{\blacktriangleleft}({}_{i}\bullet)\right)$. In addition, a µGlyph description can help to distinguish microgestures designated with the same name: `extend` [11] $\overset{\circ\circ}{\blacktriangle}_{MCP}$ and `extension` [37] $\overset{\bullet\bullet}{\blacktriangle}$(✹) or `Tap` [7] $\overset{\circ\bullet}{\blacktriangledown}$ and `Tap` [44] $\overset{\circ\bullet}{\blacktriangledown}$; $\overset{\bullet\circ}{\blacktriangle}$. Table 7 presents other examples of ambiguity.

To facilitate the work of researchers and practitioners, we have created a database compiling each of the microgestures presented in the tables in Appendix B. For each microgesture, the database contains the following information: name used in the paper, textual description, visual description, paper title and DOI, µGlyph description, intended context of use (i.e. whether the microgesture is performed free-hand or while holding an object). In addition, if the microgesture is performed while holding an object, information on the grasps and objects studied is included.

5 PRACTICAL EXPRESSIVENESS: USABILITY OF µGLYPH

The practical expressiveness refers to the usability of the µGlyph notation by researchers and practitioners. As identified for task modeling notations in [3], the usability of a notation covers two distinct notions. The first notion refers to the ease with which a µGlyph description can be read and understood. This notion of usability integrates that of learnability and readability. The second notion concerns the ease with which µGlyph descriptions are generated and modified. We structure the experimental study according to these two notions of usability: reading and writing. For the reading part, the experiment is inspired by the first experiment conducted by Hesenius et al. to evaluate the readability of GestureCards, a gesture notation [23].

5.1 Participants

The end-users of µGlyph are HCI researchers and practitioners. Therefore, we decided to recruit participants who work in HCI related fields and have an academic background. We recruited 18 unpaid participants (30 y.o ± 9): 6 HCI PhDs, 4 HCI PhD students, 4 HCI internship students, 2 HCI research engineers and 2 PhD students from another domain who work with notations and have a strong interest in HCI. For context, 6 participants had had a course with an exam less than a year ago, 4 less than 5 years ago, and 8 more than 5 years ago (7 years ago ± 8).

5.2 Setup

Participants sat at a desk in front of a computer. Descriptions and videos were displayed on the computer screen. Descriptions and videos used in the experiment are available in the supplementary material of the paper. A camera was placed in front of the participants and only captured their hands. Participants used the keyboard for pressing the Return and Space keys. Pen and paper were placed on the desk for participants to write their answers.

5.3 Sets of microgestures for comparison

To compare different ways of describing microgestures, we first defined 4 sets of 10 microgestures from the literature. 3 sets are used for the reading part (sets A, B and C) and 1 set for the writing part (set W) of the experimental study. The sets were designed to reflect the most common microgestures in the literature. Each set contains (listed below in this order): 3 taps/touches, 3 swipes/slides/drags, 1 pressure- or amplitude-based microgesture, 2 ambiguous microgestures, and 1 drawing microgesture. We distinguish two types of ambiguity. First, a microgesture whose name may induce a misinterpretation, e.g. `Extension` (Set C 8). Second, a microgesture whose name is in conflict with another microgesture of the same set, e.g. `Robin presses` (Set A 8), in µGlyph ${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i}\bullet{}_{t})$, and `Press` (Set A 7), in µGlyph $\underset{Lo \rightarrow Hi}{{}_{t}\overset{\bullet}{\blacktriangledown}}$. Moreover, each set uses similar features or combination of features while covering a broad range of µGlyph symbols. For instance, the first microgesture of each set is a `Tap thumb with finger "x"` (single actuator), with `finger "x"` different for each set. The second microgesture is a `Tap` with different parallel actuators. Finally, for the reading part of the study (sets A, B and C), each set contains 5 microgestures described with text and images in the original papers and 5 with images only. The 5 microgestures with images only are: 5, 7-10 in sets A and B, and 3-4, 7-9 in set C.

Set A:
1: `Tap thumb with ring finger` [7]
2: `Tap thumb with index and middle fingers` [7]
3: `Finger Tap` [39]
4: `Swipe accross all fingers with thumb` [7]
5: `Drag and Drop Index On Thumb` [47]
6: `Rotational thumb-to-finger slide` [39]
7: `Press` [38]
8: `Robin presses on the tip of his index finger` [8]
9: `Tab` [47]
10: `Triangle CW` [14]

Set B:
1: `Tap thumb with index finger` [7]
2: `Tap thumb with ring and pinky fingers` [7]
3: `Fist Tap` [39]
4: `Swipe middle and ring fingers with thumb` [7]
5: `Drag thumb around object` [47]
6: `Linear thumb-to-finger slides` [39]
7: `Thumb up` [47]
8: `Swipe left` [37]
9: `Multi finger snap` [12]
10: `ZigZag` [37]

Set C:
1: `Tap thumb with middle finger` [7]
2: `Tap all fingers together` [7]
3: `Snip` [47]
4: `Swipe right` [37]
5: `Drag and Drop middle on index` [47]
6: `Fingertip slide` [39]
7: `Force tap` [45]
8: `Extension` [37]
9: `Ream` [47]
10: `Draw circle` [39]

Set W:
1: `Tap thumb with pinky finger` [7]
2: `Tap palm with index, middle and ring fingers` [7]
3: `Tap and Flap` [39]
4: `Swipe index and middle fingers with thumb` [7]
5: `Drag Index or Middle finger on stylus up/down` [47]
6: `Linear finger-to-thumb slides` [39]
7: `Stretch` [38]
8: `Pressing down on the lateral side of the upper index finger` [44]
9: `Flexion` [37]
10: `Square` [14]

5.4 Procedure

A session consisted of two phases: a training phase and an experiment phase, see Figure 5. During the training phase, we informed the participants about the context of the research, and defined what a microgesture is. We also explained the purpose of the experiment which is to read microgesture descriptions and transcribe microgestures using µGlyph. After participants completed a consent form, we then gave them a hard copy of a cheatsheet (Appendix A) that they would use during the experiment. Participants then watched a 9-minute video[1] explaining µGlyph. To conclude the training phase, the participants had to describe 5 microgestures in µGlyph. The experimenter performed each microgesture in front of the participants, as many times as necessary, and helped them find the correct answers. The microgestures were: a touch with the thumb ${}_{t}\overset{\circ\bullet}{\blacktriangledown}$, a drag up or down of the thumb on the ring finger ${}_{t}\overset{\bullet\bullet}{\blacktriangledown}({}_{r}\bullet)|{}_{t}\overset{\bullet\bullet}{\blacktriangle}({}_{r}\bullet)$, a flexion of the index finger until mid-closure $\underset{\text{Op}\rightarrow\text{Ha}}{{}_{i}\overset{\circ\circ}{\blacktriangledown}}$, an extension followed by a touch on the thumb with either the index or the middle finger $x \in \{i|m\}$, ${}_{x}\overset{\circ\circ}{\blacktriangle};{}_{x}\overset{\circ\bullet}{\blacktriangledown}({}_{t}\bullet)$ and a squeeze of every finger on an object $\underset{\text{Lo}\rightarrow\text{Hi}}{{}_{t\,\|\,i\,\|\,m\,\|\,r\,\|\,p}\overset{\bullet}{\blacktriangledown}}$ (✽). Up to this point, participants could ask questions on µGlyph. Afterwards, this was forbidden. The hard copy of the cheatsheet was taken back by the experimenter. The training phase lasted around 20 minutes in total.

The experimental phase was divided into two parts: reading and writing. For the reading part, participants were asked to read a microgesture description and perform the corresponding microgesture. We used three types of description: µGlyph, concise µGlyph and text+images from the original paper. For each description type, we used one of the sets A, B or C. We used a Latin square to counterbalance the order of the description and the set used. The microgestures of each set were presented in a randomized order. To start a trial, participants pressed the Return key which prompted a description on the screen. When they understood the microgesture, participants pressed Return again. The time spent between both presses on the Return key (Reading time) was recorded. Then, the description was hidden, and participants performed the microgesture in front of a camera while the experimenter wrote down the performed microgesture using µGlyph. We also asked them to verbally describe the microgesture, and to explicitly state when it began and ended. Finally, participants rated their level of confidence in their response on a 6-point Likert scale (1-not at all confident, 6-very confident).

For the writing part, participants were asked to describe 10 microgestures in µGlyph. We used the microgesture set W and presented each microgesture in a randomized order. Participants watched a video for each microgesture. They could watch it as many times as they wanted. Then, they had to verbally describe the microgesture to the experimenter to ensure that any errors in the µGlyph description were not due to the participants describing a different microgesture than the one requested. Then, participants had to describe the microgesture in µGlyph. To do so, participants first pressed the Return key and then began to write the µGlyph description on paper. We asked them to verbally describe the microgesture as they wrote. The experimenter re-explained the microgesture if the participant verbally described a different one. We have not imposed a specific form for writing in µGlyph, i.e. standard or concise. After completing their writing, participants pressed the Return key again. The time spent between both presses on the Return key (Writing time) was recorded. Then, they rated their level of confidence on a 6-point Likert scale (1-not at all confident, 6-very confident).

[1]The URL is removed for submission and the video is included in the supplementary material.

