Brave New GES World: A Systematic Literature Review of Gestures and Referents in Gesture Elicitation Studies

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How to determine highly effective and intuitive gesture sets for interactive systems tailored to end users' preferences? A substantial body of knowledge is available on this topic, among which gesture elicitation studies stand out distinctively. In these studies, end users are invited to propose gestures for specific referents, which are the functions to control for an interactive system. The vast majority of gesture elicitation studies conclude with a consensus gesture set identified following a process of consensus or agreement analysis. However, the information about specific gesture sets determined for specific applications is scattered across a wide landscape of disconnected scientific publications, which poses challenges to researchers and practitioners to effectively harness this body of knowledge. To address this challenge, we conducted a systematic literature review and examined a corpus of N=267 studies encompassing a total of 187, 265 gestures elicited from 6, 659 participants for 4, 106 referents. To understand similarities in users' gesture preferences within this extensive dataset, we analyzed a sample of 2, 304 gestures extracted from the studies identified in our literature review. Our approach consisted of (i) identifying the context of use represented by end users, devices, platforms, and gesture-sensing technology, (ii) categorizing the referents, (iii) classifying the gestures elicited for those referents, and (iv) cataloging the gestures based on their representation and implementation modalities. Drawing from the findings of this review, we propose guidelines for conducting future end-user gesture elicitation studies.

CCS Concepts: • **Human-centered computing → Gestural input**; *User interface design*; *Participatory design.*

Additional Key Words and Phrases: Gesture elicitation studies; Systematic Literature Review; Gesture interaction; Gesture input; Gesture vocabulary; Gesture set; Referents; Gesture identification studies.

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1 INTRODUCTION

When faced with the task of developing an interactive application featuring a gestural interface, whether for a mobile device, gaming console, augmented/virtual reality system, or smart environment, one key aspect is to establish a *gesture vocabulary* [80, 138]. This vocabulary, also referred to as a set of gestures mapped to the application functions, should fulfill various quality criteria [142], including, but not limited to, naturalness [135] and memorability [75]. To address this design challenge, one can draw upon multiple sources, including general design principles, style guides provided by software vendors (for visual comparison, see GestureCons), or empirical studies.

Gesture Elicitation Studies (GESs) were introduced in 2005 by Wobbrock *et al.* [137] in the form of a "guessability" method aimed at collecting end users' preferences for symbolic input, and originally applied to inform the design of the stroke gestures constiuting the EdgeWrite vocabulary [139]. The first application of the method to hand gesture input was conducted a few years later by Wobbrock *et al.* [138] within the area of surface computing. Subsequently, GESs have gained popularity as an effective and valuable tool for informing the design of gestures that align with end users' behavior and preferences. Since then, these studies have been applied to a wide array of devices [9, 37, 38, 93, 125], applications [41, 82, 87, 113], environments [29, 55, 60, 68, 96], and contexts of use [26, 32, 67, 112, 119]. To date, we have identified a total of N=267 such studies published in peer-reviewed journals and conferences, reporting users' preferences for finger, hand, wrist, arm, head, foot, and whole-body gestures for interactive computer systems and environments.

Consequently, a substantial body of knowledge has emerged through the application of the GES research and design method, encompassing several critical aspects: (1) the extent of user consensus regarding gesture commands for interactive applications, (2) establishment of consensus gesture sets, (3) compilation of design guidelines and recommendations [6, 61], (4) creation of software tools [4, 5, 63, 79, 110], and (5) exploration of methodological variations and enhancements to the original method [63, 73, 115, 116, 121–124]. However, while the community has been busy accumulating design knowledge on new gesture types [22, 27, 36, 119] and compiling high-consensus gesture commands for new interactive systems, devices [112, 125, 136], and environments [18, 25, 28, 29, 55, 98], the outcome was an ever-growing body of gesture elicitation studies scattered throughout the various dissemination venues of the Human-Computer Interaction (HCI) field. In this context, this scattered knowledge needs consolidation in a rigorous way for the community to identify best practices and effectively use the available resources towards new discoveries in user-defined gestures as well as to transfer those results into actual gesture user interfaces for highly intuitive and usable interactions with computer systems of many kinds, tailored to and reflective of end users' needs and preferences. The contributions of this paper encompass the following:

(1) **Macroscopic-level analysis.** We conducted a new Systematic Literature Review (SLR) in the area of GESs with an expanded query covering an extended timeframe for an analysis of the macroscopic-level data acquired in a prior SLR [129]; see Section 4.
(2) **Microscopic-level examination of terms and topics.** We delved into a microscopic-level analysis of terms, topics, and associations commonly employed within the GES scientific literature. By utilizing various tools, we generated word clouds to highlight terms employed during different time periods, *e.g.,* from 2019 to 2020. We constructed a stream graph to explore topical trends and employed PhraseNet to underscore word associations for the N=267 studies examined in our SLR; see Section 4.4.
(3) **Analysis and categorization of referents.** This paper comprehensively covers a diversity of tasks, actions, and referents featured in GESs. Furthermore, it provides a list of the most frequently used referents in GESs, categorized for quantification and classification purposes. To this end, we aim to answer key questions for the GES literature, such as: *Which referents*

are most commonly utilized in the scientific literature? and *To what extent do various functions and sub-functions of these referents appear in GESs?*; please refer to Section 5.

(4) **Analysis, representation classification, gesture classification, and gesture-referent mappings.** We compile a dataset of gestures documented by previous GESs, and subsequently scrutinize those gestures in terms of representation (*e.g.,* text, images, and drawings), existing taxonomies, and associations with referents. To this end, we aim to answer questions such as: *What are the gestures most frequently proposed by end users?, How are these gestures typically represented in scientific papers?, What outcomes arise from gesture classification? What are the most notable associations between gestures and references?*; please refer to Section 6.

2 AN OVERVIEW OF GESTURE ELICITATION STUDIES

GES typically explore the three conventional dimensions of the context of use [17]: the involvement of end users to learn about their preferred interactions, the specific platforms and devices employed to perform the interactions, and the physical settings in which the interactions take place.

2.1 Glossary of Concepts and Terminology

We provide an alphabetically ordered list of definitions for the concepts and terminology used in GESs and in this paper. These definitions are also available in our previous SLR [129]:

(1) **Agreement.** The situation in which the gestures elicited from two or more participants are evaluated as being identical or substantially similar according to a set of rules, criteria, or similarity functions and, thus, equivalent from the perspective of the target application. For example, the designer of a gesture interface for a smart ring device [38] may consider that gesture direction and speed are more important than the amplitude of the finger movement.

(2) **Command.** A signal that actuates the execution of a function in the user interface, also referred to as a “gesture command,” where the signal is represented by gesture input. For example, in response to the “dim lights” referent, a participant may propose a downward movement of the finger wearing the smart ring.

(3) **Consensus gesture set.** The set of gestures that reached the largest agreement for the referents examined in the GES. For example, say that 11 of the 20 participants involved in the study believe that a downwards movement of the index finger represents the best gesture to effect “dim lights,” 9 participants consider that an upwards movement of the finger should effect “make lights brighter,” and 15 participants propose clockwise circular movements to “turn the lights on and off.” In that case, the consensus gesture set is composed of the downwards, upwards, and clockwise circular gestures of the finger wearing the ring.

(4) **Consensus rate.** A measure of agreement that employs dissimilarity functions and tolerance thresholds for the automatic computation of agreement between the elicited gestures [121].

(5) **Elicitation.** The process of involving participants in the GES to respond to referents and propose suitable gestures, reflective of their preferences, to effect those referents.

(6) **End user.** A potential user of the interactive device, application, or system for which gestures are designed. A sample of end users forms the “participants” of the GES.

(7) **Function.** A feature of the interactive system that can be controlled independently using a gesture command, *e.g.,* "make lights brighter". Same as “referent.”

(8) **Gesture.** A movement of a part of or the whole body performed in response to a referent.

(9) **Measure of agreement.** A numerical measure quantifying the magnitude of agreement among the gestures elicited from the study participants. For example, from the 20 participants of a GES, three subgroups of sizes 9, 7, and 4 emerge for the “dim lights” referent, so that all participants from each subgroup are in agreement about their gestures. The agreement score,

defined according to [137], computes $(9/20)^2 + (7/20)^2 + (4/20)^2 = .365$, while the agreement rate used by [122] returns $(9 \cdot 8 + 7 \cdot 6 + 4 \cdot 3)/(20 \cdot 19) = .332$.

(10) **Participant.** A human subject, representative of the population of end users for the particular system or application involved in the study, that volunteered to participate in the GES and propose gesture commands in response to referents.

(11) **Referent.** A feature of the interactive system that can be controlled independently using a gesture command, *e.g.,* make lights brighter. Same as "function."

(12) **Symbol.** Any artifact that evokes a referent in the form of a system function, *e.g.,* a stroke gesture, surface gesture, mid-air gesture, command keyword, voice command, icon, button label, menu item, and so forth. Also known as a "sign."

2.2 GES Method

In our previous SLR [129], we presented various adaptations of the original GES method, originally introduced by Wobbrock *et al.* [137, 138], while a recent work by Vatavu and Wobbrock [124] clarified aspects of agreement analysis. With each GES methodological iteration, researchers and practitioners have endeavored to uphold a consistent methodology while adhering to principles of scientific rigor; see Figure 1 for an overview of the overall GES process. A few specific examples are noteworthy for the historical development of GESs:

(1) Wobbrock *et al.* [137, 138] were the first to formalize the gesture elicitation method, including a definition of the agreement score measure for consensus analysis, introduced for maximizing the guessability of symbolic input [137]. Their work spawned further theoretical developments, including new agreement measures and statistical techniques for conducting agreement analysis [32, 122–124].

(2) Morris *et al.* [73] highlighted the existence of a "legacy bias" phenomenon for GESs, where the users involved in such studies are often biased by their prior experience with other interactive computer technology, in particular user interfaces based on windows, icons, menus, and pointing. This observation has led to new methodological variations of GESs.

(3) Vatavu [121] showed how the notion of agreement is relative to the criteria employed by the practitioner who is analyzing the elicited gestures, and different criteria lead to different magnitudes for the measures of agreement employed in GESs. The dissimilarity-consensus method, proposed in [121], represents an effective way to handle this problem via dissimilarity functions and tolerance thresholds.

(4) Ali *et al.* [4] and Tsandilas and Dragicevic [116] introduced formalized approaches for compiling gesture vocabularies in GESs, *i.e.,* optimization algorithms for clustering elicitation data represented as a weighted graph [4] and framing GESs as a computational optimization problem [116]. Such approaches automate the process of compiling consensus gesture sets.

(5) Vatavu and Wobbrock [124] provided a formal model of general end-user elicitation studies for HCI and clarified foundational aspects of the GES theory and practice with a comprehensive discussion and new key theoretical insights. In this process, they conducted verification and validation of the method [137, 138] and the gesture analysis process of agreement calculation [32, 122, 123, 137, 138], significantly extending prior developments. Their exposition categorized agreement analysis methods into three types: *expert*, *codebook*, and *computer*.

(6) Gheran *et al.* [39] examined and formalized aspects of the replicability and reproducibility of the results of GESs, such as the consensus gesture set, with the RepliGES conceptual space.

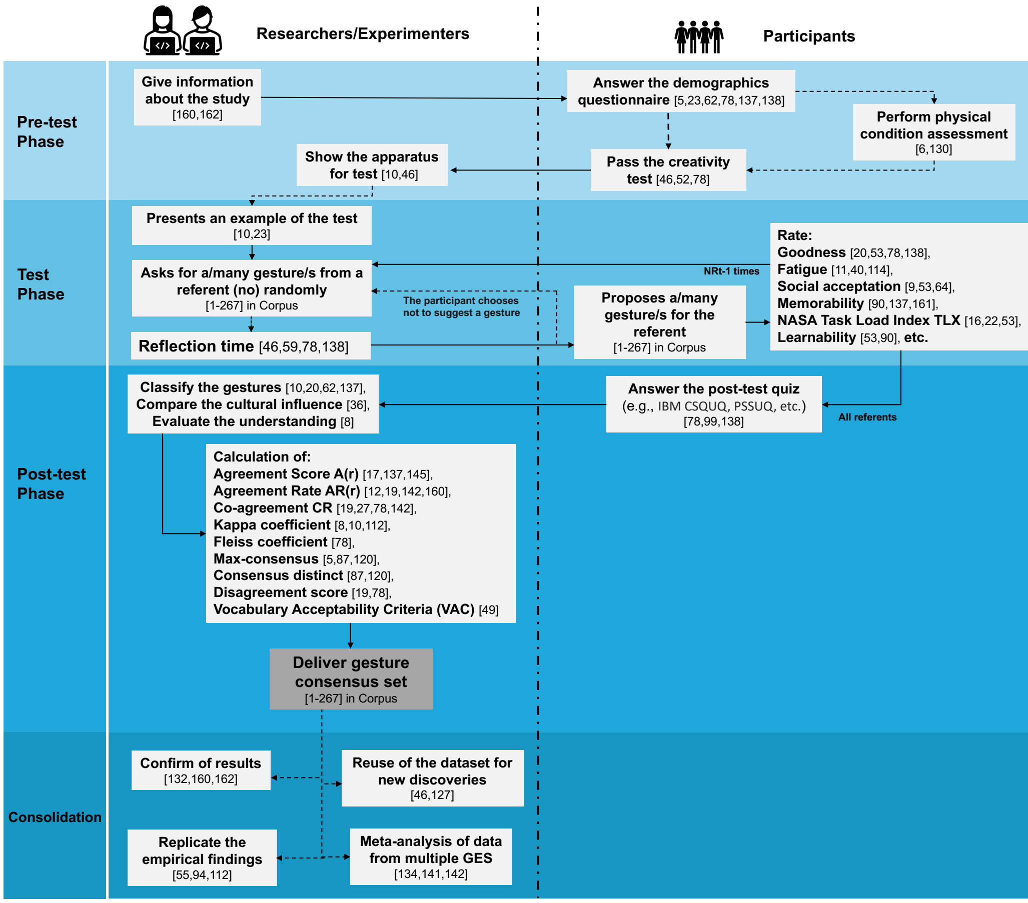

Fig. 1. Block diagram of the overall process involved by conducting gesture elicitation studies. Optional transitions between the various steps of the process are represented graphically with dashed arrows.

2.3 Surveys and Reviews of Gesture Elicitation Studies

Previous work has surveyed the area of gesture interaction from various perspectives. For instance, one survey [90] examined the effectiveness and efficiency of computer vision techniques for hand gesture recognition by comparing various recognition techniques, software platforms, and frameworks. This survey analyzed research conducted prior to the release of key gesture sensing devices, such as Microsoft Kinect and Leap Motion Controller and, thus, missing out critical evolutionary aspects of gesture technology.

