The Gesture Homunculus: A Body-Cortical Topography of User-Defined Gestures

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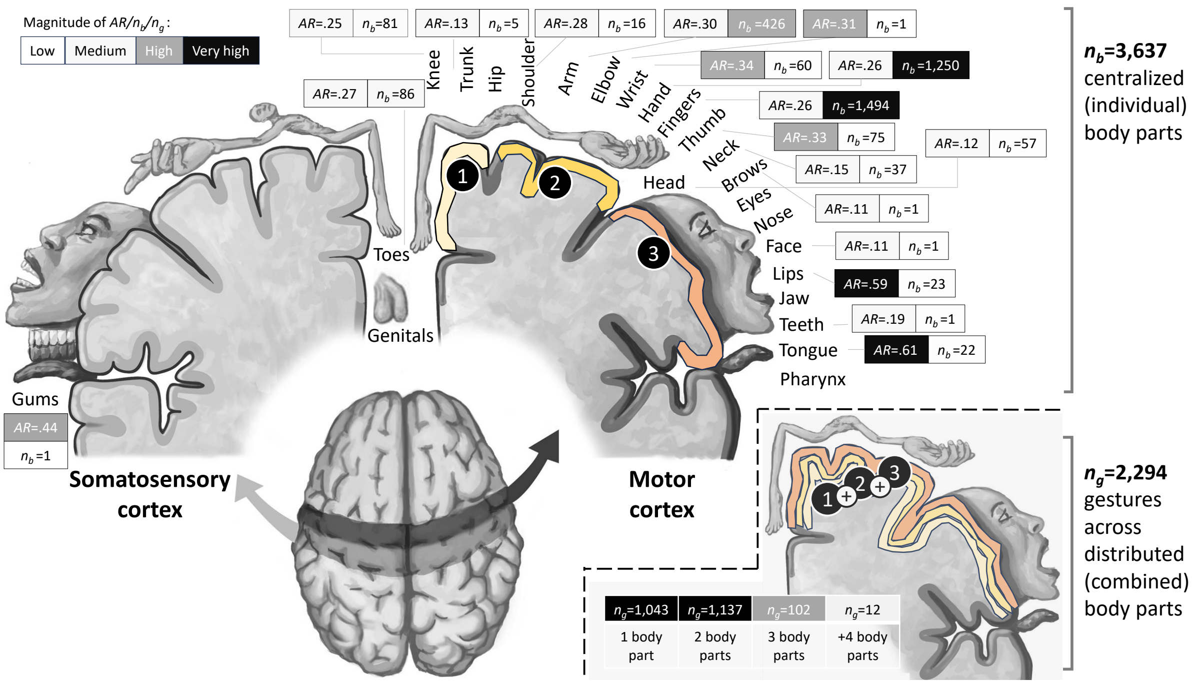

Figure 1: The Gesture Homunculus, a body-cortical representation of user-defined gestures, shows empirical data from elicitation studies (total of n_g=2, 294 gestures in this figure) over the somatosensory and motor cortical mappings of the corresponding body parts (total of n_b=3, 637, averaging 1.59 body parts per gesture). *Note:* areas denoted ❶, ❷, ❸ group three main motor regions.

Abstract

Gesture research for interactive computer systems has primarily relied on taxonomies using external dimensions of gesture articulation. While effective for documenting gestures and supporting computational recognition, this focus provides an incomplete account by overlooking internal dimensions related to how the body parts involved in gesture articulation are represented in the brain. To address this aspect, we introduce the *Gesture Homunculus*, a body-cortical topographical representation grounded in the medical literature, reinterpreted through the lens of user-defined gestures. To construct it, we analyzed 2,294 elicited gestures and 3,637 corresponding body parts, which we relate to somatosensory and motor cortical mappings. Based on this representation, we identify future work opportunities for gesture elicitation studies, such as exploration of underrepresented body parts, combination of multiple body parts within a single gesture, and designing gesture interactions that span both the somatosensory and motor cortices.

CCS Concepts

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

Keywords

User-defined gestures, gesture elicitation, gesture interaction

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1 Introduction

Existing gesture taxonomies in Human-Computer Interaction (HCI) have primarily focused on *external, overt* dimensions of gesture articulation. For example, Rossini [36] transcribed generic human gestures in terms of their timing, size, point of articulation, and locus; Wobbrock et al. [59] classified surface gestures according to their form, nature, binding, and flow; and Vatavu and Gheran [47] examined bimanual gestures with respect to their asynchrony and the distinct roles played by the two hands. While well suited for the computer systems that must interpret them, overt dimensions provide only a partial account of gesture articulation and why certain gestures are preferred over others in gesture elicitation studies (GESs) [49,59]. In contrast, *internal, covert* dimensions, reflecting processes occurring within the human body and their cortical underpinnings [11,27], can provide a complementary perspective.

In medicine, the term "homunculus" refers to a disproportionate visual representation of the human body in which certain regions, such as the hands, face, lips, and tongue, are purposefully enlarged to reflect their large representations in the somatosensory and motor cortices [27]. For example, approximately one third of the cortical areas are devoted to the hands, followed by the face, lips, tongue, and pharynx, while the remaining third corresponds to the rest of the body, including the trunk, legs, and arms [30], showing that the brain's *internal, covert* representation of the human body differs considerably from its *external, overt* morphology. Building on this representation, we introduce the *Gesture Homunculus,* a body-cortical topographical space in which user-defined gestures are aligned with body regions scaled accordingly to their relative cortical representation in the somatosensory and motor cortices; see Figure 1. Our specific representation builds on empirical data extracted from an open dataset of 267 GESs compiled in a recent systematic literature review [53]. Based on insights offered by the Gesture Homunculus, we identify future work opportunities for gesture elicitation research and practice, such as exploration of underrepresented body parts, combination of multiple body parts within a single gesture, and design of gesture-based interactions that span both the somatosensory and motor cortices.

