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LONG PAPER

Putting situational impairments in context: developing guidance for situational impairments and severely constraining situational impairments by examining parallel domains

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Abstract
Mobile device use is omnipresent in everyday life spawning design to account for the increased complexity and diversity of "Situationally Induced Impairments and Disabilities (SIID)". Although SIIDs frequently impact interactions, little research has attempted to provide generalizable guidance supporting users when these events occur. Situational impairment events may produce challenges similar to those faced by users with Health Induced Impairments and Disabilities. This study conducted an exhaustive literature review from Assistive Technology and Accessibility research and parallel domains, and found that existing guidance on designing for "impairments" can inform designing for "temporary" impairments created by the mobile interaction context. Guidance identified was validated by a panel of mobile interaction experts with a novel adaptation of the consensus-seeking approach known as the Delphi method. This research presents preliminary guidelines to support mobile interface designers and researchers to better recognize and effectively account for the new complexity present during mobile interaction.

Keywords Situationally induced impairments and disabilities (SIIDs) · Situational impairments · Severely constraining situational impairments (SCSI) · Design guidance · Design for accessibility · Mobile interaction

1 Introduction

The introduction of the smartphone to a mass audience marked a distinct paradigm shift in information consumption. While these technologies offer users the benefits of information access while on-the-go, interaction can be impacted by the presence of situational, contextual, or environmental factors known as "Situationally Induced Impairments and Disabilities (SIID)" [46] or, commonly termed, "situational impairments" [42], 40]. This nascent paradigm spawned a recognition that models describing stationary desktop interaction might not be adequate when applied in a context that is both moving and variable [60].

Research has primarily approached the situational impairment phenomenon from a more traditional usability perspective, like measuring effects of various contextual elements that may present during mobile interaction. Research has, for example, extended the principles behind Fitts' Law [13] by providing a better human factors understanding of how walking can affect the speed and accuracy of target acquisition [14, 19]. In addition, research has led to solutions in areas such as addressing limitations in battery life (e.g., [54, 63]), and addressing the challenges interacting with a touch screen while wearing gloves [49].

Considering daily mobile interaction volume and the number of situational impairments encountered, it is somewhat ironic that design guidance specifically targeted to support users experiencing these phenomena is limited and/or distributed across academic papers, rather than being centralized in one repository, making it difficult for mobile design to address these issues. Centralized guidance would

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act as a reference tool for mobile design, serving to promote standardization.

Parallels exist between challenges faced by individuals with Health Induced Impairments and Disabilities (HIIDs) and those with SIIDs. For example, conditions may prevent touch input, leading to actions similar to users where touch-based interaction may not be possible (e.g., individuals with motor disabilities). Experiences and mental models are not necessarily analogous between users with HIIDs and those with SIIDs, rather that mobile interactions can be similarly impacted. We posit that existing guidance on designing for *impairments* in general can inform designing for *temporary* impairments.

This paper presents an approach for identifying and determining whether general impairment guidance can be used to help mobile designers effectively address situational impairment events in mobile device interaction design. This exploratory research exploited existing parallels with solutions created in design/research to support users with more omnipresent impairments, extending work first suggested by Nicolau [29]. A systematic literature review of work in parallel domains produced a draft set of preliminary guidelines for addressing various types of situational impairment events. The applicability of this draft set was then examined by a panel of mobile interaction experts through a novel adaptation of a consensus-seeking process known as the Delphi method, mapping to themes from an earlier study classifying situational impairment events [43]. Specifically, the study described in this article attempted to answer the following research questions:

1. Can new guidance be created, and can existing guidance be strengthened to better account for the presence of situational impairments faced by users of mobile technology?
2. Can existing guidance that supports users with more omnipresent impairments be leveraged to inform the guidance for the supporting of users experiencing situational impairments?

2 Related work

Users face four distinct challenges in mobile device interaction: (1) cognitive load (limited attention resources); (2) physical constraints (non-mobile activities may place constraints on physical resources); (3) terrain (external environment); and (4) other people (activities often involve a social element) [26]. Environmental context [9], can significantly confound interaction. Further, because context consists of users, activities, social settings, the environment, physical conditions, infrastructure, available applications, and I/O channels [46], research needs to understand the inter-relationship of these factors, and the nature of artifacts created through the mobile inter-relationship.

