Charting Subtle Interaction in the HCI Literature

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ABSTRACT

Human-computer interaction is replete with ways of talking about qualities of interaction or interfaces, including if they are expressive, rich, fluid, or playful. An example of such a quality is *subtle*. While this word is frequently used in the literature, we lack a coherent account of what it means to be subtle, how to achieve subtleness in an interface, and what theoretical backing subtleness has. To create such an account, we analyze a sample of 55 publications that use the word subtle. We describe the variants of subtle interaction in the literature, including claimed benefits, empirical approaches, and ethical considerations. Not only does this create a basis for thinking about subtleness as a quality of interaction, it also works to show how to solidify varieties of quality in HCI. We conclude by outlining some open empirical and conceptual questions about subtleness.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**; *Interaction paradigms.*

KEYWORDS

Subtle interaction, subtle, interaction, quality, review, survey

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1 INTRODUCTION

Interaction is a core notion in the field of human-computer interaction (HCI). Hornbæk and Oulasvirta [36] identified seven views on interaction, such as viewing interaction as control, dialogue, or experience. Each view holds different assumptions about how to measure interaction, how to design interaction, and so on. The literature contains several more specific definitions of interaction; they partially compensate for the variability and lack of detail in general notions of interaction. Fluid [25], tangible [37], natural [82], casual [62], and organic [63] interaction are but a few of these definitions.

Such definitions allow making explicit the assumptions about the interaction and its goals. Two main groups of definitions stand out. One concerns the technology or *style* of interaction (e.g., voice, touch, gesture). The other concerns the characteristic *quality* of interaction (e.g., fluid, intuitive, playful). The former is easily defined: Gaze interaction requires the use of eye gaze for input. However, defining the quality of interaction is less straightforward. Whether an interaction is fluid or playful depends on the interplay of user interface elements and mechanics as well as on personal preferences.

Our interest in the quality of interaction has two motivations. First, computing today impacts not only work and production, but also most personal and social interactions. Especially in the latter, interactions, devices, and systems need not only be efficient and effective, they also need to offer good experiences. Notions like rich or fluid are used to describe interactions that target this quality. Second, whereas there is an extensive literature on styles of interaction, qualities are mostly treated as part of the general user experience. Whereas some qualities have been discussed in detail (e.g., fluid [25], casual [58, 62]), many are just used in a common-sense manner.

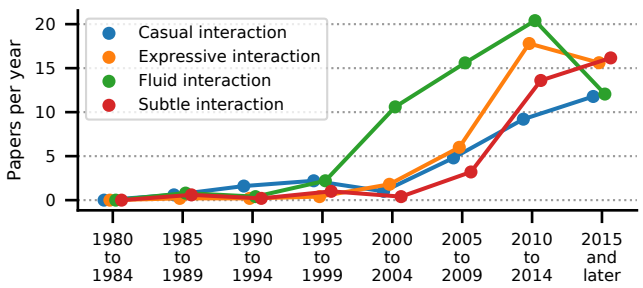

Figure 1: SIGCHI publications in the ACM Digital Library that mention each of four qualities of interaction.

In this paper we focus on *subtle interactions*. First of all, subtleness is used frequently within HCI. Figure 1 shows a selection of qualities as used in SIGCHI publications over the past decades; subtleness plays an increasingly prominent role. Second, the term subtle is difficult, because it—even as a common-sense description of quality—covers notions such as being hard-to-observe, delicate, socially agreeable, and small. Earlier work on subtle conflates those aspects (e.g., in 2005, Costanza et al. mixed slight movement, social acceptability, and unobtrusiveness [17]). Third, while subtle is extensively used, we are only aware of one paper that has attempted to analyze it: Anderson and colleagues' work on deceptive devices [1]. Other qualities have been the topic of far more papers. Furthermore, the deceptive devices paper only covers notions of deception and hiding, a subset of the meanings of subtle used in the literature.

To develop a better understanding of subtleness, we surveyed the use of the term subtle in 55 publications from the HCI literature. We discuss the benefits of being subtle, the designs that create subtleness, and the methodology used to evaluate subtleness. We also discuss ethics and the use of theory in the papers on subtle. The benefit of this is not only to elucidate a comprehensive definition of subtle, but also to show how to develop clear, testable views about the quality of interaction. Our main contributions are:

- An overview how the term subtle is used within human-computer interaction research
- A general definition of subtleness and its varieties for use in future research
- Open questions and guidelines for subsequent work on subtle interaction

2 RELATED WORK

A substantial part of HCI is concerned with conceptualizing interaction and detailing its different styles and qualities. General theories of what HCI is are one example of doing this [e.g., 12, 66]. For instance, Bannon and Bødker [6] argued for a shift to focusing on human actors and Rode [65] outlined feminist HCI. Another way of detailing interaction is by proposing different models thereof. For instance, Hornbæk and Oulasvirta [36] analyzed seven views of interaction and spelled out what they see as the crucial phenomena in HCI, what makes a good interface, and how to design and evaluate HCI. However, given our interest in subtle interaction, these general theories are not sufficiently specific.

Many more concrete ways of understanding interaction exist. They typically describe particular *styles of interaction*; those styles are much more closely coupled to the details of interaction and the technology involved. For instance, tangible and ubiquitous computing are both well-defined in seminal papers [37, 81].

In contrast to style of interaction, we may distinguish *quality of interaction*. The idea here is to focus less on the technology and means of interaction and instead attempt to capture the quality-in-use [9]: To identify characteristics of what makes the interaction good for users, for instance, whether it is fluid [25], casual [62], or aesthetic [57]. These qualities are not captured in more general models of user experience (such as [7, 32]) because the focus there is on the full range of experiences and not specifically those relating to interaction.

Natural user interfaces, and hence natural interaction, are an example of a concept that relates more to qualities of interaction. As Wigdor and Wixon describe them, "a natural user interface is one that provides a clear and enjoyable path to unreflective expertise in its use. It makes skilled behavior seem natural in both learning and expert practice" [82]. In a sense, natural interactions thus are those that seemingly have a low cost of uptake and appear effortless. Whether such interfaces are *natural* has been disputed [50, 54], mainly due to natural user interfaces commonly being built around gesture input. However, natural user interfaces have generally been well received, and there is a large body of work building upon this concept.

Other examples of qualities of interaction are fluid interaction [25] and casual interaction [62]. Elmqvist and colleagues proposed fluid interaction to capture a class of particularly well-working visualizations. They defined these interfaces using a series of exemplars as well as some theory, including direct manipulation and embodied interaction. Pohl and Murray-Smith [62] introduced casual interaction, a quality of interaction where users are enabled to be less engaged. This facilitiates designing for situations where full, focused engagement with devices is socially unacceptable, unsafe, mentally too taxing, or physically inaccessible.

In addition to these examples of qualities, many others exist (see, for instance, Figure 1). As mentioned, we are interested in *subtle*, which we argue plays a special role among the qualities of interaction. One reason is that subtle is frequently used (Figure 1; later we show more than 1300 matches in the ACM Digital Library). Another reason is that *subtle* combines several qualities, calling for clarification and analysis. Many papers use subtle to describe interaction (e.g., [1, 11, 13, 17, 18, 23, 45, 46, 77]). For instance, Constanza and colleagues [17] described a mobile interface that was considered "subtle or intimate because individuals are able to interact privately without causing distraction to their immediate environment."

Nevertheless, we are only aware of one paper that has analyzed the notion of subtle more in depth. Anderson and colleagues provided the most extensive discussion of subtle that we are aware of [1]. They defined "subtle interaction as providing input to, or receiving output from, systems without being observed." To facilitate these kind of interactions they appropriate principles from the "domain of magic and illusion" to design devices for subtle interaction. The main focus of the

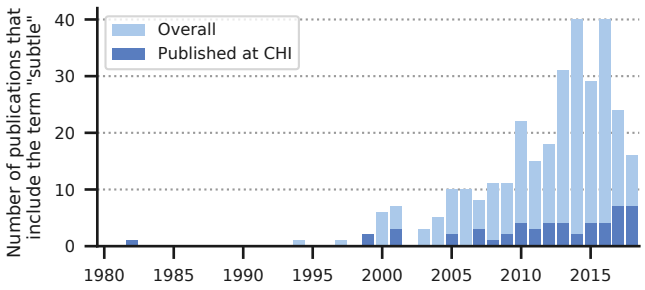

Figure 2: Historical distribution of 311 publications, collected from the ACM Digital Library, mentioning the term "subtle." Only HCI publications before June 2018 are included.

paper hence is on that design and on evaluating whether their subtle interaction devices can help successfully deceive participants. However, as we will demonstrate, the notion of subtle interaction as *hiding* is too limited. For example, it excludes other perspectives, such as framing subtle interaction as one where users themselves are not disturbed by their devices.

In sum, qualities of interaction are one way of spelling out essential characteristics of interaction styles. For subtlety, detailing all facets of those characteristics is overdue.

3 DATASET OF RELEVANT PUBLICATIONS

Our method for characterizing the notion of subtle is to collect a large sample of papers using structured search techniques [15]. We then analyze the set of papers with respect to their use of *subtle* and a content analysis of their stance on measures, ethics, theory, and a number of other categories.

We base our analysis of subtle interaction on publications available in the ACM Digital Library. As search term we used "subtle"[1]. We decided against using synonyms for subtle because one goal of our analysis was to make clear what subtle means. This search yielded 1347 results. However, we only consider publications that appeared at venues sponsored by Special Interest Groups (SIGs) relevant to HCI. Specifically, we included publications associated with SIGCHI, SIGMOBILE, and SIGMM (including conferences they co-sponsor). This yielded 340 results, which corresponds to 314 unique publications after filtering out duplicates. Furthermore, we removed 3 results which were not individual publications, but whole proceedings.

