How are Vibrotactile Experiences Visually Represented? A Taxonomy of Illustration Characteristics

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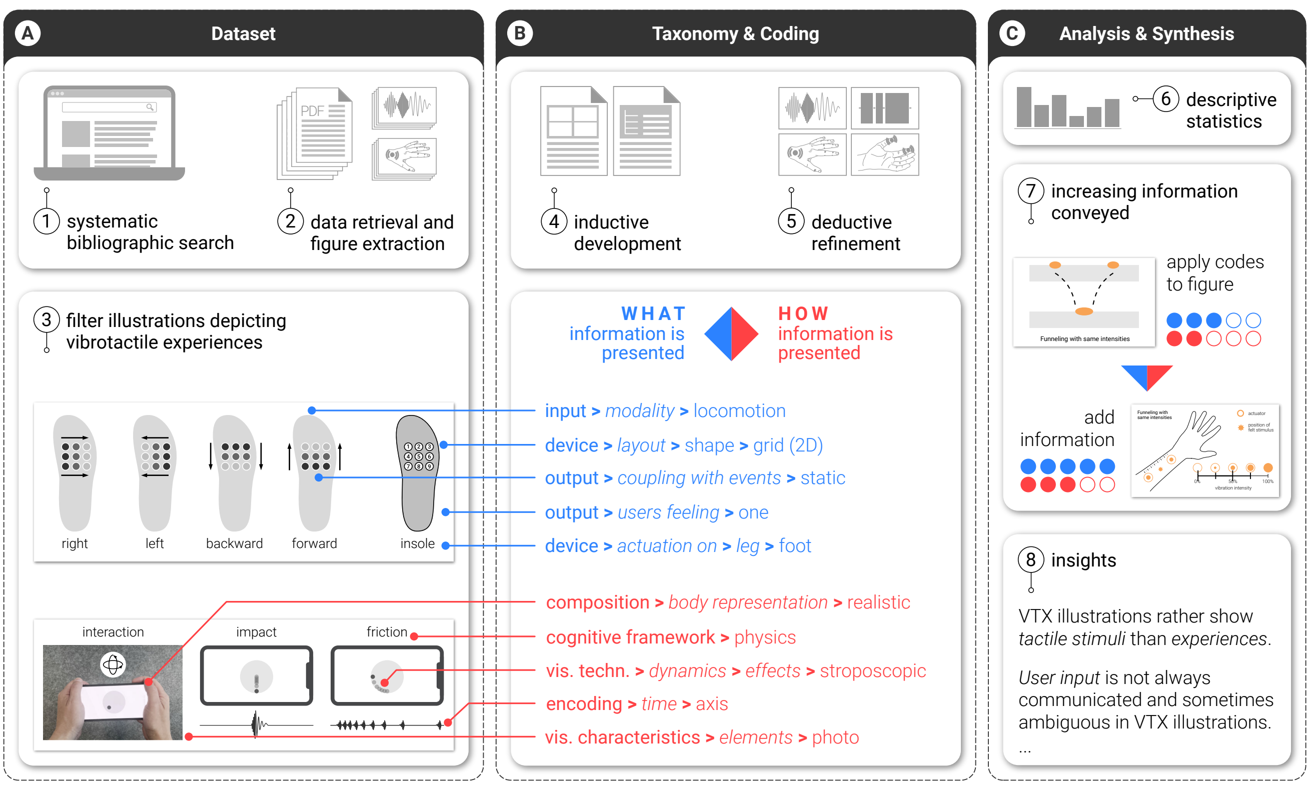


Figure 1: We collected illustrations of vibrotactile experiences from scientific literature Ⓐ. We developed and applied a novel taxonomy of illustration characteristics to code them Ⓑ. We analyzed the codes with descriptive statistics and used them to identify potential shortcomings in several illustrations for which we provide more comprehensive alternatives Ⓒ. This work uncovered several insights on the design of illustrations of vibrotactile experiences.

Abstract

Vibrotactile experiences (VTX) consist of a multitude of design parameters and experiential dimensions that can be challenging to communicate visually. To understand how this is commonly done in scientific communication, we systematically reviewed VTX illustrations in academic publications. Using inductive and deductive methods, we built a taxonomy detailing characteristics of VTX illustrations that focuses on what is illustrated and how it is depicted. Using the taxonomy, we coded a total of 768 figures spanning 409 publications. These results indicate that (1) half of the illustrations communicate on the timing of vibrotactile feedback with regards to users' actions, (2) illustrations depict stimuli rather than experiences and infrequently communicate multimodal aspects of the experiences, and (3) contextual information of vibrotactile displays and experiential aspects are often distributed across several complementary figures. We conclude by discussing the benefits and limitations of this taxonomy to support the design process.

CCS Concepts

• **Human-centered computing → Visualization theory, concepts and paradigms**; **Human computer interaction (HCI)**; *HCI theory, concepts and models.*

Keywords

haptics, vibration, vibrotactile interfaces, vibrotactile augmentation, tactile design, visualization, taxonomy, illustrations, graphical design

ACM Reference Format:

Bruno Fruchard, Dennis Wittchen, Nihar Sabnis, Paul Strohmeier, and Donald Degraen. 2026. How are Vibrotactile Experiences Visually Represented? A Taxonomy of Illustration Characteristics. In *Proceedings of the 2026 CHI Conference on Human Factors in Computing Systems (CHI '26), April 13–17, 2026, Barcelona, Spain.* ACM, New York, NY, USA, 24 pages. https://doi.org/10.1145/3772318.3790598

1 Introduction

As computing becomes increasingly multimodal [45, 68, 70], the role of touch in Human–Computer Interaction (HCI) is receiving growing attention. Vibrotactile systems are among the most prevalent technologies for tactual communication. Yet researchers and designers face a unique challenge: unlike visual or auditory communication, there is no shared standard for illustrating vibrotactile experiences. Conveying what vibrations feel like, how they are triggered in relation to user actions, and in what context they are meaningful, typically relies on translation into another modality – most often visual figures – and requires a specific visual language [7, 104] leveraging metaphors and emphasizing on their *facets* [70]. In HCI and Haptic Experience Design (HaXD) [98], where the focus is often on the emergent user experience rather than the design of the stimulus itself [2, 24], this mismatch between medium of experience and medium of communication is especially pronounced.

To support haptics researchers and designers in communicating VTX and ultimately support the replicability and reproducibility of their work [31], we take stock of the status quo. To better understand *what* information about vibrotactile design and experiences is currently encoded in illustrations and *how* this is done, we systematically reviewed figures[1] from literature. We focused on VTX that we define as *intentionally designed experiences aimed at stimulating the user's sense of touch through vibrations elicited by mechanical vibration motors*. Following a rapid review approach [109], we collected 1652 papers from ACM and IEEE[2] for the past 25 years and selected 1509 figures using eligibility criteria, then categorized them in several categories to filter out figures relating only to VTX (Figure 1 Ⓐ). We created a taxonomy both deductively by building on methods from Antoine et al. [6] that proposed a taxonomy of interaction illustrations that unifies previous work on comic books [74] and industrial design [83], and inductively by reviewing VTX figures. This taxonomy characterizes **what** is represented on an image with regard to *input*, *output* and *devices* used. It also characterizes **how** this information is represented and points out how time and vibration dynamics are *encoded*, what *visual characteristics* and *techniques*, type of *composition*, and *facets* [70] are used to represent information (Figure 1 Ⓑ).

We coded 768 VTX figures and present an empirical analysis using descriptive statistics of all the codes (Figure 1 Ⓒ). This analysis yields insights on the strategies and challenges to design VTX figures and create a coherent set of illustrations conveying significant information. Overall, we highlight that figures tend to either provide information on the vibrotactile display and its placement on the body or on the actual experiences, that for half of the figures the relation between the vibrotactile feedback and users' actions is not conveyed or ambiguous, and that experiential dimensions of VTX [53] are often not visualized.

To evaluate how this taxonomy can support illustration design, we propose two approaches. We first present 5 case studies that iterate on the design of figures from the dataset. We coded these figures and identified unchecked codes exposing information that could be added. Based on this, we provide alternate figures conveying more information on these aspects while respecting their authenticity (Figure 1 Ⓒ). We underline how these changes increase the amount of information conveyed, thus potentially better support the communication of VTX characteristics. Each case study shows how the taxonomy supports systematically investigating the illustration characteristics to identify potential shortcomings and guide the reflection on potential improvements. The second approach consists of a formative study with 11 haptic designers (4 experienced and 7 novices) whom were tasked with designing illustrations for VTX with and without support from the taxonomy. The results indicate the designers did not rely on the taxonomy to produce illustrations but used it post-hoc to analyze their decisions, and that the taxonomy was overall considered useful to guide reflections on their design choices, but required more time to fully grasp.

*Both authors contributed equally to this research.

[1]we use "illustration" and "figure" to refer to, respectively, a graphical representation of one or several VTX, and an illustration with a caption

[2]the list of all papers is available in the supplementary materials [37]

ACM ISBN 979-8-4007-2278-3/26/04
https://doi.org/10.1145/3772318.3790598

In summary, this work is guided by the following research question: *What are the characteristics of VTX illustrations in scientific papers?* To this aim, we propose a taxonomy listing characteristics of VTX illustrations and present an overview and analysis of the state of the art of visual representations of VTX. This taxonomy is designed to characterize visual representations of VTX and help reflect on their aspects while creating or analyzing them to ensure they are not missing significant information one would like to convey. We envision that, in future work, this taxonomy could also support theory development [117], for instance by acting as a mediating construct in causal modeling processes [113], thereby enabling systematic formulation, testing, and refinement of visual communication theories.

2 Related Work

This section reviews the literature on VTX and taxonomies of illustrations. We underline the various factors influencing the complexity of VTX and how they tend be to communicated in general. We then explain how previous work analyzed interaction illustrations and what taxonomies characterize them.

2.1 Diversity of VTX

Tactile receptors in the skin make the human body sensitive to vibrations, which enables to distinguish between different materials [8]. *Meissner's* and *Pacinian corpuscles* sense light touch and vibration (between 3-100Hz and 10-500Hz, respectively [18]), while *Merkel cells* and *Ruffini endings* detect sustained pressure, texture, and skin stretch [51]. Meissner's corpuscles are concentrated on the fingertips to raise acuity to shear and normal forces when picking up objects, or exploring a surface and pressing into materials [51]. Pacinian corpuscles, in contrast, are concentrated in the feet to sense vibrations relating to balance and locomotion [52]. This natural distribution over the body offers great opportunities to produce a multitude of experiences. Research in haptics and vibrotactile feedback has exploited this knowledge over decades to induce bodily experiences through controlled actuation on the skin, e.g., to reproduce material properties [28, 34, 91], simulate materials virtually [26, 29, 35, 94, 105], or create tactile illusions [61, 93].

Vibrotactile feedback can be used in numerous ways to produce different types of experiences with different goals. VTX can focus on symbolic meanings such as notifications [12, 72] or directional guidance [32, 77], or relate to sensory attributes and improve the sense of agency of physical experiences [22, 65, 92], add *physicality* to virtual visual experiences [27, 105], or produce sensory illusions [43, 59, 115]. They can be holistically characterized with *design parameters* such as timeliness, intensity, density and timbre [53], *pragmatic qualities* such as their utility, consistency, fidelity or congruency with other senses [25], and *experiential dimensions* or *mediated qualities* such as their expressivity, harmony, realism and immersion [25, 53]. The characteristics of the devices used to produce these experiences are also of great importance [18]. The type of actuators used, their form factor, their synchronicity and, ultimately, in what context they can be used all strongly influence the potential VTX felt by end-users. Depending on their design and the VT displays they rely on, the fidelity of VTX can largely vary [11, 78], impacting specific scenarios focusing on the simulation of realistic physical experiences mostly. The goal of VTX may, however, not be to maximize this fidelity, but rather rely on simple messages or metaphors that are reinforced by congruency (e.g., [45]). Authoring tools like Macaron [99], TactJam [122], CollabJam [121] or VIREO [107] (and most of the tools Terenti and Vatavu reviewed in their work) support creating such experiences with low or high-fidelity while supporting rapid design iterations.

This highlights the variety and complexity of VT displays and VTX, offering many opportunities to leverage vibrations for contextually adequate and meaningful experiences. This also underlines the many variables composing such experiences and the challenges haptic designers face when illustrating them. We present a taxonomy that exposes significant variables to consider when illustrating VTX, which can be used as a tool to guide the graphical design procedure.