A SLR systematically summarizes the existing scientific literature available on a topic in a reproducible way to explain the state of the art, while a review summarizes the evolution of a theory, concept, or technique. For example, [40] classified the mid-air hand gestures extracted from 65 papers according to the nature of their action: selection, navigation (*e.g.*, zoom, scroll, move cursor, pan, and view control), and manipulation. Such a classification is bottom-up compared to the top-down approach from our SLR, *i.e.*, starting from a taxonomy of actions [56]. Another SLR by Al-Shamayleh *et al.* [2] addressed vision-based gesture recognition. Vuletic *et al.* [134] reported the results of a SLR identifying characteristics of touchless, in-air hand gestures from 148 articles, which were classified in terms of the number of participants, gestures, applications (*i.e.*, 3D modeling, assistive technology, data input/authentication, manipulation/navigation, and touchless control), and devices. Xia *et al.* [142] conducted a SLR focused on gesture vocabulary design. Their review involved literature queries such as "gesture design," "design of gestures," "gesture tools," and others, culminating in the identification and analysis of 13 factors, such as gesture *intuitiveness*, *learnability*, *transferability*, *recognition*, and more, with the aim of informing gesture set design. Xia *et al.*'s work provides user-centered and factor-oriented guidelines for future studies in this area. Additionally, two SLRs have been conducted in the area of mid-air hand gesture interaction: one SRL aimed at reviewing empirical research related to the use of mid-air gestures across various contexts of use [50], and another focusing on GESs within the same domain [131]. It is important to note that this previous work represents only an inaugural attempt to conduct an SLR specifically dedicated to GESs, but for mid-air gestures alone. Several other papers have explored the literature surrounding GESs, but their focus has been relatively narrow. For instance, Tijana *et al.* [114] conducted a SLR on hand gestures for user interfaces, briefly mentioning the GES method, which was not the central theme of their research. Other studies have centered on surveying software tools utilized in GESs [63], concentrating on the features and qualities of such tools for the development of interactive computing systems.

The work most closely related to ours is a study conducted by Vogiatzidakis and Koutsabasis [131], in which they analyzed a corpus of N=47 papers specifically addressing GESs within the application domain of mid-air interaction. However, this work had a narrow focus, limited to gestures performed in mid-air. In contrast, our investigation encompasses the entirety of GES scientific literature, rendering our scope significantly broader with a dataset of N=267 gesture elicitation studies identified to date. Most recently, Hosseini *et al.* [44] reviewed gestures found in 172 GES papers with the goal of identifying common characteristics in different application domains. Finally, our previous SLR [129] reported general characteristics and trends in the research and practice of GESs. This paper represents a significant expansion, for which Table 1 shows a comparative overview.

3 RESEARCH METHOD

Our study aims to offer a comprehensive overview of research about gesture elicitation studies, a goal for which a SLR is a recommendable tool. The scientific literature contains various SLR methodologies, including [48], a prominent method in the field of software engineering known for its comprehensive coverage of extensive domains, similar to the approach used in medical experiments [58]. We adopted a standard SLR procedure [13], for which the resulting process is illustrated in Figure 2, adhering to the Prisma (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) four-phase flow diagram [58].

3.1 Phase 1: Identification

We searched for papers potentially relevant to our topic of investigation using the following query:

```
Q = ("Gesture" AND (guess* OR elicit*) AND (study OR experience))
```

which we ran on both single-publisher libraries (*e.g.,* IEEE Xplore) and multi-publisher engines (*e.g.,* Google Scholar). We selected the following five main digital libraries for Computer Science: (1) ACM Digital Library, (2) IEEE Xplore, (3) Elsevier ScienceDirect, (4) Elsevier Ei Compendex (also referred to as Engineering Village), and (5) SpringerLink. We utilized the restricted search feature within the ACM Digital Libary, which specifically filters for references published by ACM Press and excludes those from affiliated organizations, such as IEEE, unless jointly published. This choice was made to ensure the desired segregation. We did not consider repositories such as arXiv, since they contain heterogeneous references, not all peer-reviewed. We also used three sources of multiple

Table 1. Differences between [129] and this paper (SD=standard deviation, Mdn=median).

Criteria	Villarreal-Narvaez *et al.* [129]	This paper
Approach	Macroscopic analysis of the GES metadata	Microscopic analysis gestures and referents from GESs
Methodology	PRISMA [58]	PRISMA [58]
Corpus	N=216 papers	N=267 papers
Query	"Gesture" AND "Elicitation" AND "Study"	"Gesture" AND (guess* OR elicit*) AND (study OR experience)
Period	1994 - August 2019	1994 - January 2021
Authors	Average number of authors per GES=3 (60 studies, representing 27.8%); Minimum=1; Maximum=10; Figures: Number of authors per paper and over time	Average number of authors per GES=3 (72 studies, representing 26.97%); Minimum=1; Maximum=10; Figures updated for N=267: number of authors per reference over time (Fig. 3), number of authors per reference over time (Fig. 4); see Section 4
Participants	Total=5, 458; Minimum=1; Maximum=340; Average=25; Average Male/Female=2.10 (S.D.=2.18; Mdn=1.13); Figures: Number of participants by age groups over time	Total=6, 659; Minimum=1; Maximum=340; Average=25; Average Male/Female=1.82 (S.D.=1.98; Mdn=1.27); see Section 4
Body parts involved in gesture articulation	IFBP-Total=380; CFBP-Total=241; Figures: Heatmap representations of the number of GESs that elicited gestures performed with specific body parts	IFBP-Total=477; CFBP-Total=290; Figures updated for N=267: Heatmap representations of the number of GES that elicited gestures performed with specific body parts (Fig. 5); see Section 4
Referents	Total=3, 625; Minimum=1; Maximum=70; Average=20.10; SD=5.23	Total=4, 411; Minimum=1; Maximum=120; Average=16.52; SD=133.49
Referent classification	No	Yes; RC=4, 106; Lenorovitz *et al.* [56].
Gestures	Total=148, 340; Minimum=4; Maximum=12, 240; Average=716; SD=1, 438	Total=187, 265; Minimum=4; Maximum=12, 240; Average=723; SD=1, 354
Agreed gestures	Average=91; SD=231; Mdn=24	Average=88; SD=221; Mdn=24
Gesture classification	No	Yes; GC=3, 902; Aigner *et al.* [1]; inspired by Piumsomboon *et al.* [88] and Obaid *et al.* [81]
Gesture representation	No	Yes; classification by McAweeney *et al.* [69] and Bernsen [10]
Gesture inventory	No	Yes; associations between gestures and referents As=2, 747
Implications	Global	Specific
Contributions	(1) The first systematic literature review on gesture elicitation of N= 216 studies; (2) Method to (i) *understand* how current and new GESs position in the literature, (ii) *compare* GESs published by different authors, and (iii) *identify* opportunities for unexplored areas in gesture elicitation.	(1) Enhanced macroscopic analysis (Section 4), (2) Examination of terms, topics, and associations (Section 4.4), (3) Analysis and categorization of referents (Section 5), (4) Analysis, representation classification, classification of gestures, and gesture-referent association (Section 6).

publishers to ensure *completeness* and *coherence* of the GES references, validate independent query results, and cover other publishers as well: (6) DBLP CompleteSearch, (7) Google Scholar, and (8) Multidisciplinary Digital Publishing Institute. These last three engines were employed more as a verification and validation mechanism than for reference identification purposes.

To maintain the *consistency* and *reliability* of our queries, we gathered all the necessary resources over a span of two weeks. Initially, we compiled the list of references on a single day (December 1, 2020), which we designated as the final day for including GESs in our SLR. Subsequently, we retrieved individual papers from digital libraries over the following days, extending up to January 9, 2021. This phased approach was implemented to prevent an excessive volume of requests that could potentially jeopardize our authorized access to those libraries. The results of each query `Q` were retained according to the following rules:

(1) *The "Advanced Search" rule.* Queries were run using the most advanced search feature of each digital library, and results were sorted in decreasing order of relevance.

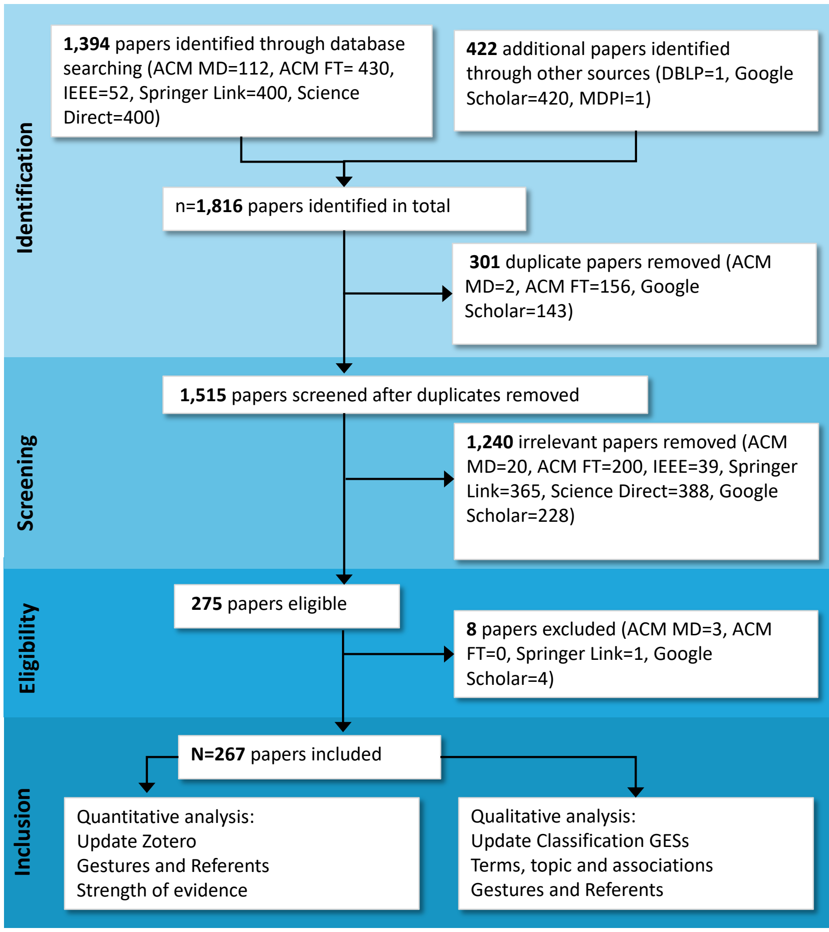

Fig. 2. The four-phase PRISMA flow diagram of our SLR examination (MD=meta-data, FT=full-text).

(2) *The "Minimum Number of References" rule.* If the query returned a small number of references (less than 400), all of those references were automatically retained.
(3) *The "No Missing References" rule.* If the query returned more than 400 references, the first 400 were automatically selected for further screening, and a manual check of the next 200 references was performed to make sure no relevant papers were discarded.

Table 2 shows the results of executing query Q for each source of references. For example, the ACM Digital Library returned a number of 7,318 references in full-text search mode, of which 400 were retained; of these, 156 duplicates were identified when compared with the results of other queries, and 200 references were excluded based on additional screening criteria in the next phase, leaving 74 papers; see the second row of Table 2. In total, our query identified 1,816 references.

3.2 Phase 2: Screening

Each paper was evaluated with respect to its relevance to GES using criteria of *form* and *content*:

- *Form.* We included papers that met the following criteria: they were written in English, subjected to peer review, and accessible in full text. This encompassed research papers published in peer-reviewed journals, conferences, symposiums, and workshops. Conversely, we

Table 2. Number of references returned by running queries in digital libraries and search engines. Citations in this table are associated with references from our corpus from Appendix A.

	Source	Query	Rules	Duplicates	Excluded	Included	References
1.	ACM DL (metadata)	112	112	2	23	87	[2–5, 8, 10–12, 14–16, 18, 19, 21, 23–25, 27–30, 32, 34, 35, 37, 40, 41, 44, 47, 48, 50, 51, 53, 56, 58–61, 63, 65–69, 71, 72, 74–76, 78, 80–82, 85, 87, 88, 91–93, 96–98, 103–106, 108–111, 114–116, 119–122, 125–128, 130, 136, 137, 140–143, 147, 149, 154–157, 159, 160, 163–166, 169, 170, 173, 175, 176, 178, 179, 181, 182, 184, 186–188, 190–194, 196–207, 209–213, 215–220, 222, 224, 227, 231–234, 239, 240, 242, 243, 246–248, 260, 262–264, 266, 267]
2.	ACM DL (full-text)	7,318	430	156	200	74	
3.	IEEExplore	52	52	0	39	13	[39, 52, 64, 95, 135, 161, 162, 167, 195, 223, 225, 241, 245]
4.	ScienceDirect	>6,000	400	0	388	12	[20, 22, 86, 100, 112, 134, 138, 208, 221, 230, 249, 261]
5.	SpringerLink	2,575	400	0	366	34	[7, 31, 33, 36, 49, 57, 62, 77, 79, 89, 90, 107, 124, 129, 131, 132, 146, 150, 153, 158, 168, 171, 174, 180, 183, 226, 229, 250–253, 258, 259, 265]
6.	DBLP	1	1	0	0	1	[235]
7.	Google Scholar	>6,000	420	143	232	45	[1, 6, 9, 13, 17, 26, 38, 42, 43, 45, 46, 54, 55, 70, 73, 83, 84, 94, 99, 101, 102, 113, 117, 118, 123, 133, 139, 144, 145, 148, 151, 152, 172, 177, 185, 189, 214, 228, 237, 238, 244, 254–257]
8.	MDPI	1	1	0	0	1	[236]
	Total	**>22,059**	**1,816**	**301**	**1,248**	**267**	

excluded materials such as PhD and Master's theses, patent descriptions, standards, extended abstracts, slideshows, summaries and reviews of books or theses, technical reports, white papers, invited talks, demonstration papers, doctoral consortium papers, tutorial papers, poster publications, editorials, prefaces, articles or columns in magazines, newsletters, encyclopedia entries, blog posts, and social network entries. References lacking completely published or accessible full-text, such as abstracts, were also omitted. Additionally, any references that required payment for access were excluded from our study.

- *Content.* We retained only those papers that (1) explicitly presented a GES for UI design; or (2) discussed GESs, emphasizing at least one discriminating feature (*e.g.,* scale [86], memorability [75], etc.); or (3) explicitly used a method to examine GESs. A number of 1,240 irrelevant references were excluded by our screening, leaving 1,515-1,240 = 275 papers.

3.3 Phase 3: Eligibility

We considered ineligible and further excluded those papers that matched any of the following situations: (1) *independent research question*: the paper explicitly mentioned a GES, but did not report its results, or the goal of the GES was not gesture UI design, *e.g.,* Yin and Davis [144] conducted a GES to collect training data for a gesture recognizer; (2) *methodology-oriented*: the paper addressed methodological aspects of GES, but did not report an actual study, *e.g.,* Morris *et al.* [73] discussed legacy bias for gesture elicitation; (3) *field mismatch*: the paper reported an actual elicitation study, but for another discipline, *e.g.,* a GES conducted to elicit user-defined gestures to train a robot. By using these rules, we further removed 8 papers, leaving a final corpus of N=267 studies for our examination. Legacy bias could be interpreted as a drawback [72], to be obviated with various techniques, such as priming [73] and soft constraints [94], but also as a benefit [43]. GESs carried out in requirements engineering, linguistics (*e.g.,* for cross-linguistic studies), multimodal discourse (*e.g.,* when the gesture is combined with speech for another purpose), communication (*e.g.,* for analyzing the presenter's behavior), psychology (*e.g.,* for emotion or expression elicitation) were among the eight excluded papers.