The 311 publications left for analysis were mostly published after the year 2000 (see Figure 2). This marked trend of increased publishing activity mirrors the general trends within HCI. The publications are split over 69 venues (see Table 1 for details). CHI papers and posters are the largest contributors to this dataset.

[1] https://dl.acm.org/results.cfm?query=subtle

However, likely not all of these publications are relevant. Instead of referring to a style of interacting the term subtle can be used in other ways. For example, in a paper on news reading behavior by Kulkarni and Chi, *subtle* was only used once. The abstract mentions that "Interviews also suggest subtle expertise effects" [43], which is not a relevant use of the term for our purposes.

To develop an understanding of relevancy criteria, we skimmed a subset of 10 % (31) of the publications. We then discussed relevancy to align internally and derive a set of guidelines (including examples) for relevancy rating. Relevant publications should:

- use subtle to describe an interaction (e.g., an input users do, a feedback they receive, the way things are displayed or worded, or the overall flavor of the interaction/experience). An example for relevancy is Tsai et al.'s *ThumbRing* poster that describes a device with which the "item selection procedure in the hand is private and subtle" [74].

At the same time, papers are not relevant if they:

- only refer to subtle in passing or as a filler word. For example, Chaney et al. describe "subtle deviations" of their user preference model from previous ones [14]. In their description, *subtle* is used instead of *small*. We observed that this use of subtle as a synonym for small is fairly common. Another example is Black and Moran's statement that "[a]pplied research in human-computer interaction is a subtle affair, with many pitfalls awaiting the unwary researcher" [10].

Table 1: Overview of the conferences we collected publications from for analysis. We queried the ACM Digital Library for publications containing "subtle" that appeared at SIGCHI, SIGMOBILE, and SIGMM venues.

Venue	SIGCHI	SIGMOBILE	SIGMM	Papers
CHI	X	—	—	53
CHI EA	X	—	—	48
UIST	X	—	—	17
IUI	X	—	—	13
CSCW	X	—	—	13
ICMI	X	—	—	13
UbiComp	X	X	—	12
MM	—	—	X	9
HRI	X	—	—	8
TEI	X	—	—	8
MobileHCI	X	X	—	6
ETRA	X	—	—	6
[57 other venues]				
Total				311

- only use subtle to describe how the environment changed outside of an interaction. For example, Wang et al. described how "[a]eration events can be very subtle (e.g. when the fish sways slowly from side to side)" [80].
- only use subtle to describe how people acted outside of an interaction. In the *Glance* system, for example, "workers identify complex or subtle events" in behavioral videos, but these events are generally not interactions with computing devices [44].
- only use subtle for human-human interaction. For example, Horn used *subtle* only with respect to "subtle communicative cues" of conversations shown on video [34].

Two authors then rated all 311 papers in the dataset independently (see Table 2). We used a relevancy scale of 0–2 (not relevant, maybe relevant, relevant). Inter-rater agreement was good, with a Krippendorff's alpha value of 0.79 (bootstrapped 95 % CI of 0.56–0.85, with 10000 samples). The 33 publications both raters considered relevant automatically went to our final dataset of relevant publications. We also immediately excluded the 248 publications that were either rated not relevant by both or at most "maybe" by one. This left us with 30 publications with ambiguous ratings.

To decide on relevancy for the ambiguous publications, a third author of this paper provided an independent third opinion. This resulted in 22 out of these 30 publications being rated as relevant and thus getting moved into the dataset. The final dataset (see Table 3) then included 55 publications.

Limitations

Using the ACM Digital Library as a source for this dataset is subject to some limitations. First of all, while some material not published by ACM is in the Digital Library, other works are not included. For example, publications from the HCI International proceedings cannot be found this way. However, we believe that for HCI, the ACM Digital Library covers the highest impact venues and all relevant specializations.

Another issue is our reliance on the search functionality of the ACM Digital Library. In particular, searching "`any field`" and searching the "`full-text`" gives different results. We used the former, but have little reason to suspect that this introduced a systematic bias in the results.

Table 2: After defining the relevancy criteria, two of the authors independently skimmed and rated each paper from the initial dataset. Shown here is their spread of ratings. For papers where the two authors disagreed, another author acted as a tiebreaker.

Rater	Not relevant	Maybe relevant	Relevant
Author A	241	32	38
Author B	231	32	48

4 CHARTING SUBTLE INTERACTION

We investigated subtle interaction based on the final set of 55 relevant papers. Two of the authors read through each of these papers to determine how the term subtle is used. Specifically, for each paper, we collected:

(1) Definitions of subtle (interaction)
(2) Used synonyms for subtle (interaction) or adjectives used together with subtle
(3) Identified related HCI concepts
(4) Motivation for targeting subtle (interaction)
(5) (or) Described Benefits of subtle (interaction)
(6) Was subtleness empirically tested in some way and if so, what measures were used for subtlety
(7) The investigated application area or scenario
(8) Type of subtle interface (device, application, conceptual)
(9) Was subtle used in the context of input, output, or both
(10) Was subtle interaction used with one or multiple users or observers
(11) Other quotes

While all papers used subtle to describe interaction in some way, we found that explicit definitions of subtle were mostly missing. Instead, use of subtle was primarily in an ad-hoc fashion and understanding of meaning dependent on context. The main exception to this rule was the paper by Anderson et al. [1], mentioned earlier, where subtle interaction is defined as:

> *providing input to, or receiving output from, systems without being observed. The primary goal is the development of a suite of technologies that enable users to leverage always-available computing without compromising privacy or social interaction.*

According to this definition, subtlety is about *hiding* interaction from other people. However, this is not a commonly shared view on subtlety, even if it is the most well-defined one. For example, within the context of notifications and feedback in general, the meaning of *subtle* commonly shifts. Instead of something being hard to observe by others, a notification could be *non-intrusive* and thus not as noticeable to oneself. Hansson and Ljungstrand put this as users perceiving notifications as "subtle and non-intrusive" [30].

These two variants are not necessarily exclusive, but can overlap. Something that is *non-intrusive* to the user is commonly also hard to observe by others, thus *hiding* the interaction from them. Yet, this is not always true the other way: Interaction can be designed to be hard to observe by others, but meanwhile remain easily available to users themselves. For example, input performed by tooth tapping [4] or foot gestures [26] falls in that category.

Table 3: List of all 55 publications we used to analyze usage of *subtle* in the HCI literature. They commonly used subtle as a way to signify (1) being non-intrusive, (2) hiding activity from others, (3) doing less, or (4) nudging users.

Title	Authors	Venue	Pages	Non-Intrusive	Hiding	Doing Less	Nudging	Ref.
The Reminder Bracelet: Subtle …	Hansson & Ljungstrand	CHI EA '00	2	X	—	—	—	[30]
Subtle and Public Notification Cues …	Hansson et al.	UbiComp '01	7	X	—	—	—	[31]
Interactive Public Ambient Displays: …	Vogel & Balakrishnan	UIST '04	10	—	—	—	—	[77]
Distant Freehand Pointing and Clicking …	Vogel & Balakrishnan	UIST '05	10	X	—	—	—	[78]
Toward Subtle Intimate Interfaces for …	Costanza et al.	CHI '05	9	—	X	X	—	[17]
Eye-q: Eyeglass Peripheral Display for …	Costanza et al.	MobileHCI '06	8	X	X	—	—	[19]
Intimate Interfaces in Action: …	Costanza et al.	CHI '07	10	—	X	—	—	[18]
Multi Modal Gesture Identification for …	Naik et al.	MindTrek '08	5	—	X	X	—	[53]
Design Requirements for Ambient …	Kim et al.	DIS '10	10	X	—	—	—	[41]
Knotty Gestures: Subtle Traces to …	Tsandilas & Mackay	AVI '10	8	X	—	—	—	[75]
Nenya: Subtle and Eyes-free Mobile …	Ashbrook et al.	CHI '11	4	—	X	X	—	[3]
Embedded Interaction in a Water …	Arroyo et al.	CHI '12	4	—	—	—	—	[2]
Impact of Subtle Gaze Direction on …	Bailey et al.	ETRA '12	8	—	—	—	X	[5]
Subtle Gaze Manipulation for Improved …	Sridharan et al.	ETRA '12	8	—	—	—	X	[68]
Augmenting the Input Space of Portable …	Liang	UIST '13 Adjunct	4	—	X	—	—	[46]
Designing Context-aware Display Ecosystems	Dostal	IUI '13 Companion	4	—	—	—	—	[23]
Exploring Internet CO2 Emissions As an …	McFarlane et al.	OzCHI '13	4	X	—	—	—	[52]
FingerPad: Private and Subtle …	Chan et al.	UIST '13	6	—	X	—	—	[13]
Magic Ring: A Self-contained Gesture …	Jing et al.	MUM '13	4	—	—	X	—	[38]
Reducing Disruption from Subtle …	Ofek et al.	CHI '13	10	X	X	—	—	[55]
Subtle Gaze-dependent Techniques for …	Dostal et al.	IUI '13	12	X	—	—	—	[24]
Ubiquitous Shortcuts: Mnemonics by …	Rissanen et al.	CHI EA '13	6	—	X	—	—	[64]
AwToolkit: Attention-aware User …	Garrido et al.	AVI '14	8	X	—	—	X	[28]
Gaze-based Awareness in Complex …	Garrido et al.	PervasiveHealth '14	4	X	—	—	—	[27]
In Situ with Bystanders of Augmented …	Denning et al.	CHI '14	10	—	X	—	—	[21]
Many Fingers Make Light Work: Non- …	Halvey & Crossan	ICMI '14	8	—	—	X	—	[29]
Overt or Subtle? Supporting Group …	Schiavo et al.	IUI '14	10	—	—	—	X	[67]
Suit Up!: Enabling Eyes-free …	Todi & Luyten	CHI EA '14	6	—	X	X	—	[72]
The Myth of Subtle Notifications	Mashhadi et al.	UbiComp '14 Adjunct	4	X	—	—	—	[51]
User Experience and Expectations of …	Väänänen-Vainio-Mattila et al.	MUM '14	4	X	—	—	—	[76]
WristFlex: Low-power Gesture Input …	Dementyev & Paradiso	UIST '14	6	—	—	X	—	[20]
Exploring Subtle Foot Plantar-based …	Fukahori et al.	CHI '15	10	—	X	—	—	[26]
Gunslinger: Subtle Arms-down Mid-air …	Liu et al.	UIST '15	9	—	X	X	—	[48]
Opportunistic At-glance Information …	Kukka et al.	MUM '15	5	—	—	—	—	[42]
ProximityHat: A Head-worn System for …	Berning et al.	ISWC '15	8	X	—	—	—	[8]
Supporting Subtlety with Deceptive …	Anderson et al.	CHI '15	10	—	X	—	—	[1]
Wrist Compression Feedback by …	Pohl et al.	CHI EA '15	4	X	—	—	—	[59]
AutoManner: An Automated Interface for …	Tanveer et al.	IUI '16	12	—	—	—	—	[71]
Bitey: An Exploration of Tooth Click …	Ashbrook et al.	MobileHCI '16	12	—	X	—	—	[4]
CloakingNote: A Novel Desktop …	L'Yi et al.	UIST '16	9	—	X	—	—	[49]
Gaze Guidance for Improved Password …	Sridharan et al.	ETRA '16	4	—	—	—	X	[69]
M.Gesture: An Acceleration-Based …	Kim et al.	CHI '16	12	—	—	X	—	[40]
ScatterWatch: Subtle Notifications via …	Pohl et al.	MobileHCI '16	10	X	—	—	—	[61]
Sidetap & Slingshot Gestures on …	Yeo et al.	UIST '16 Adjunct	2	—	—	—	—	[83]
Somaesthetic Appreciation Design	Höök et al.	CHI '16	12	—	—	—	X	[33]
The Aesthetics of Heat: Guiding …	Jonsson et al.	TEI '16	9	X	—	—	X	[39]
ThumbRing: Private Interactions Using …	Tsai et al.	MobileHCI '16	8	—	—	X	—	[74]
TouchRing: Subtle and Always-available …	Tsai et al.	MobileHCI '16	8	—	—	X	—	[73]
Chameleon Devices: Investigating More …	Pearson et al.	CHI '17	13	—	X	—	—	[56]
EmotionCheck: A Wearable Device to …	Costa et al.	GetMobile	4	X	—	—	X	[16]
Itchy Nose: Discreet Gesture …	Lee et al.	ISWC '17	4	—	—	X	—	[45]
Squeezeback: Pneumatic Compression for …	Pohl et al.	CHI '17	13	X	—	—	—	[60]
Subtle and Personal Workspace …	Wallace et al.	CHI '17	5	—	—	—	—	[79]
ForceBoard: Subtle Text Entry …	Zhong et al.	CHI '18	10	—	X	X	—	[84]
Through the Glance Mug: A Familiar …	Börütecene et al.	TEI '18	10	—	X	—	—	[11]