2.2 Communicating VTX

The design and communication of VTX can be broadly separated in techo-centric and user-centric approaches [69]. The first approach focuses on documenting the underlying *technical parameters* of the vibration such as exposing the raw signals or design parameters through diagrams and screenshots of authoring tools, which particularly supports reproducibility (e.g., [32, 71], see Figure 2). The user-centric approach consists in communicating elements of the human experience, such as experiential metaphors and sensory descriptions like feeling heavier than usual [108] or illusory motion sensations [30]. The field of affective design and social touch list also many experiences related to human communication that improve closeness over a distance (e.g., feeling distant cheek rubs [82]), supports communication during co-located medical sessions [97], or enhance other modalities when sending messages (e.g., textual or graphical messages [49]). Illustrations often echo these techno-centric and user-centric approaches of VTX by focusing rather on the technical conditions to produce a specific stimulus, or the targeted sensation (which is then inferred as an experience) [24].

Several projects proposed to document aspects of haptic experiences to support reproducibility and replicability by classifying them and using different visualizations to help navigate design spaces. Haptipedia [101] is a web interface[3] designed to support designers in choosing adequate force-feedback based on their goals. Designers can navigate the space through multiple dimensions exposing variables such as portability, robustness, or fabricability. Conversely, VibViz [102][4] lists 120 vibrotactile signals, not devices. Signals are mostly represented visually with their intensity through time (what we refer to as a response curve). They are categorized using 5 facets: physical characteristics, sensory characteristics, emotional characteristics, usage examples and metaphors. Users can navigate the signals through 3 panels focusing on a few facets, and easily compare signals over multiple dimensions. Such tools do not focus on illustrating tactile experiences, however, as they primarily support navigating large spaces of haptic information and identifying specific conditions.

[3] the web interface is available at https://haptipedia.is.tuebingen.mpg.de/
[4] the web interface is available at https://www.cs.ubc.ca/ seifi/VibViz/main.html

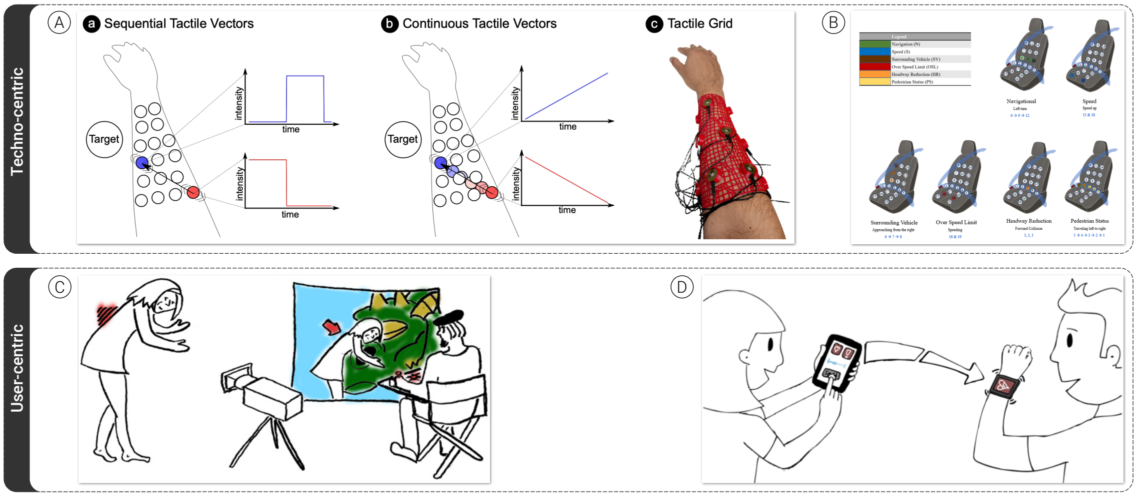


Figure 2: Examples of rather techno-centric illustrations of VTX (from [32] Ⓐ and [71] Ⓑ), as opposed to rather user-centric illustrations (from [100] Ⓒ and [49] Ⓓ).

Communicating bodily experiences is not unique to the field of haptics. Practices such as micro-phenomenology [87] and soma-design [46] regard such experiences as essential in the use of interactive systems and propose methods to facilitate designing for and reporting on them. Tools like bodymaps [4, 21, 112] illustrate body sensations on a silhouette using markers or tangible tokens and support both the reflection while designing for bodily experiences and offer means to report on them. Recently, Cavdir [16] used bodymaps to reflect on sensations to design for vibrotactile-augmented music experiences. While useful for reflection, this representation alone does not integrate technical aspects of an experience, i.e., the type of objects used to produce the bodily sensations (if any).

There exist multiple challenges when illustrating (vibro)tactile experiences. First, the illustrator must identify all the factors involved in the experience and represent them, and they must decide on what is actually significant to communicate based on their intention, i.e., should the focus be on the technical aspects, the bodily sensations, or the lived experience? Second, representing such experiences in a static format adds complexity to represent time and abstract sensations [74]. Third, there is currently no conventional graphical vocabulary to represent tactile experiences; while bodymaps are becoming more prevalent, they remain limited to convey information on VTX for instance. Illustrators, often with backgrounds in other domains than graphical design, must then come up with ideas that lack clear guidance.

The taxonomy we propose facilitates identifying what is represented on VTX illustrations and how it is represented, e.g., using visual techniques to represent timely actions in static illustrations. It also supports illustrators to reflect on missing codes that could be significant for an illustration, thus suggesting improvements by omission.

2.3 Taxonomies on Illustrations

Illustrations are useful to tell stories and convey lots of visual information that evoke specific concepts to readers. While styles and purposes can differ, illustrations are used in comic books [74], instructional illustrations [36], graphical abstract for scientific mediation [95], industrial drawings [83], to sketch user experiences [14, 40], etc. Previous work in HCI characterized illustrations of hand gestures [73], micro-gestures [60], or broader interaction scenes and scenarios [5, 6].

A comprehensive taxonomy of interaction illustrations was proposed by Antoine et al. [6] to unify previous taxonomies from various domains such as comic books [74] and industrial design [83]. It focuses on "interactive scenarios" and proposed two major types of codes indicating *how* is information represented, and *what* is being represented. Overall, they proposed six dimensions, three for each major type. *What* codes include the *interactive scenario* dimension that indicates the purpose of the image, its stillness and the activity depicted; the *users* dimension that indicates the number of users and the body part represented; the *interactive system* dimension that provides information both on input and output channels (including haptic feedback) as well as the actions being performed. *How* codes include the *composition* dimension that provides information on the point of view and layout of the illustration; the *visual technique* dimension that describes how dynamism is represented along with groups of elements and emphasis; the *visual characteristics* dimension that indicates the type of elements (i.e., text, photos, ...) and colors used.

We build on this taxonomy of interaction illustrations and its structure of *what* and *how* codes as interactive scenarios can cover many illustrations of VTX, and augment its internal structure to better match information on VTX.

3 Procedure and Methods

To answer the research question –*What are the characteristics of VTX illustrations in scientific papers?* – we structured our research process into three phases following a rapid review approach [109]. The first was *collecting figures* from literature (Section 3.1; done by two authors), the second was *establishing a taxonomy* (Section 3.2; done by all authors), and the third was *applying the taxonomy* on the data collected (Section 3.3; done by two authors).

3.1 Phase 1: Data Collection

The data collection consisted of four stages: (1) a bibliographic search, (2) the processing of bibliographic records and PDFs (Figure 3 shows the process in detail), (3) the extraction and classification of figures, and (4) the construction of the final dataset.

3.1.1 Bibliographic Search. A systematic literature search was performed on June 11, 2025 using two major digital libraries that publish research in Human–Computer Interaction (HCI) and haptics: the ACM Digital Library (ACM DL) and IEEE Xplore. The search strategy was identical across both libraries, using the keyword *"vibrotactile"* in title or abstract and restricting publication dates to the period 2000—2025.

Both the ACM DL and IEEE Xplore were filtered for peer-reviewed documents, for instance from journals and conferences[5]. We downloaded the BibTeX metadata and removed 8 duplicates using the exact matches on the combination of title, first author and publication year. The final bibliography comprises 1684 entries (532 from ACM and 1152 from IEEE). All data is available at a dedicated OSF repository [37].

3.1.2 PDF Processing. We retrieved 525 of 532 PDFs (98.7%) from the ACM DL and 1127 of 1152 from the IEEE Xplore (97.7%) and manually screened all 1652 accessible PDFs according to predefined eligibility criteria. Exclusion criteria included non-peer-reviewed works, editorials, patents, theses, articles without figures, and works focusing exclusively on other haptic modalities (e.g., pneumatic, force feedback, mid-air, electro-tactile, passive haptics, thermal, or chemical). Based on these criteria, we excluded 1097 (66.4%) PDFs and kept 555 PDFs (258 from ACM and 297 from IEEE) for further processing.

3.1.3 Image Extraction and Verification. We automatically extracted figures from the remaining 555 PDFs using `pdffigures2` [19]. It failed for 33 PDFs (21 from ACM and 12 from IEEE), which we manually reviewed to extract 80 more figures[6]. After extraction, all automatically processed PDFs (n=532) were manually checked for missing or incorrectly cropped figures.

[5]Filtering options differ between IEEE Xplore and ACM DL based on the user interface. IEEE Xplore offers conferences, journals, and early-access articles, whereas ACM DL offers more content types such as research articles, short paper, extended abstract, work in progress, etc.

[6]We manually extracted only the figures relevant for analysis.

A total of 200 figures (123 from ACM and 77 from IEEE) were added or corrected manually. In total, we collected 4425 figures (1881 from ACM and 2544 from IEEE).

3.1.4 Image Filtering and Classification. We defined five inclusion criteria to screen figures. Figures must either represent the intent behind using VT feedback, represent the context of an experience, represent one or several users, represent a VT display, or represent VT signals (see Table 1 in Appendix A for details). The filtering and classification of figures was conducted manually by two authors[7]. Out of the 4425 figures initially collected, we excluded 2916 (1185 from ACM and 1731 from IEEE), corresponding to 65.9%. We categorized the remaining 1509 figures (696 from ACM and 813 from IEEE) as *Hardware Setup*, *Study Setup*, *Study Related*, *Interactive Scenario*, *Model*, *System Architecture*, *Vibrotactile Experience*, and *Unclear* (see Figure 4).

3.1.5 Final Dataset. For the analysis, we focused on figures categorized as depicting *Vibrotactile Experiences*. Out of 837 such figures, 69 were deemed too ambiguous or insufficiently detailed and hence excluded. The final dataset consists of **768 figures depicting VTX**. These figures were retrieved from 409 papers (189 from ACM and 220 from IEEE) published between 2002 and 2025 (see Figure 18 in Appendix A), across 111 venues (43 from ACM and 68 from IEEE). The most prominent venues were: ACM CHI (50 papers), IEEE World Haptics Conference (36 papers), IEEE Transactions on Haptics (34 papers), ACM UIST (17 papers), and IEEE Haptics Symposium (17 papers).

3.2 Phase 2: Establishing a Taxonomy

To establish the taxonomy, we initially worked deductively from literature. We then iteratively tested the taxonomy on subsets of the data and further refined it to ensure its applicability to characterize VTX.

3.2.1 Deductive Design. We built on the structure of *what* and *how* codes from the taxonomy of interaction illustration by Antoine et al. [6]. We restructured the **what** codes to more specifically describe details of vibration characteristics and the physical sensations they produce. For instance, some codes focus on the characteristics of

[7]Manual filtering and classification required approximately 120 hours, completed over a three-week period.

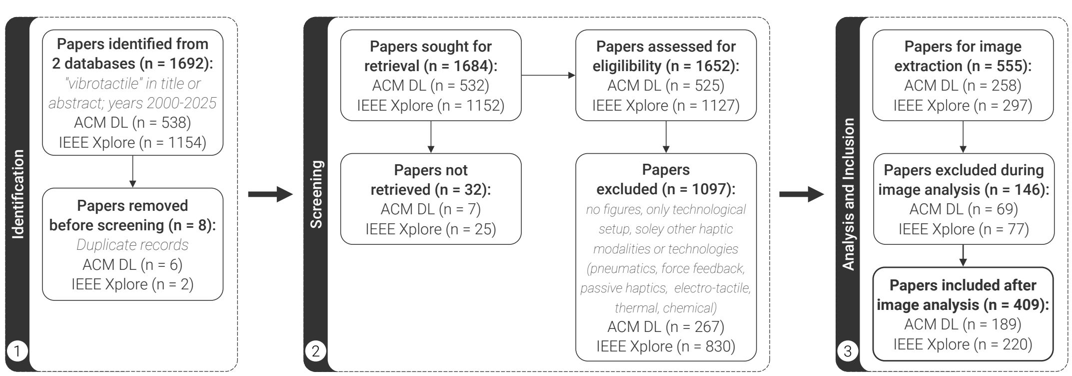


Figure 3: Flow diagram of the literature review process.