2 Related Work

We build on prior research in gesture taxonomies (Subsection 2.1) and cortical representations of sensory and motor functions via the homunculus (Subsection 2.2), at the intersection of which lies the scope of our work.

2.1 Taxonomies of Human Gestures

One influential line of work in gesture taxonomies originates in psycholinguistics, where Kendon [18] structured human gestures along a continuum depending on their relationship to speech, ranging from gesticulation to language-like gestures, pantomimes, emblems, and sign languages; McNeill [24] further revealed the importance of iconic, metaphoric, deictic, and beat gestures during speech; and, in the context of conversational interaction, Quek et al. examined gestures observed in monomodal [32] and multimodal [33] human discourse. The increasing popularity of end-user gesture elicitation studies [59] has led to the development of new taxonomies within the field of HCI. One of the most influential is Wobbrock et al.'s [59] taxonomy of surface gestures, which organizes touch and multitouch input according to form, nature, binding, and flow. Subsequent gesture elicitation studies, often focused on specific gesture types or body parts, have reported on user preferences for gestures performed with the hands [52], fingers [40], face [35], eyes [23], ears [6], nose [31], mouth [5], shoulders [45], torso [42], feet [10], lingual region [51], or belly [55]. The human gesture continuum proposed in the context of end-user gesture elicitation [53] enables the exploration of user-defined gestures according to the body parts involved in their production, but is anchored in taxonomies involving external dimensions of gesture articulation.

2.2 The Somatosensory and Motor Homunculi

Penfield and Boldrey [30] introduced the somatosensory and motor homunculi as representations of the human body derived from mappings between body regions and their corresponding cortical areas. These representations show disproportionately large cortical areas associated with certain body parts, such as the lips, tongue, and hands (Figure 1) with comparatively higher sensory acuity and motor control. For example, the fingers and hands occupy larger areas of the motor cortex compared to the proximal joints, such as the wrists, elbows, and shoulders. Subsequent work has provided empirical evidence for the somatotopic organization of the primary motor cortex, such as Cheyne et al. [8] and Roux et al. [38], who reported mappings between cortical activation patterns and specific body parts, reinforcing the homunculus representation.

These insights have found applications in interactive systems. For example, Muñoz et al. [26] developed hands-on virtual reality experiences to support learning about mechanoperception and brain mapping, resulting in visual representations of an individual's homunculus; Ranne et al. [34] applied it to malleable robotic systems; and Hoffmann et al. [13] further extended the concept to human-robot interaction with self-organizing maps to model the body's representation in a humanoid robot based on proprioceptive and tactile input. Building on this body of work, we instantiate the homunculus as a lens for analyzing user-defined gestures.

3 The Gesture Homunculus

We introduce the Gesture Homunculus, a body-cortical topographical representation of user-defined gestures that aligns empirical data from actual gesture elicitation studies with the somatosensory and motor cortical mappings of the corresponding moving body parts; see Figure 1. Specifically, the Gesture Homunculus enables visualization of GES-related numerical data, such as agreement rates [48], over the representation of different body regions as reflected in the canonical cortical maps of the somatosensory and motor homunculi [8,30]. In doing so, it aligns the focus of empirical research on specific body parts, e.g., gestures performed with the fingers [4] and hands [59] vs. the feet [10], with the corresponding motor cortical areas devoted to these regions. Through this alignment, the Gesture Homunculus provides an overview of how comprehensively the human body has been covered in the GES scientific literature. In the following, we describe how we created the Gesture Homunculus, while Section 4 presents several opportunities for future work based on this visual representation.

3.1 Definition

We define the Gesture Homunculus as a visual map of the rescaled human body according to its representation in the somatosensory and motor cortices, on top of which a specific GES measure $\zeta(p)$ is projected, where p denotes the body part(s) involved in producing a gesture. For example, ζ can be the agreement rate (*AR*) [48] (i.e., the number of pairs of participants in agreement over the gestures to effect the same referent, normalized by the maximum number of pairs in the sample) or the max-consensus [25] (i.e., the percent of participants proposing the most popular interaction for a given referent). The parameter p represents the set of body parts involved in producing a gesture, e.g., the fingers in a microgesture where the thumb swipes across the other fingers [4], both arms in an iconic gesture depicting a physical object in front of the body [14], or the hand and face in hand-to-face gesture input [19].

3.2 Construction Procedure

To build the Gesture Homunculus in Figure 1, we extracted information about user-defined gestures from the corpus of 267 GESs identified in the systematic literature review of Villarreal et al. [53], and focused on three ζ measures: the agreement rate (*AR*), the number of gestures (n_g), and the number of body parts (n_b) involved in producing the gestures. Of these studies, only 115 (43.1%) reported agreement over individual gestures, whereas the remainder only averages across an entire gesture set, of limited utility for our purposes and, thus, were excluded from the Gesture Homunculus.

For each gesture, we extracted its description, the body parts involved in its articulation, and the *AR* of its referent. We chose to construct the homunculus based on the *AR* because this measure is the most widely reported in a consistent manner across a substantial body of GESs [54]. Other measures, such as memorability or learnability, could also have been considered, but with a narrower range and limited coverage. We attributed the *AR* value to the gesture and corresponding body parts, since in in-consensus gesture sets a single gesture is typically assigned to each referent. Although this is a reasonable approximation given the lack of access to raw GES data, which prevents verification of individual gesture-referent mappings, these assignments should be interpreted as provisional rather than definitive. When more than one in-consensus gesture set was reported, such as in Bostan et al.'s [1] study of user-defined on-skin gestures, we included all alternatives. When multiple body parts were involved in a gesture, the homunculus representation was updated uniformly.

Furthermore, as some studies reported agreement scores [58] while others agreement rates [48], we standardized the extracted numerical information by applying the conversion formula derived by Vatavu and Wobbrock [48]. For example, the "raise hand" gesture corresponding to the "fly higher to user's height" referent was originally reported in [3] with an agreement score of .24 that, when recalculated as an agreement rate, gave .20. For each body part p, we averaged the *AR* values of all corresponding gestures, counted their occurrence (n_b), and analyzed separately centralized (individual) and distributed (combined) use of body parts in gesture articulation.