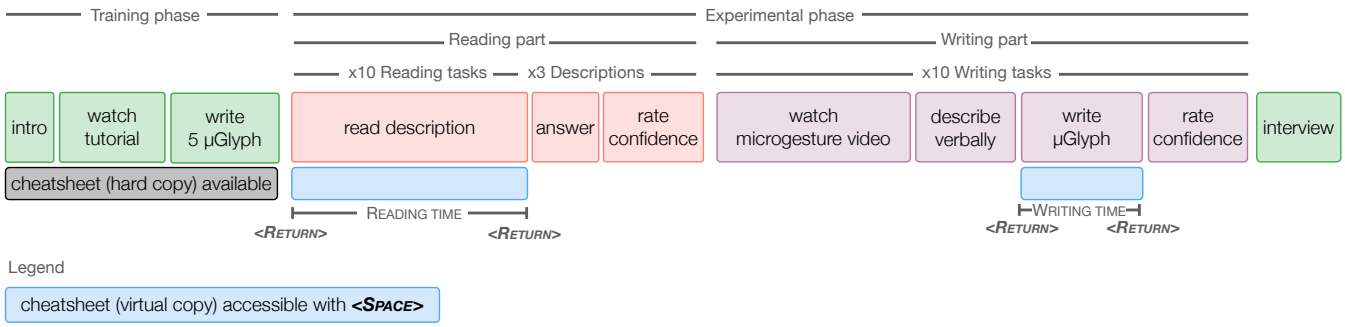


Figure 5: Experimental procedure (*<Return>* represents the return key, *<Space>* the space key).

During both reading and writing in µGlyph, participants could freely access a virtual copy of the cheatsheet by holding down the Space key. The number of times the cheatsheet was used and the time spent using it were recorded. At the end of the experiment, we asked participants which form of µGlyph they preferred, why and if they had any additional comments.

Figure 5 summaries the experimental procedure. In total, the experiment lasted around 1h.

5.5 Measures and Hypotheses

During the experiment, we recorded the following measures: the number of cheatsheet calls, the total time using the cheatsheet, the total time (Reading/Writing time) spent on a microgesture and participants' self-confidence ratings. For the reading part, the experimenter translated the participants' answers into µGlyph using his notes, the participants' explanations, and the videos. Movement and context symbols as well as sequence and parallel combinations were inferred from the microgesture performed by the participant. The choice of events and additional features were inferred from participants' oral explanations. For instance, for a `Finger Tap` (Set A 3), a participant performed a tap with the thumb on the tip of the index in front of the camera, then verbally explained that this could be done on the index, middle or ring finger and on the tip, middle or base phalanx. If the translated answer had additional, missing or incorrect symbols, the answer was considered incorrect. For the writing part, we scored a µGlyph description as incorrect if it was missing one or more symbols or if the structure was wrong. If participants were more accurate than expected but their µGlyph description still correctly described the microgesture presented in the video, e.g. `Tap thumb tip with pinky finger` instead of `Tap thumb with pinky finger` (Set W 1), the answer was considered correct. Using these measures, our first hypothesis is that µGlyph performs better than text+images descriptions in terms of answer correctness and that participants are more confident in their responses. Our second hypothesis is that µGlyph performs worse than text+images descriptions in terms of how long it takes to read a description. Our final hypothesis is that µGlyph can be used easily after a short training period, i.e., a high percentage of correct answers, and a limited number of calls to the cheat sheet and time spent on it.

6 RESULTS

The data analysis follows recommendations for "fair statistical communication in HCI" [13]. Reported confidence intervals are 95% confidence intervals computed with the formula $CI = 1.96 * \frac{\sigma}{\sqrt{n}}$, with σ the standard deviation and n the size of the considered sample. We also report the proportion overlap (POL) [10] when comparing two CIs, i.e. overlap amount / mean size of the CI arms that overlap. Using the TIP 24 of the guidelines [13], if POL < 0.25, i.e. if the CIs visually overlap by more than 1/4 of their length, then a reasoning similar to that of a p-value less than 0.05 can be used. Figure 6 presents an overview of the results.

6.1 Reading

Time: Overall, reading text+images descriptions of microgestures was the fastest (24s ± 3, n = 60), followed by standard µGlyph (36s ± 4, n = 60) and concise µGlyph (42s ± 5, n = 60). The difference between text+images and standard µGlyph (POL: -1.4) as well as between text+images and concise µGlyph (POL: -2.5) is significant, but the difference between standard and concise µGlyph (POL: 0.66) is not.

Correctness: For correctness, CIs are computed on the success rates of participants. Reading standard µGlyph led to the highest number of correct answers (90% ± 3, n = 60), followed by concise µGlyph (88% ± 3, n = 60) and text+images (46% ± 4, n = 60). There is a significant difference between text+images and µGlyph (POL: -10.9) as well as between text+images and concise µGlyph (POL: -11.1), but not between standard and concise µGlyph (POL: 1.4). There was no impact of the microgesture set on correctness (POL < -1.15 when comparing two sets for the same type of description).

Considering both µGlyph forms together, there are a total of 39 errors out of 360 readings of µGlyph descriptions. We observed the following error types:

- Choice symbol "|" mistaken for sequence symbol ";" (9 / 39)
- A symbol not taken into account (8 / 39)
- Parallel symbol "||" mistaken for choice symbol "|" (5 / 39)
- Symbol "p" interpreted as "palm" instead of "pinky" (3 / 39)
- Other types of one-off errors (8 / 39)

For text+images descriptions, out of the 97 errors made when reading 180 descriptions, the most common errors are:

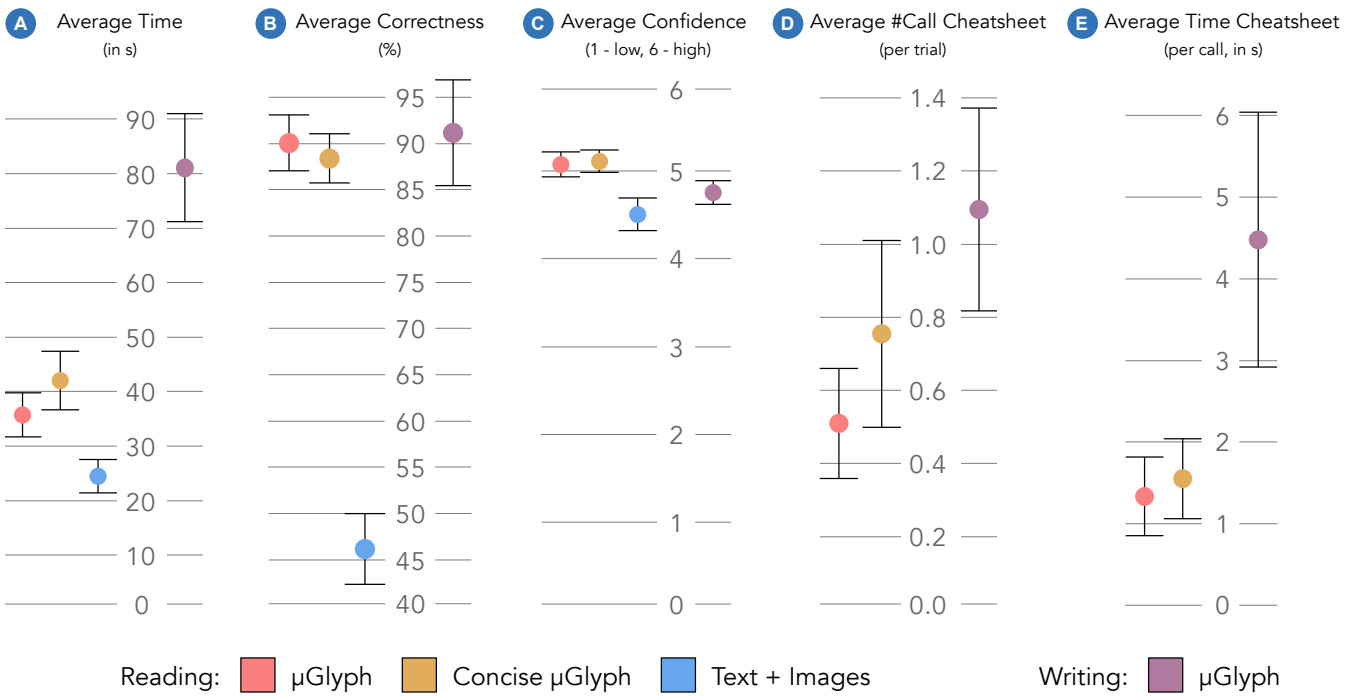


Figure 6: Overview of the study results with 95% confidence intervals. A) Average reading and writing time in seconds. B) Average percentage of correct reading and writing. C) Average confidence of the participants in their responses (1 - low confidence, 6 - high confidence). D) Average number of calls to the cheatsheet. E) Average time spent on cheatsheet for reading and writing.