3.4 Phase 4: Inclusion

This phase consisted of verifying *quantitative* and *qualitative* aspects of our corpus of papers. For the quantitative analysis, we employed the following tools to create a collection of papers and generate summary statistics:

(1) Zotero, a multi-platform bibliography management software tool for collecting, organizing, and sharing research sources. The collection of GES references examined in this SLR is available at the web address https://www.zotero.org/groups/2132650/gesture_elicitation_studies. Each reference has been completely imported into its corresponding sub-collection (*e.g.,* ACM, IEEE) with all the corresponding metadata. Automated tags were created for all keywords, both internal and external, and a colored tag corresponding to each sub-collection has also been added (*e.g.,* green for ACM, orange for IEEE, etc.).
(2) PaperMachines, a Zotero extension for metadata visualizations.
(3) PDF2Text, software for automatic extraction of text from PDF files. The extracted text was submitted to automatic language processing and analysis.

For the qualitative analysis, we replicated the method of the previous SLR [129]. Additionally, we collected the referents and gestures of each GES for the purpose of classification and analysis.

4 CHARACTERISTICS OF PUBLISHED STUDIES

In this section, we provide an overview of published GESs and analyze them based on various factors, including the number of participants, body parts involved in gesture articulation, and others. Our goal is to gain insight into the GES audience by examining where such studies were published and which ones have had the greatest impact in the field. We also assess the level of effort involved by these studies to determine whether the peak of interest in GESs has been already reached or not in the scientific community.

4.1 Authors and Venues

Fig. 3-a shows the number of authors involved in conducting and reporting GESs. On average, GESs conducted so far have involved three authors (60 studies, representing 27.8% of our paper set). However, some studies were conducted by single authors [45, 66, 120], while others required up to ten authors [108] due to multiple classification criteria or domains of expertise [21, 77]. Fig. 3-b shows the number of GESs conducted between 2009 and 2020, a period that begins with the publication of the first hand gesture elicitation paper by Wobbrock *et al.* [138]. The increasing number of studies, as indicated by the positive linear regression (R^2=.61), suggests that the GES area of investigation has not yet reached its peak yet and still presents opportunities for growing further. The graph displayed in Fig. 4 depicts the number of GESs published annually according to the number of authors. The highest point was reached in 2017, with 11 papers co-authored by 3 authors. This trend persisted in 2018, with 9 papers involving 4 authors, and in 2019, respectively, with 8 papers featuring 2 or 3 authors each, indicating a standard configuration for GES publications.

Table 3 provides a list of venues where GESs have been published. Conferences are the most common dissemination venue, accounting for 79% of all published GESs. Among these, CHI (38 papers), ITS (10), MobileHCI (9), and DIS (8 papers) have the highest number of GES publications.

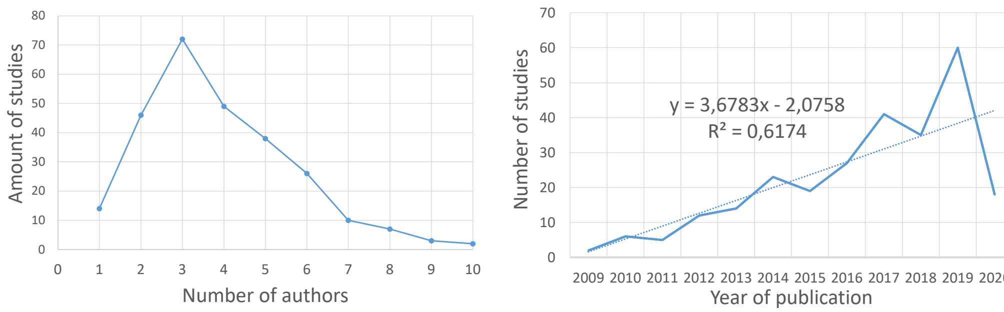

Fig. 3. Number of authors of GESs (a) over time (b).

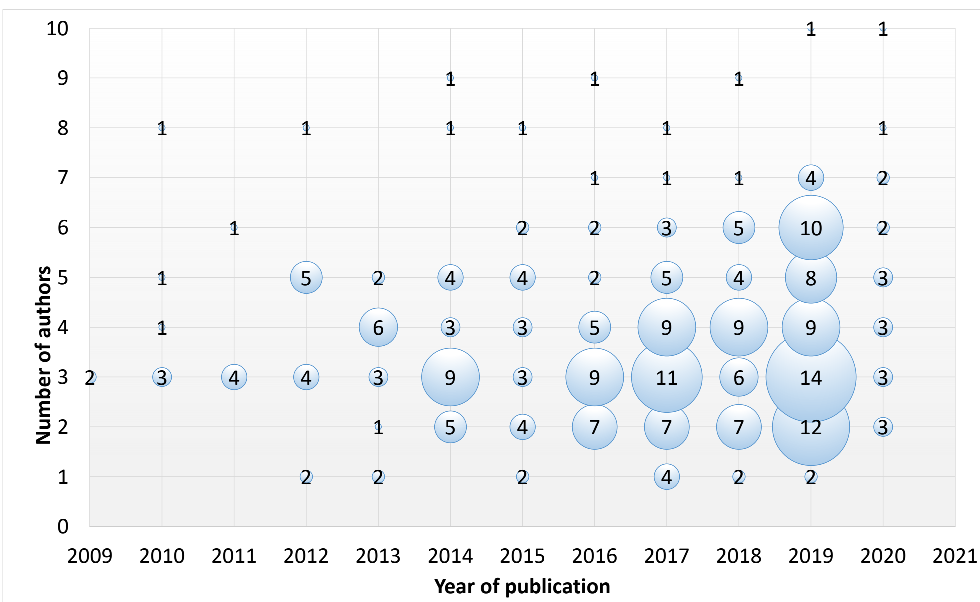

Fig. 4. Number of authors per GES over time.

Journal articles make up for the remaining 21% of all published GESs, but we did not identify any clear preferences for specific journals. This variety of dissemination venues creates a challenge for practitioners to locate relevant and specific information for their own projects, as there is a scattered body of gesture design knowledge throughout the literature of HCI and other disciplines.

Table 4 ranks the twelve most influential GESs based on the number of their Google Scholar citations. The list is arranged in descending order with the highest number of citations appearing first. The values in the table were updated on May 16, 2021 with the initial count taken on November 19, 2020. As of August 15, 2019, the most cited article was Wobbrock *et al.*'s [138] seminal paper. Over the past 20 months, this paper has gained an additional 203 citations, averaging around 10 new citations per month or 120 per year. The second most cited article is Ruiz *et al.*'s [93]. We also noted a few changes in the rankings of other articles, such as Wobbrock *et al.* [137] moving from the 5th to the 3rd position, and Cauchard *et al.* [18] advancing from 11th to the 8th place.

Table 3. Distribution of GESs in the scientific literature.

Conference proceedings	**203**	**76%**
CHI	49	18.4
MobileHCI	10	3.7
ITS	8	3
DIS	8	3
5 studies per venue: AVI, AutomotiveUI, NordiCHI, OzCHI, INTERACT, MuC	6 × 5 = 30	11.4
UIST	4	1.5
3 studies per venue: AISC, EICS, HCII, ICMI, IDC, PerDis, SUI, UbiComp, AHA,TEI, HCIK	11 × 3 = 33	12.4
2 studies per venue: DAP, HFES, HMI, HRI, ISS, IUI, TVX, 3DUI, MUM, IADIS, GI	11 × 2 = 22	8.2
One study per venue: EuroITV, APCHI, ASSETS, CASA, CCHI, CHIuXID, CNS, DAA, DAD, DC, DIGI, EuroVis, FDG, HCC, ICTD, Interaccion, ISCC, ITIE, MC, Mindtrek, MM, MMUI, MobiSys, MoMM, MS, Perspective, Reco, ROMAN, SAICSIT, SCIS, UIC, HCIS, JAUTI, IEEEVR, ICSR, INCISCO, IHDI, CAAD, MIG	39 × 1 = 39	14.6
Journals	**61**	**23%**
IJHCS	7	2.6
MTA	6	2.2
3 studies per venue: JAIS, IEEE Access, IJHCI, TOCHI	4 × 3 =12	4.5
2 studies per venue: UAHCI, MTI, IMWUT	3 × 2 = 6	2.2
One study per venue: AS, BIT, CHB, CTW, HF, IJMHCI, IMW, Informatics, Information, JCH, JCST, JIFS, JMUI, JUS, Machines, Pervasive, PLOS, Presence, PUC, TiiS, Visual, IJMERR, CaGISJ, VRIH, CAOD, JVCI, Automation in Construction, IxD&A, IJMEDINF, CSCW	30 × 1 = 30	11.2
Technical papers	**3**	**1%**
Microsoft Research	1	0.4
Book Section	2	0.7

Table 4. The twelve most influential GESs, authors, and application domains, according to the number of Google Scholar citations.

	Authors	**Study**	**Application**	**Year**	**Citations**
1.	Wobbrock *et al.* [138]	User-defined Gestures for Surface Computing	interactive tabletops	2009	1273
2.	Ruiz *et al.* [93]	User-defined Motion Gestures for Mobile Interaction	smartphones	2011	448
3.	Wobbrock *et al.* [137]	Maximizing the Guessability of Symbolic Input	stroke gestures	2005	330
4.	Kane *et al.* [46]	Usable Gestures for Blind People: Understanding Preference and Performance	tablets, smartphones	2011	322
5.	Morris *et al.* [74]	Understanding Users' Preferences for Surface Gestures	interactive tabletops	2010	289
6.	Piumsomboon *et al.* [87]	User-defined Gestures for Augmented Reality	Augmented Reality	2013	265
7.	Vatavu [120]	User-defined Gestures for Free-hand TV Control	smart TVs	2012	209
8.	Cauchard *et al.* [18]	Drone & Me: An Exploration into Natural Human-Drone Interaction	human-drone interaction	2015	202
9.	Kühnel *et al.* [51]	I'm home: Defining and evaluating a gesture set for smart-home control	smart homes	2011	198
10.	Nacenta *et al.* [75]	Memorability of Pre-designed and User-defined Gesture Sets	interactive tabletops	2013	196
11.	Lee *et al.* [54]	How Users Manipulate Deformable Displays As Input Devices	unconventional displays	2010	166
12.	Frisch *et al.* [35]	Investigating Multi-touch and Pen Gestures for Diagram Editing on Interactive Surfaces	surface computing	2009	143

4.2 Participants

All GES papers from our set clearly presented the number of participants involved in the studies. On average, there were 25 participants (M=25, SD=28), and the most common number of participants was 20, used in 49% of the studies. This value is likely to persist since Wobbrock *et al.* [138] originally used 20 participants in their GES. However, some studies required larger sample sizes, particularly those focused on cultural aspects [77], *e.g.,* Mauney *et al.* [67] used 340 participants to evaluate aspects of culturally-aware touch gestures, and Cafaro *et al.* [16] involved 227 participants in framed guessability for multiple devices. Different authors recommend various ratios for determining sample size, such as 5:1, 10:1, or ranging between 30 and 500 [117].

We conducted an analysis of the Male/Female ratio for the participants involved in GESs, and determined that the average ratio was 1.82 (*SD*=1.98, *Mdn*=1.27). For instance, Buddika *et al.* [15] recruited 12 participants, of which 7 males and 5 females, resulting in a Male/Female ratio of 7/5=1.4. Most studies (54%) had more male than female participants; only 13% of the studies had an equal distribution of male and female participants, while 17% of the studies involved more females than males. These figures indicate a gender bias that could be attributed to the availability of participants or volunteering factors. The 267 GESs are distributed as follows: exclusively male (9/267=3%), exclusively female (3/267=1%), more males than females (145/267=54%), more females than males (46/267=17%), and gender parity (34/283=13%), respectively.

Participants' age has often been reported as a range or average and standard deviation. For example, Kollee *et al.* [49] indicated the age range of their participants as 22-55, while Vatavu *et al.* [125] reported an average age of 25 years with a standard deviation of 3.1. Zuckerman *et al.* [147] identified their participants as cognitively-intact older adults. Of all the studies, 3% focused on children, 2% on teenagers, and 95% on adults, of which 1% addressing older adults.

4.3 Body Parts Involved in Gesture Articulation

We observed that certain GESs had a particular focus on distinct bodily regions, such as legs [104], or the simultaneous use of multiple body parts [82]. Conversely, other research examined gestures encompassing the whole body [22]. This perspective allows us to delineate a spectrum of investigations ranging from a single body part to the entirety of the human body, which we term the "**human gesture continuum**." In essence, this continuum refers to the spectrum of GES efforts that range from exploring gestures performed by the smallest or most isolated body parts, such as the hands, head, and shoulders [119] to investigating gestures involving multiple body parts or the entire body. We view this continuum as a framework through which to categorize gestures performed with the human body. For example, gestures performed with the upper-body limbs can be deconstructed into the various body parts involved in their execution, including the face [92, 97, 104], head [27, 104, 133], head and shoulders [119], eyes [64], nose [84, 91], mouth [20, 27, 127], shoulders [91], torso [104] and even gestures involving the belly [130]. The arms fall within a distinct part of the gesture continuum, ranging from fingers [19] to the wrist [94], wrist and hand [47], hand [7, 34, 88, 125], forearm [52, 94], arm [59], and skin-based gestures [42], generally transitioning from the hands to other parts of the body [21]. Concerning gestures originating from the lower-body, we identified foot gestures [3, 30, 31], leg gestures [103, 104], and gestures involving the whole body [22, 24], respectively. Although the vast majority of prior research has primarily concentrated on gestures performed with the limbs or external body parts, our explorations have extended to the examination of gestures emerging from internal body parts, such as the tongue [20]. This exploration has led to the emergence of interactions involving the tongue, referred to as *lingual* (pertaining to the tongue), and those involving the palate, termed *palatal* (on the palate) [127].

To assess the prevalence of different body parts in the GES literature, we used two metrics:

(1) *Individual Frequency of Body Parts (IFBP)*, indicating how often specific body parts, such as the hand [87] or head [27], have been utilized in a GES.
(2) *Combination Frequency of Body Parts (CFBP)*, revealing the frequency with which specific body parts have been combined, such as gestures involving both the head and hands [21].