Overall, we analyzed n_g=2,294 gestures involving a total of n_b=3,637 body parts (on average n_b/n_g=1.59 per gesture) across 24 distinct regions of the homunculi [8,30].

3.3 Agreement Rate Analysis

The highest *AR* values were observed for the tongue (.61), lips (.59), gums (.44), wrist (.34), and thumb (.33), followed by lower values for the arms (.30), shoulders (.28), toes (.27), hands and fingers (.26), and knee (.25). Of these body parts, the fingers, hands, and arms have been the focus of the largest number of studies, e.g., fingers were involved in 1,494/2,294=65.1% of the analyzed gestures. Overall, we found that body parts with higher agreement rates also afforded fewer degrees of freedom and more constrained possibilities for movement. Several body parts have not been covered at all in GESs [53], such as the hip, jaw, and pharynx, despite their representation in the cortical areas, whereas the absence of specific body parts, such as the genital region, reflects social and cultural taboos in HCI research [17]. Furthermore, other regions have only been sparsely explored, such as the trunk, teeth, elbow, and brows, constituting body parts that remain underrepresented in current knowledge about user-defined gestures.

3.4 Number of Gestures and Body Parts

We visualize the motor cortex in two complementary ways: *centrally* (Figure 1, center), and *regionally* (Figure 1, bottom-right), according to a grouping of three main regions of the moving body: the feet ❶, hands ❷, and face ❸. Our analysis shows that centrally represented body parts have been studied with different frequencies: very frequently (e.g., n_b=1,494 for fingers and n_b=1,250 for hands), moderately frequently (e.g., n_b=426 for arms), and infrequently (e.g., n_b=22 for the tongue, n_b=37 for the neck, and n_b=23 for the lips). Some body parts with prominent representation in the motor cortex, such as the hip, jaw, pharynx, have not been studied at all in formal GESs. Figure 1, bottom-right further shows how body parts were combined: n_g=1,043 gestures (45.5%) involve a single body part only, whereas 1,137 (49.6%) gestures combine two parts, 102 (4.4%) combine three, and 12 (0.5%) involve four or more body parts. This distribution points to opportunities for exploring more diverse multi-part gesture input in gesture elicitation research.

4 Implications for the Research and Practice of Gesture Elicitation Studies

Figure 1 shows that only the right hemisphere (the motor cortex) is covered, leaving the left hemisphere, responsible for somatosensory processing, implicitly unexamined, which is consistent with the limited attention to sensory aspects in gesture-based interaction in prior GES research. However, since somatosensory cues provide key perceptual feedback and support the sense of embodiment, they could be leveraged to make gesture-based interaction feel more intuitive [57,60]. In some areas, this feedback is essential for bridging the gap between movement in the physical world and effects occurring in a virtual one [7], e.g., sensory feedback in response to performing a gesture helps establish a strong sense of agency since movement is directly linked to system response. Moreover, activity in the somatosensory cortex is strongly increased when users see their hands grasping virtual objects [44]. In other application areas, covered by proprioceptive interaction [22], the sense of agency is purposefully manipulated with somatosensory cues from a body part, such as the wrist, moving independently. Furthermore, since

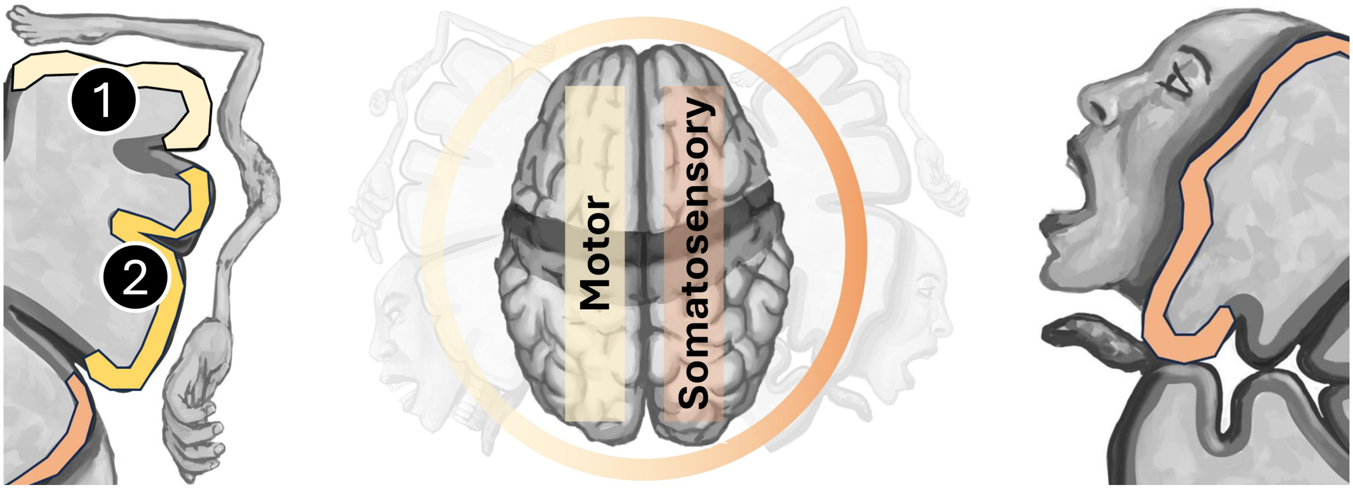

Figure 2: Visual illustrations of the three implications derived from our findings: elicit end-user preferences for gestures involving different body parts (left); design gesture interactions that span both the somatosensory and motor cortices (middle); and address body parts that are underrepresented in gesture research, yet have large dedicated cortical areas (right).

each body part is represented in both the somatosensory and motor cortices, designing gesture-based interactions across the whole brain may lead to new discoveries regarding user preferences, particularly in scenarios where gestures are employed for both input and output [37]. This perspective implies introducing new factors into experimental designs to encourage users to focus more on sensations caused by gesture movement [39], rather than solely on gesture-to-function mappings [59]. Moreover, the somatosensory aspects of gesture movement offer an additional dimension for interactions involving body parts with limited motor capacity and, thus, fewer available movement possibilities.