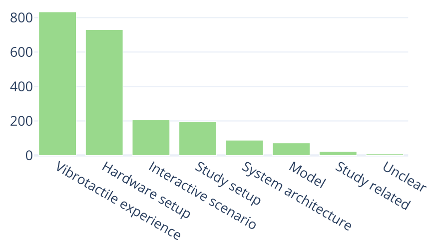


Figure 4: Count of figure types for the 1509 figures included in the dataset (696 from ACM and 813 from IEEE).

the vibrotactile displays used and the timing of vibrations with regard to users' actions. We also integrated frameworks from haptics research to identify important categories to consider. We included information on the device's *grounding* from Culbertson et al. [23] and Adilkhanov et al. [1], some experiential dimensions and design parameters of VTX from the HX model developed by Kim and Schneider [53], and the *facets* of VTX described by Seifi et al. [102] and MacLean et al. [70].

3.2.2 Inductive refinement. Once the data collection was concluded and the initial taxonomy established, we brought data and taxonomy together to ensure alignment. Four co-authors collaboratively coded 3 subsets of the datasets iteratively using Antoine et al.'s coding tool [6][8], comparing and discussing after each iteration (authors coded 42, 20 and finally 15 figures) to refine the codes.

To ensure the coherency of the resulting taxonomy, the two first authors independently coded the same two subsets of 100 figures each. Krippendorff's alpha [58] indicated satisfactory inter-rater reliability in line with previous work [6]: 62.1 (σ = 13.9) and 60.6 (σ = 12.3). Then, they collaboratively reviewed the lowest 25% of figures with the highest disagreement for each set to identify confusions and refine the taxonomy's codes.

3.3 Phase 3: Applying the Taxonomy

The remaining dataset was split between the two first authors who reviewed and coded the other 581 figures. After initial coding, each of the two authors reviewed the other's coded figures and made revisions as deemed necessary. Differences between initial and revised coding were automatically extracted and the original coder reviewed the proposed changes and either accepted or rejected them. If significant disagreements remained, both coders discussed the figure collaboratively until a consensus was reached. This procedure was designed to ensure a reliable and consistent application of the taxonomy while allowing for critical reflection and discussion to resolve ambiguity.

3.3.1 Identifying Illustration Categories. While analyzing illustrations, we identified a few categories that codes alone or even combinations of codes may not clearly distinguish. To ensure we could identify them in our analysis, we created 4 meta-codes that we used during the coding procedure. We tagged illustrations presenting *multiple experiences* which sometimes listed entire sets of VTX, illustrations depicting *tactile illusions*, illustrations exposing *design parameters* of experiences with screenshots of authoring tools or mathematical formula, and illustrations depicting vibrations as *"raw" signals* by using audio signals such as response curves (as done with VibViz [102]).

[8]accessible at https://github.com/LokiResearch/IllustrationTaxonomy

4 A Taxonomy of Illustration Characteristics

In this section, we present the dimensions, categories and codes of the taxonomy.

4.1 Dimensions, Categories and Codes

A comprehensive visual representation of the taxonomy is depicted in Figure 5. These codes were both deductively and inductively produced, which means they build on the literature of illustrations taxonomies and descriptive frameworks from haptics research, and were refined using the dataset of 768 VTX illustrations. Based on this methodology, the resulting codes comprehensively characterize all images we analyzed from the state-of-the-art. As research scenarios extend and include other input for VTX, the codes should reflect these changes and include more categories (e.g., other types of input modalities) to characterize them better.

The codes are rarely mutually exclusive. A combination of them can be used in a single category to describe experiences that involve multiple, related factors. For instance, experiences relying on a vibrotactile tablet could be considered both *touchable* or *graspable* depending on whether the tablet is being held (see Section 4.1.3 for details on these codes), in which case both codes could be checked to describe a "mixed" scenario.

4.1.1 Input (what). This dimension considers all kinds of input that impact the VTX, whether by triggering the experience or modulating it in some ways (e.g., walking while an augmented ground vibrates [114]). The dimension's overall purpose is to clarify the relation between users' actions and vibrotactile feedback (i.e., *timeliness* and *expressivity* [53]), as well as clarify the type of input and devices used for interaction. The **action** category indicates whether users are *passive*, performing *discrete* actions such as pointing at a target, or performing *continuous* movements. The **modality** category lists four primary modalities we encountered in the dataset, namely *gaze*, *locomotion*, *vocal* or *manual* interactions; manual interactions include both (virtual) object manipulation and mid-air movements. We list less modalities than previous work [6] as other categories were not representative of the illustrations we studied; note that other input modalities could be integrated in this category if it better supports the analysis. We leverage Buxton's [15] framework on input device characteristics to further describe manual interactions (**manipulation** category) using two sub-categories: the *type* and *degrees-of-freedom* of the input. We then consider the type of device used to **mediate** the users' actions, as well as the number of **users interacting** together. The last category indicates the **effect of the input on the output** and whether it is *causing* it (e.g., a vibration triggers when pressing a button or reaching a pressure threshold) or *modulating* it (e.g., rotating one's body would affect world-centric directional cues).

4.1.2 Output (what). This dimension describes the number of **users feeling** the experience, which can be different from the number of users interacting, as it is the case with an audience experiencing vibrotactile feedback during artistic representations [111].

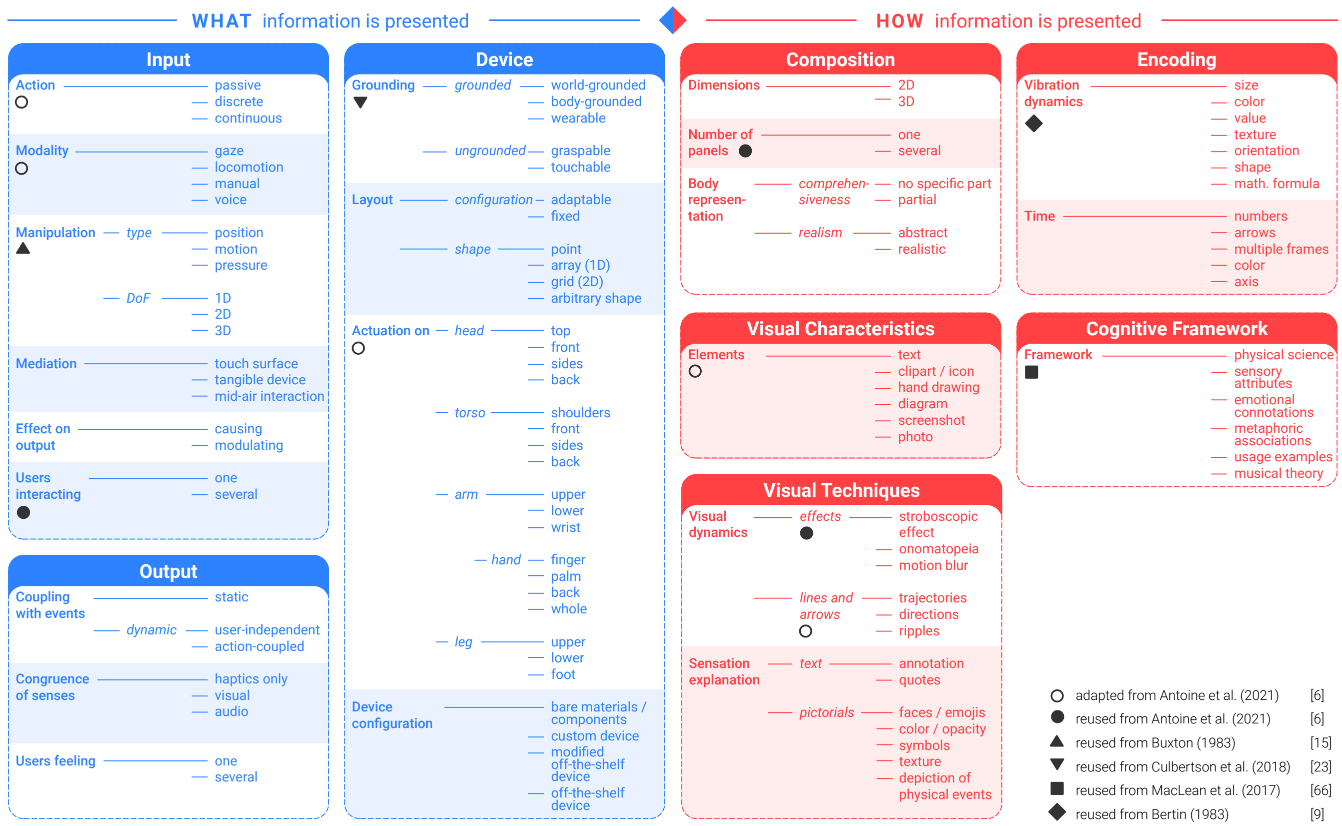


Figure 5: Taxonomy of VTX illustration characteristics. It is split in *what* and *how* codes including 3 and 5 dimensions respectively.

The **congruence of senses** category is directly inspired by the unified HX model from Dalsgaard and Schneider [25]; it indicates whether the VTX is multimodal and includes more than just the tactile sense (e.g., displaying a texture on a virtual ground [103, 105]). The last category describes the **coupling** between vibration signals and other events, i.e., whether their parameters vary according to them. These parameters can depend on events that are *user-independent* when watching an augmented movie [42], or *coupled* to user input, such as pressing on a car pedal [92] or twisting a rod [43]. If vibration signals are immutable audio messages [12] such as notifications triggered upon receiving a message, they are considered *static*.

4.1.3 Device (what). The first category describes the **grounding** of the device; we directly used types of grounding described by Culbertson et al. [23], i.e., the device is *grounded* either in the *world* or the *body* while its effector is in direct contact with the body, or is a *wearable*, meaning that the entire device is directly attached to the skin and does not move (e.g., a smartwatch). If *ungrounded*, the device can be either *graspable* (e.g., a smartphone) or *touchable* (e.g., an interactive surface like a tabletop).

We categorize the **layout** (arrangement) of actuators as being *fixed* or *adaptable*, i.e., actuators are part of the same structure or can be moved independently, and consider the effective *shape* of these layouts, i.e., whether they are independent *points*, an *array (1D)* or a *grid (2D)* (e.g., they are coordinated to produce phantom illusions [3] or apparent motion [48]), or other types of *arbitrary shapes*. We also consider the placement of actuators on the body (i.e., **actuation on** category), and consider several zones (*head*, *torso*, *arm*, *leg*), with a specific focus on *hands* as they are known to be especially sensitive to tactile stimuli [50, 118].

The last category describes the VT display **configuration**. We define four levels of configuration: *bare materials / components* describe actuators directly placed on the skin (e.g., Kinesiotape [122]), *custom assembled* devices providing a structural frame around actuators to either fix them in place or constrain their movements (e.g., integration in a shoe sole [120]), some VT displays *modify / augment off-the-shelf* devices with VT capacities (e.g., adding an actuator to a VR controller [27]), and some VTX are directly produced with *off-the-shelf devices* (e.g., using the Meta Quest 3 VR controllers [116]).

4.1.4 Composition (how). This dimension focuses on the structure of the illustration. It indicates the **number of panels** composing the illustration and the number of **dimensions** used to convey information, e.g., *2D* diagrams, or *3D* pictures. The **body representation** category indicates whether users' bodies are represented, and to what detail. This representation is *realistic* when representing actual body limbs or parts, and *abstract* when suggesting a body part (e.g., showing a cylinder as a transversal cut of a forearm, see left of Figure 6 Ⓐ). It can represent the body *partially* by focusing