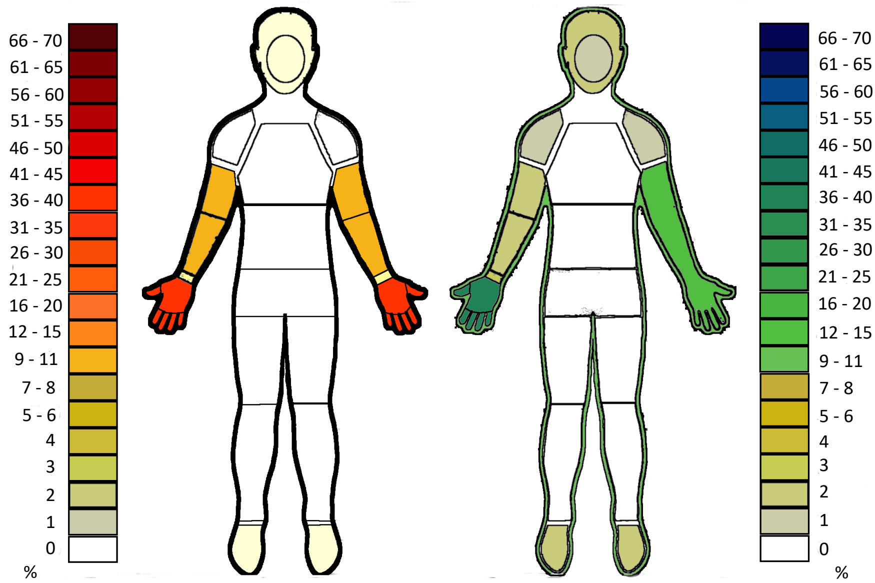

Fig. 5. Heatmap representations of the number of GESs that elicited gestures performed with specific body parts. *Left:* gestures involving one body part only, *e.g.,* face or feet gestures. *Right:* gestures produced as the combination of at least two body parts, *e.g.,* hand and head gestures or wrist and forearm gestures.

The first measure reports on the importance of individual body parts, while the second reveals their combination, including whole-body gestures. We found a number of 477 occurrences of individual body parts, of which 290 were combined. The most frequent gestures were distributed as follows (see Figure 5): finger (185/477=39%; 45/290=16%), hand (174/477=36%; 28/290=10%), arm (41/477=9%; 1/290<1%), body (36/477=8%; 30/290=10%), wrist (9/477=2%; 9/290=3%), voice (8/477=2%; 8/290=3%), feet (5/477=1%; 5/290=2%), and head (7/477=1%; 5/290=2%). The face, shoulders, torso, and skin represent each 1% or less. However, the hand and fingers have been covered by 105/290 = 36% of all combinations, followed by arm + hand + fingers (34/290=12%) and arm + hand (6/290=2%), respectively. Consequently, the most mobile limbs, *i.e.,* the fingers, hands, and arms, are the most frequently covered both in isolation and combination. Gestures performed with other body parts, such as For example, belly gestures, were the subject of only one GES [130].

4.4 Terms and Topics

Before delving into analysis, we were curious about the insights we could gain from studying the most commonly used terms in GESs, for which we used a Word Cloud generated from Term Frequency-Inverse Document Frequency (TF-IDF) [141] (Fig. 6). We primarily seek insights into the approach used in GESs, the referents and gestures involved, and the relationship between gestures and their corresponding referents. The Word Cloud prominently displays recurring terms, including "gesture(s)," "participant(s)," "hand(s)," "user(s)," "interaction," and "design." These terms indicate that prior research has often focused on interactions with various devices (such as mobile devices, displays, smartphones, tablets, and TVs), gesture recognition, and gestures proposed by participants, whether individually or as part of a group. Participants have been typically prompted based on specific referents, which include tasks, commands, and actions about home, menu, target, select, and volume. The analysis also highlights specific body parts, such as the hands, fingers, arms, heads, and wrists, frequently associated with gestures. These gestures can also be categorized

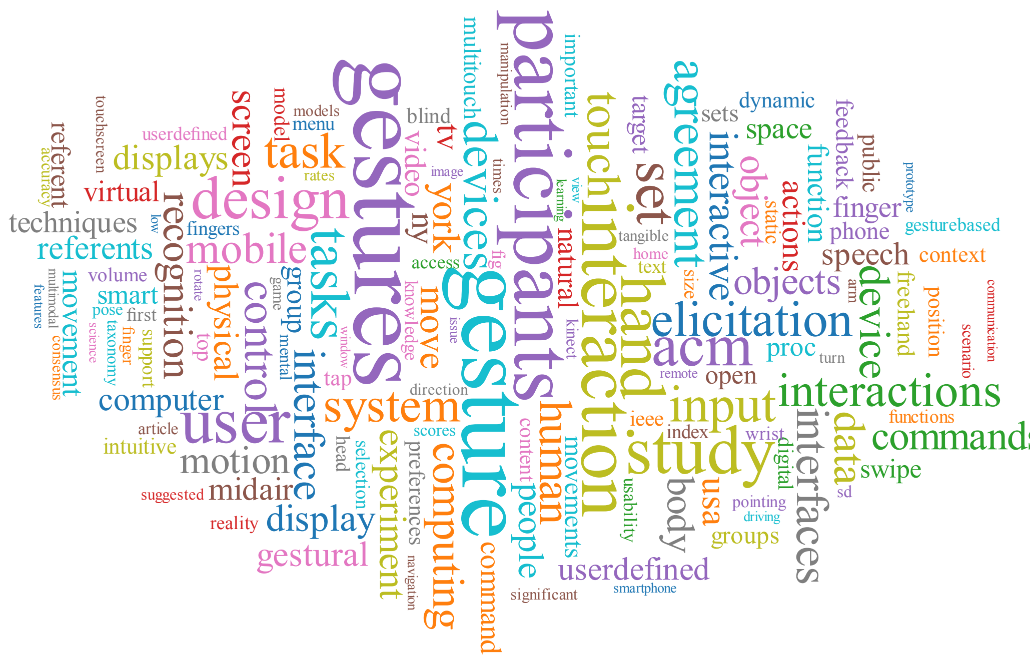

Fig. 6. Word Cloud of the 267 GESs generated by the TF-IDF algorithm.

by their type, such as "freehand," "midair," "multi-touch," "surface," "phone," and "driving." Common gestures discovered include movements like "move," "swipe," "tap," "turn," "pointing," "pose," and "rotate." Additionally, the analysis suggests that, after compiling a set of gestures, researchers often calculate agreement and subsequently perform their classification.

We generated chronological Word Clouds to trace the evolution of terminology within GESs over time. This process yielded thirteen distinct word clouds (see Fig. 7 and Appendix B.1), spanning the timeline from 1994 to 2021. In this figure, light blue shading represents studies conducted before Wobbrock *et al.* 's [138] seminal work, while dark blue signifies studies conducted thereafter.

From each time period, we selected the most prominent terms, denoted by blue boxes, as well as domains, which are represented in gray boxes. Initially, GES primarily related to the areas of human-machine interaction, neural networks, hand movements, and speech. These early studies also explored referents related to computer interaction, text entry, and image processing. Gestures such as left rotation, touch/gestures/screens, finger tapping, double tapping, arm gestures, hand poses, and head movements were the main subject of investigation.

Between 2008 and 2009, the analysis extended to pen gestures and the utilization of bimanual and dominant/non-dominant hand gestures. In 2010, the term "gesture elicitation study" emerged as a focal point in research, concentrating on referents associated with video games, music players, augmented reality, full-body gestures, and the categorization of gestures into taxonomies (*e.g.,* static vs. dynamic). From 2018 onwards, there was a more systematic exploration of gestures, encompassing aspects like gesture vocabulary, types, patterns, combined gestures, gesture knowledge, and manual classification. Concurrently, research also delved into cultural heritage preservation.

The period spanning from 2019 to 2021 witnessed the ascendance of the Internet of Things (IoT) with a notable emphasis on referents pertaining to interactions with various devices and environments, including home devices, smart homes, in-vehicle interactions, urban planning, VR

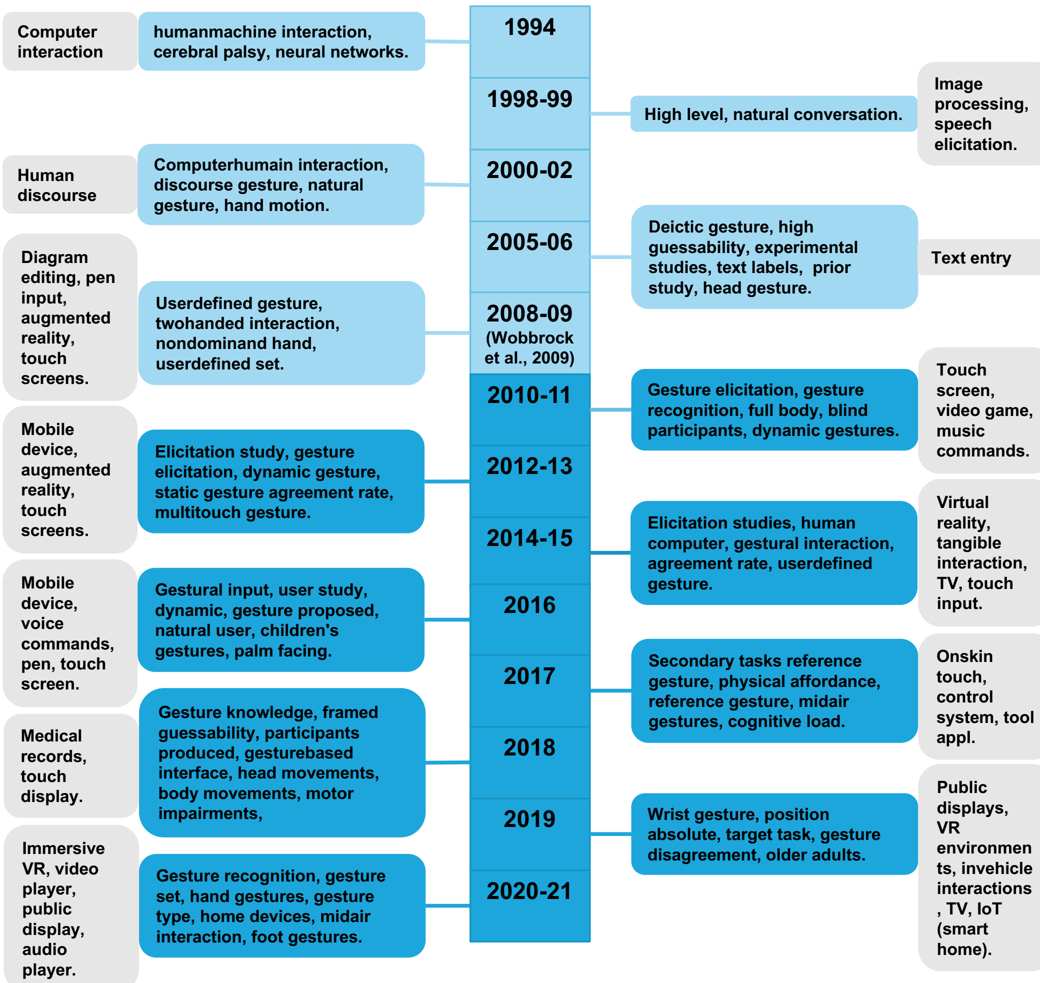

Fig. 7. Terms appearing frequently in our corpus of GES papers, organized chronologically.

environments, wearable devices, and radar sensors [62]. GESs for radar-based sensing are still in their infancy and conducting more GESs in this area was recently suggested [126] since radars can capture gestures in conditions unsupported by other devices, like in the dark or behind a surface or a volume, which are contexts of use particularly applicable to Ambient Intelligence (AmI) scenarios [102]. Furthermore, GESs have addressed specific challenges, such as the disagreement problem and advanced gesture recognition techniques.

We utilized PhraseNet [57] and applied various operators and placeholders X and Y from Fig. 37 to Fig. 40 (see Appendix B.3). We discovered that "gesture" is primarily associated with "touch" and "hold", "wrist" and "motion", but also with performance and speech, with no connection to other modalities, but a link with user preference. We also discovered ways to make gestures such as "draw" and "circle", "form" and "rectangle", "form" and "circle", "make" and "fist", and "pressing" and "button". Although we were interested in finding an association between gesture and referent or device, we did not find any such relationship. However, we did find that certain devices such

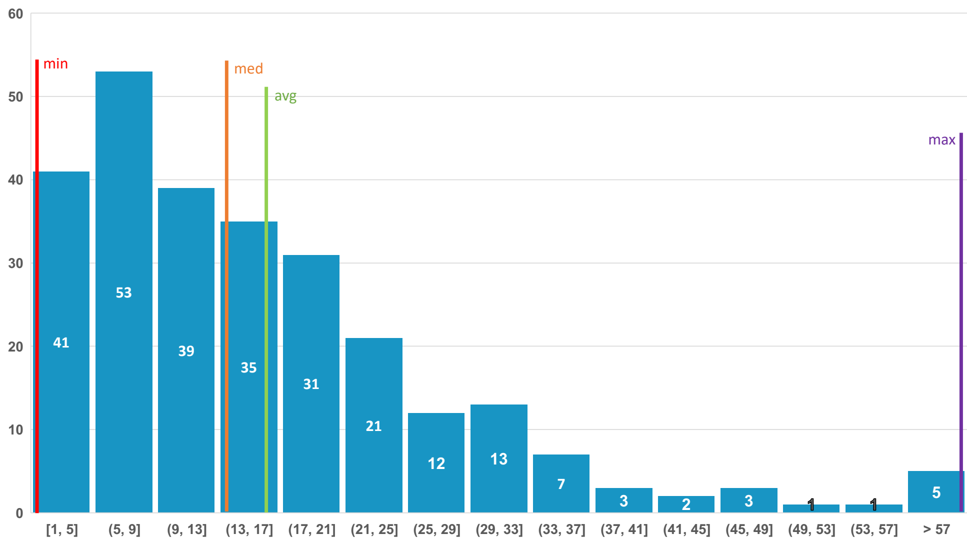

Fig. 8. Distribution of the number of referents per GES (min=minimum, med=median, max=maximum, avg=average).

as "UAVs" and "Drones" are associated with "navigate", "control", and "command", while the term "device" is associated with "moved".

5 REFERENTS

Overall, a total number of N_{Ref}=4, 106 referents was found in the 267 GESs considered in our analysis (M=16.57, Mdn=14, SD=13.48, Min=1 [89] to Max=120 [99]), indicating that the number of referents can vary from a few to many (Fig. 8). Referents are typically presented to participants in a visual format (called visual priming [74]), predominantly through the use of images, animations, videos, or user interface prototypes, whether they are in mock-up or functional form. This observation aligns with a previous study that identified the most commonly used and effective representations for referents [69]. Referents are often categorized based on established sets of categories [125, 145], including:

- *Basic functions*, which encompass actions like turning the TV on/off, changing channels, adjusting the volume, displaying/hiding menus, and opening/closing items.
- *Generic functions*, also known as context-independent functions, covering tasks like making simple or multiple choices, selecting a date, or specifying a value.
- *Specific functions*, also known as context-dependent functions, which pertain to particular activities, such as accessing the TV guide or controlling playback.

These functions can be further described as either *analog* (when they mimic a physical effect in the real world, such as moving, selecting, rotating, resizing, panning, zooming in/out, navigating to the previous or next item, maximizing, or minimizing) or *abstract* (when they do not replicate any physical real-world effect, examples of which include inserting, deleting, modifying, cutting, duplicating, pasting, undoing, accessing menus, or opening files).