Recognizing the importance of situation, context and environment where interaction takes place, researchers have attempted to measure the effects. Barnard et al. [4], for example, demonstrated that attempting an interaction while walking coupled with varying lighting conditions influenced task performance. Studies have also examined environmental factors on user interaction performance such as acute cold [39], wet touch screens [53], ambient noise [41], and "Situational Visual Impairments (SVI)" [52]. Some studies suggest guidance for addressing situational impairment challenges. For example, in the above-referenced study relating to SVIs, Tigwell et al. [52] recommend extending existing industry and accessibility guidelines to include various issues that present during SVIs.

Other studies outline why health-induced challenges are not that different from those that are *situationally* induced. Wobbrock et al. [61] argued for focusing on "ability" (as opposed to "disability") when creating systems to leverage the full range of human potential. They note, "…people do not have dis-abilities any more than they have dis-money or dis-height." [61]. A model for Assistive Technology (AT) called The Person–Environment–Tool (PET) suggests that activity and participation are a function of factors making no distinction between people of differing abilities, environmental modifications intended for people of differing abilities, or between different function-enhancing technologies [18]. Nicolau [29] examined whether situational and health-induced impairments affect users in similar ways by focusing on walking with a tremor disorder and similar situational conditions. Modeling users with a generalized set of abilities independent of their impairment, the goal was to posit an inclusive universal design approach connecting Assistive Technology and situational impairment domains [29].

Some recent research has begun to examine situational impairments from a more qualitative and phenomenological perspective. Saulynas et al. [43] deployed a diary study to collect a corpus of situational impairment events. Theoretical sampling and analysis revealed at least five themes to describe the types of situational impairment events experienced by study participants. These five themes: (1) Ambient-Environmental, (2) Complexity, (3) Social-Cultural, (4) Technical, and (5) Workspace-Location provided the framework for the guidance developed in this study. In addition to these five themes, the research revealed a special severely constraining subset, where the multitude and complexity of ambient agents contributing to mobile I/O transaction disruption were found and defied conventional classification. These were dubbed "Severely Constraining Situational Impairments (SCSI)" and were also part of the framework of this study. Each theme/sub-theme definition, along with the characteristics of a SCSI as defined in Saulynas et al. [43], is detailed in "Appendix 1".

While research has measured the effects of contextual elements present in the mobile problem space, and some work has attempted to classify various aspects of the phenomenon, no centralized, generalizable guidance currently exists for the addressing of situational impairments. The following section describes a two-step methodology undertaken to identify and determine the feasibility of guidance for addressing situational impairment events.

3 Methodology

To address the two research questions, (1) Can new guidance be created, and can existing guidance be strengthened to better account for the presence of situational impairments faced by users of mobile technology; and (2) Can existing guidance that supports users with more omnipresent impairments be leveraged to inform the guidance for the supporting of users experiencing situational impairments; a two-stage approach was developed. A systematic literature review was undertaken to identify appropriate guidance to support all impairments, including health-related support for all types of interaction (mobile and other). In the second stage, design and research professionals evaluated potential guidance to determine applicability for interactions affected by situational impairments. Ethical approval was gained through the Institutional Review Board (Protocol: 19-042: IRB Chair: Dr. Jeffrey D. Elliot, Stevenson University), which involved users signing a consent form for their participation.

3.1 Stage 1: systematic literature review

A systematic literature review (SLR) produces comparisons from a scientifically selected set of primary studies allowing for creation of generalizations [5]. Similar to Groenewald et al. [15], the SLR conducted in Stage 1 produced a corpus of direct and indirect examples of guidance that might address issues represented when a situational impairment presents. That corpus was then phenomenologically analyzed to determine whether generalizable themes could be gleaned. This resulted in the framework for the set of draft guidelines presented to a panel of experts in Stage 2. Figure 1 outlines the process used (detailed in the subsections below).