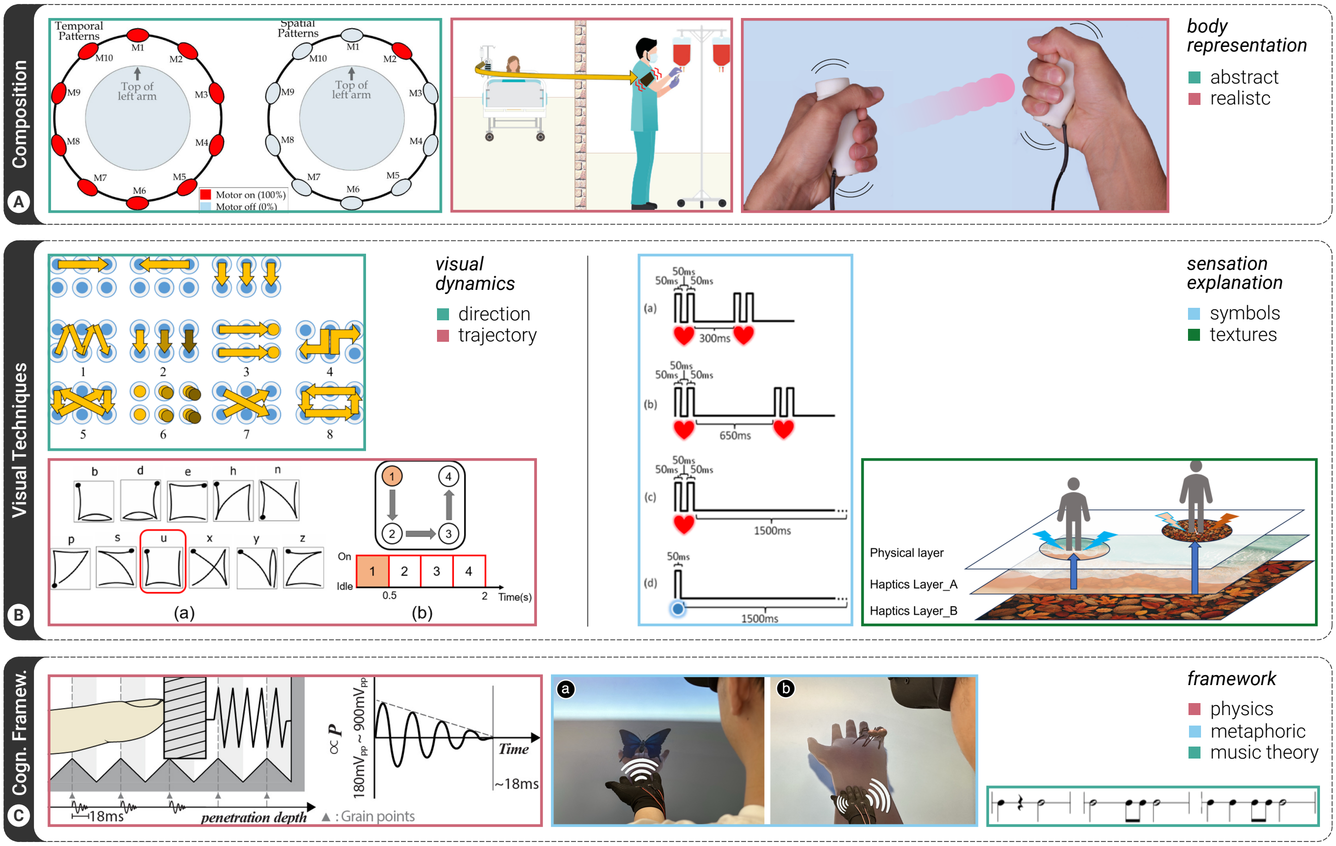


Figure 6: Ⓐ shows examples of body representation extracted from [84], [20] and [86] (left to right). Ⓑ shows on the left examples that use lines and arrows to illustrate directions (from [67]) and trajectories (from [57]) of vibrotactile feedback through time and between actuators; and on the right illustrations conveying information on the physical sensation, through symbols (from [75]) or through textures (from [110]). Ⓒ shows illustrations using different cognitive framework: physical science (from [54]), metaphors (from [106]), and music theory (from [44]).

on specific parts (e.g., one hand), or without a focus (e.g., showing the entire torso).

4.1.5 Visual Characteristics (how). This dimension indicates the textual and pictorial **elements** used in the illustration. We reuse the codes from Antoine et al.'s [6] work, excluding information on color types and line styles.

4.1.6 Visual Techniques (how). This dimension points out the techniques used to convey time-related or sensory information. We reuse the **dynamic** category from Antoine et al. [6] that includes the *stroboscopic*, *motion blur*, and *onomatopoeia* visual effects to indicate temporal events, as well as lines and arrows for *trajectories* and *directions*. We added the *ripples* code as many illustrations represent vibrations using them. The trajectories and directions codes include both objects or people moving in space and the "displacement" of vibrations between actuators through time (Figure 6 Ⓑ left).

The **sensation explanation** category indicates whether the illustration provides information on the sensation *targeted* (theoretically) or *induced* (verified empirically). We differentiate textual information such as *quotes* and *annotations* from pictorial elements such as *symbols* or *textures* (Figure 6 Ⓑ right).

4.1.7 Encoding (how). While visual techniques convey information on time, we wanted to go beyond and characterize how variables like time or vibration dynamics (intensity, frequency) are encoded on the illustration. **Time**, for instance, can be encoded through the *axis* of a plot, using *numbers*, or *multiple frames*. **Vibration dynamics** include design parameters of vibrations described by Kim and Schneider [53], i.e., the intensity, timbre and density. We code these using Bertin's visual variables [9] and add the *mathematical* representation that was used in several illustrations.

4.1.8 Cognitive Framework (how). We integrated the five *facets* of haptic experiences described in MacLean et al.'s [70, p. 114] work, originally from Seifi et al.'s [102] work. These facets are aspects of VTX, and can be seen as a framework to present them and reflect on them. For instance, a VTX can be described using *physical science* with plots and measures, or through *metaphors* such as representing a butterfly landing on the hand (Figure 6 Ⓒ, middle). They can relate to *usage examples* like directional guidance when walking [85] or mappings of letters to vibration patterns [79], or focus on *sensory attributes* to describe tactile illusions. We call these facets *cognitive framework*, and add *music theory* to the list

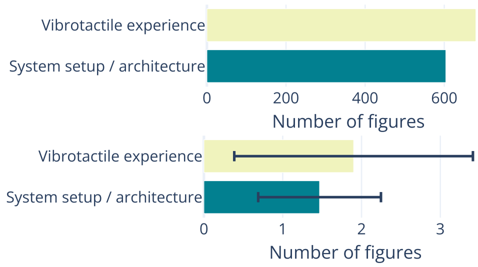


Figure 7: Count (top) and average per paper (bottom) of figures depicting VTX and hardware setup / system architecture. All figures belonging to both categories were removed, so the two sets are exclusive.

as some illustrations use concepts related to tempo and pitch to describe vibrations (Figure 6 Ⓒ).

5 Statistical Analysis of the Coded Figures

In this section, we present a descriptive statistical analysis of the coding procedure results. We provide information on the figure types and their proportion in papers, and provide descriptive statistics per dimension and category. To support reproducibility and allow other or further analyses, all the data and statistical analysis can be found online in the OSF repository [37].

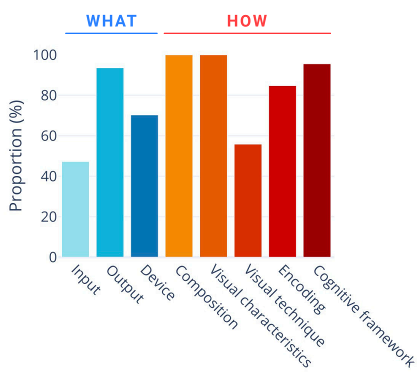
5.1 How is Information on Devices Conveyed?

Figure 7 depicts the number of figures representing VTX and hardware setup(s) or system architecture(s). The two sets represented are mutually exclusive, which means that these VTX figures are not providing information on the system (i.e., no codes used in the **Device** dimension). These results indicate that, overall, both types of figures seem to be used in papers, thus information on the vibrotactile display(s) can often be presented outside the context of VTX.

5.2 What Information is Primarily Conveyed in VTX Illustrations?

Figure 8 shows the proportion of figures coded with codes from each dimension and category. We counted a figure only once per dimension/category, even if it used several codes from it.

The most striking result is that the *Input* and *Visual Technique* dimensions were used in 363 figures (47.3%) and 429 figures (55.9%) respectively. This indicates that user input is explicit for half of the figures, and remains ambiguous or unspecified for the rest. While this information might clearly be conveyed verbally or through the context of the paper, this shows an important trend in VTX illustrations.



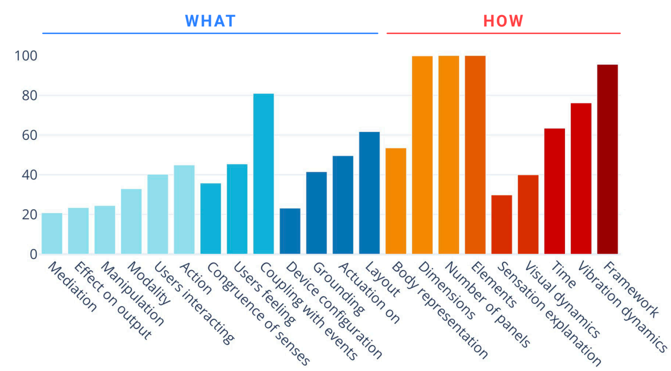


Figure 8: Proportion of dimensions (left) and categories (right) used for all figures in the dataset. Each figure is counted only once per dimension/category, even when using several codes from it.

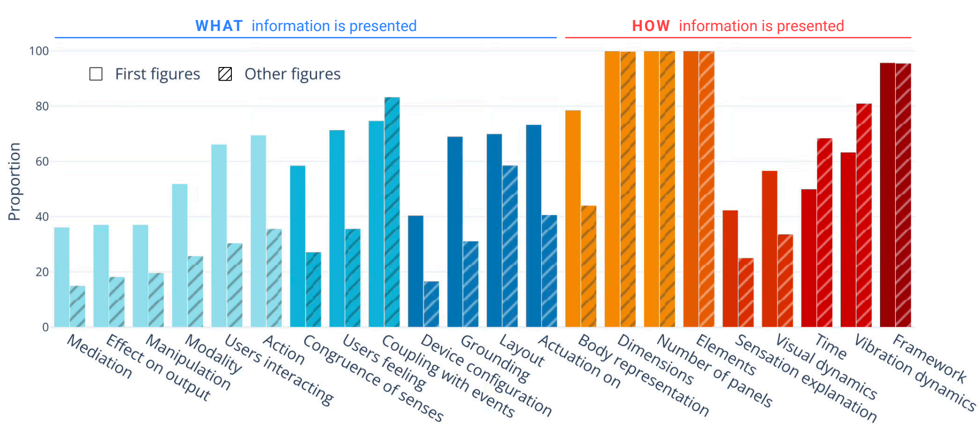


Figure 9: Proportion of codes per category for the *first figures* in a paper (plain bars), and all *others* (striped bars).

The *Device* dimension is also considerably less represented than others with 540 figures (70.3%). This resonates with the results from section 5.1, suggesting that information on devices is likely conveyed in figures that are not focused on VTX.

Details regarding categories (Figure 8-right) indicate that illustrations are often not including information on the number of users involved (users interacting 40.2%, users feeling 45.4%), whether senses are used congruently (35.8%), which part of the body are actuators placed on (body representation 53.5%), explanations of sensations (29.8%), and visual dynamics (40%). We detail results regarding each category in Section 5.3.

5.2.1 The first appearing figures in papers tend to provide broader information than the others. We consider for this analysis the position of a figure in a paper. We compare the first figures appearing in papers, that are sometimes teaser figures[9] located right underneath the title, to the others; Figure 9 shows the proportion of codes used for first figures (210 figures in total) and the others (558 figures). This analysis yields that the first figures in papers provide more information than others on multiple aspects, especially with regard to *what* is represented as differences are remarkable[10] for 7 *what* categories and a single *how* category. Considering only remarkable differences larger than 25%, first figures depict more often the users involved (interaction 35.7%, feeling 35.8), their action (33.9%) and the input modality (26.1%), the device's grounding (37.9%), the body representation (34.5%) and body parts used for actuation (32.7%).

5.3 Descriptive Analysis for Each Dimension of Codes

We present the descriptive statics for all dimensions and codes on Figure 10 (*what* codes) and Figure 12 (*how* codes). Note that one figure can use several codes from the same dimension, meaning that proportions within a dimension can go beyond 100%. For instance, actuators can be placed on the forearm and the hand.

5.3.1 Input. Codes from this dimension are used in total for 363 figures (Figure 10). Most figures depict a single user interacting (75.8%,

[9]Teaser figures are only found in ACM papers.