Apart from subtle meaning *non-intrusive*, or *hiding*, we also identified two further variations: *nudging* users and empowering them to *do less* while interacting. In *nudging*, the goal is to influence user behavior in a less overt way, for example, by manipulating their gaze [68]. Finally, there is a group of work, centered primarily on input techniques, where interactive devices and applications are presented, with which users have to *do less* while using them. For example, Halvey and Crossan described this as striving "to develop discrete, low effort interactions" [29].

The corresponding variant of *subtle* for each publication is shown in Table 3. Of the 55 publications in the dataset, all but 8 have an associated variant, with 11 falling under multiple variants. Most used subtle as *non-intrusive* (19), or *hiding* (19). Uses of subtle as *nudging* and *doing less* were used in 8 and 13 publications respectively.

The publications not assigned to any of the variants fall in two different groups. Some were very short, such as doctorial consortium or poster abstracts, and thus did not provide sufficient details for analysis. For example, Dostal's consortium abstract refers to subtle interaction in a relevant way, but is only three pages long [23]. Other publications did not fit into our categorization, because they, upon closer inspection, turned out irrelevant for the present review. For example, Tanveer et al. described a "subtle feedback technique", yet that technique centers around asking questions and *subtle* means indirect inquiry [71]. Other publications, like one from Arroyo et al. [2], mention subtle interaction, but do not provide enough detail to classify what *subtle* entails.

We also found that some publication lean on a previous definition, such as Vogel and Balakrishnan's concept of a "subtle interaction phase" [42, 77–79], but do not provide additional details on their own. Hence while these publications seemed relevant while skimming, they did not add to the subsequent analysis.

These publications demonstrate many variants of how subtle interaction is understood. While some aspects of subtlety are shared between these variants, they each provide their own lens on subtle interaction. In the following sections, we analyze each variant. In particular, we investigate *what* each variant sees as subtle, *why* they strive for subtlety, and *how* the goal of subtlety is achieved. Furthermore, we describe the *design*, *system*, and *empirical* approaches of each subtle variant. Where applicable, we also discuss *ethical* issues raised by the publications.

Subtle as Non-Intrusive

The first variation of subtlety is one that centers on the user's own perception, in particular, their attention. Papers that use subtle in this way are commonly focusing on feedback modalities or notification approaches.

An early example of this use of subtle is Hansson and Ljungstrand's work on the *reminder bracelet* [30]. Instead of "sounds and beeps" that device used "light, color and patterns" to convey notifications. Their ambition was "to explore non-intrusive, or subtle ways of notifying users, to hide the technology and make room for aesthetic considerations." In follow-up work with Redström, their definition of subtlety is refined [31]. In that work, they "use the term subtlety to describe how well a notification cue conveys information in a non-intrusive and gentle manner." For example, "Vibration [is] very subtle." This is in contrast to an "intrusive notification," which might "contribute to the creation of attention overload since it, in social contexts, often demands the attention of the user as well as of other people nearby."

In their paper on design guidelines for haptic feedback in cars, Väänänen-Vainio-Mattila et al. stated subtleness as one aspect to consider. They claimed that, to achieve subtleness, "[h]aptic messages should remain in the background of the primary task, i.e. driving. Haptic feedback could be targeted at subliminal level" [76]. This targeting of the subliminal also implies a design for messages that are non-intrusive. Providing feedback in the background can be done with low intensity feedback, but as Jonsson et al. pointed out, subtleness can also be achieved via "the slowness of the interaction, with slow temperature changes, and heat lingering on after the actual stimuli" [39].

Benefits. Non-intrusive feedback does not demand a large amount of attention from users. This was highlighted by Costa et al., who set out to provide feedback "in a subtle and non-distracting way" [16]. As they noted, this is in contrast to other interfaces that can "require too much attention and effort from the users, which may affect their concentration during ongoing tasks and even increase their stress." Pohl et al. described subtle feedback as being well suited for "intimate communication and background feedback" [60]. Furthermore, Dostal et al. demonstrated that "distraction reduction was one of the main aims and benefits" of using their subtle gaze-dependent visualization technique [24].

Another often mentioned aspect, closely related to distraction, is overload or obtrusiveness. The idea here is that existing systems commonly put themselves too much in the center, blocking other stimuli. *ProximityHat*, for example, was described as "not blocking or affecting other senses of the user" [8]. Similarly, Tsandilas and Mackay described how the "subtle marks" users could make during writing were "visible, but not obtrusive" [75]. Thus, they blend in with the text instead of resulting in a page full of scribbles. Costanza et al. emphasized how the, "priority or importance" of a notification should determine the "level of disruption", where "less important alerts result in less distracting cues" [19].

Non-intrusive, and thus hard to perceive, feedback is also hard to see for others, and thus closely related to the notion of subtle as hiding. In hiding there is a focus on deception, but hiding in general can also be framed benevolently. For example, Hansson and Ljungstrand argued that "there is [a] need for new ways of attracting a user's attention, while at the same time not disturbing other people" [30]. Thus the benefit of non-intrusiveness extends to others as well. This connection also is brought up by Costanza et al., who stated that "[u]sing a mobile device in a social context should not cause embarrassment and disruption to the immediate environment. Interaction with mobile and wearable devices needs to be subtle, discreet and unobtrusive" [17]. Designing systems with "subtle gestures" would then help "gain social acceptance."

Not steering attention to a device also has additional aesthetic benefits. As also noted by Hansson and Ljungstrand, technology should be "aesthetically pleasing and easy to integrate with the normal outfit in order to be well accepted among potential users" [30]. Blending in thus would also increase overall device acceptability, especially for wearables.

Instantiations. A large share of systems that use *subtle* as *non-intrusive* provide feedback to the user. Examples are peripheral displays [19] and indirect light [61] in wearables. Similarly, the *reminder bracelet* also included LEDs as a component for notifying "its users in a subtle and silent manner using light, color and patterns" [30]. In addition to light, subtle as a property has been used for modalities such as pneumatic/compression [59, 60, 76], thermal [39], auditory [52], and vibrotactile [8, 16] feedback. This shows that subtle stimuli can be created in a wide range of modalities, for example, by reducing the intensity of a stimulus.

Apart from haptic feedback, non-intrusive behavior can also manifest in applications. For example, Dostal et al. presented several "subtle visualization techniques" for informing the user of display changes [24]. This focus on awareness of display changes is also found in two publications by Garrido et al. [27, 28].

Empirical Approach. Evaluating whether something is hard to perceive commonly is done by measuring reaction time (including failure to react). For example, Costanza et al.'s *eye-q* system (for "subtle intimate notifications"), was evaluated in two studies: (1) noticeability of different stimuli, and (2) noticeability of stimuli under different workloads [19]. However, there is no straightforward answer to what kind of reaction time constitutes a subtle kind of feedback. As Costanza et al. pointed out themselves, "[t]he gradual response in reaction time [shows] that the display is subtle in delivering cues." A similar definition was given by Pohl et al. in their evaluation of *ScatterWatch*, where they noteed that the "[s]low reaction by participants showed that the stimuli did not occupy the focus of attention and that it is a viable form of subtle feedback" [61].