To assess the recurring usage of referents in GESs, we classified referents extracted from our papers dataset according to their abstract task types based on the taxonomy introduced by Lenorovitz *et al.* [56]. Within the scope of our research, we transcribed the referents from each article and sought their corresponding equivalents in Lenorovitz *et al.*'s taxonomy. In certain case, we encountered challenges in identifying referents within a GES, such as for Connell *et al.* [22], who indicated that the children involved in their study carried out 22 tasks (referents) structured by categories: *object manipulation* (moving, resizing, rotating, panning, zooming), *spatial interaction* (spatial zooming, spatial planning, and manipulation of objects within space), and *utility or navigation-based tasks* (including start, pause, and menu navigation). Another example is referents directly related to the highest consensus: "Move object from left to right", "Make object disappear from left and reappear on right", "Move object along a path", "Relocate stack of objects from left to right", "Resize the object", "Pan within a 3D room", "Menu selection", "Menu panning". To properly establish the relationship between a referent and the task in the taxonomy, we analyzed its functionality and context of use. For example, Medrano *et al.* [78] used the referent "If you would like to open a business here, where would you place it?," which was assigned to "Select item" in the category of *Generic Referents*, with "Indicate" for *function type* and "Select" for *function subtype*.

We found that "Perform action" was the most frequent category (Table 5), which can be used for classifying referents such as "Jump," "Run," "Pick item," "Push box," "Catch ball," [103, 104], "Land," "Take off," "Follow," "Get attention," "Fly to precise location," [18, 28]. Some referents share similar percentages in ir distribution, such as "Increase value" (*e.g.,* Volume up, Increase speed, Brightness up, Increase temperature) and "Decrease value" (*e.g.,* Volume down, Decrease speed, Brightness down, Decrease temperature), "Activate and Deactivate", "Ok" (*e.g.,* Accept) and "Ko" (*e.g.,* Cancel), "Move up and down," and "Move to next or previous item."

We also categorized the referents into high, medium, and low classes (Table 7). We did not find any experiment designed to quantify the number of referents for which participants should be elicited in a single trial or study. The determinants of this number are strongly contingent upon the specific context of use, including factors such as the type of device and environment. As participants endeavor to invent new gestures beyond a certain threshold, they encounter escalating challenges. Over time, the process can become more challenging, leading to a tendency to propose gestures somewhat arbitrarily, without establishing a meaningful connection to the referent, primarily because of limited creativity. Participants may also experience difficulties recalling which gestures they have previously proposed or employed for referents, therefore presenting the risk of repeating a previously proposed gesture, unless permitted by the study. The constraints imposed by the device itself can also exert an influence, where the participants may encounter difficulties envisioning the range of novel gestures that the device is capable of detecting and recognizing.

6 GESTURES

The average number of gestures proposed across all GESs examined in our SLR was M=723 (SD=1354, Mdn=378, Min=4 [146], Max=12, 240 [100, 101]; see Fig. 9). After grouping the gestures into clusters of identical or similar types, the average number of proposed gestures reduced to M=88 (SD=221, Mdn=24; see Fig. 10). Of these, an average of C=21 was selected to form consensus gesture sets. Often, C is smaller than the number of referents, since one gesture may be assigned to more than one referent, thus posing some ambiguity. For example, a GES for multiple devices [132] collected 1,047 gestures for 14 referents using several devices, but the gestures were captured by different devices. In the original method [137], if the same gesture is proposed for multiple referents, then a conflict resolution process assigns the gesture with the highest agreement to the first referent, and the next referent receives the second most agreed gesture. Many studies did not use this step, although it was part of the original GES procedure.

In our examination of the gestures extracted from the GESs analyzed in our SLR, we observed varying formats, methodologies, and approaches employed to present the outcomes of a GES. Some of them primarily aim to compare, investigate, or establish taxonomies for gestures. Consequently,

Table 5. Number and percentage of referents found in the GESs analyzed in our SLR.

Number of Referents	**Percentage**
Perform action (581)	14%
Scale (291)	7%
Move to next (225) Select (223) Move to previous (217) Draw object, letter, number, or symbol (185) Rotate (185)	5%
Move all direction (178) Increase value (149) Decrease value (148) Deactivate (144) Activate (155)	4%
Open (132) Delete (104)	3%
Create (89) Move up (80) Move down (74) Close (77) Play (72) Move left (70) Ok (accept) (71) Ko (cancel) (68) Stop (65) Move to item (64)	2%
Move right (58) Copy (53) Move to home (45) Pause (42) Help (32) Answer call (31) Search (29) End call (22)	1%
Save (19) Edit (18) Menu (activate menu) (18) Decline call (17) Send (15) Notification (14) Move to end (8) Group (7) Place call (7) Ungroup (4) Ignore call (4) Emergency call (3)	<1%

Table 6. Classification example of the referents extracted from the GESs analyzed in our SLR.

Referent	Generic Referent	Function Type	Function Subtype
Music Player	Move to item	Manipulate	Menus
Navigation System	Move to item	Manipulate	Menus
Generic Help	Move to item	Manipulate	Menus
Home/Menu access	Move to home	Manipulate	Menus
List Up	Move up	Manipulate	Menus
List down	Move down	Manipulate	Menus
Play	Play	Activate	Execute
Stop	Stop	Activate	Execute
Next Song	Move to next	Manipulate	Menus
Previous Song	Move to previous	Manipulate	Menus
Volume Increase	Increase value	Manipulate	Menus
Volume Decrease	Decrease value	Manipulate	Menus
Zoom In	Scale	Manipulate	Navigation
Zoom Out	Scale	Manipulate	Navigation
Pan Map	Move left, Move right, Move up, Move down	Manipulate	Navigation
Rotate Map	Rotate	Manipulate	Navigation
New Destination	Search	Perceive	Search
On/Off	Activate/Deactivate	Activate	Execute
Increase Brightness	Increase value	Manipulate	Menus
Decrease Brightness	Decrease value	Manipulate	Menus
Increase Fan Speed	Increase value	Manipulate	Menus
Decrease Fan Speed	Decrease value	Manipulate	Menus
Auto Mode On	Activate	Activate	Execute

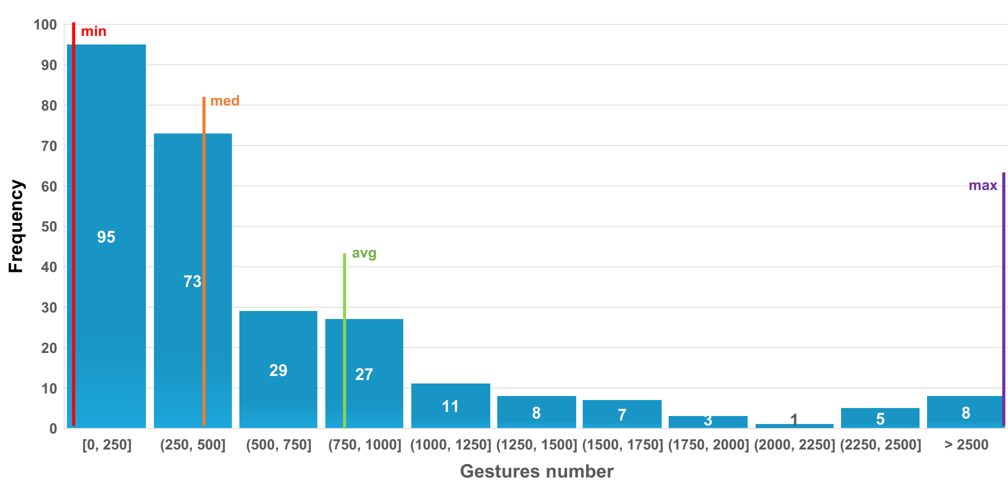

Fig. 9. Distribution of the number of proposed gestures per GES (min=minimum, med=median, max=maximum, avg=average).

these studies may not provide a comprehensive list of all the gestures resulting from their investigations. To illustrate this observation with an example, Ousmer *et al.* [83] put forth an ontology for structuring body-based gestures. While this study conducted a GES as a proof of concept, the paper enumerated various gesture categories (*e.g.*, “Swipe”, “Rotate a control knob”, “Tap”, “Raise”, “Remote control”, “Point with fingers”, “Shape a phone”, and “Press”) without depicting the

Table 7. Results of the referent classification.

Function Type		
Category	**Function (number/Total number of Referents)**	**Percentage**
High	Manipulate ($\frac{2,086}{4,106}$)	50%
	Activate ($\frac{1,365}{4,106}$)	33%
Medium	Indicate ($\frac{223}{4,106}$)	5%
	Create ($\frac{215}{4,106}$)	5%
Low	Communicate ($\frac{123}{4,106}$)	3%
	Eliminate ($\frac{107}{4,106}$)	3%
	Perceive ($\frac{31}{4,106}$)	1%
Function Subtype		
Category	**Function (number/Total number of Referents)**	**Percentage**
High	Navigation ($\frac{1,668}{4,106}$)	40%
	Execute 1364 ($\frac{1,364}{4,106}$)	33%
Medium	Menus ($\frac{420}{4,106}$)	10%
	Select ($\frac{223}{4,106}$)	5%
Low	Associate ($\frac{102}{4,106}$)	3%
	Remove ($\frac{103}{4,106}$)	3%
	Phone ($\frac{91}{4,106}$)	2%
	Replicate ($\frac{59}{4,106}$)	1%
	Introduce ($\frac{42}{4,106}$ = 1%)	1%
	Notification ($\frac{31}{4,106}$)	1%
	Search ($\frac{31}{4,106}$)	1%
	Assemble ($\frac{16}{4,106}$)	< 1%
	Disassemble ($\frac{4}{4,106}$)	< 1%
	Identify ($\frac{0}{4,106}$)	0%

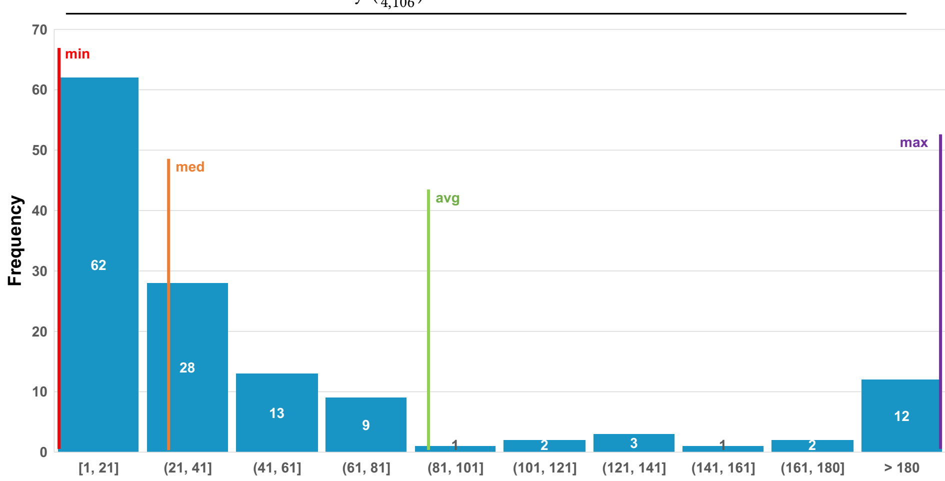

Fig. 10. Distribution of the number of agreed gestures per GES (min=minimum, med=median, max=maximum, avg=average).

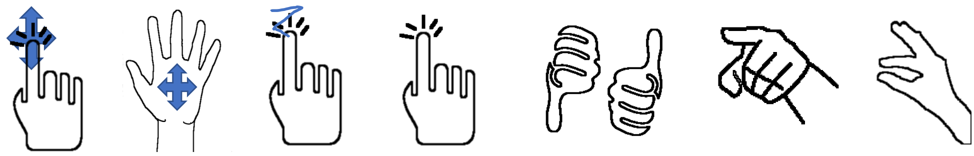

Fig. 11. Elicited gestures presented in descending order of users' preferences.

resulting gestures or specifying which gesture corresponds to which referent. Instead, the paper offered video where examples of the elicited gestures could be viewed. Additionally, two studies by Modanwal *et al.* [70, 71] explored static gestures involving the extension of individual fingers. These gestures were not tied to specific tasks or objects, but rather associated to letters, numbers, symbols, and special characters. Schipor *et al.* [96] investigated gestures related to pointing to specific locations in a room to access digital content. The study examined various ways in which the participants performed pointing actions in the room, including the index finger, hand, pinching, or tapping. Similarly, Medrano *et al.* [78] concentrated on the diverse methods that the participants in their study used to point to specific places. In contrast, Sharma *et al.* [99] identified various micro-gestures that users employed when interacting with objects and how they grasped those objects, *e.g.,* grabbing, pinching, or clawing.

We counted the times that a gesture was repeatedly found in the 267 GESs considered in our analysis. To know which gestures were repeated more frequently in our corpus, we were confronted with the problem of how the gestures were described, associated to referents, or named in different ways and, thus, we used all of the available information, such as the accompanying illustrations from the corresponding papers. For example, the gesture of moving the hand in different directions was referred by Zaiti *et al.* [145] and Dong *et al.* [27] using "Move hand up", "Move hand down", "Move the hand from right to left" or "Move hand left", while moving the hand horizontally appeared in Dim *et al.* [26] as "Palm up", "Palm down", "Swipe hand to left" and "Swipe hand to the right." Our analysis resulted in a total number of 2, 304 gestures, ranked as follows (Fig. 11): Swipe (11%), Move (10%), Draw (9%), Tap (8%), Use Thumbs (5%), Point (5%), Pinch (3%), Drag (3%), Rotate (3%), Turn (3%), Fist use, Push, Touch, Grab, Press, Slide, Pull, Flick, Ok sign (2%); Wave, Click, Clap, Cross, Spread, Bend, Thumb(s) up, Shake, Pinch in, Pinch out, Step, Put, Open hand, Stop sign (1%), Splay, Splash, Spin, Raise, Jump, X sign, Thumb down, and Close hand (<1%).

6.1 Gesture Representation

To analyze the representation of the gestures extracted from the GESs analyzed in our SLR, we employed two taxonomies:

(1) McAweeney *et al.* [69] focused on different quality factors of the gesture representation., while Peshkova *et al.* [85] represented the gestures and commands proposed by the participants in two mapping tables: by *Perspective* (*e.g.,* third person, mirror, and bird's eye), *Frame* (*e.g.,* one or many frames, especially when the gesture was complex), *Body context* (*e.g.,* upper-body vs. full-body), *Environmental context* (*e.g.,* according to the physical objects found in the surrounding), *Color*, and *Gesture element* (*e.g.,* 1-Sided Arrow, 2-Sided Arrow, Dotted lines, Finger Trail, Other motion lines, Ghost). The result of our analysis of the representation of the gestures found in the 267 GESs is presented in Table 8.
(2) Bernsen [10] proposed a classification of interaction modalities structured into 20 generic levels further grouped into 4 super levels. According to this classification, Peshkova *et al.* [85] employs a *Super level* in Linguistic modalities, a *Generic level* (Standard analog graphic

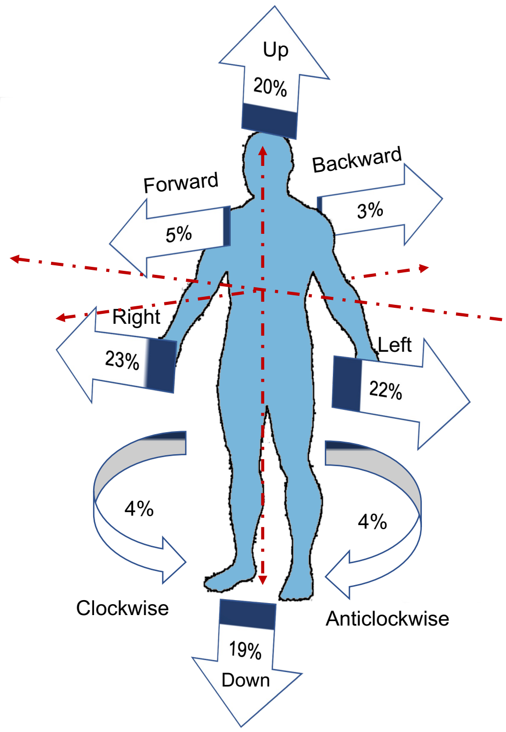

Fig. 12. Users' preferences for the direction of the elicited gestures.

element and Standard non-analog graphic), an *Atomic level* equal to "5b. Written lab", and so forth. Table 9 shows the results of this classification.