[10]We consider differences as "remarkable" beyond 25% gaps

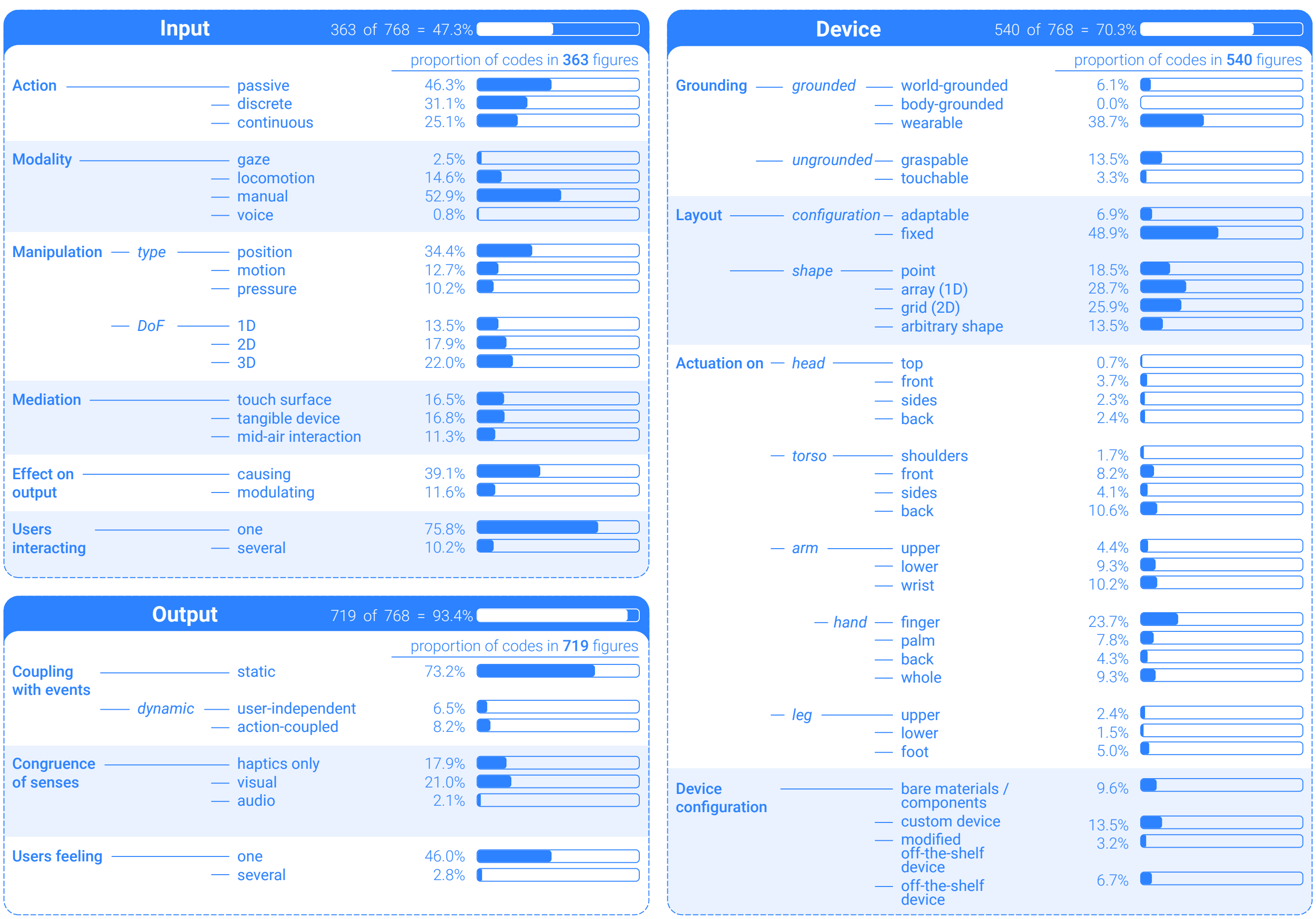


Figure 10: Descriptive statistics for all *what* dimensions, categories and codes. Proportions at the dimension level are calculated relative to the entire dataset (e.g., 363 out of 768 figures for Input), whereas proportions within a dimension are calculated relative to the total number of figures in that specific dimension (e.g., 363 figures as baseline for Input).

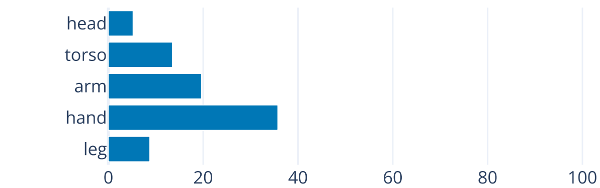


Figure 11: Aggregated results for each body part as proportion of the 540 figures in the *Device* dimension.

275 figures) as opposed to only a few showing two users collaborating (10.2%, 37). Users were almost evenly depicted performing discrete (31.1%, 113) and continuous (25.1%, 91) actions, than being passive (46.3%, 168) while experiencing the feedback. 25% of these "passive" figures depicted locomotion, while the primary modality was manual (52.9%, 192). Most actions indeed consisted of isometric pointing (34.4%, 125), often using mediated objects like tangible devices (16.8%, 61) or touch surfaces (16.5%, 60).

5.3.2 Output. Codes from this dimension are used for 719 figures in total (Figure 10). The results yield three important insights: (1) the VT feedback is much more often static (73.2%, 526 figures) than dynamic (14.7%, 106 - both action-coupled and user-independent codes combined), at least in their depiction; (2) the number of users experiencing VT feedback is explicit for about half of the figures we reviewed (417 figures do not convey this information in the dataset), and scenarios are often including single users (46%, 331) rather than several (2.8%, 20); (3) less than half of the illustrations provide information on the congruence of senses (41.0%, 295). The tactile sense is associated the most with the visual sense (21.0%, 151), and very rarely with hearing (2.1%, 15). Many figures (17.9%, 129) depict scenarios in which no congruence is depicted.

5.3.3 Device. Codes from this dimension are used for 540 figures in total (Figure 10). Many illustrations depict fixed configurations of actuators (48.9%, 264 figures) as opposed to independent actuators offering adaptable topologies (6.9%, 37). Actuators are more often used as arrays (28.7%, 155) than 2D grids (25.9%, 140). Devices are

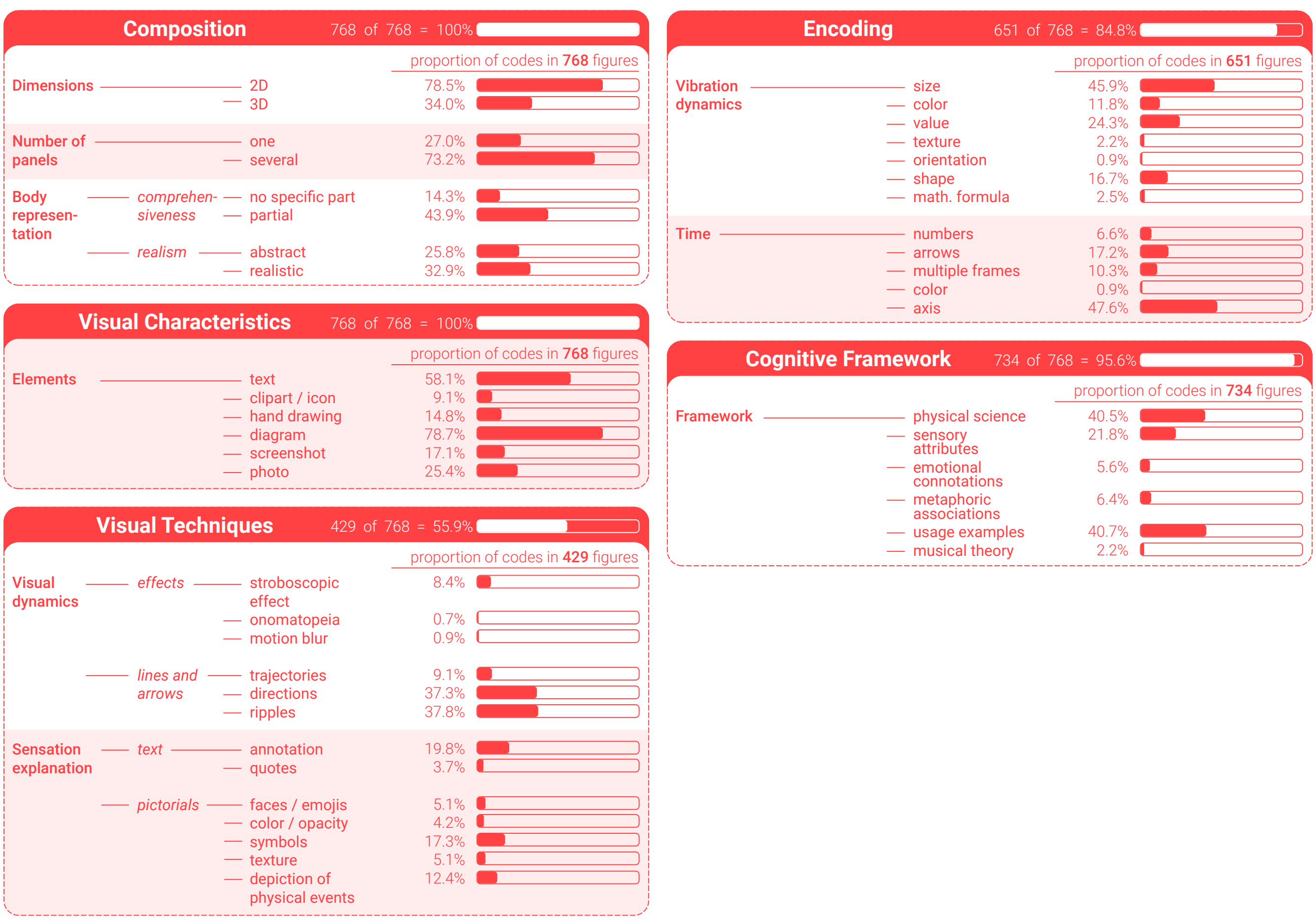


Figure 12: Descriptive statistics for all *how* dimensions, categories and codes. Proportions at the dimension level are calculated relative to the entire dataset (e.g., 651 out of 768 figures for Encoding), whereas proportions within a dimension are calculated relative to the total number of figures in that specific dimension (e.g., 651 figures as baseline for Encoding).

more often wearables (38.7%, 209) than graspable (13.5%, 73) or world-grounded (6.11%, 33).

We aggregate on Figure 11 all codes for each body parts to assess which ones are the most represented. Hands are the most often depicted or mentioned to place actuators (35.7%, 193), followed by the arms (19.6%, 106) and the torso (13.5%, 73). These results indicate VTX primarily involve the upper body, especially the wrist (10.2%, 55) and hands, with a focus on fingers (23.7%, 128).

5.3.4 Composition. Codes from this dimension are used for 768 figures in total (Figure 12). The results yield that 447 figures (58.2%) represent body parts, either in a realistic or abstract way, while the others do not. A bit less than half of the figures depict body areas in detail (337, 43.9%) while the rest shows larger body parts (110, 14.3%). Illustrations often use 2D (78.5%, 603) as opposed to 3D (34%, 261) to convey information.

5.3.5 Visual Characteristics. Codes from this dimension are used for 768 figures (Figure 12). Interestingly, most illustrations are composed of diagrams (78.6%, 604 figures) and textual annotations (58.1%, 446) showing an overall trend towards technical illustrations.

5.3.6 Visual Techniques. Codes from this dimension are used for 429 figures in total (Figure 12), which is about half of the entire set. Most of the visual effects were depicted with ripples (37.8%, 162 figures) or directions (37.3%, 160). Trajectories (9.1%, 39) and stroboscopic effects (8.4%, 36) were less used. When information on sensations is conveyed, illustrations mostly use annotations (19.8%, 85), symbols (17.2%, 74) or depict physical events (12.4%, 53).

5.3.7 Encoding. Codes from this dimension are used for 651 figures in total. For about half of the figures, time is encoded in illustrations as an axis (47.6%, 310), which is commonly used when representing response curves or vibration signals. Time is sometimes encoded as arrows (17.2%, 112) or using multiple frames (10.3%, 67) and numbers (6.6%, 43) to show what actuators are triggered in a sequence.

Visual variables are used to show vibration dynamics, usually by varying the size when showing signals as response curves or diagrams on 2D plots (45.9%, 299), using the value (i.e., opacity) as intensity of actuators (24.3%, 158), or shapes (16.7%, 109) and colors (11.8%, 77).

5.3.8 Cognitive Framework. Codes from this dimension are used for 734 figures in total. Illustrations represent mostly VTX as usage examples (40.7%, 299 figures), and use physical science to describe their characteristics (40.5%, 297). This resonates with time being often represented as an axis, and illustrations including diagrams. A little more than a fifth of the figures leverage sensory attributes to describe haptic experiences (21.8%, 160), and less utilize metaphoric associations (6.4%, 47) or emotional connotations (5.9%, 43).

5.4 Identifying and Characterizing Categories of Illustrations

Figure 13 shows the set of codes used the most with each meta-codes we presented in Section 3.3.1. For context, it is important to know that the most frequent codes in the dataset are: *visual characteristics* > diagram (78.6%), *composition* > dimensions 2D (78.5%), *composition* > several panels (73.2%), *output* > static (68.5%), *visual characteristics* > text (58.1%); the rest is below 50%.

Looking at codes used more than 80% for each category of illustrations, *how* codes seem to be the most representative of these categories. Figures showing *multiple experiences* are represented mostly by multiple panels, 2D diagrams and static vibration patterns. Figure 14 Ⓐ shows examples of such illustrations.

Figures *showing signals* are intersecting with the previous category (see Figure 13). A few codes are particularly relevant for this category: time is almost always represented as an axis (94%), vibration dynamics (e.g., signal intensity) are often mapped to size (87.6%), and these illustrations rely mostly on *physical science* (86.2%) to explain the experiences. Illustrations are also often composed of 2D diagrams (*2D*, 93.5%; *diagram*, 88%). All these results point to the fact that signals are often depicted using response curves. Figure 14 Ⓑ shows examples of such illustrations.

Illustrations depicting or explaining *tactile illusions*, on the other hand, use codes more evenly, making them challenging to identify with code combinations. The codes the most used indicate again that illustrations use 2D elements and diagrams, which does not help in identifying specific characteristics of these illustrations.