While reaction time to subtle stimuli is comparatively easy to measure, this approach also provides only a limited view on subtlety. As Dostal et al. noted, their"[subtle] system does not naturally lend itself to a traditional evaluation approach, such as a short controlled experiment." Therefore, they "instead carried out a qualitative longitudinal study" [24]. They built a system to subtly visualize display changes that happened while the user was not looking. Participants used the different system variants and experience, behavior, and performance measurements were collected throughout the study. Dostal et al. found that the subtle techniques decreased participants' distraction while not being intrusive.

Subtle as Hiding and Deception

In the previous section we looked at a notion of subtlety where something is hard to notice or outside the focus of attention. This related to the users themselves. Another way to look at that is from the perspective of others. In that case, something is hidden from observers or, when not hidden, designed in a way that deceives them. An example of such a system is *CloakingNote*, which was designed for "subtle writing", where L'Yi et al. defined subtlety as "not only making the input text subtle, but also hiding the use of the subtle interface itself" [49]. They noted that this *hiding* can prevent shoulder surfing and allows users to "write the texts more confidently."

In movement input, subtlety is often ensured by the lack of observability. For example, Fukahori et al. explored foot gestures, which "are subtle; they are private and not annoying to others" [26]. Naik et al. used surface EMG to detect gestures and note that this input modality has a "sublety" [53]. They describe this subtlety as "the fact that commands can be issued without [...] observable movements." But even when observable, subtle movements can still be hidden. For example, in their evaluation of *M.Gesture*, Kim et al. found that their "subtle swipe" gesture "was designed not to draw people's attention in a public space" [40].

Similarly, Denning et al. used *subtle* in the context of other people noticing a recording device [21]. They noted how "AR glasses are potentially a more subtle form of recording than other form factors (Subtleness). Participants indicated that bystanders consequently may not be aware that they are being recorded. This concept of subtleness is somewhat intertwined with the fact that it is relatively easy to initiate a recording."

Benefits. A main driver for hiding interactions is the low social acceptability of technology use. By obscuring interaction, users can continue to use a device where this otherwise might not be appropriate. The *Glance Mug*, for example, was designed to allow hidden searches for information while in a meeting [11]. This prevents one from appearing as "rude or disruptive" to others at the meeting. Costanza et al. phrased

this as gaining "social acceptance", by limiting "embarrassment and disruption to the immediate environment" [17]. Apart from disruption of others, the issue with acceptance, according to Ofek et al., is the "lack of interest" other people would perceive [55].

In addition to questions of social acceptability, users can have a desire for privacy. Instead of being nice by not annoying others, the focus then is on keeping things private. For example, with *CloakingNote*, users can "protect their private text from others [...] as well as write the text more confidently" [49]. This benefit of private means of input was also brought up for *FingerPad* [13].

Instantiations. From the investigated variants, this is the most diverse one. Primarily, this is the case because hiding and deception can happen through both input and output. For example, this can be devices that can are controlled with small movements [3] or peripheral displays integrated into eye glasses [19]. These systems generally also relate to the *non-intrusive* and *doing less* variants of subtle and are discusses more in those sections.

However, some publications are especially noteworthy in this context. An example are *Chameleon Devices*, where approaches for hiding phones in plain sight were investigated [56]. Instead of reducing the intensity of what is shown, the idea here was for the phone to mimic the background and then "employ subtle changes [...] to provide discreet notifications [while remaining] hidden." A similar "hiding in plain sight" approach is also applied for Anderson et al.'s *Deceptive Devices* [1]. Interactive capability there was hidden inside objects such as books, glasses, or mugs.

Empirical Approach. In general, hiding and deception allow for a comparably straightforward evaluation. A common approach is for participants to observe an action or feedback and then inquiring whether they noticed it. For example, Ofek et al. had two participants engage in conversation during which one of them received visual or auditory messages [55]. They measured both the receiver's ability to respond to messages (by interleaving them into the conversation), as well as the other participant's ability to detect when the former was distracted. To evaluate how well others would notice subtle input via small muscle contractions, Costanza et al. had participants watch video footage of others using their system and answer whether they saw input happening [18]. Anderson et al. also had participants watch video where an interaction might have occurred [1].

A second empirical approach is to evaluate the usability of systems that engage in hiding and deception. As interaction is made harder to observe for others, it commonly also becomes harder to handle for its users. For the subtle writing in *CloakingNote*, for example, L'Yi et al. evaluated the "trade-off between subtlety and writing performance" [49].

Ethics Issues. Ethical concerns around hiding and deception were raised by multiple publications. A key issue here is *privacy*. As Börütecene et al. put it, their *Glance Mug* device "creates a way for deception, can compromise privacy as well as decrease social engagement by making eye contact difficult" [11].

In addition, Anderson et al. raised the issue of "[d]eceiving observers into believing you are cognitively present while you attend to remote information" [1]. According to them, users are unable to stop this behavior and "will interact with their devices regardless of the subtlety of the interaction." The proposed solution then is to support "interactions that are more secretive", because that increases "the probability that the interactions go unnoticed and observers remain unoffended." They furthermore projected that "[a]dvances in subtle interaction could be beneficial as users could check the time, for example, without seeming as if they are bored with the current situation." Hence, while they identified an ethical issue, their proposed solution of more advanced technology to better hide the deception is troublesome.

In contrast to this, Denning et al. bring up the idea of "offsetting subtleness and negotiating permission" in their exploration of using AR headsets for public recording [21]. For devices where it is less obvious to others a recording is taking place, the authors offered several design considerations, such as providing bystanders a way to opt out of recordings by sharing privacy preferences. While video recording is a particularly sensitive technology for subtle use, these considerations could be extended to other areas. For example, families might want to agree on and have devices enforce rules on technology use during meal time.

Subtle as a Way to do Less

This variation of subtle interaction is focused primarily on input. Specifically, *effort* plays a central role in doing less. This can be related to the magnitude of the movements performed for input. For example, Costanza et al. framed this as "[input related to] very subtle or no movement at all" [17].

As that quote indicates, there is an inherent connection to the *hiding* and *non-intrusive* variants described above. However, we decided to separate this into a dedicated section. Compared to the variants discussed earlier, an additional point brought in here is the subtlety of *actions of the user*.

This focus on action also shows in the *Gunslinger* subtle gesturing system by Liu et al. [48]. Striving for gestures to be "smaller, more comfortable, and more socially acceptable", they propose that such gestures "should be made more subtle, meaning 'fine or delicate in meaning or intent.'" For input using surface EMG, Naik et al. described actions as subtle when they involved only "low level contraction" [53]. Similarly, in *WristFlex* this connection is hinted at as "pinching two fingers

is subtle and involves only minor hand movements" [20]. Subtlety there was also defined as "without physical discomfort or embarrassment."

A more extensive description was given for *Nenya*—a device "designed for subtle use" [3]. According to Ashbrook et al., that "subtle use" is achieved in seven ways: (1) small form factor, (2) interaction via "small, discreet movements," (3) "more subtle one-handed use," (4) eyes-free operation due to tactile landmarks, (5) being "immediately available and fast to access," (6) allowing for easy interrupting of use in social situations, and (7) sporting a "familiar appearance." While many of these relate to other variants, point 2 highlights the importance of the gesture magnitude itself.

Benefits. Some benefits of subtle interactions where the user does less relate back to non-intrusiveness. For example, Lee et al. stated that the "subtle gestures" used in their *Itchy Nose* system, "may allow users to respond to notifications quickly without distracting nearby colleagues" [45].

But, as Zhong et al. remarked, less pronounced input gestures also are "space-saving" and thus well suited for small devices, such as smartwatches [84]. For *Gunslinger* this was put as "[reducing] physical input space", also leading to less "fatigue" [48].

However, doing less might also just be a question of "convenience", as pointed out by Todi and Luyten [72]. This is closely related to the concept of casual interaction [58, 62].

Instantiations. Two device categories stand out for this variant of subtle: (1) wearables, and (2) gesture controllers. The former category contains several ring-like devices, such as *Nenya* [3], *ThumbRing* [74], and *TouchRing* [73]. Gesture input was more varied and included hand gestures [20, 53], device gestures [40], and face gestures [45]. Ring-like devices naturally invite small-scale input, while gesturing can cover a wider range from subtle to overt.

Empirical Approach. For this set of publications, the only mention of subtlety in an empirical context came up in Kim et al.'s work on *M.Gesture* [40]. They ran an elicitation study to find accelerometer-based gestures their participants "were likely to use in their everyday lives." As they noted, "[m]ost of the collected gestures were subtle and simple." However, there was no direct comparison of suble and non-subtle input in the investigated publications. Instead, evaluation primarily focused on the technical performance of the presented input devices, such as the gesture recognition accuracy.

Subtle Nudging

Nudging [70] generally describes the act of influencing in a gentle way. In the surveyed publications, this influencing manifested in guiding the gaze, bringing attention to the body, as well as changing social group dynamics.

In *subtle gaze direction* nudging occurs by systems exerting influence on where a user is looking. An example definition was provided by Sridharan et al., who stated that "[s]ubtlety is achieved by presenting the modulations only to the low-acuity peripheral regions of the field of view so that the viewer is never allowed to scrutinize the modulations" [5, 68]. This is in contrast to *overt* techniques, which use "highly salient cues or permanent alterations to the image," while "[s]ubtle techniques on the other hand, rely on temporary or subdued changes in the imagery to guide visual attention" [69]. Hence, the underlying idea of this approach is to guide users without them being able to easily notice this fact.