- Incorrect start and end positions of the microgesture, e.g. a `tap`[7, 39] (∘•▼) performed as ∘•▼; •∘▲ (43 / 97)
- Incorrect or incomplete microgesture direction (11 / 97)
- A choice interpreted as a sequence (5 / 97)
- A `press` [8] (∘•▼) performed as a `press` [38] (•▼) and the opposite case (4 / 97)

  Lo → Hi

Confidence: Participants were more confident in their responses after reading standard µGlyph (5 ± 0.1, n = 60) and concise µGlyph (5 ± 0.1, n = 60) than text+images descriptions (4.5 ± 0.2, n = 60). There is a significant difference between text+images and µGlyph (POL: -2) as well as between text+images and concise µGlyph (POL: -2), but not between µGlyph and concise µGlyph (POL: 2).

Cheatsheet: On average, the cheatsheet was called more often with concise µGlyph (0.8 ± 0.5, n = 180) than with standard µGlyph (0.5 ± 0.3, n = 180). Participants spent on average 1.5s ± 1.0 reading the cheatsheet for concise µGlyph and 1.3s ± 1.0 for standard µGlyph. A more detailed analysis reveals that the cheatsheet has never been called on average for 37% of microgestures (corresponding to 11 out of 30 microgestures) when using standard µGlyph and for 20% of microgestures (6 out of 30 microgestures) when using concise µGlyph.

6.2 Writing using µGlyph

Time: On average, participants wrote a µGlyph expression in 1min 20s ± 19s. As expected, the more symbols there are to write and the less common the symbols are, for example l for left, the longer it takes to write a µGlyph expression. Indeed, the expressions with the least number of symbols, namely `flexion`, `stretch`, `square` and `tap thumb with pinky`, are, on average, written in less than 40s. The expressions with the highest number of symbols, namely `tap and flap`, `linear finger to thumb slides` and `swipe index with middle and thumb`, are, on average, written in over 1min 50s. The three other expressions, namely `tap palm with index middle and ring finger`, `drag index or middle on stylus up/down`, and `pressing down on the lateral tip of the index`, take between 1min 4s and 1min 44s to write.

Correctness: Using µGlyph, participants wrote the correct microgesture 91% ± 6 of the time. There were 16 errors out of 180 µGlyph descriptions written. The most common errors are:

- Merged contexts, i.e. ∘∘ written ∘ and •• written • (5 / 16)
- Merged events, i.e. ∘•▼; ••▼ written ∘•▼ (2 / 16)
- Incorrect or missing movement direction (2 / 16)
- Parallel symbol "||" instead of choice symbol "|" (2 / 16)
- Incorrect symbol placement and missing contact glyph (2 / 16)

Confidence: Participants had a confidence in their responses of 4.8 ± 0.13.

Cheatsheet: On average, per microgesture, participants called the cheatsheet 1.1 ± 0.6 times for a total of 4.5s ± 3.1 spent on it.

µGlyph forms of expression used: On average, participants used standard µGlyph 33% of the time and concise µGlyph 67% of the time. It varies considerably depending on the microgesture to be written. Indeed, `Tap thumb with pinky`, `Tap palm with index, middle and ring` and `stretch` are written in standard µGlyph by 8 participants (44%) and in concise µGlyph by 10 participants (56%). `Linear finger-to-thumb slides`, `Flexion`, `Drag index or middle on stylus up or down` are written in standard µGlyph by 3 participants (17%) and in concise µGlyph by 15 participants (83%).

7 DISCUSSION

In this section, we report the lessons learned from the conceptual and experimental study of µGlyph.

7.1 Improvement of the notation

The experimental results, for both reading and writing µGlyph, show errors in the interpretation of two symbols, namely choice "|" and parallel "||" symbols. We observed that the error of reading a choice symbol "|" as a sequence symbol ";" occurred only if the choice symbol was in long descriptions on a single line, but never occurred when it was placed at the beginning of a new line. Therefore, we recommend that µGlyph users spread long descriptions over several lines by cutting them off before a choice symbol.

The participants who misinterpreted a parallel symbol "||" as a choice symbol "|" explained to us that based on their knowledge of programming languages, the symbol "||" means to them a logical *or*. One way to solve this problem is to use a slanted parallel symbol: "//".

7.2 µGlyph is usable

The experimental results show that µGlyph is usable by researchers and practitioners. Our participants first found µGlyph "frightening" [P3] and text+images "simpler to understand" [P4], but in the end, µGlyph is "comprehensible" [P3], "precise" [P4], and "simpler than text+images for complex microgestures" [P4]. P8, an HCI researcher, appreciated the high level of precision on the description of the microgesture. Moreover, P9, also an HCI researcher, pointed out that "having two symbols ["t"and "p"] with different meanings depending on their position, to the right or left of the glyph, requires mental attention", yet, "µGlyph remains simple to understand".

Like any notation, µGlyph requires some training to be mastered, even if "it looks intuitive" [P11]. As a concrete example of the need for training, we observed a common error during the training phase that never occurred during the experiment after the experimenter pointed it out to participants: many participants represented a thumb flexion using the symbol ▲ (since the thumb goes "up, toward the other fingers") while the correct glyph is ▼ (since it goes "down, toward the palm"). This point should be highlighted in the µGlyph tutorial video. However, even though P6 thought that "[he] would need an hour of training", based on the results of the experiment, participants still managed to read and write µGlyph correctly after a 9 min video tutorial and 10 min of writing practice.

It is unclear which form of expression is preferred by participants when reading µGlyph descriptions. While P7 and P15 found the concise µGlyph form "simpler", "more logical" and "more visual" than the standard µGlyph form, P12 found the concise µGlyph form "not intuitive" and thought she would not remember its meaning in a week. However, for writing, 15 of the 18 participants, including those who preferred the standard µGlyph form, used the concise form to write microgestures requiring specification of a finger choice, i.e. the two microgestures `Linear finger-to-thumb slides` and `drag index or middle finger on stylus up/down`. Overall, participants thought that standard µGlyph is simpler to understand [P3, P4, P11, P18, P19] but becomes too verbose for microgestures with many features [P13, P18, P20]. Thus, they prefer concise µGlyph, called "expert form" by a participant [P11], to write and read "complex microgestures", i.e. microgestures with choices of events and/or many features [P4, P6, P9, P10, P13, P14, P17, P18, P19]. We conclude that both forms of µGlyph expression are useful.

7.3 Literature is ambiguous

The experimental results confirm the terminological problems identified in the literature. Participants made several errors when reading descriptions from the literature and were not completely confident in their responses.

It was not uncommon for participants to be unsure of how to approach certain microgestures, such as "ream" or "tab". The names did not give a clear idea of the corresponding microgestures. In these cases, participants relied solely on the associated images. For "ream" and "tab", this led to respectively only 16% and 50% of correct answers. For `press`, however, the images did help participants to differentiate between $\overset{\circ\bullet}{\blacktriangledown}$ and $\underset{\text{Lo}\rightarrow\text{Hi}}{\overset{\bullet}{\blacktriangledown}}$, leading to 75% of correct answers. However, to avoid ambiguity, we recommend using the name "touch" for $\overset{\circ\bullet}{\blacktriangledown}$, as in [11, 47].

We also observed several errors due to a misunderstanding of the initial and final states of a microgesture, even if the textual description is precise. For instance, based on the precise description of a tap "pressing one part of the hand onto another part" [7] ($\overset{\circ\bullet}{\blacktriangledown}$), participants read the microgesture as $\overset{\circ\bullet}{\blacktriangledown}$; $\overset{\bullet\circ}{\blacktriangle}$, 61% of the time. Participants' comments indicated that they were biased by their HCI expertise, particularly in touch interaction. P7, a computer science student, thought the name and description did not match, so he read the taps in a way that was familiar to him, i.e., a tap on a touchscreen $\overset{\circ\bullet}{\blacktriangledown}$; $\overset{\bullet\circ}{\blacktriangle}$. P11 reported that "in [his] experience [as an HCI research engineer], a tap is similar to a mouse click, whereas here it is similar to a mouse-down event". Therefore, even if a microgesture is precisely described, its name can be misleading.

P16 was surprised that text+images descriptions were "less comprehensible than µGlyph", specifically "to determine the actuator". Additionally, during the writing part of the experiment, P13 noted that determining the actuator is difficult in the videos, especially for tapping since both the actuator and the receiver are moving.