Based on these insights, we propose three implications for gesture interaction design grounded in both the motor and somatosensory cortices of the Gesture Homunculus (Figure 2). Although these implications are not exclusively enabled by cortical visualization, the homunculus serves as a powerful visual framework that makes these connections explicit and supports systematic reasoning about novel gesture designs involving specific body parts, unique combinations of body parts, and the relationship between perception and action in gesture-based interaction—all connections that would be less apparent in the absence of such a visualization.

4.1 Implication/Future Work Opportunity #1: Conduct Gesture Elicitation Studies for Underrepresented Body Parts

Involving body parts beyond those frequently addressed in GESs, such as the fingers and hands, can open new opportunities to expand natural interaction [57]. As revealed by Figure 1, several other body parts, such as the face, nose, knee, and toes, are routinely used in real-world interaction and have dedicated representations in the motor cortex, yet user preferences for employing them in interactive computer systems remain little known or even entirely unexplored. The feet, hip, trunk, or knee have received limited attention, despite their potential to be integrated into meaningful whole-body interactions defined by the end users themselves. Another prominent example appears in the center of Figure 1: although body regions associated with sexual sensation have a well-documented representation in the somatosensory cortex, they have been comparatively underrepresented in HCI research on sexuality and technology [28]. The pharynx, an internally moving and covert body part that has been largely neglected in gesture research, could also be examined in relation to other natural modalities, such as speech, or less conventional ones, such as swallowing [56] and breathing [2], for novel interaction designs. For example, a designer exploring alternative input modalities for an action video game could prototype an interface that detects controlled breathing to trigger commands during stealth scenarios where gestures or speech would reveal the player's position. Although the HCI community has only sparsely examined these possibilities, dedicated cortical representations provide a strong motivation for further scientific inquiry in this direction.

GEStory is an on-line visualization software for systematizing and consolidating knowledge on user-defined gestures [12]. It could therefore benefit from the Gesture Homunculus to offer an alternative visualization that complements the original body-oriented positioning of GESs. Other classifications of user-defined gestures could also offer an alternative representation of their distribution by body parts. For example, Siean et al.'s [41] classification of radar-based gestures can be reformulated in terms of the Gesture Homunculus to better evoke how motor and somatosensory cortices cooperate to produce gestures with an unobstrusive device like a radar [50]. Finally, some GESs focusing on underrepresented body parts have produced gestures with a high average agreement rate, which is commendable. However, this does not mean that they should no longer be replicated: cross-cohort, cross-platform, and cross-environment replications [46] are applicable to investigate whether the agreement rate is maintained when the context of use changes.

4.2 Implication/Future Work Opportunity #2: Elicit User Preferences for Gestures Involving Different Body Parts

The distributed nature of cortical control calls for greater consideration of how multiple body parts can be synchronized in gesture production for interactive computer systems. To date, the hand-fingers pair has been the most frequently studied combination in gesture elicitation research. New studies are recommended to examine combinations of body parts that form continuous regions in the Gesture Homunculus, such as feet ❶ and fingers/hands ❷, as well as combinations that integrate discontinuous body regions, such as feet ❶ and eye/face ❸, toward novel gesture-based interactions. Recent work on intermanual deictics [47] illustrates this direction with a new class of asymmetrical gestures involving the two arms that play distinct roles. Such approaches also enable gesture interaction design with mixed movement granularity. For example, coarse gestures, such as mid-air arm swipes [16] or shoulder movements and rotations [45], correspond to relatively lower cortical precision and can be mapped to discrete actions with few states (e.g., accept vs. cancel) or to low-precision input (e.g., four-directional navigation). In contrast, gestures that require high precision for tasks such as item selection, text entry, or fine adjustments in user interface widgets should be aligned with body parts that have a large corresponding representation in the motor cortex. However, specific body part dominance in prior GES research may also reflect higher technological sensing capabilities for those regions, not necessarily a research bias. Nevertheless, by encouraging users to integrate multiple body parts during elicitation, new interactions may emerge that are more expressive, better balance gross and fine control, and are more closely aligned with the context of use. For example, a researcher conducting whole-body gesture elicitation for a video game study might prompt participants to combine hand, torso, and head movements to make them reflect on how multi-limb coordination supports better balance in complex actions.

4.3 Implication/Future Work Opportunity #3: Reinforce Gesture Interaction with Congruent Somatosensory Feedback

Localized feedback during gesture interaction should be aligned with the body part performing the gesture, such as vibrations delivered to the fingers or wrist during touch input [43] or to the trunk to accompany whole-body movements [21]. Conveniently, the somatosensory cortex is somatotopically organized: feedback delivered to the same body part involved in movement can strengthen perception, learnability, and motor memory. More broadly in HCI, movement can support faster thinking and learning by establishing embodied representations of information, with promising applications [29]. By visualizing the motor and somatosensory cortices side by side, designers can more easily recognize that delivering feedback during gesture input is as important as the underlying movement. For example, a design decision could involve providing high-pitched auditory feedback for large-amplitude movements that exceed a sensor's active area, and localized haptic feedback on the hand to confirm correct registration of hand pose and finger gestures, which would align feedback modality with gesture scale.