6.2 Gesture Classification

We also used the gesture classification proposed by Aigner *et al.* [1]. While this classification primarily focuses on hand gestures, we extended it to encompass gestures performed by other body parts as well. For instance, Lee *et al.* [53] d gestures performed with the feet, and Yan *et al.* [143] with the head, as illustrated in Fig. 13. Additionally, we utilized the taxonomy presented in Table 10 for a secondary classification. This taxonomy draws inspiration from the classifications used by Piumsomboon *et al.* [88] for Augmented Reality gestures and Obaid *et al.* [81] for whole-body gestures designed to control humanoid robots. Both of these taxonomies were adapted from Wobbrock *et al.* [138]. The findings, summarized in Table 10, are as follows:

(1) *Form.* Most of the gestures proposed by the participants of GESs involve some form of movement, which suggests that participants tend to prefer gestures with a dynamic component.
(2) *Body part.* In our microscopic analysis of the elicited gestures, we found that the area of the body most used to perform gestures was the middle body, such as the hands, arms, belly, wrist, and most of the gestures were proposed with the fingers, hands, wrists, and the arms.
(3) *Nature.* Most of the elicited gestures are the representation of a simulation that the user is performing an action. A minority of the gestures represent icons or symbols.
(4) *Symmetry.* Most of the gestures were carried out unilaterally. Studies such as [11] and [83] revealed that gestures are performed mostly on the dominant side of the body. There is a

Table 8. Gesture representations according to McAweeney *et al.*'s taxonomy [69].

Criteria	Classification	Number of GES	Percentage
Perspective	1st Person	82	31%
	3st Person	61	23%
	Mirror	59	22%
	Bird's eye	23	9%
	Side angle	33	12%
Frame	Single	170	64%
	Multi	90	34%
Body context	Full-Body	32	12%
	Lower-Body	3	1%
	Upper-body	56	21%
	Other part body	128	48%
Environment	Physical Objects	144	54%
	Virtual Objects	65	24%
Color	Yes	138	52%
	No	76	28%
Gesture Elements	1-Sided Arrow	151	57%
	2-Sided Arrow	82	31%
	Dotted lines	47	18%
	Ghost	78	29%
	Finger Trail	130	49%
	Other motion lines	97	36%
	Touchpoints	94	35%
	Text	130	49%
	Numbers	56	21%
	Bending joints	7	3%
	Axis	16	6%

Table 9. Gesture representations according to Bernsen's taxonomy [10].

Super level	Generic level	Atomic level	Sub-Atomic level
Linguistic modalities 204 (76%)	1. Sta. an. graphic ele. 129 (48%)		
	5. Sta. non-an. graphic 150 (56%)	5a. Written text 70 (26%)	5a1. Typed text 65 (24%)
			5a2. Hand-writ text 2 (1%)
		5b. Written lab. 96 (36%)	5b1. Typed lab. 91 (34%)
			5b2. Hand-writ la 5 (2%)
Analogue modalities 91 (34%)	9. Static graphic 98 (37%)	9a. Images 92 (34%)	
		9b. Maps 3 (1%)	
		9d. Graphs 3 (1%)	
Arbitrary modalities 1 (<1%)	13. Sta. Graphic 1 (<1%)		

small difference between bilateral symmetry and bilateral asymmetry. However, users tend to prefer performing gestures in the same way with both body sides.

(5) *Locale.* The gestures selected in our sample were performed in the air. Few studies combine gestures performed with one hand in the air and another hand on a surface [8], a condition often referred to as "Air+Touch" gestures.

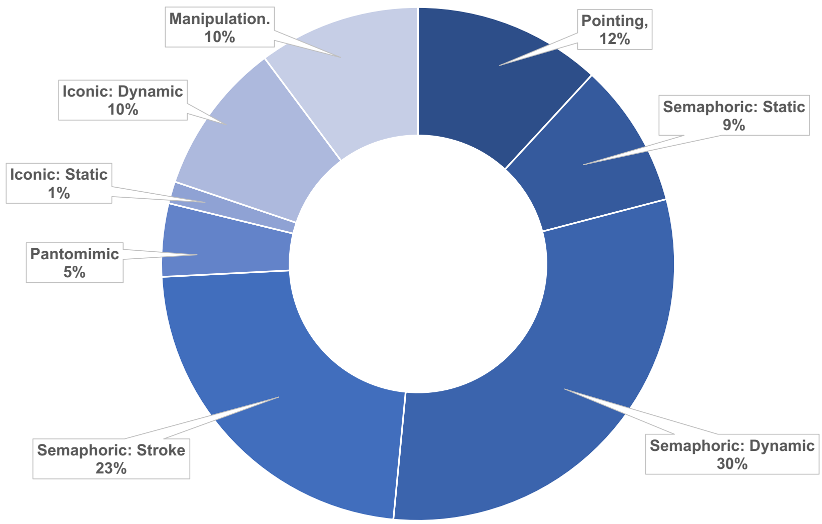

Fig. 13. Gesture classification according to the taxonomy of Aigner *et al.* [1]. Pointing gestures are used to show a particular location or object. Pantomimic acting gestures are used to depict an action or object. Manipulation gestures are used to control objects physically. Semaphoric gestures are used to convey meaning through symbolic representation. Iconic gestures are used to imitate an object or concept.

Table 10. Gesture taxonomies used for analyzing the gestures in our SLR.

Form	Static Gesture	The body parts are kept in the same position during gesture articulation	10%
	Dynamic Gesture	There is displacement by any body part to perform the gesture	90%
Body part	Upper body	Body parts located from the shoulders to the head (*e.g.,* head, nose, ears)	3%
	Middle body	Hand, wrist, finger, arm, chest, belly, and elbow	88%
	Lower body	Body parts located from the hip to the feet (*e.g.,* legs, knee, feet, toes)	3%
	Full body	Use two body zones or the whole body	6%
Nature	Deictic	The gesture is indicating a position or direction	19%
	Iconic	The gesture represents an icon or symbol	15%
	Miming	The gesture is equal to the referent or acts a pantomime of an action	39%
	Physical	The gesture acts physically on objects	28%
Symmetry	Unilateral	The gesture is executed only with one side of the body	72%
	Bilateral symmetric	The gesture is performed in the same way with both sides of the body	15%
	Bilateral asymmetric	The movements involving the two body sides are not the same	13%
Locale	On the object	The gesture involves a contact with a real physical object	35%
	In the air	The gesture occurs in the air with no physical contact	64%
	Mixed locales	The gesture involves both locales	1%

6.3 Gesture Inventory

The primary focus of our research is identifying the most prevalent mappings between referents and gestures. We aim to determine if there exists a significant occurrence where users associate a specific gesture with a particular referent. To achieve this, we consider three key aspects: the study's referent, the general referent description, and the associated gesture. It is worth noting that when a study proposed one, two, or three gestures with a substantial consensus for a referent, we recorded all of these associations. The number of gestures linked to each referent varies across studies. In cases where studies concentrate on taxonomies, ontologies, or gesture classifications, they often list the gestures acquired without assigning them to specific referents. For instance, Ousmer *et al.* [83] and Cui *et al.* [23] provided video links as supplementary materials, possibly due to page limitations. Taralle *et al.* [113], on the other hand, assigned a unique gesture to each referent, distinct from all other gestures, with the goal of reducing ambiguity. Vanderdonckt *et al.* [119], Uva *et al.* [118], and Nanjappan *et al.* [76] proposed a primary gesture for each referent, but also listed additional gestures that received high consensus. Table 11 presents the associations that we identified in our analysis.

7 RECOMMENDATIONS AND FUTURE WORK

Based on the findings reported in the previous sections, we propose a number of avenues for conducting future end-user gesture elicitation studies. These recommendations are intended for researchers and practitioners who wish to examine users' preferences for intuitive gesture input and design gesture sets reflective of these preferences. We suggest the following:

☞ **Conduct GESs for all body parts**. Human body parts having little or no coverage in our analysis, such as the knees, eyes, tongue, or chest, deserve dedicated GESs to understand users' preferences for gestures articulated with or involving these body parts. Furthermore, very few GESs have explored gestures for the belly, nose, ear, and feet. In principle, every moving limb of the human body can serve as input to an interactive computer system.

☞ **Use the term "referent" in a systematic manner**. We recommend that the term "referent" be used instead of associated concepts, such as tasks, commands, actions, or executions in GESs, to avoid any confusion and foster a common vocabulary across GES practitioners. Furthermore, we recommend that GESs specify how the referent was rendered, according to which representation. Instead of predefining the referents, future GESs could let participants decide the referents by themselves, representing the functions of an interactive computer system that are relevant to them or even be conducted in a referentless manner. Additionally, GESs could be conducted with or without an experimenter, namely to give more freedom to participants and avoid the Hawthorne or other carry-over effects.

☞ **Conduct GESs with cutting-edge devices**. We recommend conducting GESs with cutting-edge devices issued with the latest gesture technology available, [126], depth cameras, etc. For instance, Augmental has developed *MouthPad^*, a tongue-driven interface that can be used to control a computer, smartphone, or tablet via Bluetooth, for which we recommend a dedicated GES involving both users with and without motor impairments. Also, Şiean *et al.*[102] examined possibilities for placing radar sensors in a smart living room, but no GESs were conducted to understand users' preferences for those placements and the kind of gestures that are comfortable to articulate with respect to those placements. Another example is Villarreal *et al.* [128], who conducted a GES with an interactive cushion to explore user-defined squeeze gestures. We recommend that other objects, with different form factors, be investigated to extend the design knowledge in this area.

☞ **Describe the context of use**. The three classical facets of a context of use are end users and potential referents, the object/device/platform, and the physical and psychological environment in which the GES is conducted [17]. These three facets should be systematically and thoroughly specified when describing a GES, preferably using common terminology to foster incremental research. A potential approach would be deriving a dedicated taxonomy for GES, inspired by the body parts involved in gesture articulation and the International Classification of Functioning,

Table 11. Associations between gestures and referents.

Gesture (number of associations)	Referent	Percentage
Move/Swipe left (99)	Move to previous	24%
	Move left	21%
	Move to next	9%
	Decrease value	8%
	Move right	7%
	Perform action	6%
	Increase value	5%
	Move down	
	Deactivate	<5%
	Cancel	
Move/Swipe right (83)	Move to next	29%
	Move right	20%
	Move to previous	10%
	Perform action	
	Move up	
	Move left	<5%
	Increase value	
	Decrease value	
	Move to home	
Move/Swipe up (95)	Increase value	34%
	Move up	25%
	Decrease value	11%
	Perform action	9%
	Move to next	6%
	Move down	
	Deactivate	<5%
	Move to previous	
Move/Swipe down (84)	Move down	25%
	Decrease value	23%
	Move up	10%
	Increase value	6%
	Move to previous	
	Perform action	<5%
	Move left	
Tap (275)	Select	22%
	Perform action	15%
	Play	5%
	Call	
	Open	
	Close	
	Stop	
	Ok	
	Cancel	<5%
	Pause	
	Deactivate	
	Activate	
	Delete	
Pinch (110)	Scale (zoom)	63%
	Perform action	11%
	Select	3%
Point (150)	Select	25%
	Perform action	14%
	Decrease value	
	Increase value	
	Deactivate	<5%
	Play	
	Stop	
Rotate/turn/spin (198)	Rotate	33%
	Move	23%
	Perform action	14%
	Deactivate	7%
Draw (271)	Open	11%
	Perform action	8%
	Move to item	6%
	Rotate	5%
	Cancel	
	Play	
	Select	
	Ok	
	Move up, down, right, left	<5%
	Increase value	
	Decrease value	
	Close	
	Deactivate	

Disability and Health (ICF).

☞ **Replicate GESs with different formats and types**. The RepliGES [39] conceptual space for GESs distinguishes among eight types of GES replications, such as using the same or new data, same or new participants, same or new population, and same or new goal, in order to consolidate the GES body of knowledge. This aspect is crucial since designing a gesture vocabulary by relying on a single GES may overlook other potential gesture alternatives. For example, Gheran *et al.* [36] showed that a simple replication of a previous GES conducted with smart rings [38] can lead to a significant portion of gestures not discovered in the original study. Unfortunately, only a few types of GES replications have been achieved insofar.

☞ **Properly calibrate the referents and parameters of GESs**. Table 12 summarizes the values of all metrics computed in this SLR, thus helping any future GES to calibrate its parameters. For example, the average number of referents is N_{Ref}=16 (ompared to the previous finding [129] of N=20). This result constitutes an argument to calibrate any future GES against this value, but also a risk of overfitting to this value. Furthermore, conducting studies with fewer referents makes sense, given that users can memorizes only a limited number of gestures [75].

☞ **Assign each referent to a single action**. Referents are understood in a more unambiguous way when they are associated with a single action at a time, rather than abstract actions covering multiple interpretations. For instance, single-action referents, such as "Turn TV on", "Increase volume", "Go right", are more easily understood than multi-action referents, such as "Find a place in Google Maps", "Fly to the place marked with an X", "Navigate in a website". Another example is related to directions (Fig. 12): referents related to movement or navigation should be set for each direction, such as "Up", "Down", "Left", "Right", "Forward", "Backward", "Clockwise', and "Counterclockwise." Referents related to commands executed in a smart environment or with a smart device are preferably defined according to a simple sentence scheme, consisting of an action verb followed by a noun referring to the concept affected by the action and followed by parameters. For instance, "Turn TV on", "Move Drone left", "Raise hand vertically", foster defining referents by hierarchical and congruent representations. Furthermore, using the verbs "Increase" or "Decrease" should refer to a variable, such as volume, temperature, light level, or object size.

☞ **Generalize the referent**. If the referent is specific to a particular environment or context of use, a generic referent could be preferable over a specific one. Even if the referent is manipulated in a specific context, its generic formulation would help it be transposed, related, and possibly generalized to new contexts of use. For instance, the navigation within a list, a pull-down menu, or a 3D menu, could be termed as "Next item", "Previous item", "First item", or "Last item" in a more generic way. When a particular object, such as involved by a tangible UI, is used for capturing gestures, the referent should not mention the specific device, but rather abstract its actions.