In other works, nudging is closely connected to the notion of non-intrusive subtlety. For example, in Costa et al.'s *EmotionCheck* vibration was used to change how users perceive their heart rate [16]. Their participants reported not paying much attention to these, yet the system succeeded in reducing their anxiety by simulating a lower heart rate.

A similar kind of nudging was explored by Höök et al. in the context of their concept of *somaesthetic appreciation design* [33]. This design approach is targeted at "applications where the interaction subtly supports users' attention inwards, towards their own body, enriching their sensitivity to, enjoyment and appreciation of their own somatics." One of the qualities of such designs is "subtle guidance." Interactions within such guidance were described to "need to be very subtle — sometimes almost barely noticeable." The authors concluded that "the notion of subtle guidance should be understood as mechanisms that both provides a changing stimuli that helps the shifting of attention between areas or functions of the body as well as providing support for attention to linger and stay focused in one movement or area, keeping the mind from wandering." This idea of shifting of attention to parts of the body can also be found in a paper by Jonsson et al., where "inwardlooking" was supported [39].

Finally, Schiavo et al. presented a system for facilitating better group conversations [67]. This used visualizations that provided "subtle directives," in order to steer attention of the group to people not participating as much as others. As they stated, the nudging is "achieved through social influence, but not through coercion, deception and with a minimal obtrusiveness." This relates back to the aspects of non-intrusiveness and deception, where the former is desirable in this context, but the latter is not.

Benefits. For subtle gaze direction, Sridharan et al. noted that "the cues used to attract the viewer's attention have minimal impact on the viewing experience as they occur only in the viewer's peripheral vision and do not permanently alter the overall appearance of the image being viewed." [68]. In contrast, overt gaze direction has a more noticeable impact on what the user sees.

For other applications of subtle nudging, the benefits were not stated as clearly. However, there are general connections to calmness [67], as well as lower demands on effort and attention [16]. This again relates to *non-intrusiveness*, which could be seen as a necessary property to apply subtle nudging.

Instantiations. Subtle gaze direction systems all worked with visual feedback to steer the gaze [5, 68, 69]. Visualization were also used for social nudging [67]. Yet, for influencing attention to the body, vibrotactile [16] and thermal stimuli [39] were used. As discussed in the designs of somaesthetic appreciation, "modalities that allow for a felt, subtle, inward-looking experience are key" [33].

Empirical Approach. For subtle gaze direction, the studies in the examined publications focused only on the success of directing users, not on the level of subtlety of the direction method. However, for investigating effects on group conversations, Schiavo et al. used a design that allowed for comparisons between overt and subtle influencing [67]. Yet, they did not measure subtleness, but instead focused on measuring the resulting effects, such as group cohesion and attention. We found a similar focus on subjective measurements of experiences in the other publications, such as asking participants to rate distraction after using *EmotionCheck* [16].

Orthogonal Uses of Subtlety

The definitions we have discussed so far describe subtle as a concept or aspect on its own. However, in some publications, notions of subtleness are embedded in a larger conceptual framework. The specific use of subtle in those cases aligns with the variations described above. Yet, when publications explicitly define levels *above* and *below* subtle, this provides additional information on the *boundaries* of subtleness.

An example of this approach is work by Vogel and Balakrishnan [77]. In the context of interaction with public displays, they developed an interaction framework. This framework "[spans] four continuous phases with fluid inter-phase transitions: Ambient Display, Implicit Interaction, Subtle Interaction, and Personal Interaction." Interaction zones here are not just delineated by proximity to the display, but also take into account aspect such as attention cues. The subtle interaction zone "is meant to be used for a very short time and viewed from more than arm's length from the display [...]." At the same time "[t]he information shown in this phase can be personal, but should be harmless, in that it should not be something that a user is highly protective of." This notion of a subtle interaction zone was also applied by Wallace et al. [79]. Similarly, Kukka et al. studied two phases of interaction with a public display: "1) subtle interaction, where users can interact with the display through gestures or movement, and 2) direct interaction, when users interact with the display by directly manipulating it through e.g. a touch-screen interface" [42].

Garrido et al. investigated awareness and its application to notifications in the context of a healthcare environment [27]. They were interested in how to notify users of changes dependent on the corresponding importance, urgency, and level of user concentration. Four different levels of "subtlety of information regarding a change" were defined: disruptive, intrusive, subtle, and unnoticeable. Thus, subtle is what is already noticeable, but is not yet intrusive. As they described it, "the user is alerted, attention is attracted but their gaze is directed at the location of the change." In a second paper, the same authors defined the subtle level as one where "the user is alerted more lightly and their attention is attracted to the display change" [28]. There they generalized and noted that "the way the developer defines what visual marks appear and for how long, will determine the level of subtlety."

Of particular interest here is the notion that *subtle* sits at a low level of engagement—users do notice something and do interact a bit, but no full attention is devoted to the interaction yet. Once people move in closer or pay more attention, they leave the zone of subtle interaction and continue in a different style.

5 DISCUSSION

In this section, we combine the different notions of subtle to arrive at a more encompassing definition. Furthermore, we provide concrete guidelines for application of subtle interaction, as well as research directions for further conceptual refinement of the concept.

Synthesizing Subtle Interaction

Receiving subtle feedback can allow users to remain focused elsewhere, yet also does not disturb others around them. Interestingly, the same device or system can achieve both goals. Hence, we posit that the different variants of subtle interaction stem primarily from different *intentions* and *foci*.

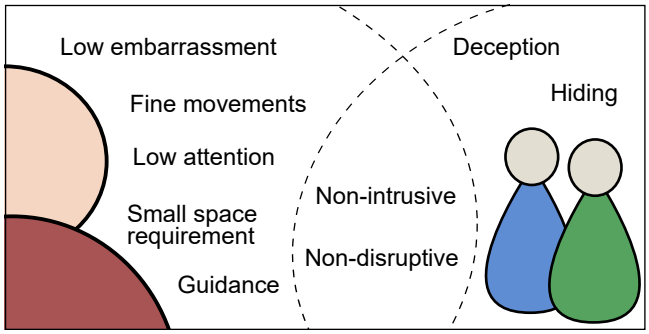

Figure 3: Our synthesized version of subtle interaction distinguishes aspects relevant to the users themselves, relevant to others, and those shared.

Independent of the variant, we have seen a range of words used to describe subtle interactions with similar meanings. Interactions are desired to be: unobtrusive, discreet, intimate, socially acceptable, non-intrusive, subliminal, non-distracting, calm, without embarrassment, simple, slow, inconspicuous, delicate, minimal, private, and low effort. However, each of these can be *applied* in different ways. We argue that the main difference between the subtle variants in this respect is whether they focus on the *user* or on *others*. Depending on this perspective, what matters in an interaction changes (see Figure 3 for an overview).

The main shared property of the variants presented was the focus on reduced intrusion. This can manifest as a system not intruding on a user or the usage of a system not intruding on others. Similarly, non-intrusive input can be done on the side, without severely impacting a primary task. Finally, nudging by definition lacks intrusion, as nudging has to remain in the background.

From the benefit of non-intrusion, secondary benefits derive, depending on the concrete applied focus. In the example above, a direct consequence in situations with others could be increased *social acceptability* (by not intruding on them). Similarly, a single-user scenario would see increased *calmness* once devices reduce intrusion and provide only subtle feedback to their users.

This overarching goal of non-intrusion needs to manifest in concrete systems, which need ways to *reduce* said intrusion. How this is done depends on the specific system, but common approaches are (1) reduced intensity, (2) reduced fidelity, and (3) reduced frequency. For example, an input device designed for subtle interaction could (1) detect small movements, (2) work with coarse actions, or (3) only require infrequent user input.

As we noted in Section 4, impact on others is comparatively straightforward to evaluate. Whether others are able to notice a subtle interaction can, for example, be evaluated with an study design similar to the on used by Anderson et al. [1]. In contrast, gauging the influence on single users is complex and no common empirical approach has emerged yet. For evaluation of how much a device intrudes on users, several approaches have been applied: (1) measuring the time it takes participants to *react* to a stimuli [19, 61], (2) *asking* participants about their experience [16, 24, 30], or (3) analyzing *user behavior* to, for example, determine where they are looking [27], or whether performance on a primary task suffered [49].

The main ethical issue for subtle interaction is that this interaction is often designed to be hidden from others. This can be framed as (1) not intruding on others, but also as (2) deceiving others. How much this impacts others is then dependent on their personal preferences. Where many might appreciate a lack of intrusion and not being bothered, others might fell deceived and exploited when interaction is hidden from them.

While we found no discussion of ethics issues within publications associated with other variant of subtleness, there are a range of potential ethics issues that warrant further investigation. One main issue here is the question of how much control users have and how much systems respectively act without being explicitly instructed to. When nudging or acting in a non-intrusive way (or even subliminal [76]), systems deliberately keep users out of the loop. Users can potentially notice this which could result in a loss of agency. For example, in the case of subtle gaze direction, some participants noted they detected some modifications in the periphery of their view, "but were never able to focus on them" [5].

This generalized description of subtle interaction includes all four earlier variants. Being *non-intrusive* remains the main goal, while *hiding* is covered by extending that lack of intrusion to others. To account for *deception* there needs to be an added user intent to further conceal an interaction. *Nudging* is performed when the user is influenced in a non-intrusive way. Finally, *doing less* is a consequence of designing input methods so they are not imposing on users (i.e., intrude in a way that requires strong engagement). We believe that this synthesis can thus form a basis for further inquiry into subtle interaction and guide future work in this space.

Open Questions Around Subtle Interaction

While we have presented an overview of the state of subtle interaction, several aspects of it are not well explored and further research is needed on many fronts.