5 Conclusion

Based on a publicly available GES corpus, we extracted information about the body parts involved in the articulation of user-defined gestures to construct the Gesture Homunculus in Figure 1. This visualization revealed new opportunities for research and practice in end-user gesture elicitation, where gestures can integrate underutilized body parts with large cortical representation, combine multiple body parts within a single gesture, and inform the design of interaction techniques that couple gesture articulation with somatosensory feedback. However, our findings need to be interpreted with the same caution accompanying general reasoning about the homunculus in medicine [30] due to known simplifications and distortions inherent in its schematic representation, and also due to our analysis aggregating agreement measures across different tasks and contexts of use [53]. Accounting for different sample sizes in homunculus representations, given variation found in the GES literature [53], would further support more cautious interpretation of the findings. Lastly, our use of the homunculus is intended as a visual support for organizing empirical observations involving various measures relevant to user-defined gestures, which makes it an analytical or interpretive lens, not a definitive model to assert mechanistic links between user preference and cortical representations, which can be examined in future work.

Future instantiations of the Gesture Homunculus could also update it with newly published GESs, e.g., involving bimanual [47], ring [9], controller [15], or scent-based [20] gestures, since our version in Figure 1 reflects a snapshot of GES research as of May 2024 when the corpus of Villarreal et al. [53] was released. Alternative measures, such as co-agreement [48], ϵ-agreement [49], correlation analysis between *AR* and allocated area size in the homunculus, or specific measures of learnability, memorability, and physical comfort could surface other insights. Further exploring mappings between user-defined gestures and the corresponding cortical areas with new homunculus visualizations will enable designers to propose new interaction techniques that engage multiple and diverse body regions and span both the somatosensory and motor cortices.

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References

[1] Idil Bostan, Oğuz Turan Buruk, Mert Canat, Mustafa Ozan Tezcan, Celalettin Yurdakul, Tilbe Göksun, and Oğuzhan Özcan. 2017. Hands as a Controller: User Preferences for Hand Specific On-Skin Gestures. In *Proceedings of the ACM International Conference on Designing Interactive Systems (DIS '17)*. Association for Computing Machinery, New York, NY, USA, 1123–1134. doi:10.1145/3064663.3064766

[2] Lisa Anneke Burr, Julius Šula, Julia Mayrhauser, and Alexander Meschtscherjakov. 2023. BREATHTURES: A First Step Towards Breathing Gestures as Distinct Input Modality. In *Proceedings of the ACM International Conference on Human Factors in Computing Systems - Extended Abstracts (CHI EA '23)*. Association for Computing Machinery, New York, NY, USA, Article 60, 6 pages. doi:10.1145/3544549.3585787

[3] Jessica R. Cauchard, Jane L. E, Kevin Y. Zhai, and James A. Landay. 2015. Drone & Me: An Exploration into Natural Human-Drone Interaction. In *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '15)*. Association for Computing Machinery, New York, NY, USA, 361–365. doi:10.1145/2750858.2805823

[4] Edwin Chan, Teddy Seyed, Wolfgang Stuerzlinger, Xing-Dong Yang, and Frank Maurer. 2016. User Elicitation on Single-Hand Microgestures. In *Proceedings of the ACM International Conference on Human Factors in Computing Systems (CHI '16)*. Association for Computing Machinery, New York, NY, USA, 3403–3414. doi:10.1145/2858036.2858589

[5] Victor Chen, Xuhai Xu, Richard Li, Yuanchun Shi, Shwetak Patel, and Yuntao Wang. 2021. Understanding the Design Space of Mouth Microgestures. In *Proceedings of the ACM International Conference on Designing Interactive Systems (DIS '21)*. Association for Computing Machinery, New York, NY, USA, 1068–1081. doi:10.1145/3461778.3462004

[6] Yu-Chun Chen, Chia-Ying Liao, Shuo-wen Hsu, Da-Yuan Huang, and Bing-Yu Chen. 2020. Exploring User Defined Gestures for Ear-Based Interactions. *Proceedings of the ACM on Human-Computer Interaction* 4, ISS, Article 186 (nov 2020), 20 pages. doi:10.1145/3427314

[7] Ming Cheung, Guobin Xia, and Zhan Xu. 2025. A Scoping Review of Somatosensory Interaction Design for Mental Health and Well-Being. *Acta Psychologica* 253 (2025), 104641. doi:10.1016/j.actpsy.2024.104641

[8] Douglas Cheyne, Rumyana Kristeva, and Lüder Deecke. 1991. Homuncular Organization of Human Motor Cortex as Indicated by Neuromagnetic Recordings. *Neuroscience Letters* 122, 1 (1991), 17–20. doi:10.1016/0304-3940(91)90182-S

[9] Guillem Cornella-Barba, Bruno Dumas, Mehdi Ousmer, Santiago Villarreal-Narvaez, Jean Vanderdonckt, Eudald Sangenis, and Adrien Chaffangeon Caillet. 2025. TapStrapGest: Elicitation and Recognition of Ring-based Multi-Finger Gestures. *Proceedings of the ACM on Human-Computer Interaction* 9, 4, Article EICS001 (June 2025), 27 pages. doi:10.1145/3733047

[10] Yasmin Felberbaum and Joel Lanir. 2018. Better Understanding of Foot Gestures: An Elicitation Study. In *Proc. of the ACM International Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, New York, NY, USA, 12 pages. doi:10.1145/3173574.3173908

[11] Bettina Forster, Maria Tziraki, and Alexander Jones. 2016. The Attentive Homunculus: ERP Evidence for Somatotopic Allocation of Attention in Tactile Search. *Neuropsychologia* 84 (2016), 158–166. doi:10.1016/j.neuropsychologia.2016.02.009

[12] Bogdan-Florin Gheran, Santiago Villarreal-Narvaez, Radu-Daniel Vatavu, and Jean Vanderdonckt. 2022. RepliGES and GEStory: Visual Tools for Systematizing and Consolidating Knowledge on User-Defined Gestures. In *Proceedings of the ACM International Conference on Advanced Visual Interfaces* (Frascati, Rome, Italy) *(AVI '22)*. Association for Computing Machinery, New York, NY, USA, Article 5, 9 pages. doi:10.1145/3531073.3531112