☞ **Determine the most appropriate representation for the referents.** While McAweeney *et al.* [69] identified the most frequent and common referent representations used in GESs, it remains to formulate recommendations for the representation of referents according to the context of use, *e.g.,* following Fothergill *et al.* [33]. Video, with or without text, is best for ensuring the correctness of coding the collected gestures, while image and text are best for coverage.

☞ **Consider new referents in new environments**. The gestures proposed by participants in a 2D setup do not easily transpose to other setups, such as in 3D. As a consequence, more GESs are required to explore user-defined gestures for the same referents when used in another environment. For instance, we recommend that environments such as Augmented Reality (AR), eXtended Reality (XR), and the metaverse, be investigated, keeping in mind that their novelty can also prevent participants from proposing new gestures that fully take advantage of the characteristics of those environments. Sometimes, participants' curiosity when they discover a new device or environment takes precedence over their creativity.

☞ **Collect one gesture per referent and participant.** While some GES procedures allow collecting several different gestures for the same referent [16] or even to repeat a gesture for different referents, we believe it is best to focus on a single gesture per referent and participant to avoid potential conflicts in mapping gestures to system functions. As a result, participants may run out of ideas and come up with nonsensical gestures that may not be related to the referents, a hypothesis that remains to be verified.

☞ **Prefer hierarchical, congruent referents and gestures.** When the vocabulary includes gestures associated with opposite, symmetrical referents, it is preferable for the referents to be defined hierarchically and congruently so that the associated gestures are also hierarchical and congruent. For example, the referent "Turn TV On" could be associated with a sequence of three gestures, one for each term, rather than a single gesture for the whole referent, reducing thus the number of gestures to be remembered by combining them. Similarly, the distribution between the opposite directions of gestures, such as "Left" vs. "Right", "Up" vs. "Down", "Clockwise" vs. "Anti-clockwise", "Forward" and "Backward," could be compared to the distribution of opposite referents.

☞ **Conduct GESs with multiple perspectives.** Collecting gestures from participants remains a time-consuming task, whether it is for elicitation, identification, or training a gesture recognizer [33]. Therefore, it might be appropriate to consider multiple perspectives at once when the gestures are collected, such as with multiple instances of the same device (*e.g.,* a Microsoft Kinect positioned to capture movement in the transversal and sagittal planes of the body) or using different devices in combination. For example, zenithal gestures captured from a ceiling-anchored 3D camera [65] can offer a new perspective for mid-air gestures that fosters user privacy. A quantitative measure, coined as the *Variant Rate*, could estimate, on a scale from 0 to 1, the variation with which gestures are similar or different for the same referent when issued in different perspectives. A score of 0 would indicate no variation, while a score of 1 would indicate that all gestures classified under the same name were performed differently. For instance, Sluÿters *et al.* [105] collected gestures using two radars and a Leap Motion Controller that were subsequently subject to validation for efficient recognition [106].

☞ **Determine the optimization approach and the computational complexity of the GES**. To ensure transparency and reproducibility of the research results, GESs should include a detailed description of the research methodology used during the study. This recommendation helps other researchers and practitioners understand the steps taken to study the gestures proposed by the end users through various optimization approaches, including taxonomic [6, 81, 83, 88, 138], pragmatic [12, 78, 111, 113], semantic [1, 109], syntactic [70, 89], functional [89], cultural [14, 28, 67], developmental [22, 95, 109], neurocognitive [109, 112, 118], or naturalistic systems [18, 140].

☞ **Clarify and follow up the GES results against those obtained with other types of**

Table 12. Summary of the metrics employed in our SLR.

Metric	Minimum	Maximum	Average	Std. Dev.
Number of authors	1	10	3	1.8
Number of Google Scholar citations	0	1,273	34	99.17
Number of Participants	1	340	25	28.62
Male/Female Ratio	-1	14	1.82	1.98
Number of Referents	1	120	16	13.49
Number of Gestures proposed	4	12,240	723	1,354
Number of Agreed gestures	1	1,707	88	221
Agreement Score	0.01	1	0.31	0.23
Agreement Rate	0.004	1	0.25	0.2

user studies. Identification studies [5] implement the inverse process of a GES, in which a predefined list of gestures is presented to participants to elicit referents. The results of an identification study may corroborate, invalidate, or clarify those obtained with a GES. For instance, Sluÿters *et al.* [107] conducted a multi-context GES for eliciting mid-air hand gestures to interact with multimedia content presented on a large vertical display. The resulted gesture vocabulary has been subjected to gesture recognition to determine to what extent user-defined gestures can be recognized by a system, but it could equally be followed up by an identification study where new participants are asked to identify suitable referents from a list of gestures performed in relation to a large display.

8 OPEN DATA

We established a repository at https://tinyurl.com/brave-new-ges-world-data, where we provide access to the files containing the unprocessed data utilized in our analysis. Additionally, our Zotero collection, which includes the GES references evaluated in this SLR, can be found at https://www.zotero.org/groups/2132650/gesture_elicitation_studies.

9 CONCLUSION

We conducted a systematic literature review of gesture elicitation studies, their referents, and corresponding gesture vocabularies by examining a corpus of N=267 studies conducted with 6,659 participants and 4,106 referents, which elicited a grand total of 187,265 individual gestures (see Table 12). To foster future exploration of these data, we give access to our online collection along with its dedicated visualization tool. We also refer readers to our web site to access the corresponding sources and various outcomes of our SLR, such as the set of papers, our spreadsheet file comprising the detailed comparison of the 267 GESs, and the visualizations of the specific measures employed in this work. We hope that the findings we unveiled about the characteristics and outcomes of end-user gesture elicitation studies will be useful to researchers and practitioners interested in leveraging the gesture elicitation method towards innovations in gesture-based interaction for computer systems.

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A CORPUS OF GESTURE ELICITATION STUDIES

This section gathers the bibliographic references of our corpus of N=267 gesture elicitation studies analyzed. They are also accessible via a Zotero group.

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B WORD CLOUDS, TOPICS, AND TOPIC MODELLING

B.1 Word Cloud

We have created two sets of word cloud figures - one that shows the chronological order and the other one that contains 267 studies.

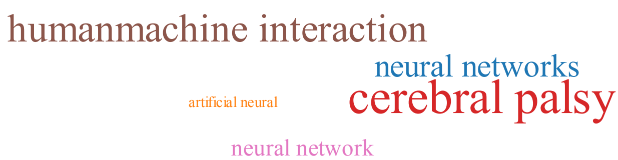


Fig. 14. Chronological Word Cloud 1994 Dunning algorithm

Fig. 15. Chronological Word Cloud 1998-1999 Dunning algorithm (left) and Mann Whitney U test (right)

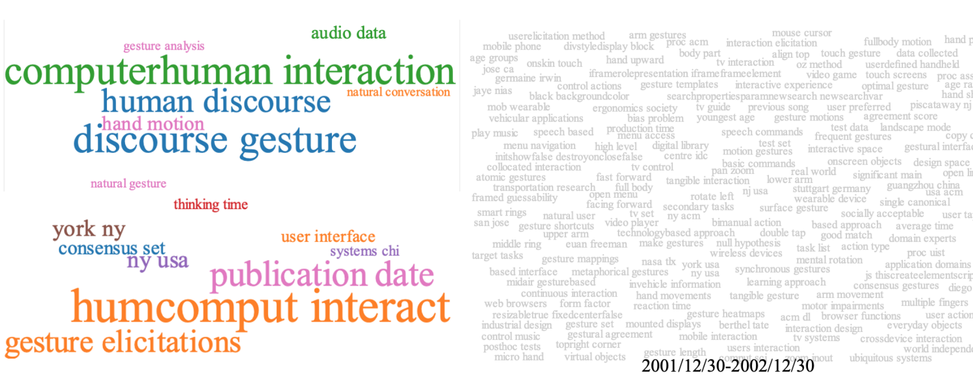


Fig. 16. Chronological Word Cloud 2000-2002 Dunning algorithm (left) and Mann Whitney U test (right)

Fig. 17. Chronological Word Cloud 2005 Dunning algorithm (left) and Mann Whitney U test (right)

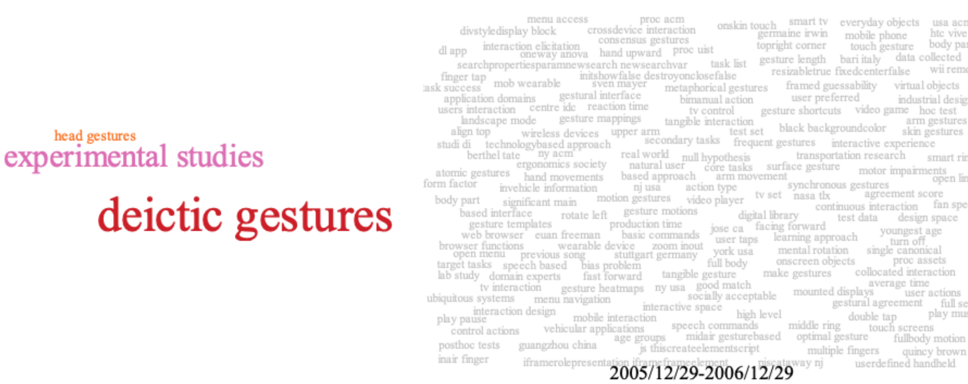


Fig. 18. Chronological Word Cloud 2006 Dunning algorithm (left) and Mann Whitney U test (right)

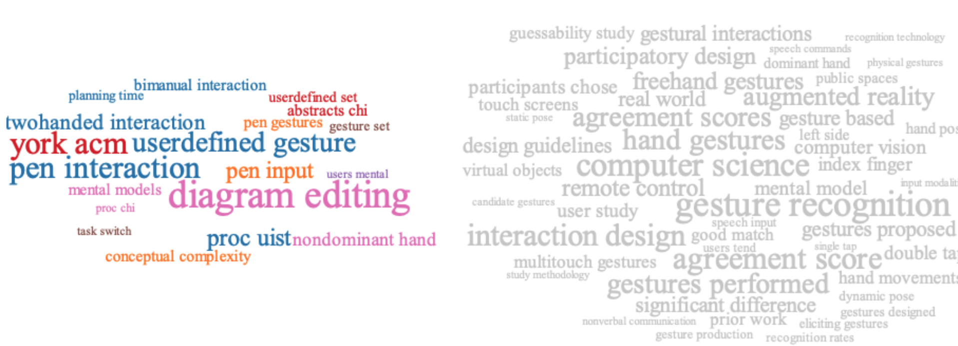


Fig. 19. Chronological Word Cloud 2008-2009 Dunning algorithm (left) and Mann Whitney U test (right)

Fig. 20. Chronological Word Cloud 2010 Dunning algorithm (left) and Mann Whitney U test (right)

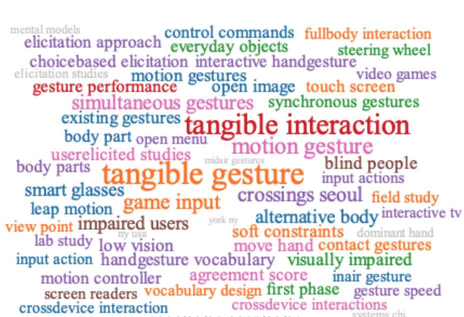
[H]

Fig. 21. Chronological Word Cloud 2011 Dunning algorithm (left) and Mann Whitney U test (right)

Fig. 22. Chronological Word Cloud 2012 Dunning algorithm (left) and Mann Whitney U test (right)

Fig. 23. Chronological Word Cloud 2013 Dunning algorithm (left) and Mann Whitney U test (right)

Fig. 24. Chronological Word Cloud 2014 Dunning algorithm (left) and Mann Whitney U test (right)



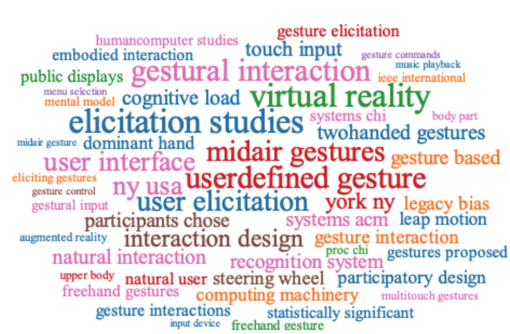


Fig. 25. Chronological Word Cloud 2015 Dunning algorithm (left) and Mann Whitney U test (right)

Fig. 26. Chronological Word Cloud 2016 Dunning algorithm (left) and Mann Whitney U test (right)

Fig. 27. Chronological Word Cloud 2017 Dunning algorithm

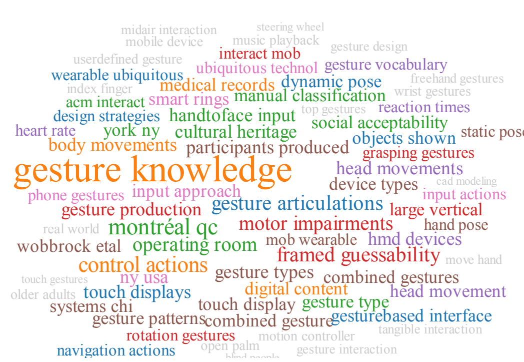


Fig. 28. Chronological Word Cloud 2018 Dunning algorithm

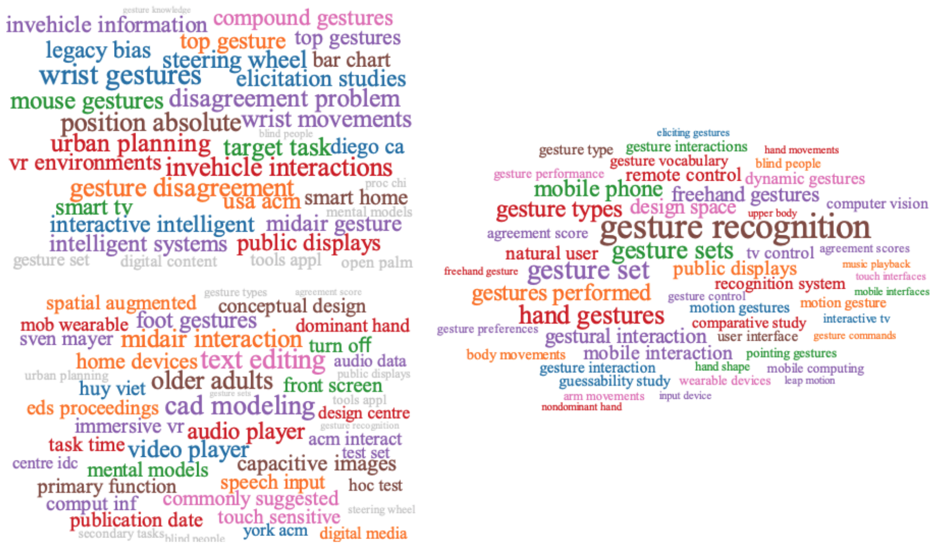


Fig. 29. Chronological Word Cloud 2019 Dunning algorithm (top left), 2020 Dunning algorithm (bottom left) and 2019-2020 Mann Whitney U test (right)