Technical Challenges. There is currently no standardized way for building subtle interaction systems and, in fact, a wide range of modalities have been explored for their potential for subtleness. Subtlety is delicate and there is a thin line between a device that is distracting and one that is not noticeable at all. For example, large error margins around detection thresholds are acceptable if feedback can be provided well above them. But if a system is designed to target non-intrusiveness, that threshold needs to be more precisely defined.

Empirical Approaches. While there are straightforward ways to test whether others are annoyed by a device or notice it, empirical approaches for subtlety of one's own interactions are lacking. We need to come up with shared experimental procedures to establish whether a device or interaction actually *is* subtle. Currently, this is commonly claimed, but little evidence of the fact is presented.

A challenge in the evaluation of subtle interactions is the lack of a direct measure for subtleness. While there are some proxy measures (e.g., interruption), it is unclear how much these correspond to subtleness. Similarly, the relationship between proxy measures is also unclear. For example, there can be an interplay of interruption, attention, effort, and control, but the most desirable combination is not easy to quantify.

Especially noteworthy are issues around the common measure of reaction time. Reaction time is often used to establish whether a feedback method is subtle or not. There is no commonly agreed-on threshold in the literature to denote what reaction times are considered subtle and which are not. Hence, the question of subtleness is left to the authors of each paper and is usually implicit. This is similar to how task completion time in general can mean both task efficiency when it is low and engagement when it is high [35]. Detailing this relation for subtle seems important to allow cross-study comparisons and for selecting thresholds for individual studies.

Quantifying Subtleness. While it is tempting to talk about subtleness in degrees, it is difficult to find examples of quantitative measures that make those degrees concrete and measurable. This issue extends to the proxy measures used to quantify aspects of subtleness. For example, it is unclear how much interruption makes for a subtle or non-subtle feedback system. Similarly, investigation of the benefits of subtleness are stymied by the lack of a way to put subtleness in relation to other measures. For example, although many papers use *subtle* as a way to do less, no paper in the sample employed a principled approach to quantifying effort and thereby reason about the relationship between expressivity/subtleness, and effort.

Ethics. The question of consent is a critical aspect of all hidden or unobtrusive interaction. Denning et al. proposed the idea of "negotiating permissions" [21], yet how this can be applied to the range of subtle interaction devices is unclear. Furthermore, how to handle consent in the cases of subtle and subliminal guidance is an open question.

Social Acceptability. There is a common underlying assumption that systems that are hard to detect by others increase social acceptability. However, such systems potentially have a strong impact on social acceptability if uncovered. Where interaction in general is seen as unacceptable, deliberate effort to deceive others is likely at least equally so. For example, consider finding out that your date has been texting the whole time and deliberately hid this from you. An investigation of this cost is still missing in the literature.

Relationship to Other Qualities. There is increasing interest in different kinds of interaction [22, 47], of which subtle is just one kind. Use of *subtle* is growing, as well as the use of other qualities, such as *expressive* or *fluid*. It is presently unclear how these qualities relate to each other. Just as we have seen with different variants of subtle interaction, there likely are shared components, but also differing perspectives and values. For example, the aspect of *doing less* is shared with casual interaction [58, 62]. However, the focus there is more on control–effort trade-offs, while subtle interaction is more concerned with intrusion and social acceptability.

6 CONCLUSION

Subtle interaction has been used in many HCI publications, yet so far has not been adequately defined. Starting from a set of publications that mention the term subtle, we first identified relevant publications and then analyzed them for use and definitions of subtleness. We found that subtle is used in four main ways: (1) signifying feedback that is *non-intrusive* to the user, (2) *hiding* interaction from others and potentially *deceiving* them, (3) employing *less effort* for input and generally *doing less*, and (4) *nudging* users.

While these variations of subtle interaction share some properties, they each provide their own perspective. We have proposed a synthesized definition of subtle interaction that combines these variants. Furthermore, we have pointed to open research challenges around subtle interaction that require further investigation.

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REFERENCES

[1] Fraser Anderson, Tovi Grossman, Daniel Wigdor, and George Fitzmaurice. 2015. Supporting Subtlety with Deceptive Devices and Illusory Interactions. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 1489–1498. https://doi.org/10.1145/2702123.2702336

[2] Ernesto Arroyo, Leonardo Bonanni, and Nina Valkanova. 2012. Embedded Interaction in a Water Fountain for Motivating Behavior Change in Public Space. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM, New York, NY, USA, 685–688. https://doi.org/10.1145/2207676.2207773

[3] Daniel Ashbrook, Patrick Baudisch, and Sean White. 2011. Nenya: Subtle and Eyes-free Mobile Input with a Magnetically-tracked Finger Ring. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 2043–2046. https://doi.org/10.1145/1978942.1979238

[4] Daniel Ashbrook, Carlos Tejada, Dhwanit Mehta, Anthony Jiminez, Goudam Muralitharam, Sangeeta Gajendra, and Ross Tallents. 2016. Bitey: An Exploration of Tooth Click Gestures for Hands-free User Interface Control. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '16)*. ACM, New York, NY, USA, 158–169. https://doi.org/10.1145/2935334.2935389

[5] Reynold Bailey, Ann McNamara, Aaron Costello, Srinivas Sridharan, and Cindy Grimm. 2012. Impact of Subtle Gaze Direction on Short-term Spatial Information Recall. In *Proceedings of the Symposium on Eye Tracking Research and Applications (ETRA '12)*. ACM, New York, NY, USA, 67–74. https://doi.org/10.1145/2168556.2168567

[6] Liam J. Bannon and Susanne Bødker. 1989. Beyond the Interface: Encountering Artifacts in Use. *DAIMI Report Series* 18, 288 (oct 1989). https://doi.org/10.7146/dpb.v18i288.6666

[7] Javier A. Bargas-Avila and Kasper Hornbæk. 2011. Old Wine in New Bottles or Novel Challenges: A Critical Analysis of Empirical Studies of User Experience. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA,

2689–2698. https://doi.org/10.1145/1978942.1979336

[8] Matthias Berning, Florian Braun, Till Riedel, and Michael Beigl. 2015. ProximityHat: A Head-worn System for Subtle Sensory Augmentation with Tactile Stimulation. In *Proceedings of the 2015 ACM International Symposium on Wearable Computers (ISWC '15)*. ACM, New York, NY, USA, 31–38. https://doi.org/10.1145/2802083.2802088

[9] Nigel Bevan. 1999. Quality in use: Meeting user needs for quality. *Journal of systems and software* 49, 1 (1999), 89–96.

[10] John B. Black and Thomas P. Moran. 1982. Learning and Remembering Command Names. In *Proceedings of the 1982 Conference on Human Factors in Computing Systems (CHI '82)*. ACM, New York, NY, USA, 8–11. https://doi.org/10.1145/800049.801745

[11] Ahmet Börütecene, Idil Bostan, Ekin Akyürek, Alpay Sabuncuoglu, Ilker Temuzkusu, Çaglar Genç, Tilbe Göksun, and Oguzhan Özcan. 2018. Through the Glance Mug: A Familiar Artefact to Support Opportunistic Search in Meetings. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '18)*. ACM, New York, NY, USA, 674–683. https://doi.org/10.1145/3173225.3173236

[12] John M Carroll. 2003. *HCI models, theories, and frameworks: Toward a multidisciplinary science*. Elsevier.

[13] Liwei Chan, Rong-Hao Liang, Ming-Chang Tsai, Kai-Yin Cheng, Chao-Huai Su, Mike Y. Chen, Wen-Huang Cheng, and Bing-Yu Chen. 2013. FingerPad: Private and Subtle Interaction Using Fingertips. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology (UIST '13)*. ACM, New York, NY, USA, 255–260. https://doi.org/10.1145/2501988.2502016

[14] Allison J.B. Chaney, Mike Gartrell, Jake M. Hofman, John Guiver, Noam Koenigstein, Pushmeet Kohli, and Ulrich Paquet. 2014. A Large-scale Exploration of Group Viewing Patterns. In *Proceedings of the ACM International Conference on Interactive Experiences for TV and Online Video (TVX '14)*. ACM, New York, NY, USA, 31–38. https://doi.org/10.1145/2602299.2602309

[15] Harris Cooper, Larry V Hedges, and Jeffrey C Valentine. 2009. *The handbook of research synthesis and meta-analysis*. Russell Sage Foundation.

[16] Jean Costa, Alexander T. Adams, Malte F. Jung, François Guimbretière, and Tanzeem Choudhury. 2017. EmotionCheck: A Wearable Device to Regulate Anxiety Through False Heart Rate Feedback. *GetMobile: Mobile Comp. and Comm.* 21, 2 (Aug. 2017), 22–25. https://doi.org/10.1145/3131214.3131222

[17] Enrico Costanza, Samuel A. Inverso, and Rebecca Allen. 2005. Toward Subtle Intimate Interfaces for Mobile Devices Using an EMG Controller. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '05)*. ACM, New York, NY, USA, 481–489. https://doi.org/10.1145/1054972.1055039

[18] Enrico Costanza, Samuel A. Inverso, Rebecca Allen, and Pattie Maes. 2007. Intimate Interfaces in Action: Assessing the Usability and Subtlety of Emg-based Motionless Gestures. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07)*. ACM, New York, NY, USA, 819–828. https://doi.org/10.1145/1240624.1240747

[19] Enrico Costanza, Samuel A. Inverso, Elan Pavlov, Rebecca Allen, and Pattie Maes. 2006. Eye-q: Eyeglass Peripheral Display for Subtle Intimate Notifications. In *Proceedings of the 8th Conference on Human-computer Interaction with Mobile Devices and Services (MobileHCI '06)*. ACM, New York, NY, USA, 211–218. https://doi.org/10.1145/1152215.1152261

[20] Artem Dementyev and Joseph A. Paradiso. 2014. WristFlex: Low-power Gesture Input with Wrist-worn Pressure Sensors. In *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology (UIST '14)*. ACM, New York, NY, USA, 161–166. https://doi.org/10.1145/2642918.2647396