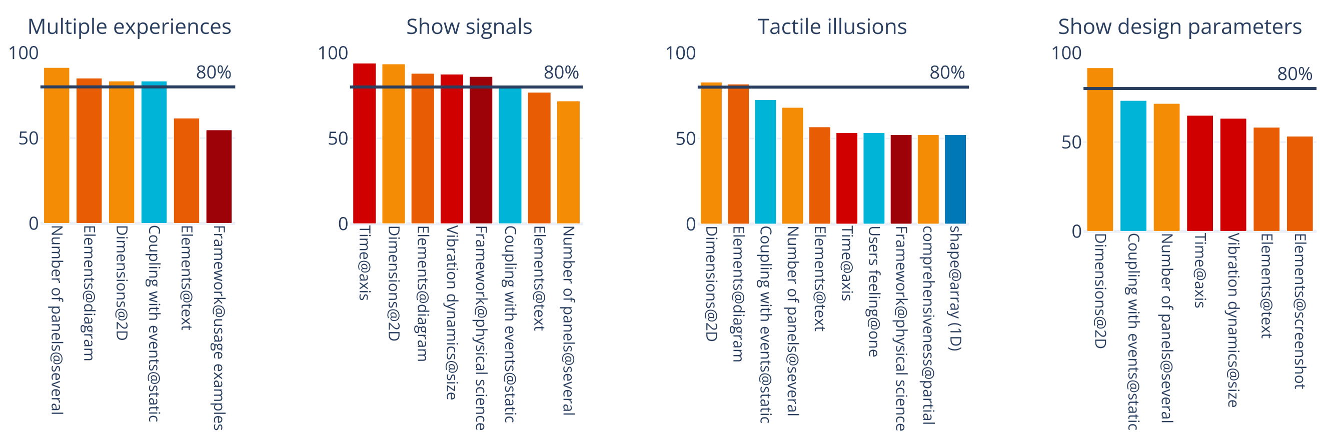


Figure 13: Proportions of the most used codes (above 50%) for the four meta-codes. Each subset represents, from left to right, 290, 217, 88 and 60 figures. We use an 80% threshold to highlight largely used codes.

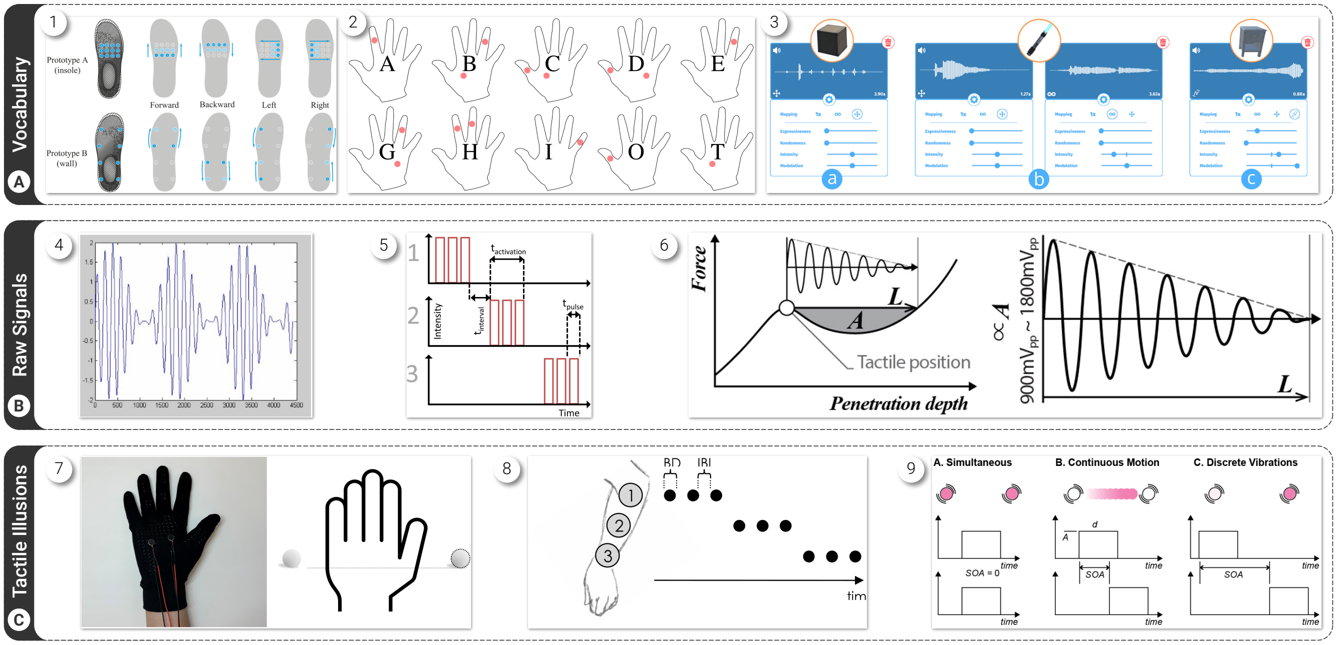


Figure 14: Examples of Ⓐ "vocabulary" figures presenting multiple experiences, Ⓑ "raw signal" figures depicting signals' response curves, and Ⓒ "tactile illusions." Figures are extracted from: [76] ①, [66] ②, [27] ③, [13] ④, [100] ⑤, and [54] ⑥, [106] ⑦, [88] ⑧, and [86] ⑨.

Figure 14 Ⓒ shows examples of illustrations of two tactile illusions, which elicit the sensation of a moving object on the skin.

Regarding illustrations that *expose design parameters*, they also do not rely on specific characteristics as their most frequent characteristic is to use mostly flat graphical elements (91.7%, 55). Like tactile illusions, the type of content represented to show such parameters is too broad to exactly pinpoint a specific code combination.

6 Reviewing VTX Illustrations

In this section, we illustrate how the taxonomy can support the review and iteration of the design of VTX illustrations. We reviewed five illustrations from the dataset in depth by applying codes from the taxonomy and identifying those which could be added to support visual communication. Based on this analysis, we propose variants (Figure 15) that convey information on these other categories while preserving VTX authenticity, based on their caption and explanations in the paper.

It is important to note that these figures may not include certain information *on purpose*, and that this information may be provided with other figures or other means in the original paper. Besides, we can only interpret their original purpose and intention based on their caption and explanations in the paper. Thus, we do not claim to correct these illustrations; our endeavor is solely to demonstrate how the taxonomy supports identifying potential shortcomings and guide the reflection on finding solutions in further design iterations.

Figure 15 Ⓐ shows two users interacting and feeling vibrations through a blanket [97]. This illustration provides ambiguous information on the *manipulation* performed, the device's *layout* and the *time abstraction* as the timing of events is unclear. The alternate illustration uses several panels to clarify the timing of events, clarifies that a button is being pressed to trigger and control the intensity of vibrations, and that one user controls the input while the other feels the vibrotactile feedback. We added a speculative quote that would potentially describe the sensation.

Figure 15 Ⓑ shows a funneling illusion [17]. In this case, no information is provided on the *actuators' positions* on the skin, and the symbol used for *explaining the sensation* is similar to the shape of actuators, introducing ambiguity. The alternate illustration situates the experience on the forearm (which was the position used in the experiment [17]), and visually clarifies the position of actuators, their intensity, and the actual sensation their combination produces.

Figure 15 Ⓒ represents vibrotactile messages felt on the fingertips, conveying the relative position of a flying drone to a physical object [47]. The paper presents this experience as visually immersive, but the illustration does not convey this (*congruence of senses*). Furthermore, the number of *users interacting/feeling* and the trigger for vibrations are ambiguous (*coupling with events*). The alternate version adds information on the *congruence of senses* by depicting the virtual scene, it shows that VT feedback are associated to the drone's position, and it proposes a speculative trigger for vibrations as none is presented in the paper.

Figure 15 Ⓓ is described in [96] as "the user uses his index finger to interact with a virtual object" and presents the user's finger trajectories with visual and visual+tactile feedback. We identified that the user's movement (*visual dynamics*) and the visual/tactile congruence (*congruence of senses*) could be more explicit. In our alternate version, we added this information with a stroboscopic effect and drawing a trajectory, and explicitly visualized that the user is manipulating a visual virtual object.

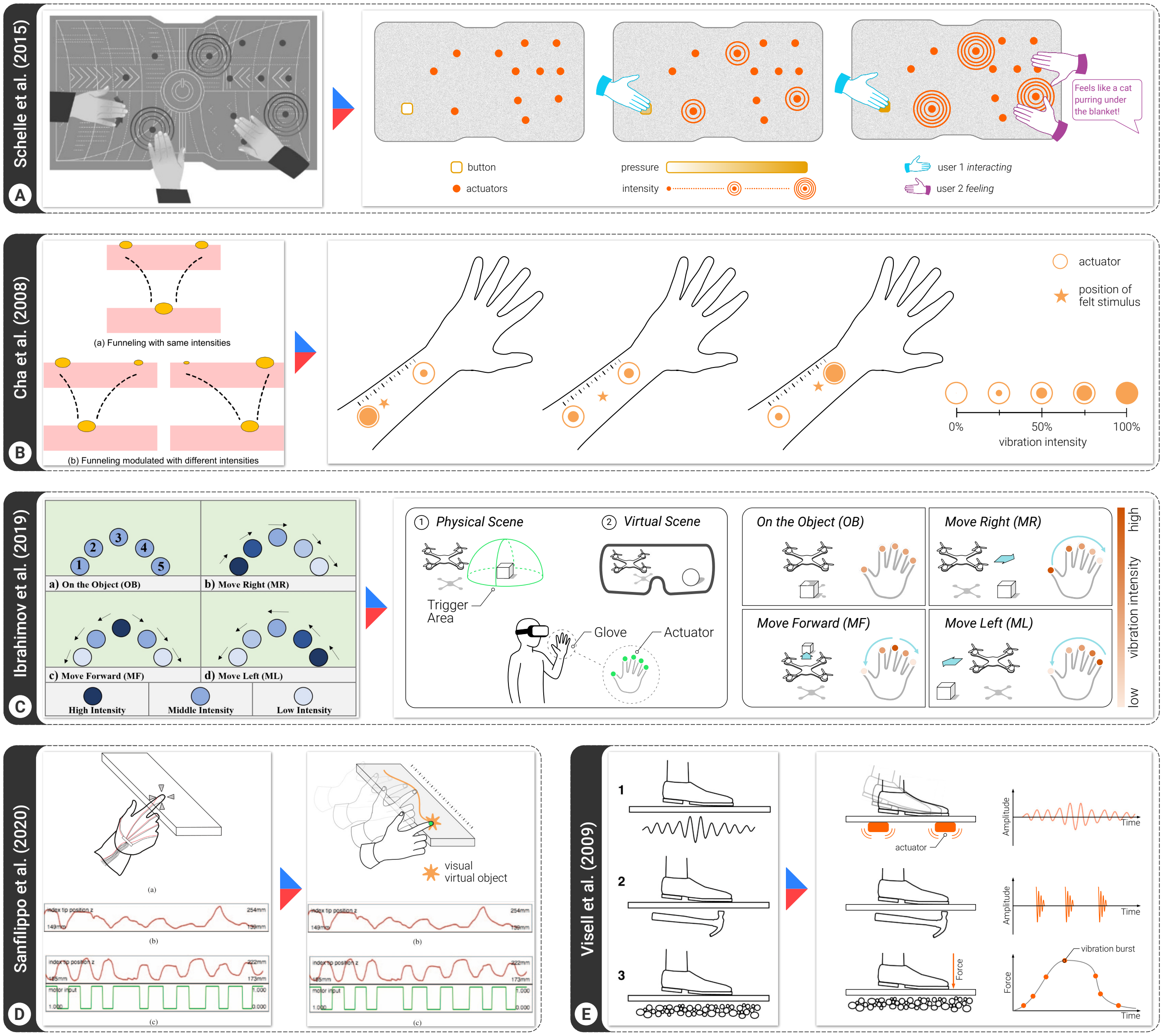


Figure 15: Examples of figures that do not convey all information about the VTX they depict (left-hand side). We propose alternate, more comprehensive illustrations (right-hand side). Figures are extracted from: [97] Ⓐ, [17] Ⓑ, [47] Ⓒ, [96] Ⓓ, [114] Ⓔ.

Figure 15 Ⓔ shows a VTX when walking on an augmented floor [114]. The illustration does not include codes on *actuator placement*, nor on *user input* as the user's walking activity is not explicit. Also, the sensations are only suggested and their *coupling with events* could be clarified. The alternate illustration adds a stroboscopic effect to clarify the user is walking on the ground, clarifies the position of actuators in the floor, and clarifies the action-coupling behavior of the "gravel" experiment.

7 Designing VTX Illustrations

We conducted a formative study to evaluate 1) *whether the taxonomy is understandable and usable*, and 2) *how it supports the design of VTX illustrations*. This study included participants with and without experience in haptic design and VTX to assess whether prior knowledge is required to make use of the taxonomy. They were provided with textual prompts describing VTX and asked to illustrate the experience. We used a within-subject design and captured textual data through semi-structured interviews (verbal transcripts).