These observations suggest that beyond precise descriptions as in µGlyph, the community needs to agree on names for classes of microgestures. Often, the name implies initial and final states in reference to the more established domains of touch interaction and 3D gesture interaction. As a first step towards this terminological goal, we suggest the following names for the classes of microgestures described in µGlyph at a high level of abstraction:

- Tab, Touch: $\overset{\circ\bullet}{-}$ (e.g. $\overset{\circ\bullet}{\blacktriangledown}$)
- Tap: $\overset{\circ\bullet}{-}$; $\overset{\bullet\circ}{-}$ (e.g. $\overset{\circ\bullet}{\blacktriangledown}$; $\overset{\bullet\circ}{\blacktriangle}$)
- Slide, Drag: $\overset{\bullet\bullet}{-}$
- Ream: $\overset{\bullet\bullet}{\blacktriangledown}$; $\overset{\bullet\bullet}{\blacktriangle}$ | $\overset{\bullet\bullet}{\blacktriangle}$; $\overset{\bullet\bullet}{\blacktriangledown}$ and extension to horizontal Ream: $\overset{\bullet\bullet}{\blacktriangleright}$; $\overset{\bullet\bullet}{\blacktriangleleft}$ | $\overset{\bullet\bullet}{\blacktriangleleft}$; $\overset{\bullet\bullet}{\blacktriangleright}$
- Directional Swipe, Multi-finger snap, Drag&Drop: $\overset{\circ\bullet}{-}$; $\overset{\bullet\bullet}{\blacktriangledown}$; $\overset{\bullet\circ}{-}$ | $\overset{\circ\bullet}{-}$; $\overset{\bullet\bullet}{\blacktriangle}$; $\overset{\bullet\circ}{-}$ | $\overset{\circ\bullet}{-}$; $\overset{\bullet\bullet}{\blacktriangleright}$; $\overset{\bullet\circ}{-}$ | $\overset{\circ\bullet}{-}$; $\overset{\bullet\bullet}{\blacktriangleleft}$; $\overset{\bullet\circ}{-}$ in other words $\overset{\circ\bullet}{-}$; $\overset{\bullet\bullet}{-}$; $\overset{\bullet\circ}{-}$

7.4 Rare properties

In building the database, we found very few examples of microgestures that would require the addition of textual symbols, such as those for phalanges, to µGlyph. For instance, Whitmire et al. uses two-handed taps for text input [45]. For the standard µGlyph, instead of introducing a new symbol, one can simply duplicate and mirror the graphical structure: _---- ----_ . Another example would be to further differentiate fingertips to describe a tap on the very tip of the index by the thumb [8]. We purposefully decided not to increase the number of textual symbols in order not to overwhelm µGlyph users with abbreviations for only one or two studied microgestures. Instead, we let users take advantage of the fact that µGlyph is an hybrid notation, partly graphical and partly textual. This leaves the possibility of accurately describing new contact areas using words. For instance, ${}_{t}\overset{\circ\bullet}{\blacktriangledown}{}_{\text{left hand}}({}_{i}\bullet{}_{\text{left hand}})$; ${}_{t}\overset{\bullet\circ}{\blacktriangle}{}_{\text{left hand}}$ describes a tap of the thumb of the left hand on the index finger of the left hand. Similarly, ${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i}\bullet{}_{\text{very tip}})$; ${}_{t}\overset{\bullet\circ}{\blacktriangle}$ describes a tap of the thumb on the very tip of the index. This trade-off can be mitigated in the future: if the literature evolves, or if many studies make extensive use of previously understudied receivers, new textual symbols can be added to µGlyph, as was done for other notations such as Labanotation [20]. However, no matter how many textual symbols are added, the core of the notation, i.e., movements, contexts, and event compositions, will remain the same, demonstrating a certain completeness and self-sufficiency of the µGlyph notation.

8 ONLINE TOOL TO FACILITATE THE USE OF µGLYPH

To promote the adoption of µGlyph by researchers and practitioners, the proposed online website[2] offers three main services. Figure 7 shows a screenshot of these services.

First, we implemented a visual editor for µGlyph descriptions with an export function to LaTeX. We used this editor to translate the literature microgestures into µGlyph and the LaTeX export feature to create the tables in Appendix B.

The website also contains the complete database, described above, along with a search engine allowing users to formulate targeted searches based on: 1) µGlyph descriptions 2) keywords that match the names and descriptions of the microgestures as well as the descriptions of the grasps and objects studied in conjunction with the microgestures. This search engine allows users to efficiently explore the database of existing microgestures, to relate and compare existing studies. To add a new paper, researchers can find our contact information on the website to send us their document and descriptions in µGlyph.

Finally, to visually present a microgesture, the website includes a view of a 3D hand model using three-js and a tool to generate animations based on µGlyph descriptions[3]. After inputting a µGlyph description, users can watch an animation of the hand reproducing the microgesture. Each part of the µGlyph description is used to create a keyframe of the animation. To play the animation, the keyframes are interpolated over a number of frames. Users can rotate the hand model to play the animation from any angle. Such a tool can be used to explain microgestures to users, similar to the Hololens 2 hand coach that teaches the pinch gesture [32]. In addition, users can export a SVG file containing all the animation keyframes. This feature was inspired from Esquisse [1], to help researchers easily export a graphical description of a microgesture with different hand orientations, as illustrated in Figure 8. The export function is implemented using the three SVG rendering plugin[4]. Usage scenarios of the tool are available in the accompanying video figure.

9 FUTURE RESEARCH BASED ON µGLYPH

In this paper, we have presented µGlyph, studied its expressiveness and usability, and presented tools that support the use of µGlyph. While this is an important step toward a more rigorous hand microgesture field, there are clearly many avenues of research that this work does not directly address. Several of these are topics of current work by the authors. We outline these research avenues according to the main phases of the life cycle of an interactive system based on microgesture interaction: designing, developing, and evaluating.

9.1 Designing and developing microgesture interaction

Designing new microgestures. Using µGlyph, it is possible to build a tree of all possible glyph combinations. By considering all the sequences of two µGlyph events, without even taking the µGlyph features into account, we already obtain more than 250 different microgestures. New types of microgestures, which have not yet been studied, can be identified. For instance, microgestures with momentum (e.g., the microgesture $\overset{\circ\circ}{\blacktriangle}$; $\overset{\circ\bullet}{\blacktriangledown}$ is the momentum version of $\overset{\circ\bullet}{\blacktriangledown}$), or back and forth microgestures in the air (e.g., $\overset{\circ\circ}{\blacktriangledown}$; $\overset{\circ\circ}{\blacktriangle}$).

However, given the already wide variety of microgestures and the small number of human factor studies, we argue that at this time, the generation of new microgestures should be approached with caution. Nevertheless, the µGlyph notation can help systematize the human factor studies.

Developing microgesture recognizers. One barrier for microgesture recognition is the training usually required [12, 37, 39] for a given set of microgestures. When a new microgesture is added to the set, beyond adding new sensors if required, new data from users must be collected to re-train the model. One promising avenue is to create a classifier capable of recognizing elementary µGlyph events. The recognition of a new microgesture, composed of elementary

[2]https://mic.imag.fr/microglyph/

[3]The animation tool is a proof of concept. The tool is a work in progress and, at the time of writing, only works for some simple and concise µGlyph expressions.

[4]https://github.com/LokiResearch/three-svg-rendering.

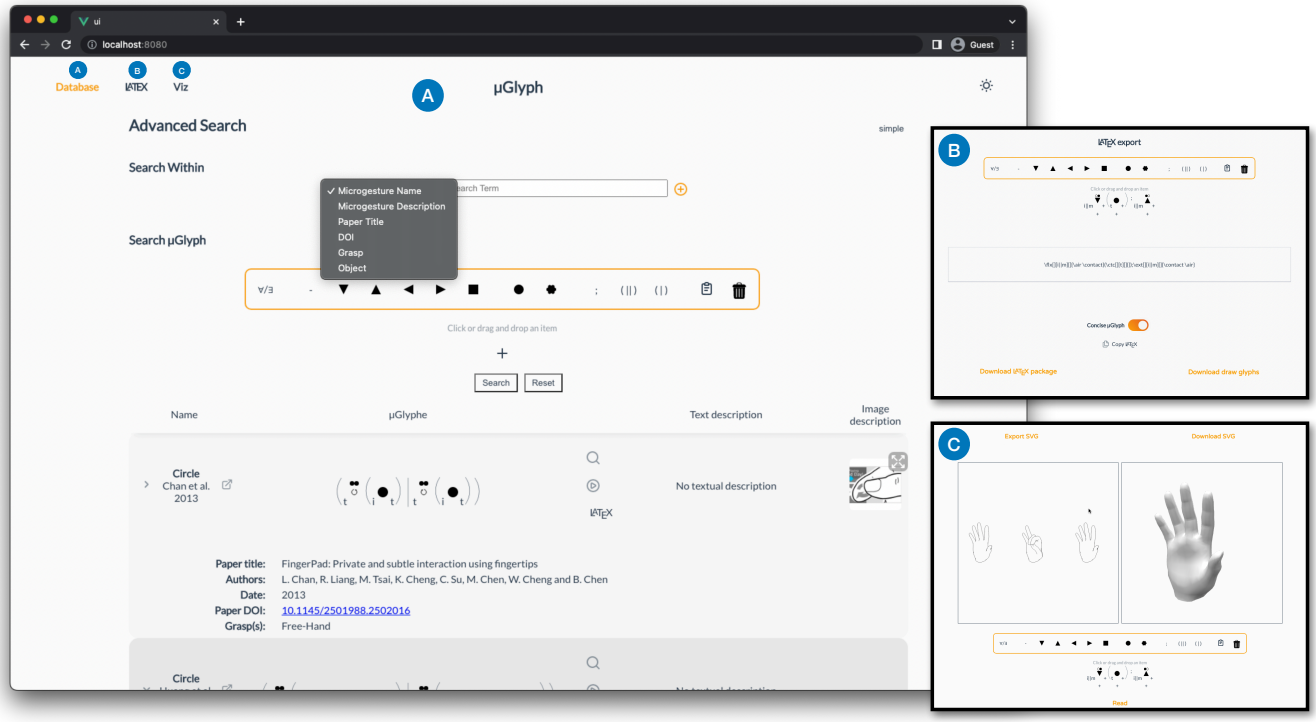


Figure 7: Screenshot of the µGlyph website. A) Database of microgestures: for each microgesture, name, description, paper and µGlyph description. B) µGlyph visual editor with LaTeXexport. C) 3D animated hand generated from a µGlyph description and SVG export of the animation keyframes.