[21] Tamara Denning, Zakariya Dehlawi, and Tadayoshi Kohno. 2014. In Situ with Bystanders of Augmented Reality Glasses: Perspectives on Recording and Privacy-mediating Technologies. In *Proceedings of the 32nd Annual ACM Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 2377–2386. https://doi.org/10.1145/2556288.2557352

[22] Sarah Diefenbach, Eva Lenz, and Marc Hassenzahl. 2013. An Interaction Vocabulary. Describing the How of Interaction.. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems (CHI EA '13)*. ACM, New York, NY, USA, 607–612. https://doi.org/10.1145/2468356.2468463

[23] Jakub Dostal. 2013. Designing Context-aware Display Ecosystems. In *Proceedings of the Companion Publication of the 2013 International Conference on Intelligent User Interfaces Companion (IUI '13 Companion)*. ACM, New York, NY, USA, 1–4. https://doi.org/10.1145/2451176.2451178

[24] Jakub Dostal, Per Ola Kristensson, and Aaron Quigley. 2013. Subtle Gaze-dependent Techniques for Visualising Display Changes in Multi-display Environments. In *Proceedings of the 2013 International Conference on Intelligent User Interfaces (IUI '13)*. ACM, New York, NY, USA, 137–148. https://doi.org/10.1145/2449396.2449416

[25] Niklas Elmqvist, Andrew Vande Moere, Hans-Christian Jetter, Daniel Cernea, Harald Reiterer, and TJ Jankun-Kelly. 2011. Fluid Interaction for Information Visualization. *Information Visualization* 10, 4 (oct 2011), 327–340. https://doi.org/10.1177/1473871611413180

[26] Koumei Fukahori, Daisuke Sakamoto, and Takeo Igarashi. 2015. Exploring Subtle Foot Plantar-based Gestures with Sock-placed Pressure Sensors. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 3019–3028. https://doi.org/10.1145/2702123.2702308

[27] Juan E. Garrido, Victor M. R. Penichet, María D. Lozano, P. O. Kristensson, and Aaron Quigley. 2014. Gaze-based Awareness in Complex Healthcare Environments. In *Proceedings of the 8th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth '14)*. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), ICST, Brussels, Belgium, Belgium, 410–413. https://doi.org/10.4108/icst.pervasivehealth.2014.255346

[28] Juan E. Garrido, Victor M. R. Penichet, Maria D. Lozano, Aaron Quigley, and Per Ola Kristensson. 2014. AwToolkit: Attention-aware User Interface Widgets. In *Proceedings of the 2014 International Working Conference on Advanced Visual Interfaces (AVI '14)*. ACM, New York, NY, USA, 9–16. https://doi.org/10.1145/2598153.2598160

[29] Martin Halvey and Andy Crossan. 2014. Many Fingers Make Light Work: Non-Visual Capacitive Surface Exploration. In *Proceedings of the 16th International Conference on Multimodal Interaction (ICMI '14)*. ACM, New York, NY, USA, 156–163. https://doi.org/10.1145/2663204.2663253

[30] Rebecca Hansson and Peter Ljungstrand. 2000. The Reminder Bracelet: Subtle Notification Cues for Mobile Devices. In *CHI '00 Extended Abstracts on Human Factors in Computing Systems (CHI EA '00)*. ACM, New York, NY, USA, 323–324. https://doi.org/10.1145/633292.633488

[31] Rebecca Hansson, Peter Ljungstrand, and Johan Redström. 2001. Subtle and Public Notification Cues for Mobile Devices. In *Proceedings of the 3rd International Conference on Ubiquitous Computing (UbiComp '01)*. Springer-Verlag, Berlin, Heidelberg, 240–246. http://dl.acm.org/citation.cfm?id=647987.741347

[32] Marc Hassenzahl and Noam Tractinsky. 2006. User experience-a research agenda. *Behaviour & information technology* 25, 2 (2006), 91–97.

[33] Kristina Höök, Martin P. Jonsson, Anna Ståhl, and Johanna Mercurio. 2016. Somaesthetic Appreciation Design. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 3131–3142. https://doi.org/10.1145/2858036.2858583

[34] Daniel B. Horn. 2001. Is Seeing Believing?: Detecting Deception in Technologically Mediated Communication. In *CHI '01 Extended Abstracts on Human Factors in Computing Systems (CHI EA '01)*. ACM, New York, NY, USA, 297–298. https://doi.org/10.1145/634067.634243

[35] Kasper Hornbæk. 2006. Current practice in measuring usability: Challenges to usability studies and research. *International journal of human-computer studies* 64, 2 (2006), 79–102.

[36] Kasper Hornbæk and Antti Oulasvirta. 2017. What Is Interaction?. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*. ACM Press, New York, New York, USA, 5040–5052. https://doi.org/10.1145/3025453.3025765

[37] Hiroshi Ishii and Brygg Ullmer. 1997. Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. In *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '97*. ACM Press, New York, New York, USA, 234–241. https://doi.org/10.1145/258549.258715

[38] Lei Jing, Zixue Cheng, Yinghui Zhou, Junbo Wang, and Tongjun Huang. 2013. Magic Ring: A Self-contained Gesture Input Device on Finger. In *Proceedings of the 12th International Conference on Mobile and Ubiquitous Multimedia (MUM '13)*. ACM, New York, NY, USA, Article 39, 4 pages. https://doi.org/10.1145/2541831.2541875

[39] Martin Jonsson, Anna Ståhl, Johanna Mercurio, Anna Karlsson, Naveen Ramani, and Kristina Höök. 2016. The Aesthetics of Heat: Guiding Awareness with Thermal Stimuli. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '16)*. ACM, New York, NY, USA, 109–117. https://doi.org/10.1145/2839462.2839487

[40] Ju-Whan Kim, Han-Jong Kim, and Tek-Jin Nam. 2016. M.Gesture: An Acceleration-Based Gesture Authoring System on Multiple Handheld and Wearable Devices. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 2307–2318. https://doi.org/10.1145/2858036.2858358

[41] Tanyoung Kim, Hwajung Hong, and Brian Magerko. 2010. Design Requirements for Ambient Display That Supports Sustainable Lifestyle. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems (DIS '10)*. ACM, New York, NY, USA, 103–112. https://doi.org/10.1145/1858171.1858192

[42] Hannu Kukka, Jorge Goncalves, Alexander Samodelkin, and Timo Ojala. 2015. Opportunistic At-glance Information Acquisition on Interactive Public Displays. In *Proceedings of the 14th International Conference on Mobile and Ubiquitous Multimedia (MUM '15)*. ACM, New York, NY, USA, 323–327. https://doi.org/10.1145/2836041.2836074

[43] Chinmay Kulkarni and Ed Chi. 2013. All the News That's Fit to Read: A Study of Social Annotations for News Reading. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, New York, NY, USA, 2407–2416. https://doi.org/10.1145/2470654.2481334

[44] Walter S. Lasecki, Mitchell Gordon, Danai Koutra, Malte F. Jung, Steven P. Dow, and Jeffrey P. Bigham. 2014. Glance: Rapidly Coding Behavioral Video with the Crowd. In *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology (UIST '14)*. ACM, New York, NY, USA, 551–562. https://doi.org/10.1145/2642918.2647367

[45] Juyoung Lee, Hui-Shyong Yeo, Murtaza Dhuliawala, Jedidiah Akano, Junichi Shimizu, Thad Starner, Aaron Quigley, Woontack Woo, and Kai Kunze. 2017. Itchy Nose: Discreet Gesture Interaction Using EOG Sensors in Smart Eyewear. In *Proceedings of the 2017 ACM International Symposium on Wearable Computers (ISWC '17)*. ACM, New York, NY, USA, 94–97. https://doi.org/10.1145/3123021.3123060

[46] Rong-Hao Liang. 2013. Augmenting the Input Space of Portable Displays Using Add-on Hall-sensor Grid. In *Proceedings of the Adjunct Publication of the 26th Annual ACM Symposium on User Interface Software and Technology (UIST '13 Adjunct)*. ACM, New York, NY, USA, 33–36. https://doi.org/10.1145/2508468.2508470

[47] Youn-kyung Lim, Sang-Su Lee, and Kwang-young Lee. 2009. Interactivity Attributes: A New Way of Thinking and Describing Interactivity. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*. ACM, New York, NY, USA, 105–108. https://doi.org/10.1145/1518701.1518719

[48] Mingyu Liu, Mathieu Nancel, and Daniel Vogel. 2015. Gunslinger: Subtle Arms-down Mid-air Interaction. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology (UIST '15)*. ACM, New York, NY, USA, 63–71. https://doi.org/10.1145/2807442.2807489

[49] Sehi L'Yi, Kyle Koh, Jaemin Jo, Bohyoung Kim, and Jinwook Seo. 2016. CloakingNote: A Novel Desktop Interface for Subtle Writing Using Decoy Texts. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16)*. ACM, New York, NY, USA, 473–481. https://doi.org/10.1145/2984511.2984571

[50] Alessio Malizia and Andrea Bellucci. 2012. The Artificiality of Natural User Interfaces. *Commun. ACM* 55, 3 (mar 2012), 36–38. https://doi.org/10.1145/2093548.2093563

[51] Afra Mashhadi, Akhil Mathur, and Fahim Kawsar. 2014. The Myth of Subtle Notifications. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication (UbiComp '14 Adjunct)*. ACM, New York, NY, USA, 111–114. https://doi.org/10.1145/2638728.2638759

[52] Stuart McFarlane, Frank Feltham, and Darrin Verhagen. 2013. Exploring Internet CO2 Emissions As an Auditory Display. In *Proceedings of the 25th Australian Computer-Human Interaction Conference: Augmentation, Application, Innovation, Collaboration (OzCHI '13)*. ACM, New York, NY, USA, 225–228. https://doi.org/10.1145/2541016.2541081