Fig. 30. Word Cloud of 267 studies, Dunning algorithm (left) and TF-IDF algorithm (right)

B.2 Topic

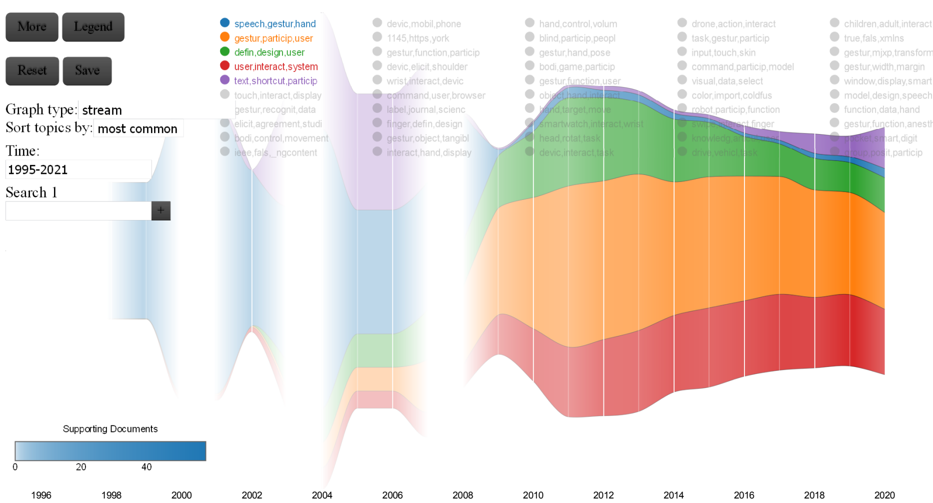


Fig. 31. Stream graph by most common, 5 topics

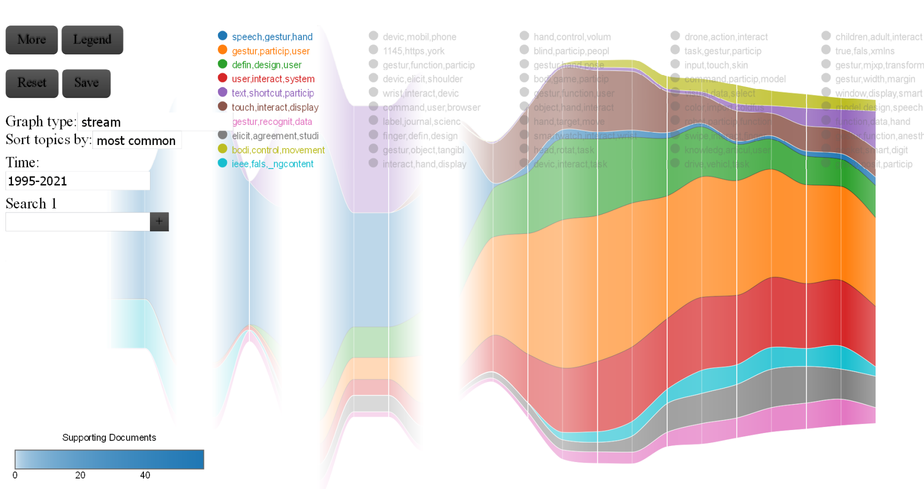


Fig. 32. Steam graph by most common, 10 topics

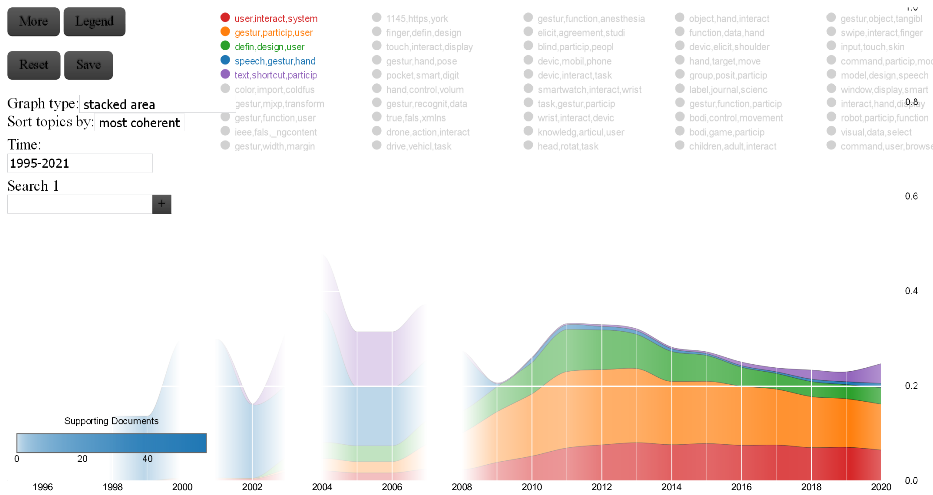


Fig. 33. Stacked area graph by most coherent, 5 topics

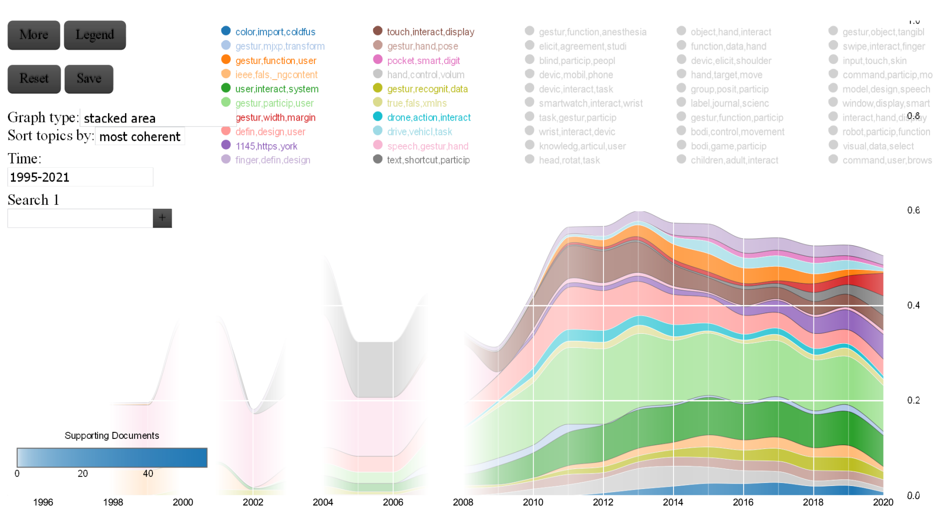


Fig. 34. Stacked area graph by most coherent, 20 topics

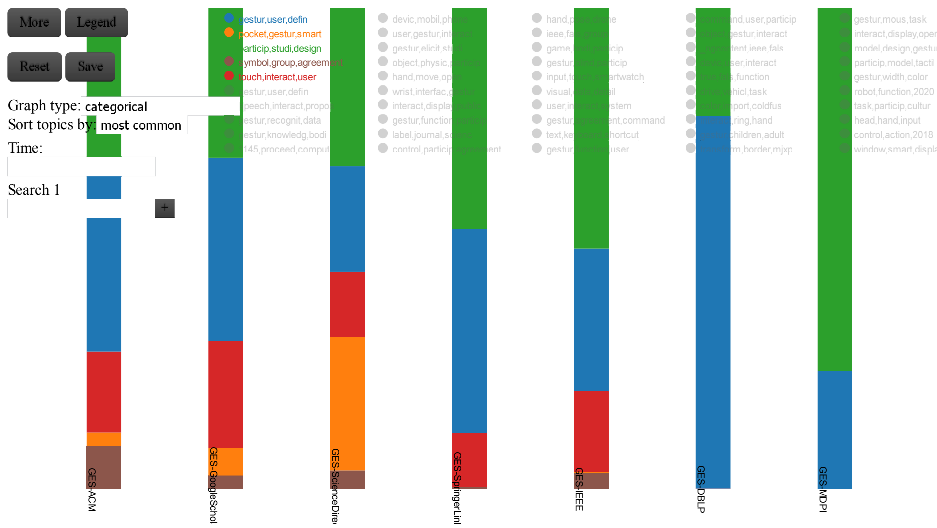


Fig. 35. Categorical graph by most common, 5 topics

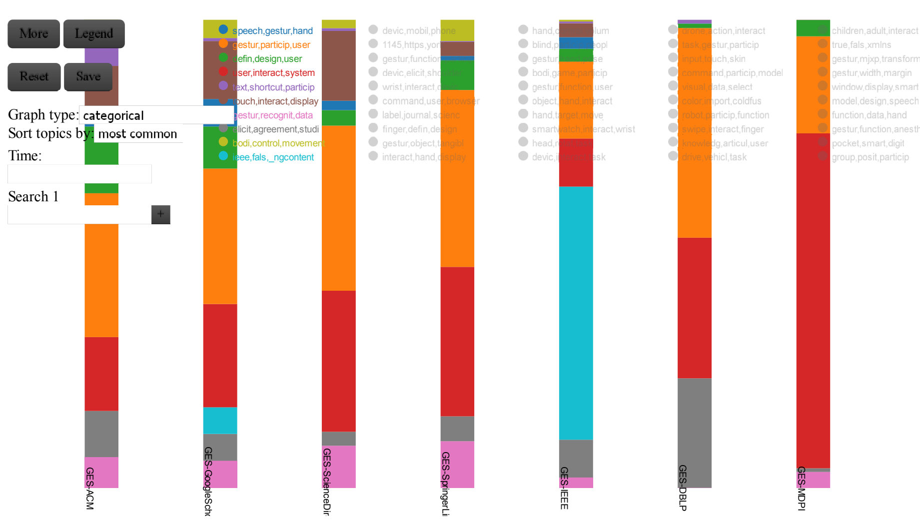


Fig. 36. Categorical graph by most common, 10 topics

B.3 Topic modelling

The connections between different terms or concepts.

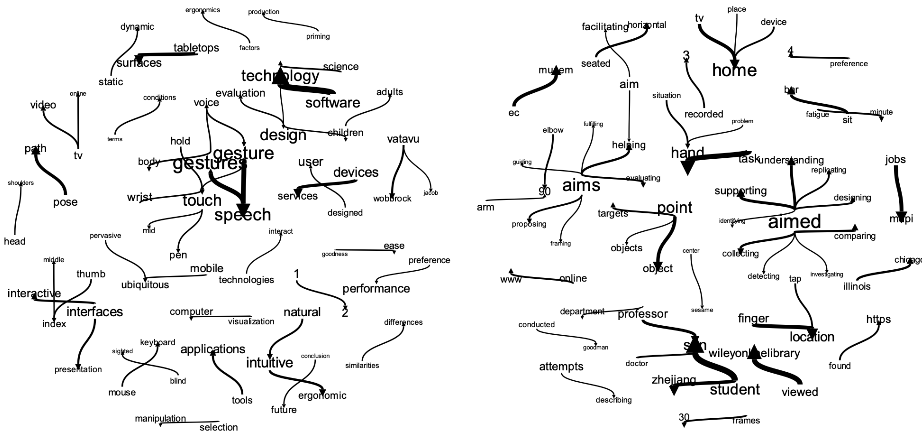


Fig. 37. associations between terms X and Y (left), X at Y (right)

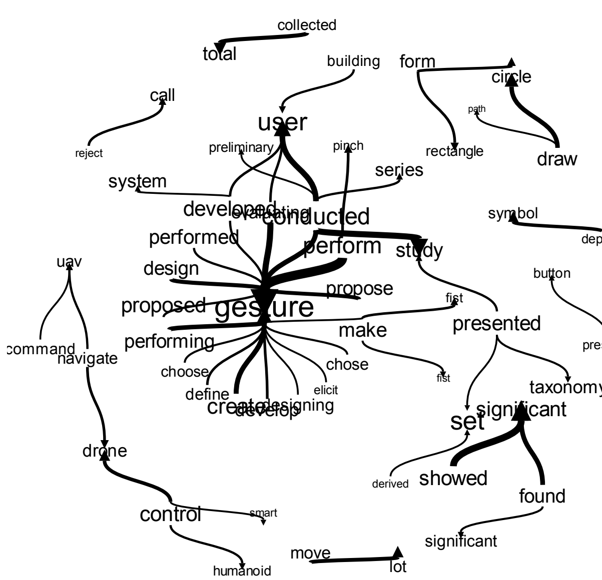


Fig. 38. associations between terms X a Y

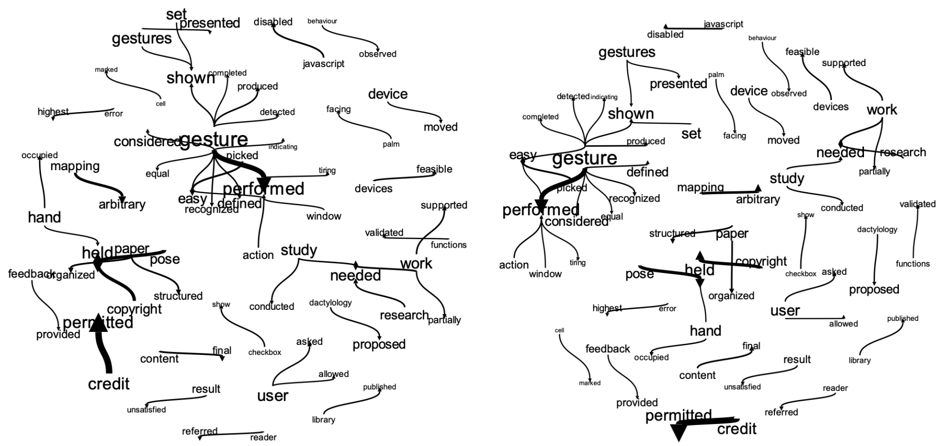


Fig. 39. associations between terms X is Y

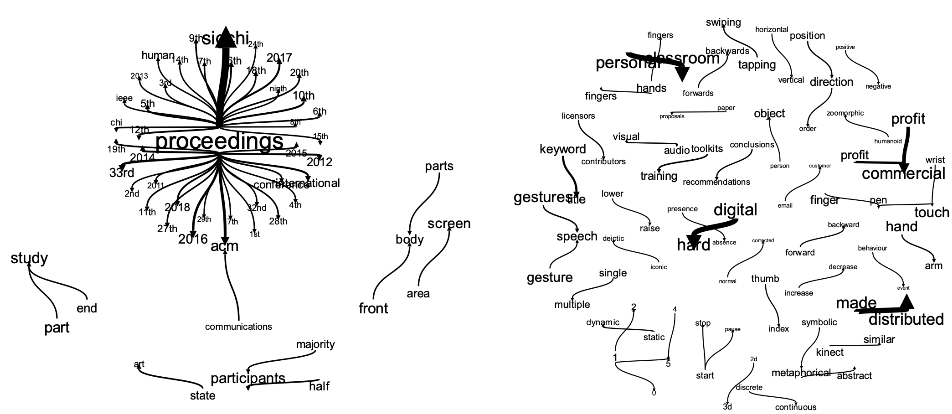


Fig. 40. associations between terms X of the Y (left), X or Y (right)

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