[13] Matej Hoffmann, Zdeněk Straka, Igor Farkaš, Michal Vavrečka, and Giorgio Metta. 2018. Robotic Homunculus: Learning of Artificial Skin Representation in a Humanoid Robot Motivated by Primary Somatosensory Cortex. *IEEE Trans. Cogn. Dev. Syst.* 10, 2 (2018), 163–176. doi:10.1109/TCDS.2017.2649225

[14] Christian Holz and Andrew Wilson. 2011. Data Miming: Inferring Spatial Object Descriptions From Human Gesture. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. Association for Computing Machinery, New York, NY, USA, 811–820. doi:10.1145/1978942.1979060

[15] Lei Hong, Chun-Cheng Hsu, I-Chin Chen, and Yueh-Yin Kuo. 2025. Is Holding Better? A Gesture-Elicitation Study with Controllers in Virtual Reality. In *Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '25)*. Association for Computing Machinery, New York, NY, USA, Article 360, 7 pages. doi:10.1145/3706599.3719703

[16] Masoumehsadat Hosseini, Tjado Ihmels, Ziqian Chen, Marion Koelle, Heiko Müller, and Susanne Boll. 2023. Towards a Consensus Gesture Set: A Survey of Mid-Air Gestures in HCI for Maximized Agreement Across Domains. In *Proceedings of the ACM International Conference on Human Factors in Computing Systems (CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 311, 24 pages. doi:10.1145/3544548.3581420

[17] Gopinaath Kannabiran, Jeffrey Bardzell, and Shaowen Bardzell. 2011. How HCI Talks About Sexuality: Discursive Strategies, Blind Spots, and Opportunities for Future Research. In *Proceedings of the ACM International Conference on Human Factors in Computing Systems (CHI '11)*. Association for Computing Machinery, NY, USA, 695–704. doi:10.1145/1978942.1979043

[18] Adam Kendon. 1988. How Gestures Can Become Like Words. In *Cross-Cultural Perspectives in Nonverbal Communication*, F. Poyatos (Ed.). Hogrefe & Huber Publishers, USA, 131–141. https://psycnet.apa.org/record/1992-98173-004

[19] DoYoung Lee, Youryang Lee, Yonghwan Shin, and Ian Oakley. 2018. Designing Socially Acceptable Hand-to-Face Input. In *Proceedings of the 31st International ACM Symposium on User Interface Software and Technology (UIST '18)*. Association for Computing Machinery, New York, NY, USA, 711–723. doi:10.1145/3242587.3242642

[20] Junxian Li, Yanan Wang, Zhitong Cui, Jas Brooks, Yifan Yan, Zhengyu Lou, and Yucheng Li. 2025. Mid-Air Gestures for Proactive Olfactory Interactions in Virtual Reality. In *Proceedings of the ACM International Conference on Human Factors in Computing Systems (CHI '25)*. Association for Computing Machinery, New York, NY, USA, Article 549, 18 pages. doi:10.1145/3706598.3713964

[21] Robert W. Lindeman, Robert Page, Yasuyuki Yanagida, and John L. Sibert. 2004. Towards Full-Body Haptic Feedback: The Design and Deployment of a Spatialized Vibrotactile Feedback System. In *Proceedings of the ACM Interntional Symposium on Virtual Reality Software and Technology (VRST '04)*. Association for Computing Machinery, New York, NY, USA, 146–149. doi:10.1145/1077534.1077562

[22] Pedro Lopes, Alexandra Ion, Willi Mueller, Daniel Hoffmann, Patrik Jonell, and Patrick Baudisch. 2015. Proprioceptive Interaction. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. Association for Computing Machinery, New York, NY, USA, 939–948. doi:10.1145/2702123.2702461

[23] Diako Mardanbegi, Dan Witzner Hansen, and Thomas Pederson. 2012. Eye-based Head Gestures. In *Proceedings of the ACM International Symposium on Eye Tracking Research and Applications (ETRA '12)*. Association for Computing Machinery, New York, NY, USA, 139–146. doi:10.1145/2168556.2168578

[24] David McNeil. 1995. *Hand and Mind: What Gestures Reveal About Thought*. The University of Chicago Press, Chicago, IL, USA.

[25] Meredith Ringel Morris. 2012. Web on the Wall: Insights From a Multimodal Interaction Elicitation Study. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces (ITS '12)*. Association for Computing Machinery, New York, NY, USA, 95–104. doi:10.1145/2396636.2396651

[26] John E. Muñoz, Maria F. Montoya, David S. Lopez, and Oscar A. Henao. 2020. Embodying the Homunculus in Virtual Reality: Creating an Interactive Laboratory Procedure for Brain Mapping and Visualization. In *Proceedings of the 5th Workshop on ICTs for Improving Patients Rehabilitation Research Techniques (REHAB '19)*. Association for Computing Machinery, New York, NY, USA, 144–147. doi:10.1145/3364138.3364168

[27] Akinori Nakamura, Takako Yamada, Atsuko Goto, Takashi Kato, Kengo Ito, Yuji Abe, Teruhiko Kachi, and Ryusuke Kakigi. 1998. Somatosensory Homunculus as Drawn by MEG. *NeuroImage* 7, 4 (1998), 377–386. doi:10.1006/nimg.1998.0332

[28] Dilisha Patel, Ekat Osipova, Katta Spiel, and Giulia Barbareschi. 2025. A Critical Review of Sexuality, Technology and Disability. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25)*. Association for Computing Machinery, New York, NY, USA, Article 287, 20 pages. doi:10.1145/3706598.3713994

[29] Rakesh Patibanda, Nathan Arthur Semertzidis, Michaela Vranic-Peters, Joseph Nathan La Delfa, Josh Andres, Mehmet Aydin Baytaş, Anna Lisa Martin-Niedecken, Paul Strohmeier, Bruno Fruchard, Sang-won Leigh, Elisa D. Mekler, Suranga Nanayakkara, Josef Wiemeyer, Nadia Berthouze, Kai Kunze, Thanassis Rikakis, Aisling Kelliher, Kevin Warwick, Elise van den Hoven, Florian Floyd Mueller, and Steve Mann. 2020. Motor Memory in HCI. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems (CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 8 pages. doi:10.1145/3334480.3375163