[53] Ganesh R. Naik, Dinesh K. Kumar, and Sridhar P. Arjunan. 2008. Multi Modal Gesture Identification for HCI Using Surface EMG. In *Proceedings of the 12th International Conference on Entertainment and Media in the Ubiquitous Era (MindTrek '08)*. ACM, New York, NY, USA, 90–94. https://doi.org/10.1145/1457199.1457219

[54] Donald A. Norman. 2010. Natural user interfaces are not natural. *interactions* 17, 3 (may 2010), 6–10. https://doi.org/10.1145/1744161.1744163

[55] Eyal Ofek, Shamsi T. Iqbal, and Karin Strauss. 2013. Reducing Disruption from Subtle Information Delivery During a Conversation: Mode and Bandwidth Investigation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, New York, NY, USA, 3111–3120. https://doi.org/10.1145/2470654.2466425

[56] Jennifer Pearson, Simon Robinson, Matt Jones, Anirudha Joshi, Shashank Ahire, Deepak Sahoo, and Sriram Subramanian. 2017. Chameleon Devices: Investigating More Secure and Discreet Mobile Interactions via Active Camouflaging. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 5184–5196. https://doi.org/10.1145/3025453.3025482

[57] Marianne Graves Petersen, Ole Sejer Iversen, Peter Gall Krogh, and Martin Ludvigsen. 2004. Aesthetic interaction: a pragmatist's aesthetics of interactive systems. In *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques*. ACM, 269–276.

[58] Henning Pohl. 2017. *Casual Interaction: Devices and Techniques for Low-Engagement Interaction*. PhD Thesis. Leibniz Universität Hannover. https://www.tib.eu/en/search/id/TIBKAT%3A886617138/Casual-interaction-devices-and-techniques-for-low/

[59] Henning Pohl, Dennis Becke, Eugen Wagner, Maximilian Schrapel, and Michael Rohs. 2015. Wrist Compression Feedback by Pneumatic Actuation. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '15)*. ACM, New York, NY, USA, 315–318. https://doi.org/10.1145/2702613.2725427

[60] Henning Pohl, Peter Brandes, Hung Ngo Quang, and Michael Rohs. 2017. Squeezeback: Pneumatic Compression for Notifications. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 5318–5330. https://doi.org/10.1145/3025453.3025526

[61] Henning Pohl, Justyna Medrek, and Michael Rohs. 2016. ScatterWatch: Subtle Notifications via Indirect Illumination Scattered in the Skin. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '16)*. ACM, New York, NY, USA, 7–16. https://doi.org/10.1145/2935334.2935351

[62] Henning Pohl and Roderick Murray-Smith. 2013. Focused and Casual Interactions: Allowing Users to Vary Their Level of Engagement. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '13*. ACM Press, New York, New York, USA, 2223–2232. https://doi.org/10.1145/2470654.2481307

[63] Jun Rekimoto. 2008. Organic Interaction Technologies: From Stone to Skin. *Commun. ACM* 51, 6 (jun 2008), 38–44. https://doi.org/10.1145/1349026.1349035

[64] Mikko J. Rissanen, Owen Noel Newton Fernando, Horathalge Iroshan, Samantha Vu, Natalie Pang, and Schubert Foo. 2013. Ubiquitous Shortcuts: Mnemonics by Just Taking Photos. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems (CHI EA '13)*. ACM, New York, NY, USA, 1641–1646. https://doi.org/10.1145/2468356.2468650

[65] Jennifer A. Rode. 2011. A theoretical agenda for feminist HCI. *Interacting with Computers* 23, 5 (sep 2011), 393–400. https://doi.org/10.1016/j.intcom.2011.04.005

[66] Yvonne Rogers. 2012. HCI theory: classical, modern, and contemporary. *Synthesis Lectures on Human-Centered Informatics* 5, 2 (2012), 1–129.

[67] Gianluca Schiavo, Alessandro Cappelletti, Eleonora Mencarini, Oliviero Stock, and Massimo Zancanaro. 2014. Overt or Subtle? Supporting Group Conversations with Automatically Targeted Directives. In *Proceedings of the 19th International Conference on Intelligent User Interfaces (IUI '14)*. ACM, New York, NY, USA, 225–234. https://doi.org/10.1145/2557500.2557507

[68] Srinivas Sridharan, Reynold Bailey, Ann McNamara, and Cindy Grimm. 2012. Subtle Gaze Manipulation for Improved Mammography Training. In *Proceedings of the Symposium on Eye Tracking Research and Applications (ETRA '12)*. ACM, New York, NY, USA, 75–82. https://doi.org/10.1145/2168556.2168568

[69] Srinivas Sridharan, Brendan John, Darrel Pollard, and Reynold Bailey. 2016. Gaze Guidance for Improved Password Recollection. In *Proceedings of the Ninth Biennial ACM Symposium on Eye Tracking Research & Applications (ETRA '16)*. ACM, New York, NY, USA, 237–240. https://doi.org/10.1145/2857491.2857537

[70] Cass R. Sunstein. 2014. Nudging: A Very Short Guide. *Journal of Consumer Policy* 37, 4 (01 Dec 2014), 583–588. https://doi.org/10.1007/s10603-014-9273-1

[71] M. Iftekhar Tanveer, Ru Zhao, Kezhen Chen, Zoe Tiet, and Mohammed Ehsan Hoque. 2016. AutoManner: An Automated Interface for Making Public Speakers Aware of Their Mannerisms. In *Proceedings of the 21st International Conference on Intelligent User Interfaces (IUI '16)*. ACM, New York, NY, USA, 385–396. https://doi.org/10.1145/2856767.2856785

[72] Kashyap Todi and Kris Luyten. 2014. Suit Up!: Enabling Eyes-free Interactions on Jacket Buttons. In *Proceedings of the Extended Abstracts of the 32nd Annual ACM Conference on Human Factors in Computing Systems (CHI EA '14)*. ACM, New York, NY, USA, 1549–1554. https://doi.org/10.1145/2559206.2581155

[73] Hsin-Ruey Tsai, Min-Chieh Hsiu, Jui-Chun Hsiao, Lee-Ting Huang, Mike Chen, and Yi-Ping Hung. 2016. TouchRing: Subtle and Always-available Input Using a Multi-touch Ring. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct (MobileHCI '16)*. ACM, New York, NY, USA, 891–898. https://doi.org/10.1145/2957265.2961860

[74] Hsin-Ruey Tsai, Cheng-Yuan Wu, Lee-Ting Huang, and Yi-Ping Hung. 2016. ThumbRing: Private Interactions Using One-handed Thumb Motion Input on Finger Segments. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct (MobileHCI '16)*. ACM, New York, NY, USA, 791–798. https://doi.org/10.1145/2957265.2961859

[75] Theophanis Tsandilas and Wendy E. Mackay. 2010. Knotty Gestures: Subtle Traces to Support Interactive Use of Paper. In *Proceedings of the International Conference on Advanced Visual Interfaces (AVI '10)*. ACM, New York, NY, USA, 147–154. https://doi.org/10.1145/1842993.1843020

[76] Kaisa Väänänen-Vainio-Mattila, Jani Heikkinen, Ahmed Farooq, Grigori Evreinov, Erno Mäkinen, and Roope Raisamo. 2014. User Experience and Expectations of Haptic Feedback in In-car Interaction. In *Proceedings of the 13th International Conference on Mobile and Ubiquitous Multimedia (MUM '14)*. ACM, New York, NY, USA, 248–251. https://doi.org/10.1145/2677972.2677996

[77] Daniel Vogel and Ravin Balakrishnan. 2004. Interactive Public Ambient Displays: Transitioning from Implicit to Explicit, Public to Personal, Interaction with Multiple Users. In *Proceedings of the 17th Annual ACM Symposium on User Interface Software and Technology (UIST '04)*. ACM, New York, NY, USA, 137–146. https://doi.org/10.1145/1029632.1029656

[78] Daniel Vogel and Ravin Balakrishnan. 2005. Distant Freehand Pointing and Clicking on Very Large, High Resolution Displays. In *Proceedings of the 18th Annual ACM Symposium on User Interface Software and Technology (UIST '05)*. ACM, New York, NY, USA, 33–42. https://doi.org/10.1145/1095034.1095041

[79] James R. Wallace, Ariel Weingarten, and Edward Lank. 2017. Subtle and Personal Workspace Requirements for Visual Search Tasks on Public Displays. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 6760–6764. https://doi.org/10.1145/3025453.3025500

[80] Nancy Xin Ru Wang, Sarika Cullis-Suzuki, and Alexandra Branzan Albu. 2015. Automated Analysis of Wild Fish Behavior in a Natural Habitat. In *Proceedings of the 2Nd International Workshop on Environmental Multimedia Retrieval (EMR '15)*. ACM, New York, NY, USA, 21–26. https://doi.org/10.1145/2764873.2764875

[81] Mark Weiser. 1991. The Computer for the 21st Century. *Mobile Computing and Communication Review* 3, 3 (1991), 3–11. https://doi.org/10.1145/329124.329126

[82] Daniel Wigdor and Dennis Wixon. 2011. *Brave NUI World: Designing Natural User Interfaces for Touch and Gesture.*

[83] Hui-Shyong Yeo, Juyoung Lee, Andrea Bianchi, and Aaron Quigley. 2016. Sidetap & Slingshot Gestures on Unmodified Smartwatches. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16 Adjunct)*. ACM, New York, NY, USA, 189–190. https://doi.org/10.1145/2984751.2984763

[84] Mingyuan Zhong, Chun Yu, Qian Wang, Xuhai Xu, and Yuanchun Shi. 2018. ForceBoard: Subtle Text Entry Leveraging Pressure. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, Article 528, 10 pages. https://doi.org/10.1145/3173574.3174102