7.1 Participants

We recruited 11 participants from our institutes and research network with different experience levels in haptics and VTX (7 novices and 4 experienced, respectively denoted by NPx and EPx). None of the participants were familiar with the objectives of this research before the study. Demographics are listed in subsection B.2.

7.2 Procedure

The study included three sketching tasks involving different VTX illustrations: (1) a warm-up exercise, (2) a prompted VTX illustration created without reference to the taxonomy, and (3) a prompted VTX illustration produced after participants had been introduced to the taxonomy. We denote the first task as *VTX-0*, the second as *VTX-1* and the third as *VTX-2*. *VTX-1* and *VTX-2* were counterbalanced to avoid order effects. The full prompts are provided in subsection B.1.

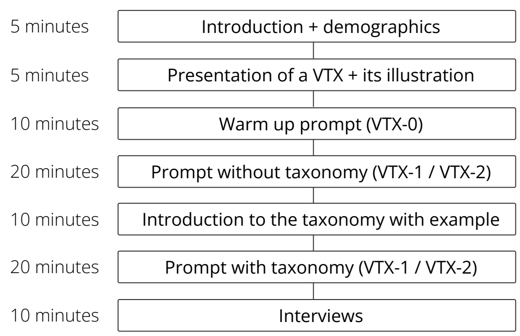


Figure 16: Structure of the formative study for each participant.

The procedure is detailed in Figure 16. After completing demographics forms, participants were introduced to the study and the concept of VTX using several examples from the dataset. They were first provided with a warm-up prompt (VTX-0) and had time to ask question before sketching for five minutes. This helped participants become familiar with the task and response format, and ensured smooth engagement with the main tasks. Then, they were provided with another prompt – VTX-1 or VTX-2 – (up to 5 minutes for explanation and potential questions) and had 15 minutes for sketching. This task served as the baseline for participants' reflection during the post-hoc interview. After this sketch, the experimenter introduced them to the taxonomy through verbal examples of VTX and their codes, and answered any questions they might have. Then, they were introduced to the last prompt (either VTX-1 or VTX-2) and had to sketch for up to 15 minutes with support from the taxonomy; the taxonomy as seen in Figure 5 was provided as a printout to each participant. The study finished with semi-structured interviews composed of the following guiding questions: *"How did the taxonomy influence your design choices?"*, *"Did you rely on the taxonomy to guide your choices?"*, *"How constraining was was the taxonomy?"*, *"Was there something missing in the taxonomy?"*

The study was conducted in different sessions. The experienced participants were interviewed individually, three online (EP1, EP2, EP3) and one in person (EP4). The novice participants participated in person in the context of a design research seminar. They were interviewed in groups of three and four depending on the prompt order. Each session lasted about 80 minutes.

7.3 Analysis

Two co-authors independently reviewed the interview transcripts and inductively coded them using thematic analysis [10]. Their goal was to identify how participants appropriate the taxonomy, as well as patterns or strategies when using it, and if and how the taxonomy supports designing images for VTX. All transcripts and the code-book are available as supplementary materials [37].

7.4 Results

We list in this section all codes inductively created from the transcripts in 3 general themes: the *benefits* and *challenges* of using the taxonomy, and how it was integrated in the *design process*. Overall, we did not observe clear differences in judgment between novice and experienced participants towards the taxonomy and its usage.

7.4.1 Benefits of using the taxonomy. First, the taxonomy has potential to *spark ideas* in one's mind, and particularly point out information that could be useful to convey to others (*"What I did use was the visual characteristics and the visual techniques. [...] It sparked some ideas [and] might help me communicate it to others. Not just as like a recording for myself to come back later on, but what would be needed to help someone else without me being present to understand what I wanted to say. So in that sense, I think that was really helpful" EP1*). The taxonomy was mostly useful to *provide a list of characteristics* to consider for illustrations (*"it's always good to know your options. So yeah, I think it's definitely a tool that can be helpful" EP3*, *"I don't have this [characteristic] at all. [...] I could have done that." NP4*, *"I found it a good instruction to always have the possibility space in front of my eyes and then to think a little about it" EP4*), which sometimes led to *changing the structure* of their sketches (*"[with the taxonomy] you had the possibilities what you could do and some ideas how you could maybe structure your illustration. And I did some things differently." NP4*). This list was sometimes, however, *missing clear guidelines* to better support the design process (*"knowing your options are good, but it doesn't help you to make the choice on which options you should choose" EP3*, *"I had the feeling that it was more of a categorization sheet for me, that it was a possibility space" EP4*, *"this is like interesting to see [...] what am I missing? Where do I put like the actual work that I did, but less as a guiding tool" EP2*). It helped participants *reflect on their choices* (*"I [don't] think [the taxonomy] changed that much [my] own ideation [...] but it definitely have like an influence in the way that I was like: 'oh, okay, what I'm doing is a metaphoric association"' EP3*).

7.4.2 Challenges when using the taxonomy. Several participants noted that the codes were sometimes *too abstract and challenging to understand* without clear visual examples (*"in some instance, I was a bit confused on the wording" EP1*, *"it's hard to visualize text. If you have examples on each of the things [...] then it's easier to visualize" NP3*). They also remarked they would have *needed more time* to fully grasp the taxonomy and use it to its full extent (*"having it explained once is maybe not enough exposure for you to really have like the appropriation of it" EP3*, *"I maybe would need some time [...] to integrate [...] the taxonomy and to [...] use it really as a tool" EP2*). One participant stated they *did not use the taxonomy* as it did not match their design process (*"I didn't really use the [taxonomy] [...] this didn't really affect any of my sketch" NP1*), highlighting they did not see benefits in this approach.

7.4.3 Design process with the taxonomy. The only process we observed during the study was participants using the taxonomy post-hoc, after a first round of sketches. They did not seem to use it in a generative manner, looking at codes to get inspirations on what type of information to convey. Some participants commented on this, highlighting this was consciously part of their process (*"I would use this after I create it so I can check if there's anything else to improve on my sketch" NP1*, *"I was more trying to fit my way of representing into the taxonomy than fit the taxonomy to my way to represent it" EP3*).

8 Discussion

In this section, we discuss insights on VTX illustrations and how the taxonomy supports the visual design process. Our analysis of VTX illustrations yields several important insights on their characteristics and uses:

(1) information on vibrotactile displays tends to be shown in other dedicated figures,
(2) information on the context of use of VTX is visualized in dedicated figures if represented visually at all,
(3) categories of illustrations are challenging to distinguish based on their visual appearance,
(4) VTX illustrations tend to represent static scenes without direct links to users' actions, and
(5) they rather provide information on *stimuli* than *experiences* produced by vibrotactile displays.

We also uncovered insights on the benefits of the taxonomy to design illustrations through the case studies and formative study: it does not guide the design process but facilitates identifying potentially missing information in VTX illustrations, and while designers might have difficulties to leverage it on the short term, it helps them reflect on their choices and may spark ideas.

8.1 Illustrations Are Complementary: VT Displays and Contexts of Use Are Represented in Dedicated Figures

Our analysis shows, on one hand, that a third to half of the figures do not provide information on users' actions (47.3% of figures provide such information), device (70.3%) and body parts (53.5%). On the other hand, papers contain in general figures providing information about system / hardware that are separated from VTX illustrations (Figure 7). Taken together, this indicates that information on the context of use of VTX and the system they rely on is distributed over multiple dedicated figures, or explained textually without visual representations.

We identified an emphasis in the first figures of papers on this aspect. As opposed to other figures, teaser figures focus on the input type and modality used by end-users, the grounding and layout of the device, and body parts involved in the experience (Figure 9). This choice of narration can be explained through the theory of *pictorial semiotics* [41, 104] and the fact that VTX illustrations are used to narratively focus [39] on specific instances of *stimuli* or *sensations* a system can produce.

However, identifying the exact purpose of VTX illustrations remains challenging. We identified combinations of codes representing "vocabulary" figures that incorporate multiple VTX intentionally and others representing figures that depict *raw* signals (see Figure 13 for the codes and Figure 14 for examples). We did not, however, identify such combinations for figures depicting *tactile illusions*, nor exposing *design parameters* of VTX. Our interpretation of this is that such figures can be approached differently, and while showing similar content, have very different visual characteristics. For instance, a tactile illusion can be represented with or without context as shown in Figure 14 Ⓒ.

8.2 Illustrations Tend to Represent Static Scenes

Time is a crucial factor, particularly for vibrotactile feedback, as vibrations have inherent duration and produce certain *density* of information through periods of time. Their timing to users' actions (called *timeliness* by Kim and Schneider [53]) is essential in certain scenarios, for instance, to reproduce the feeling of exploring materials surfaces [62, 63, 91], create the experience of movement [30], or produce virtual materials [105]. Yet, our analysis indicates that more than half of the illustrations are not providing information on users' actions (47.3% of all figures, see Figure 10), that visual dynamics are used on 40% of the figures (Figure 12), and that 73.2% of the experiences rely on static vibration patterns (Figure 10) that do not adapt to external events (either action-coupled or user-independent). Figure 17 Ⓐ depicts examples of figures not showing user input.

The illustrations in the dataset can be described using three categories [104], represented in Figure 17 Ⓑ; they either present events happening through time (called an *action scheme* [104]) and are *multi-phasic pictures*, or they show static pictures of recognizable events and are *implied temporality pictures*. They are simply *static pictures* if they do not represent an action scheme. Our analysis indicates that illustrations tend to fall more often in the last category, thus possibly not conveying information on the timing of users' actions. Conversely, some illustrations particularly detail the action-coupling behavior (Figure 17 Ⓒ) while remaining static by encoding users' actions with visual variables, thus representing action schemes through abstraction.

These insights *do not* mean that user input is rarely presented or even depicted in scientific papers; we only reviewed VTX illustrations and information could be conveyed textually or in other figures dedicated to present experimental setups of system architectures for instance. What it rather means is that figures serve several purposes in the narration of papers [7, 104] by focusing on specific aspects of VTX. This points out an interesting contrast: previous work investigated illustrations of interaction scenarios and showed that many illustrations in HCI show interaction sequences to clarify what users do (773 figures in [6]), but results on VTX illustrations are more mixed in that regard, suggesting that the goal of such illustrations is rather the tactile output.

8.3 Illustrations Depict Stimuli Rather Than Experiences

Tactile experiences inferred from vibrotactile stimuli are intrinsically personal and conventionally captured with questionnaires [25]. Similar to how visual stimuli can induce positive and negative emotions [33, 64, 80], VTX illustrations also have the potential to convey experiential information. Using the five experiential dimensions from Kim and Schneider [53] (namely *harmony*, *expressivity*, *autotelics*, *realism*, *immersion*) we evaluated whether VTX figures potentially convey such information.

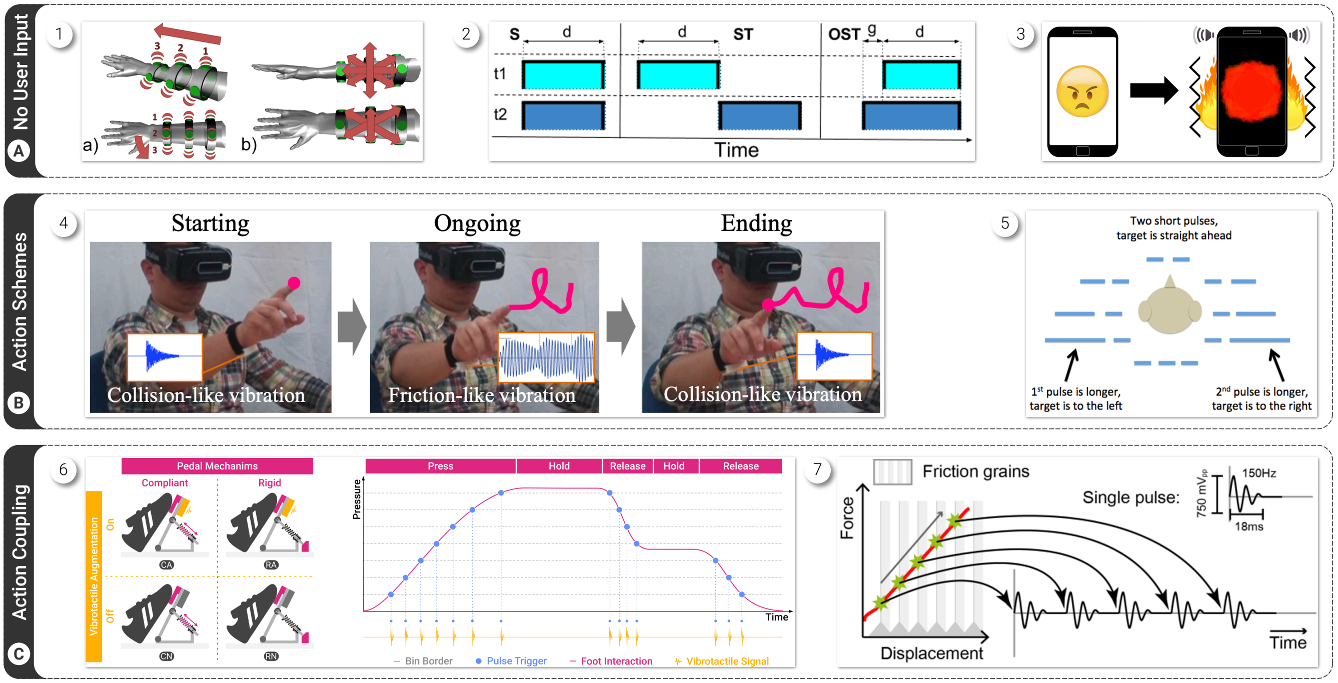


Figure 17: Illustrations may not represent user input Ⓐ, represent sequences of events or *action schemes* [104] Ⓑ through multi-phasic ④ or static illustrations ⑤, and explicit the action-coupling behavior of the system Ⓒ. All illustrations are extracted from: [100] ①, [66] ②, [119] ③, [56] ④, [38] ⑤, [92] ⑥ and [55] ⑦.