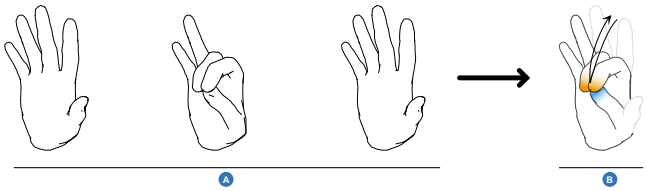


Figure 8: Creation of a graphical description of a microgesture using the SVG export. A) Keyframes exported from the 3D hand viewer (Figure 7 C). B)The graphical description created with the keyframes.

µGlyph events, will then be straightforward, by combining the outputs from the classifier.

9.2 Evaluating microgesture interaction

Keystroke [6] or its extension for touch interaction [17, 35], makes it possible to accurately predict user performance. Such performance models do not yet exist for microgestures, but they are necessary for the field to develop further. We propose three approaches based on µGlyph to build such models

Using medical knowledge. Since the atomic movements of µGlyph are derived from biomechanics of the finger, i.e. extension, flexion, abduction and adduction, microgestures can be evaluated according to feasibility and/or human performance by relying on the medical literature, e.g. [2, 28, 29]. This may be even more important in defining inclusive microgesture sets that account for limitations due to specific conditions, such as finger arthritis. Although previous work has already used medical knowledge [24, 47], many questions related to the physical feasibility of microgestures remain. For instance, is it easier to perform a horizontal swipe, i.e. adduction or abduction, than a vertical swipe, i.e. flexion or extension.

Studying the memorability of microgesture sets. The size of microgesture sets varies considerably in the literature from three microgestures [31] to more than fifty [39]. But we have yet to understand how many microgestures a user can retain. µGlyph can be used as a basis for understanding which properties of a microgesture are easier to remember. For instance, it might be easier to remember a set of several taps (e.g. thumb-to-finger taps: $x \in \{i|m|r|p\}, y \in \{b|m|t\}, {}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{x}\bullet_{y}); {}_{t}\overset{\bullet\circ}{\blacktriangle}$), than a set of 5 different microgestures(e.g. tap: $\overset{\circ\bullet}{\blacktriangledown}$; $\overset{\bullet\circ}{\blacktriangle}$, press: $\underset{\text{Lo}\rightarrow\text{Hi}}{\overset{\bullet}{\blacktriangledown}}$, swipe up: $\overset{\circ\bullet}{-}$; $\overset{\bullet\bullet}{\blacktriangle}$; $\overset{\bullet\circ}{-}$, swipe down: $\overset{\circ\bullet}{-}$; $\overset{\bullet\bullet}{\blacktriangledown}$; $\overset{\bullet\circ}{-}$ and stretch: $\overset{\circ\circ}{\blacktriangle}$).

Studying the proximity between microgestures. We have noted much confusion due to the fact that the microgestures are very close to each other, e.g. tab, touch, press, tap or swipe, slide, drag, drag and drop. µGlyph could be used to assess how different,

two microgestures are, from the user's perspective. This could allow a designer to assign critical tasks to the most different microgestures and thus reduce the risk of false activation.

10 CONCLUSION

We have presented µGlyph, a notation to unambiguously and precisely describe microgestures at different levels of abstraction. µGlyph is based on a graphical and textual representation of the finger movements, the execution context, and optional features of the movements. µGlyph aims to standardize microgesture descriptions by providing a convenient notation to researchers and practitioners. To evaluate the usability of the µGlyph notation, we conducted an experiment with 18 participants. After a 9-minute course and a 10-minute training phase, our participants could accurately read µGlyph 89% of the time and write correctly 91% of the time, as compared to 46% with conventional descriptions. To illustrate the descriptive power of the µGlyph notation, we translated in µGlyph a set of 118 microgestures from 17 literature papers. We gathered these translations, along with their original text and image descriptions, in an online database. To ease the adoption of the µGlyph notation, we developed a set of tools for searching the database, writing and embedding µGlyph expressions within LaTeX based research papers, as well as visualizing microgestures. We put forth that µGlyph can serve as a common language amongst researchers and practitioners to advance the field of microgesture interaction.

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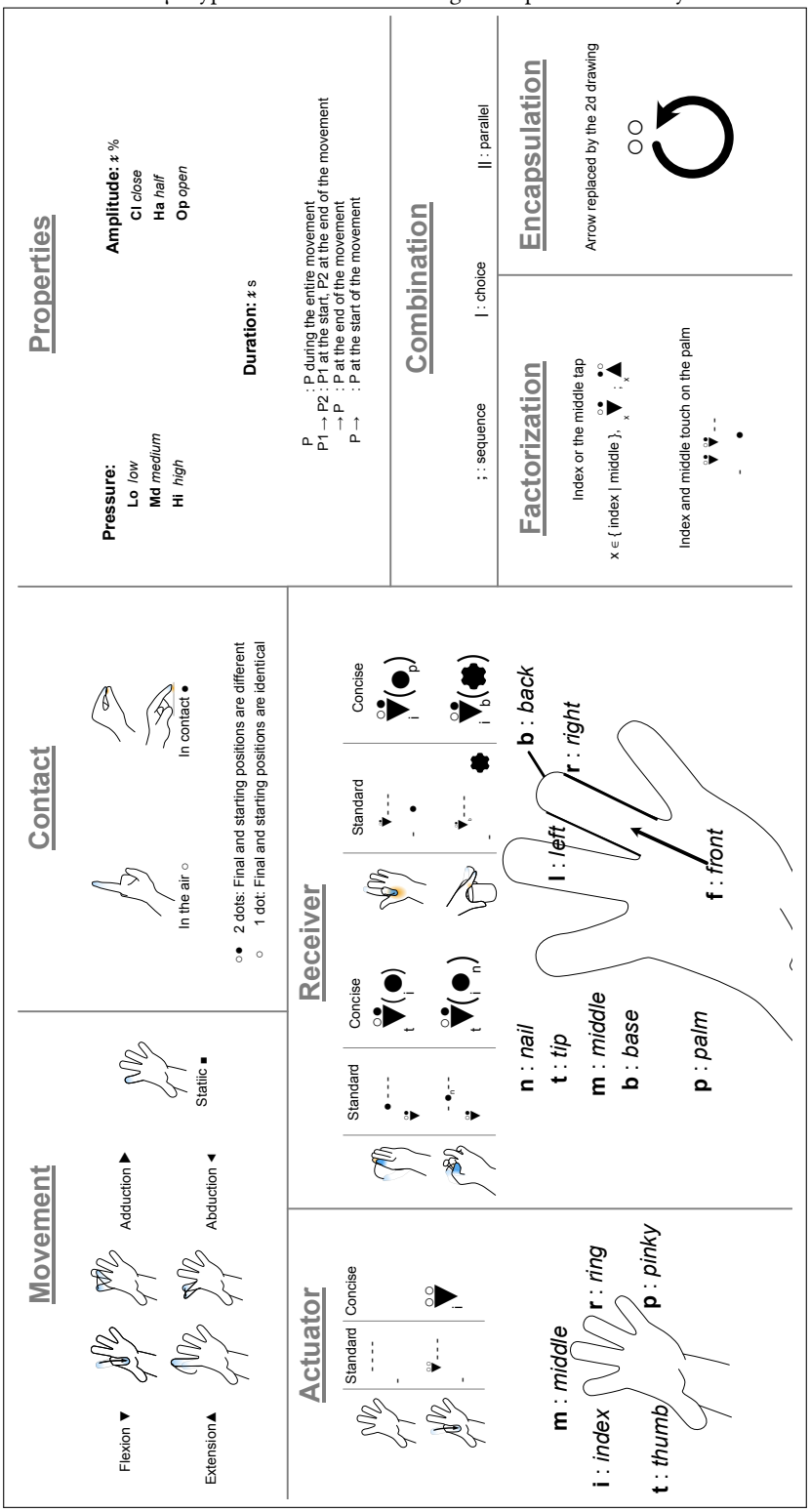
A THE µGLYPH CHEATSHEET

The µGlyph cheatsheet used during the experimental study.



B MICROGESTURES FROM LITERATURE PAPERS

The tables below show microgestures from literature papers. Each µGlyph description was exported from our website using the LaTeX export for µGlyph.

Table 8: First part of the set of microgestures derived from the pattern $\overset{\circ\bullet}{-}; \overset{\bullet\circ}{-}$.