[30] Wilder Penfield and Edwin Boldrey. 1937. Somatic Motor and Sensory Representation in the Cerebral Cortex of Man as Studied by Electrical Stimulation. *Brain* 60, 4 (12 1937), 389–443. doi:10.1093/brain/60.4.389

[31] Jorge Luis Pérez-Medina, Santiago Villarreal, and Jean Vanderdonckt. 2020. A Gesture Elicitation Study of Nose-Based Gestures. *Sensors* 20, 24 (2020), 7118. doi:10.3390/s20247118

[32] Francis Quek, David McNeill, Rashid Ansari, Xin-Feng Ma, Robert Bryll, Susan Duncan, and Karl E. McCullough. 1999. Gesture Cues for Conversational Interaction in Monocular Video. In *Proceedings of the International Workshop on Recognition, Analysis, and Tracking of Faces and Gestures in Real-Time Systems. In Conjunction with ICCV'99*. IEEE Press, Piscataway, NJ, USA, 119–126. doi:10.1109/RATFG.1999.799234

[33] Francis Quek, David McNeill, Robert Bryll, Susan Duncan, Xin-Feng Ma, Cemil Kirbas, Karl E. McCullough, and Rashid Ansari. 2002. Multimodal Human Discourse: Gesture and Speech. *ACM Transactions on Computer-Human Interaction* 9, 3 (2002), 171–193. doi:10.1145/568513.568514

[34] Alex Ranne, Angus B. Clark, and Nicolas Rojas. 2022. Augmented Reality-Assisted Reconfiguration and Workspace Visualization of Malleable Robots: Workspace Modification Through Holographic Guidance. *IEEE Robotics & Automation Magazine* 29, 1 (2022), 10–21. doi:10.1109/MRA.2022.3141973

[35] Isabel Benavente Rodriguez and Nicolai Marquardt. 2017. Gesture Elicitation Study on How to Opt-in & Opt-out from Interactions with Public Displays. In *Proceedings of the ACM International Conference on Interactive Surfaces and Spaces (ISS '17)*. Association for Computing Machinery, New York, NY, USA, 32–41. doi:10.1145/3132272.3134118

[36] Nicla Rossini. 2004. The Analysis of Gesture: Establishing a Set of Parameters. In *Proceedings of the 5th International Gesture Workshop, Gesture-Based Communication in Human-Computer Interaction (Lecture Notes in Computer Science, Vol. 2915)*, Antonio Camurri and Gualtiero Volpe (Eds.). Springer, Berlin, Heidelberg, 124–131. doi:10.1007/978-3-540-24598-8_12

[37] Anne Roudaut, Andreas Rau, Christoph Sterz, Max Plauth, Pedro Lopes, and Patrick Baudisch. 2013. Gesture Output: Eyes-Free Output Using a Force Feedback

Touch Surface. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. Association for Computing Machinery, New York, NY, USA, 2547–2556. doi:10.1145/2470654.2481352

[38] Franck-Emmanuel Roux, Mahamadou Niare, Saloua Charni, Carlo Giussani, and Jean-Baptiste Durand. 2020. Functional Architecture of the Motor Homunculus Detected by Electrostimulation. *The Journal of Physiology* 598, 23 (2020), 5487–5504. doi:10.1113/JP280156

[39] Jaime Ruiz and Daniel Vogel. 2015. Soft-Constraints to Reduce Legacy and Performance Bias to Elicit Whole-body Gestures with Low Arm Fatigue. In *Proceedings of the 33rd International ACM Conference on Human Factors in Computing Systems (CHI '15)*. Association for Computing Machinery, New York, NY, USA, 3347–3350. doi:10.1145/2702123.2702583

[40] Adwait Sharma, Joan Sol Roo, and Jürgen Steimle. 2019. Grasping Microgestures: Eliciting Single-hand Microgestures for Handheld Objects. In *Proceedings of the ACM International Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 13 pages. doi:10.1145/3290605.3300632

[41] Alexandru-Ionut Siean, Cristian Pamparau, Arthur Sluÿters, Radu-Daniel Vatavu, and Jean Vanderdonckt. 2023. Flexible gesture input with radars: systematic literature review and taxonomy of radar sensing integration in ambient intelligence environments. *Journal of Ambient Intelligence and Humanized Computing* 14, 6 (2023), 7967–7981. doi:10.1007/S12652-023-04606-9

[42] Chaklam Silpasuwanchai and Xiangshi Ren. 2015. Designing Concurrent Full-Body Gestures for Intense Gameplay. *International Journal of Human-Computer Studies* 80 (2015), 1–13. doi:10.1016/j.ijhcs.2015.02.010

[43] Mihail Terenti and Radu-Daniel Vatavu. 2025. Distal-Haptic Touchscreens: Understanding the User Experience of Vibrotactile Feedback Decoupled from the Touch Point. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25)*. Association for Computing Machinery, New York, NY, USA, Article 500, 19 pages. doi:10.1145/3706598.3713555

[44] Nikola Valchev, Emmanuele Tidoni, Antonia F. de C. Hamilton, Valeria Gazzola, and Alessio Avenanti. 2017. Primary Somatosensory Cortex Necessary for the Perception of Weight from Other People's Action: A Continuous Theta-Burst TMS Experiment. *NeuroImage* 152 (2017), 195–206. doi:10.1016/j.neuroimage.2017.02.075