Regarding the *harmony* of senses, only 154 figures (20.1%) present clear cases of congruence. Regarding the *expressivity* of vibrotactile displays and how they adapt to end-users' actions, "vocabulary" figures indicate the potential sensations or experiences a system can produce, and figures describing action-coupling behaviors underline how the system adapts. Both sets represent in total 349 figures (45.4%). Illustrations conveying information on positive emotions (*autotelics*[11]) may be coded through the *sensation explanation* category, including 229 figures (29.8%). The two last experiential dimensions, *immersion* and *realism*, have no related codes in the taxonomy.

Overall, we conclude illustrations do not directly address experiential dimensions of VTX as (1) the taxonomy's codes were in part inductively created and do not fully integrate concepts related to experiential dimensions, and (2) only a subset of illustrations *potentially*[12] provide information on these experiential dimensions. While depicting actual experiences remains challenging, the taxonomy's codes hint at possible ways to do so (cf., the *sensation explanation* category); illustrations can, for instance, quote participants verbalizing their experiences while using the system (e.g., [92, 121]). Furthermore, bodymaps [4] are tools designed to facilitate reporting on bodily experiences, but they remain scarcely used in the context of VTX illustrations. We explain this by the fact that VTX illustrations rather focus on representing stimuli than experiences, likely because papers presenting novel results related to vibrotactile feedback tend to be techno-centric.

8.4 Benefits and Limitations of Using the Taxonomy for Designing Illustrations

This research identified essential characteristics of VTX illustrations and produced a taxonomy, which can be used as an actionable analytical tool to guide the analysis of illustrations, supporting research work as we demonstrated. Through five case studies, we also demonstrated how the taxonomy helps pointing out potentially missing or ambiguous information in VTX illustrations. Used as such, the taxonomy can support iterating on existing illustrations by listing *what* information to consider when visually conveying information on VTX and *how* to represent it. It therefore enables to estimate the type and quantity of visual information conveyed within one or several VTX, though it does not assess the quality of these illustrations or determine which visualization might be more efficient at conveying the same information. For instance, the revised illustrations depicted in Figure 15 increase the amount of information conveyed and provide more context on user input and actuator placement, and details the felt or targeted experiences. Whether they actually improved the original illustrations depends on their context and purpose which requires further research using other methods to thoroughly evaluate. This quality essentially builds on the designer's knowledge and skills to produce meaningful images and is outside the scope of this work.

[11] The term is arguably too broad as it refers to different aspects of hedonic models in HCI. Dalsgaard and Schneider [25] discuss this extensively and propose a unified model to add precisions to the older from Kim and Schneider [53].

[12] e.g., being immersed in a virtual environment does not imply that senses are in harmony (*harmony*), describing multiple stimuli does not imply that humans perceive them as such (*expressivity*), and sensation explanations can be technical and not particularly relate to (positive) emotions (*autotelics*)

The results of the formative study point in the same direction; they show that the taxonomy can support designers in reviewing their sketches and reflect on their choices, but not necessarily guide them. The taxonomy can "spark ideas" and "be helpful" to "know your options", however, participants remarked it did not directly provide guidelines on how to create illustrations from scratch (see section 7.4). This was indeed not the goal of this work as we aimed to identify the existence and use of atomic visual characteristics of illustrations, rather than analyzing how efficiently and why they convey specific information. In contrast to co-authors, participants were only shortly exposed to the taxonomy, and they remarked this short exposure might not have been sufficient to fully explore the benefits it can provide. Further work is thus required to better understand how longer exposure to the taxonomy may impact the design process of VTX illustrations.

9 Limitations of the Methodology

One limitation of our data collection approach is the restriction to only two databases – ACM and IEEE – which may have potentially confounded the comprehensiveness of the findings. While these platforms are highly representative of the HCI and Haptics research communities, hosting many key conferences and journals, other databases such as Web of Science[13] or Scopus[14] could have provided additional coverage. Antoine et al. [6] included patents in their review strategy, suggesting that important contributions may also exist outside the scope of academic publications.

Additionally, our methodology, like previous work [6], considers images independently from the context of their paper. The rationale is to holistically investigate graphical characteristics regardless of their context (i.e., additional textual information or other figures across the paper). A drawback of this approach is that it becomes challenging to grasp whether they purposefully provide limited details on certain aspects of VTX because such information is addressed elsewhere in the paper. While our analysis indicates figures convey specific types of information, it remains limited to identify exact strategies used by authors to distribute this information in their paper. Future work on this aspect could complement our methodology and provide further details on these strategies.

10 Conclusion and Future Work

We collected 1652 papers from the ACM DL and IEEE Xplore databases, from the past 25 years that included the keyword "vibrotactile" in their title or abstract. We categorized in total 1509 figures from 535 papers, then analyzed and coded 768 figures representing vibrotactile experiences from 409 papers using a taxonomy we created deductively from previous work on illustrations and inductively from samples of vibrotactile experience (VTX) illustrations. From these codes, we uncovered several insights that may impact the design of VTXs illustrations overall: information on vibrotactile displays and VTX are often divided in dedicated figures, VTX illustrations tend to be static and not provide much information on the timing between VT feedback and users' actions, and they rather provide information on the stimuli rather than actual *experiences*. Our analysis also underlined that categories of illustrations are challenging to identify only from their visual characteristics, as different approaches and strategies are used to present similar content. We then demonstrated how the taxonomy can be used to review in depth VTX figures and help identifying potentially missing information to address them in future design iterations if necessary. We also conducted a formative study with experienced and novice haptic designers to evaluate how the taxonomy could support their workflow. Results indicate the taxonomy is challenging to fully grasp in a short time, but that it lists important characteristics to consider and helps to analyzing one's design choices.

Beyond manual analyses, the structure of this taxonomy could be leveraged by generative AI approaches to address two major challenges of illustration design: 1) suggest adding significant information in the form of recommendations or graphical elements, and 2) propose generated images as drafts to build on. Such AI models, for instance, can be trained on existing images in the literature (e.g., [90]) in addition to those from the dataset including their respective codes from the taxonomy and verbal representations as their descriptions. This avenue shows strong potential as recent work produced interesting initial results for automatically generated scientific illustrations [89]. Future work can build on these approaches, for instance, by leveraging methods such as fine-tuning existing models or employing retrieval-augmented generation, and by developing multi-modal tools to support users in the creative process of designing illustrations [81].

This taxonomy was designed for VTX illustrations but its scope likely encompasses other types of haptic experiences. Many dimensions are inspired from the literature on comic books and interactive scenarios (*composition*, *visual characteristics*, *visual techniques*), or come from the haptic literature and already include more than VTX (*device > grounding*, *cognitive framework*). The only codes that actually strongly depend on vibration characteristics are the *encoding of their dynamics*, and even these codes could be adapted to other modalities (e.g., electro-stimulation uses similar characteristics). Future work should nevertheless thoroughly investigate and validate whether this taxonomy can characterize images of haptic experiences leveraging other modalities such as electro-stimulation, ultrasonic haptics, force feedback, or thermal haptics, and what significant information would be missing or irrelevant. This would ensure that the taxonomy remains inclusive and relevant across a broader range of haptic applications.

Acknowledgments

We would like to thank all participants in the study. All illustrations that are not our own were reused with permission, either from the authors of the papers, the ACM (copyrighted to Bruno Fruchard / Inria), or IEEE (copyrighted to Dennis Wittchen / Max Planck Institute for Informatics).

This work is funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Council Executive Agency. Neither the European Union nor the granting authority can be held responsible for them. This work is supported by ERC grant Kinesthetic Displays, Grant agreement ID: 101165100.

[13]https://clarivate.com/products/web-of-science/
[14]https://www.scopus.com/

Funded by the European Union
European Research Council
Established by the European Commission

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A Details: Data Collection

B Formative Study Details

B.1 Prompts

VTX-0 *"A person is riding a bike in the city. They are wearing a device (haptic display) with two small vibration motors attached to their temples–one on each side of the head. When it's time to turn right at an intersection, the motor on the right temple vibrates three short times in a row. This tells the rider to turn right."*

VTX-1 *"A person wears a haptic suit with four vibration motors–one on each foot and one on each arm. As they watch a 2D game character move on a screen, the vibrations respond to what the character is doing. When the character jumps and grabs a wall, the motors vibrate to simulate the feeling of physical effort–like pulling or gripping."*

VTX-2 *"A person wears a shirt with a row of 10 vibration motors along their spine, from the neck down to the lower back. The motors activate one after another in a smooth sequence–starting at the top and moving down to the bottom. Each motor vibrates for a short time, overlapping slightly with the one before it. This creates the illusion of something moving quickly down the spine–like a hopping rabbit."*

B.2 Participants

Table 1: Eligibility criteria for figures (IF=include, EF=exclude).

	Short	Description
IF-1	*Representing Intent*	Figures that illustrate the purpose or rationale behind the use of vibrotactile feedback (e.g., user goals, design motivations).
IF-2	*Representing Context*	Figures showing the environment or scenario in which vibrotactile interaction/experience occurs.
IF-3	*Representing User(s)*	Figures that depict the presence, posture, role, or actions of users interacting with the system.
IF-4	*Representing Vibrotactile Display*	Visualizations of hardware setups of vibrotactile displays. Include clear hardware depictions even if the device is off-body or shown in an abstract manner.
IF-5	*Representing Vibrotactile Signals*	Figures showing signal characteristics or how vibration is delivered or designed, e.g. waveform diagrams, frequency/amplitude/time graphs, spatial/temporal maps of vibration points, conceptual illustrations of vibration patterns, graphical user interfaces of design tools.
EF-1	*No Connection to Vibrotactile Elements*	General illustrations unrelated to touch or vibrotactile feedback such as UI mockups without haptic components, graphs of unrelated (system) performance metrics.
EF-2	*Irrelevant Technical Diagrams*	Electrical schematics, PCB layouts, or signal processing diagrams without clear indication of vibrotactile output or relevance to the user experience.
EF-3	*Purely Textual or Tabular Data*	Tables or figures with only text, numbers, or codes and no visual representation.
EF-4	*Results-Only Figures*	Bar graphs, line plots, or statistical figures that show only performance results (e.g., accuracy, response time) without context of design or implementation.
EF-5	*Vibrotactile Display Components*	Photos or any other type of illustration showing only components of the vibrotactile display, e.g. actuators, PCB etc.

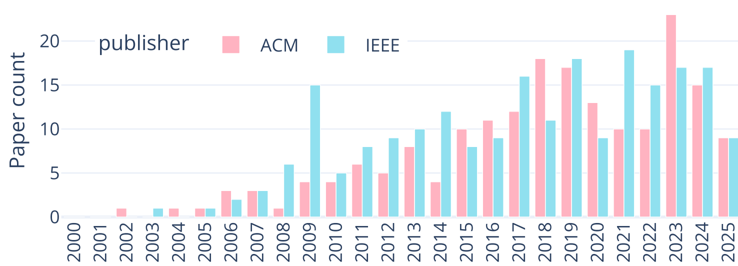

Figure 18: Count of papers included in the final dataset (n=409), split by year and publisher (189 from ACM and 220 from IEEE).

Table 2: Demographics of experienced (EP) and novice (NP) participants.

ID	Experience with haptics/VTX (years)	Level of expertise	Age	Gender
EP1	4–6	Expert	31	M
EP2	1–3	Intermediate	25	M
EP3	1–3	Advanced	29	M
EP4	4–6	Advanced	44	M
NP1	<1	Beginner	22	F
NP2	<1	Beginner	20	F
NP3	<1	Beginner	27	M
NP4	<1	Beginner	21	F
NP5	<1	Beginner	21	F
NP6	<1	Beginner	22	F
NP7	<1	Beginner	22	F