Microgesture	Paper	µGlyph
Click	Chan et al. 2013 [8]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i}\bullet{}_{t}); {}_{t}\overset{\bullet\circ}{\blacktriangle}$
Closed Gap touch	Way et al. 2014 [11]	$x0 \in \{t\|i\|m\|r\|p\}$, $x1 \in \{t\|i\|m\|r\|p\}, x0 \neq x1$, ${}_{x0}\overset{\circ\bullet}{-}({}_{x1}\bullet)\|\|_{x1}\overset{\circ\bullet}{-}({}_{x0}\bullet)$
Double Tap	Song et al. 2011 [40]	${}_{i}\overset{\bullet\circ}{\blacktriangle}; {}_{i}\overset{\circ\bullet}{\blacktriangledown}(\clubsuit); {}_{i}\overset{\bullet\circ}{\blacktriangle}; {}_{i}\overset{\circ\bullet}{\blacktriangledown}(\clubsuit)$
External Surface Touch	Way et al. 2014 [11]	${}_{t\|i\|m\|r\|p}\overset{\circ\bullet}{\blacktriangledown}(\clubsuit)$
Flick	Deyle et al. 2007 [12]	$x \in \{i\|m\|r\|p\}, {}_{x}\overset{\bullet}{\blacksquare}{}_{n}({}_{t}\bullet); {}_{x}\overset{\bullet\circ}{\blacktriangle}$
Finger Pinch	Way et al. 2014 [11]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i\|m\|r\|p}\bullet{}_{b\|m\|t})$
Finger Tap	Soliman et al. 2018 [39]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i\|m\|r}\bullet{}_{b\|m\|t})$
Fist Tap	Soliman et al. 2018 [39]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i}\bullet)\|\|_{i\|\|m\|\|r\|\|p}\overset{\circ}{\blacksquare}$
Make a fist	Chan et al. 2016 [7]	${}_{t\|\|i\|\|m\|\|r\|\|p}\overset{\circ\bullet}{\blacktriangledown} \rightarrow cl$
Mult Flicks	Lee et al. 2020 [30]	$x \in \{i\|\|m \mid m\|\|r \mid r\|\|p \mid i\|\|m\|\|r \mid m\|\|r\|\|p \mid i\|\|m\|\|r\|\|p\}$, ${}_{x}\overset{\bullet}{\blacksquare}{}_{n}({}_{t}\bullet); {}_{x}\overset{\bullet\circ}{\blacktriangle}$
Mult Taps	Lee et al. 2020 [30]	$x \in \{i\|\|m \mid m\|\|r \mid r\|\|p \mid i\|\|m\|\|r \mid m\|\|r\|\|p \mid i\|\|m\|\|r\|\|p\}$, $y \in \{\text{nail center}\|\text{nail tip}\}$, ${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{x}\bullet{}_{y}); {}_{t}\overset{\bullet\circ}{\blacktriangle}$
Pinch gesture	Saponas et al. 2009 [36]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i\|m\|r\|p}\bullet)\|_{t}\overset{\bullet\circ}{\blacktriangle}$
Press on tip of index	Chan et al. 2013 [8]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i}\bullet{}_{t})$
Snip	Wolf et al. 2011 [47]	$\left({}_{i}\overset{\circ\bullet}{\blacktriangleright}({}_{m}\bullet)\|\|_{m}\overset{\circ\bullet}{\blacktriangleleft}({}_{i}\bullet)\right); \left({}_{i}\overset{\bullet\circ}{\blacktriangleleft}\|\|_{m}\overset{\bullet\circ}{\blacktriangleright}\right)$
Stretch	Sharma et al. 2019 [38]	${}_{r\|\|p}\overset{\bullet\circ}{\blacktriangle}(\clubsuit)$
Stretch	Sharma et al. 2019 [38]	${}_{m\|\|r\|\|p}\overset{\bullet\circ}{\blacktriangle}(\bullet{}_{p})$

Table 9: Second part of the set of microgestures derived from the pattern $\overset{\circ\bullet}{-}$; $\overset{\bullet\circ}{-}$.

Microgesture	Paper	µGlyph
Tab	Wolf et al. 2011 [47]	${}_{i\|m\|r\|p}\overset{\circ\bullet}{\blacktriangledown}({}_{t}\bullet_{t})$
Tab	Wolf et al. 2011 [47]	${}_{i\|m\|r\|i\|m}\overset{\circ\bullet}{\blacktriangledown}(\bullet)$
Tab index or middle on object	Wolf et al. 2011 [47]	$x \in \{i\|m\}$, $y \in \{\}$, ${}_{x}\overset{\circ\bullet}{\blacktriangledown}(\bullet)$; ${}_{x}\overset{\bullet\circ}{\blacktriangle}$
Tap	Huang et al. 2016 [24]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i\|m\|r\|p}\bullet_{b\|m\|t})$
Tap	Lee et al. 2020 [30]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i\|m\|r\|p}\bullet_{\text{nail tip\|nail root\|nail inner\|nail outer\|nail center}})$; ${}_{t}\overset{\bullet\circ}{\blacktriangle}$
Tap	Sharma et al. 2019 [38]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}(\bullet)$; ${}_{t}\overset{\bullet\circ}{\blacktriangle}$
Tap	Sharma et al. 2019 [38]	${}_{m}\overset{\circ\bullet}{\blacktriangledown}(\bullet)$; ${}_{m}\overset{\bullet\circ}{\blacktriangle}$
Tap	Sharma et al. 2019 [38]	${}_{i}\overset{\circ\bullet}{\blacktriangledown}(\bullet)$; $\overset{\bullet\circ}{\blacktriangle}$
Tap	Sharma et al. 2021 [37]	${}_{t\|i\|m}\overset{\circ\bullet}{\blacktriangledown}(\bullet)$; ${}_{t\|i\|m}\overset{\bullet\circ}{\blacktriangle}$
Tap	Whitmire et al. 2017 [45]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i\|m\|r\|p}\bullet_{b\|m\|t})$; ${}_{t}\overset{\bullet\circ}{\blacktriangle}$
Tap all fingers together	Chan et al. 2016 [7]	${}_{t\|i\|m\|r\|p}\overset{\circ\bullet}{\blacktriangledown}({}_{t\|i\|m\|r\|p}\bullet)$
Tap and Flap	Soliman et al. 2018 [39]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i}\bullet_{b\|m\|t})\|\|\left(\underset{op \to cl}{{}_{m\|r\|p}\overset{\circ\circ}{\blacktriangledown}} \mid \underset{cl \to op}{{}_{m\|r\|p}\overset{\circ\circ}{\blacktriangle}}\right)$
Tap index and middle finger together	Chan et al. 2016 [7]	${}_{i}\overset{\circ\bullet}{\blacktriangleright}({}_{m}\bullet)\|\|{}_{m}\overset{\circ\bullet}{\blacktriangleleft}({}_{i}\bullet)$
Tap of the thumb on other fingers phalanx and nail	Wambecke et al. 2021 [44]	$\left({}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i\|m}\bullet_{b\|m\|t})\|{}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i}\bullet_{t,l})\|{}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{r}\bullet_{n})\right)$; ${}_{t}\overset{\bullet\circ}{\blacktriangle}$
Tap palm with index, middle and ring fingers	Chan et al. 2016 [7]	${}_{i\|m\|r}\overset{\circ\bullet}{\blacktriangledown}(\bullet_{p})$
Tap palm with thumb	Chan et al. 2016 [7]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}(\bullet_{p})$
Tap the wheel	Wolf et al. 2011 [47]	$x \in \{t\|i\|m\|r\|p\}$ ${}_{x}\overset{\circ\bullet}{\blacktriangledown}$; ${}_{x}\overset{\bullet\circ}{\blacktriangle}$
Tap thumb and pinky	Chan et al. 2016 [7]	${}_{p}\overset{\circ\bullet}{\blacktriangledown}({}_{t}\bullet)$
Tap thumb with middle finger	Chan et al. 2016 [7]	${}_{m}\overset{\circ\bullet}{\blacktriangledown}({}_{t}\bullet)$
Tap thumb with index and middle finger	Chan et al. 2016 [7]	${}_{i\|m}\overset{\circ\bullet}{\blacktriangledown}({}_{t}\bullet)$
Tap thumb with index finger	Chan et al. 2016 [7]	${}_{i}\overset{\circ\bullet}{\blacktriangledown}({}_{t}\bullet)$
Tap thumb with ring and pinky finger	Chan et al. 2016 [7]	${}_{r\|p}\overset{\circ\bullet}{\blacktriangledown}({}_{t}\bullet)$
Tap thumb with ring finger	Chan et al. 2016 [7]	${}_{r}\overset{\circ\bullet}{\blacktriangledown}({}_{t}\bullet)$
Tap to the very tip	Chan et al. 2013 [8]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i}\bullet_{\text{very tip}})$; ${}_{t}\overset{\bullet\circ}{\blacktriangle}$
Thumb Up	Wolf et al. 2011 [47]	${}_{t}\overset{\bullet\circ}{\blacktriangle}$
Touch	Wolf et al. 2011 [47]	${}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{i\|m\|r\|p}\bullet_{n})$

Table 10: Microgestures using pressure.