[45] Jean Vanderdonckt, Nathan Magrofuoco, Suzanne Kieffer, Jorge Pérez, Ysabelle Rase, Paolo Roselli, and Santiago Villarreal. 2019. Head and Shoulders Gestures: Exploring User-Defined Gestures with Upper Body. In *Design, User Experience, and Usability. User Experience in Advanced Technological Environments (Lecture Notes in Computer Science)*, Aaron Marcus and Wentao Wang (Eds.). Springer, Berlin, Heidelberg, 192–213. doi:10.1007/978-3-030-23541-3_15

[46] Jean Vanderdonckt and Radu-Daniel Vatavu. 2025. Context is Key for Reproducibility of Empirical Studies in Human-Computer Interaction. In *Proceedings of the 3rd ACM International Conference on Reproducibility and Replicability (REP '25)*. Association for Computing Machinery, New York, NY, USA, 41–50. doi:10.1145/3736731.3746142

[47] Radu-Daniel Vatavu and Bogdan-Florin Gheran. 2025. Intermanual Deictics: Uncovering Users' Gesture Preferences for Opposite-Arm Referential Input, from Fingers to Shoulder. In *Proceedings of the ACM International Conference on Human Factors in Computing Systems (CHI '25)*. Association for Computing Machinery, New York, NY, USA, Article 283, 16 pages. doi:10.1145/3706598.3713474

[48] Radu-Daniel Vatavu and Jacob O. Wobbrock. 2015. Formalizing Agreement Analysis for Elicitation Studies: New Measures, Significance Test, and Toolkit. In *Proceedings of the 33rd ACM International Conference on Human Factors in Computing Systems (CHI '15)*. Association for Computing Machinery, New York, NY, USA, 1325–1334. doi:10.1145/2702123.2702223

[49] Radu-Daniel Vatavu and Jacob O. Wobbrock. 2022. Clarifying Agreement Calculations and Analysis for End-User Elicitation Studies. *ACM Trans. Comput.-Hum. Interact.* 29, 1, Article 5 (Jan. 2022), 70 pages. doi:10.1145/3476101

[50] Santiago Villarreal-Narvaez, Alexandru-Ionuţ Şiean, Arthur Sluÿters, Radu-Daniel Vatavu, and Jean Vanderdonckt. 2022. Informing Future Gesture Elicitation Studies for Interactive Applications That Use Radar Sensing. In *Proceedings of the ACM International Conference on Advanced Visual Interfaces* (Frascati, Rome, Italy) *(AVI '22)*. Association for Computing Machinery, New York, NY, USA, Article 50, 3 pages. doi:10.1145/3531073.3534475

[51] Santiago Villarreal-Narvaez, Jorge Luis Pérez-Medina, and Jean Vanderdonckt. 2023. Exploring User-Defined Gestures for Lingual and Palatal Interaction. *J. Multimodal User Interfaces* 17, 3 (2023), 167–185. doi:10.1007/S12193-023-00408-7

[52] Santiago Villarreal-Narvaez, Arthur Sluÿters, Jean Vanderdonckt, and Efrem Mbaki Luzayisu. 2022. Theoretically-Defined vs. User-Defined Squeeze Gestures. *Proceedings of the ACM on Human-Computer Interaction* 6, ISS, Article 559 (nov 2022), 30 pages. doi:10.1145/3567805

[53] Santiago Villarreal-Narvaez, Arthur Sluÿters, Jean Vanderdonckt, and Radu-Daniel Vatavu. 2024. Brave New GES World: A Systematic Literature Review of Gestures and Referents in Gesture Elicitation Studies. *ACM Comput. Surv.* 56, 5, Article 128 (jan 2024), 55 pages. doi:10.1145/3636458

[54] Santiago Villarreal-Narvaez, Jean Vanderdonckt, Radu-Daniel Vatavu, and Jacob O. Wobbrock. 2020. A Systematic Review of Gesture Elicitation Studies: What Can We Learn from 216 Studies?. In *Proceedings of ACM International Conference on Designing Interactive Systems* (Eindhoven, The Netherlands) *(DIS '20)*, Ron Wakkary, Kristina Andersen, Will Odom, Audrey Desjardins, and Marianne Graves Petersen (Eds.). Association for Computing Machinery, 855–872. doi:10.1145/3357236.3395511

[55] Dong-Bach Vo, Eric Lecolinet, and Yves Guiard. 2014. Belly Gestures: Body Centric Gestures on the Abdomen. In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction (NordiCHI '14)*. Association for Computing Machinery, New York, NY, USA, 687–696. doi:10.1145/2639189.2639210

[56] William Walker and Dinesh Bhatia. 2011. Swallow Sound Analysis for Automated Ingestion Detection. In *Proceedings of the 4th International Conference on PErvasive Technologies Related to Assistive Environments (PETRA '11)*. Association for Computing Machinery, New York, NY, USA, Article 22, 8 pages. doi:10.1145/2141622.2141649

[57] Daniel Wigdor and Dennis Wixon. 2011. *Brave NUI World: Designing Natural User Interfaces for Touch and Gesture* (1st ed.). Morgan Kaufmann Publishers Inc., San Francisco, CA, USA. doi:10.1016/C2009-0-64091-5

[58] Jacob O. Wobbrock, Htet Htet Aung, Brandon Rothrock, and Brad A. Myers. 2005. Maximizing the Guessability of Symbolic Input. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems (CHI EA '05)*. Association for Computing Machinery, New York, NY, USA, 1869–1872. doi:10.1145/1056808.1057043

[59] Jacob O. Wobbrock, Meredith Ringel Morris, and Andrew D. Wilson. 2009. User-Defined Gestures for Surface Computing. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI '09)*. Association for Computing Machinery, New York, NY, USA, 1083–1092. doi:10.1145/1518701.1518866

[60] Haijun Xia, Michael Glueck, Michelle Annett, Michael Wang, and Daniel Wigdor. 2022. Iteratively Designing Gesture Vocabularies: A Survey and Analysis of Best Practices in the HCI Literature. *ACM Trans. Comput.-Hum. Interact.* 29, 4, Article 37 (May 2022), 54 pages. doi:10.1145/3503537