Microgesture	Paper	µGlyph
Force Tap	Whitmire et al. 2017 [45]	$x \in \{i\|m\|r\|p\}, y \in \{b\|m\|t\}, {}_{t}\overset{\circ\bullet}{\blacktriangledown}({}_{x}\bullet_{y}); \underset{lo \to hi}{{}_{t}\overset{\bullet}{\blacktriangledown}}({}_{x}\bullet_{y}); \underset{hi \to lo}{{}_{t}\overset{\bullet}{\blacktriangle}}({}_{x}\bullet_{y}); {}_{t}\overset{\bullet\circ}{\blacktriangle}$
Press	Saponas et al. 2009 [36]	$\underset{lo \to hi}{{}_{t\|i\|m\|r\|p}\overset{\bullet}{\blacktriangledown}}$
Press	Sharma et al. 2019 [38]	$\underset{lo \to hi}{{}_{i\|m\|r\|p}\overset{\bullet}{\blacktriangledown}}(\bullet); \underset{hi \to lo}{{}_{i\|m\|r\|p}\overset{\bullet}{\blacktriangle}}$
Press	Sharma et al. 2019 [38]	$\underset{lo \to hi}{{}_{t}\overset{\bullet}{\blacktriangledown}}(\bullet); \underset{hi \to lo}{{}_{t}\overset{\bullet}{\blacktriangle}}(\bullet)$
Press	Sharma et al. 2019 [38]	$\underset{lo \to hi}{{}_{i}\overset{\bullet}{\blacktriangledown}}(\bullet); \underset{hi \to lo}{{}_{i}\overset{\bullet}{\blacktriangle}}(\bullet)$
Press	Wolf et al. 2011 [47]	$\underset{lo \to hi}{{}_{i\|m\|r\|p}\overset{\bullet}{\blacktriangledown}}({}_{t}\bullet)$
Press	Yi et al. 2019 [48]	$\underset{lo \to hi}{{}_{t\|i\|m\|r\|p}\overset{\bullet}{\blacktriangledown}}; \underset{hi \to lo}{{}_{t\|i\|m\|r\|p}\overset{\bullet}{\blacktriangle}}$
Pull	Saponas et al. 2009 [36]	$\underset{lo \to hi}{{}_{t\|i\|m\|r\|p}\overset{\bullet}{\blacktriangledown}}$

Table 11: First part of the set of microgestures derived from the pattern $\overset{\bullet\bullet}{-}$.

Microgesture	Paper	µGlyph
Drag Index or Middle finger on stylus up or down	Wolf et al. 2011 [47]	${}_{i\|m}\overset{\bullet\bullet}{\blacktriangledown}(\bullet)\|_{i\|m}\overset{\bullet\bullet}{\blacktriangle}(\bullet)$
Drag and Drop Index on Thumb	Wolf et al. 2011 [47]	${}_{i}\overset{\circ\bullet}{-}({}_{t}\bullet);\ {}_{i}\overset{\bullet\bullet}{\blacktriangledown}({}_{t}\bullet);\ {}_{i}\overset{\bullet\circ}{-}$
Drag and Drop Middle on Index	Wolf et al. 2011 [47]	${}_{m}\overset{\circ\bullet}{-}({}_{i}\bullet_{d});\ {}_{m}\overset{\bullet\bullet}{\blacktriangledown}({}_{i}\bullet_{d});\ {}_{m}\overset{\bullet\circ}{-}$
Drag and Drop Thumb on Index-side	Wolf et al. 2011 [47]	$x \in \{i\|m\|r\|p\},\ {}_{t}\overset{\circ\bullet}{-}({}_{x}\bullet_{n});\ {}_{t}\overset{\bullet\bullet}{\blacktriangleright}({}_{x}\bullet_{n});\ {}_{t}\overset{\bullet\circ}{-}$
Drag fingers around the wheel	Wolf et al. 2011 [47]	${}_{i\|m\|r\|p}\overset{\bullet\bullet}{\blacktriangledown}(\bullet)$
Drag middle finger above object	Wolf et al. 2011 [47]	${}_{m}\overset{\bullet\bullet}{\blacktriangle}(\bullet)$
Drag thumb along object	Wolf et al. 2011 [47]	${}_{t}\overset{\bullet\bullet}{\blacktriangleleft}(\bullet)\|_{t}\overset{\bullet\bullet}{\blacktriangleright}(\bullet)$
Drag thumb around object	Wolf et al. 2011 [47]	${}_{t}\overset{\bullet\bullet}{\blacktriangledown}(\bullet)\|_{t}\overset{\bullet\bullet}{\blacktriangle}(\bullet)$
Extension	Sharma et al. 2021 [37]	${}_{t\|i\|m}\overset{\bullet\bullet}{\blacktriangle}(\bullet)$
Fingertip slide	Soliman et al. 2018 [39]	${}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{i\|m\|r}\bullet_{n})\|_{t}\overset{\bullet\bullet}{\blacktriangleright}({}_{i\|m\|r}\bullet_{n})$
Flexion	Sharma et al. 2021 [37]	${}_{t\|i\|m}\overset{\bullet\bullet}{\blacktriangledown}(\bullet)$
Flip	Wolf et al. 2011 [47]	${}_{i\|m\|r\|p}\overset{\bullet\bullet}{\blacktriangle}({}_{t}\bullet);\ {}_{i\|m\|r\|p}\overset{\bullet\circ}{\blacktriangle}$
HSwipe	Lee et al. 2020 [30]	x ∈ {i|m|r|p}, y ∈ {nail top|nail center|nail root}, ${}_{t}\overset{\circ\bullet}{-}({}_{x}\bullet_{y});\ \left({}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{x}\bullet_{y})\|_{t}\overset{\bullet\bullet}{\blacktriangleright}({}_{x}\bullet_{y})\right);\ {}_{t}\overset{\bullet\circ}{-}$
Linear Finger to Thumb slide	Soliman et al. 2018 [39]	${}_{i\|m\|r}\overset{\bullet\bullet}{\blacktriangledown}({}_{t}\bullet)\|_{i\|m\|r}\overset{\bullet\bullet}{\blacktriangle}({}_{t}\bullet)$
Linear Thumb to Finger slide	Soliman et al. 2018 [39]	${}_{t}\overset{\bullet\bullet}{\blacktriangledown}({}_{i\|m\|r}\bullet_{l\|r})\|_{t}\overset{\bullet\bullet}{\blacktriangle}({}_{i\|m\|r}\bullet_{l\|r})$
Move	Chan et al. 2016 [7]	${}_{t}\overset{\bullet\bullet}{-}({}_{i}\bullet_{t})$
Mult HSwipe	Lee et al. 2020 [30]	x ∈ {i||m | m||r | r||p | i||m||r | m||r||p | i||m||r||p}, y ∈ {nail tip|nail center|nail root}, ${}_{t}\overset{\circ\bullet}{-}({}_{x}\bullet_{y});\ \left({}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{x}\bullet_{y})\|_{t}\overset{\bullet\bullet}{\blacktriangleright}({}_{x}\bullet_{y})\right);\ {}_{t}\overset{\bullet\circ}{-}$
Multi-finger snap	Deyle et al. 2007 [12]	${}_{t}\overset{\circ\bullet}{-}({}_{p}\bullet);\ {}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{r}\bullet);\ {}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{m}\bullet);\ {}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{i}\bullet);\ {}_{t}\overset{\bullet\circ}{-}$
Ream	Wolf et al. 2011 [47]	${}_{i\|m\|r\|p}\overset{\bullet\bullet}{\blacktriangledown}({}_{t}\bullet_{t})\|_{i\|m\|r\|p}\overset{\bullet\bullet}{\blacktriangle}({}_{t}\bullet_{t})$
Rotational thumb-to-finger slide	Soliman et al. 2018 [39]	${}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{i\|m\|r}\bullet_{b\|m})\|_{t}\overset{\bullet\bullet}{\blacktriangleright}({}_{i\|m\|r}\bullet_{b\|m})$
Slide	Whitmire et al. 2017 [45]	x ∈ {i|m|r|p}, y ∈ {b|m|t}, ${}_{t}\overset{\circ\bullet}{-}({}_{x}\bullet);\ \left({}_{t}\overset{\bullet\bullet}{\blacktriangledown}({}_{x}\bullet)\|_{t}\overset{\bullet\bullet}{\blacktriangle}({}_{x}\bullet)\right);\ {}_{t}\overset{\bullet\circ}{-}$

Table 12: Second part of the set of microgestures derived from the pattern $\overset{\bullet\bullet}{-}$.

Microgesture	Paper	µGlyph
Swipe	Sharma et al. 2019 [38]	${}_{t}\overset{\bullet\bullet}{\blacktriangleleft}(\bullet)\vert{}_{t}\overset{\bullet\bullet}{\blacktriangleright}(\bullet)$
Swipe	Sharma et al. 2019 [38]	${}_{t}\overset{\bullet\bullet}{\blacktriangledown}(\bullet);{}_{t}\overset{\bullet\bullet}{\blacktriangle}(\bullet)$
Swipe	Sharma et al. 2019 [38]	${}_{m}\overset{\bullet\bullet}{\blacktriangleleft}(\bullet)\vert{}_{m}\overset{\bullet\bullet}{\blacktriangleright}(\bullet)$
Swipe	Sharma et al. 2019 [38]	${}_{m}\overset{\bullet\bullet}{\blacktriangledown}(\bullet)\vert{}_{m}\overset{\bullet\bullet}{\blacktriangle}(\bullet)$
Swipe	Sharma et al. 2019 [38]	${}_{i}\overset{\bullet\bullet}{\blacktriangleleft}(\bullet)\vert{}_{i}\overset{\bullet\bullet}{\blacktriangleright}(\bullet)$
Swipe	Sharma et al. 2019 [38]	${}_{i}\overset{\bullet\bullet}{\blacktriangledown}(\bullet)\vert{}_{i}\overset{\bullet\bullet}{\blacktriangle}(\bullet)$
Swipe	Song et al. 2011 [40]	${}_{i\vert t}\overset{\bullet\bullet}{-}$
Swipe Left	Sharma et al. 2021 [37]	${}_{t\vert i\vert m}\overset{\bullet\bullet}{\blacktriangleleft}(\bullet)$
Swipe Right	Sharma et al. 2021 [37]	${}_{t\vert i\vert m}\overset{\bullet\bullet}{\blacktriangleright}(\bullet)$
Swipe across all fingers with thumb	Chan et al. 2016 [7]	${}_{t}\overset{\circ\bullet}{-}({}_{p}\bullet);{}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{r}\bullet);{}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{m}\bullet);{}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{i}\bullet);{}_{t}\overset{\bullet\circ}{-}$
Swipe index and middle fingers with thumb	Chan et al. 2016 [7]	${}_{t}\overset{\circ\bullet}{-}(\bullet);\left({}_{t}\overset{\bullet\bullet}{\blacktriangledown}({}_{i\Vert m}\bullet)\vert{}_{t}\overset{\bullet\bullet}{\blacktriangle}({}_{i\Vert m}\bullet)\right);{}_{t}\overset{\bullet\circ}{-}$
Swipe index finger with thumb	Chan et al. 2016 [7]	${}_{t}\overset{\circ\bullet}{-}({}_{i}\bullet);\left({}_{t}\overset{\bullet\bullet}{\blacktriangledown}({}_{i}\bullet)\vert{}_{t}\overset{\bullet\bullet}{\blacktriangle}({}_{i}\bullet)\right);{}_{t}\overset{\bullet\circ}{-}$
Swipe middle and ring fingers with thumb	Chan et al. 2016 [7]	${}_{t}\overset{\circ\bullet}{-}({}_{m\Vert r}\bullet);\left({}_{t}\overset{\bullet\bullet}{\blacktriangledown}({}_{m\Vert r}\bullet)\vert{}_{t}\overset{\bullet\bullet}{\blacktriangle}({}_{m\Vert r}\bullet)\right);{}_{t}\overset{\bullet\circ}{-}$
Swipe middle finger with thumb	Chan et al. 2016 [7]	${}_{t}\overset{\circ\bullet}{-}({}_{m}\bullet);\left({}_{t}\overset{\bullet\bullet}{\blacktriangledown}({}_{m}\bullet)\vert{}_{t}\overset{\bullet\bullet}{\blacktriangle}({}_{m}\bullet)\right);{}_{t}\overset{\bullet\circ}{-}$
Swipe thumb leftward	Chan et al. 2013 [8]	${}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{i}\bullet{}_{t})$
Thumb index rub backward	Deyle et al. 2007 [12]	${}_{t}\overset{\bullet\bullet}{\blacktriangleleft}({}_{i}\bullet)$
V Swipe	Lee et al. 2020 [30]	$x \in \{i\vert m\vert r\vert p\}$, $y \in \{\text{nail inner}\vert\text{nail center}\vert\text{nail outer}\}$, ${}_{t}\overset{\circ\bullet}{-}({}_{x}\bullet{}_{y});\left({}_{t}\overset{\bullet\bullet}{\blacktriangledown}({}_{x}\bullet{}_{y})\vert{}_{t}\overset{\bullet\bullet}{\blacktriangle}({}_{x}\bullet{}_{y})\right);{}_{t}\overset{\bullet\circ}{-}$

Table 13: Microgestures derived from the pattern $\overset{\circ\circ}{-}$.

Microgesture	Paper	µGlyph
Down	Endres et al. 2011 [14]	$\overset{\circ\circ}{\underset{\mathrm{i}}{\blacktriangledown}}$
Finger Curl	Way et al. 2014 [11]	$\overset{\circ\circ}{\underset{\mathrm{t\|i\|m\|r\|p}}{\blacktriangledown}}$
Finger Extend	Way et al. 2014 [11]	$\overset{\circ\circ}{\underset{\mathrm{t\|i\|m\|r\|p}}{\blacktriangle}}\ \mathrm{MCP}$
Finger Lift	Way et al. 2014 [11]	$\overset{\circ\circ}{\underset{\mathrm{t\|i\|m\|r\|p}}{\blacktriangledown}}\ \mathrm{MCP}$
Left	Endres et al. 2011 [14]	$\overset{\circ\circ}{\underset{\mathrm{i}}{\blacktriangleleft}}$
Open Palm	Hauslschmid et al. 2015 [22]	$\overset{\circ\circ}{\underset{\mathrm{t\|\|i\|\|m\|\|r\|\|p}}{\blacktriangle}}$
Right	Endres et al. 2011 [14]	$\overset{\circ\circ}{\underset{\mathrm{i}}{\blacktriangleright}}$
Stretch	Sharma et al. 2019 [38]	$\overset{\circ\circ}{\underset{\mathrm{r\|\|p}}{\blacktriangle}}$
Swipe	Hauslschmid et al. 2015 [22]	$\overset{\circ\circ}{\underset{\mathrm{i}}{\blacktriangleright}}\Big\vert\overset{\circ\circ}{\underset{\mathrm{i}}{\blacktriangleleft}}$
Up	Endres et al. 2011 [14]	$\overset{\circ\circ}{\underset{\mathrm{i}}{\blacktriangle}}$

Table 14: Drawing microgestures.

Microgesture	Paper	µGlyph
Clock wise and counter clockwise circle	Hauslschmid et al. 2015 [22]	$\overset{\circ\circ}{\circlearrowright} \mid \overset{\circ\circ}{\circlearrowleft}$
Circle	Chan et al. 2013 [8]	${}_{t}\overset{\bullet\bullet}{\circlearrowright}({}_{i}\bullet{}_{t}) \mid {}_{t}\overset{\bullet\bullet}{\circlearrowleft}({}_{i}\bullet{}_{t})$
Circle	Huang et al. 2016 [24]	${}_{t}\overset{\bullet\bullet}{\circlearrowright}({}_{i\mid m\mid r\mid p}\bullet{}_{b\mid m\mid t}) \mid {}_{t}\overset{\bullet\bullet}{\circlearrowleft}({}_{i\mid m\mid r\mid p}\bullet{}_{b\mid m\mid t})$
Circle	Sharma et al. 2021 [37]	${}_{t\mid i\mid m}\overset{\bullet\bullet}{\circlearrowright}(\bullet)$
Circle CW	Endres et al. 2011 [14]	${}_{i}\overset{\circ\circ}{\circlearrowright}$
Circle CCW	Endres et al. 2011 [14]	${}_{i}\overset{\circ\circ}{\circlearrowleft}$
Circle CW & CCW	Wolf et al. 2011 [47]	$x \in \{i\mid m\mid r\mid p\}, {}_{t}\overset{\bullet\bullet}{\circlearrowright}({}_{x}\bullet{}_{n}) \mid {}_{t}\overset{\bullet\bullet}{\circlearrowleft}({}_{x}\bullet{}_{n})$
Circle sidewise	Wolf et al. 2011 [47]	${}_{t}\overset{\bullet\bullet}{\circlearrowright}\,{}_{t}({}_{i\mid m\mid r\mid p}\bullet) \mid {}_{t}\overset{\bullet\bullet}{\circlearrowleft}\,{}_{t}({}_{i\mid m\mid r\mid p}\bullet)$
Circle thumb over side of index finger	Chan et al. 2016 [7]	${}_{t}\overset{\bullet\bullet}{\circlearrowright}({}_{i}\bullet)$
Draw Circle	Soliman et al. 2018 [39]	${}_{t}\overset{\bullet}{\blacksquare}({}_{i}\bullet{}_{b}); {}_{t}\overset{\bullet\bullet}{\circlearrowright}({}_{i\mid\mid m\mid\mid r\mid\mid p}\bullet)$
Square	Huang et al. 2016 [24]	${}_{t}\overset{\bullet\bullet}{\square}({}_{i\mid m\mid r\mid p}\bullet{}_{b\mid m\mid t}) \mid {}_{t}\overset{\bullet\bullet}{\square}({}_{i\mid m\mid r\mid p}\bullet{}_{b\mid m\mid t})$
Square CW	Endres et al. 2011 [14]	${}_{i}\overset{\circ\circ}{\square}$
Square CCW	Endres et al. 2011 [14]	${}_{i}\overset{\circ\circ}{\square}$
Triangle	Huang et al. 2016 [24]	${}_{t}\overset{\bullet\bullet}{\triangle}({}_{i\mid m\mid r\mid p}\bullet{}_{b\mid m\mid t}) \mid {}_{t}\overset{\bullet\bullet}{\triangle}({}_{i\mid m\mid r\mid p}\bullet{}_{b\mid m\mid t})$
Triangle CW	Endres et al. 2011 [14]	${}_{i}\overset{\circ\circ}{\triangle}$
Triangle CCW	Endres et al. 2011 [14]	${}_{i}\overset{\circ\circ}{\triangle}$
Zigzag	Sharma et al. 2021 [37]	${}_{t\mid i\mid m}\overset{\bullet\bullet}{\lightning}(\bullet)$