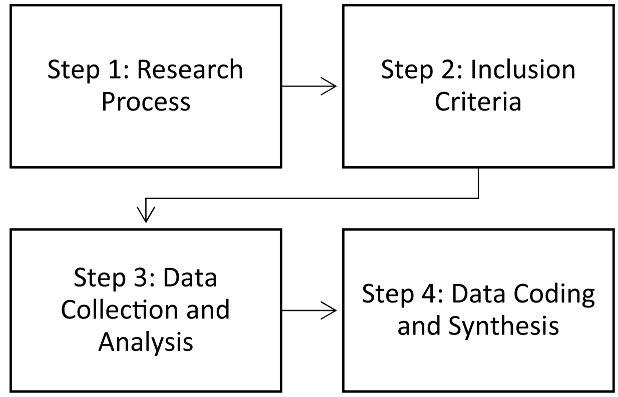

Fig. 1 Outline of the systematic literature review process

3.1.1 Steps 1 and 2. Research process and inclusion/exclusion criteria

Keywords used were generated based on a systematic approach similar to Anthony et al. [3]. A sampling of papers was added to a customized software program that scanned text and tallied the frequency of words used, which helped produce possible search terms.

It was imperative to confirm that minimal direct situational impairment guidance existed. Therefore, one set of keywords used was "situational impairments" and "SIID". In addition, to amass guidance from relevant domains, the keywords ("mobile interaction", "assistive technology", "accessibility", and "universal design") were also used. These keywords were then paired with the generalized terms "guidelines", "principles", or "recommendations" (e.g., "SIID + Guidelines"). The resulting 6 × 3 search criteria matrix for every relevant combination appears in Table 1. To assist in targeting relevant sources, various filter words/phrases were added to exclude clearly irrelevant topics. Books, standards, courses, and titles that required payment were also excluded from consideration.

Each search phrase was deployed on two databases: (1) ACM Digital Library and (2) IEEE Xplore. These two sources are very common choices for SLRs in the HCI domain (e.g., [15, 2, 28]), enabling researchers to identify peer-reviewed content.

Any reasonable set of guidance relating to solving one or more of the situational impairment event themes or characteristics of Severely Constraining Situational Impairments (as described in 43) was included. The process was designed to end when data saturation[1] was achieved.

3.1.2 Steps 3 and 4. Data collection and analysis and data coding and synthesis

If a paper met inclusion criteria, (1) A bibliographical entry was created and catalogued to include the relevant research domain(s) and (2) The source content that

[1] Additional discovery becomes redundant, reasonably assuring further data collection would only yield similar results [12]

Table 1 Search phrases used in the systematic literature review

	Guidelines	Recommendations	Requirements
SIID	SIID guidelines	SIID recommendations	SIID requirements
Situational impairment	Situational impairment guidelines	Situational impairment recommendations	Situational impairment requirements
Mobile interaction	Mobile interaction guidelines	Mobile interaction recommendations	Mobile interaction requirements
Accessibility	Accessibility guidelines	Accessibility recommendations	Accessibility requirements
Assistive technology	Assistive technology guidelines	Assistive technology recommendations	Assistive technology requirements
Universal design	Universal design guidelines	Universal design recommendations	Universal design requirements

contained guidelines was then added to a corpus database. Each extracted guideline was coded using qualitative content analysis. After obvious duplicates were identified and removed, each corpus item was examined by applying the following: (1) Does it offer a suggestion that can be utilized to directly or indirectly solve any of the situational impairment themes or characteristics of Severely Constraining Situational Impairments? (e.g., a guideline that addressed a visual or motor impairment offers an analogous solution to a situational impairment); or (2) Does it approach the problem space from a different or unique angle? The process continued until a final set of developed draft guidelines was synthesized and prepared for Stage 2.

3.2 Stage 2: methodology (Delphi)

To evaluate the applicability of the guidance from Stage 1, and to determine which items gleaned can offer guidance for mobile designers, a novel adaptation of the Delphi method was used. Using a series of controlled feedback exercises, the Delphi method is a way of structuring group communication to obtain a reliable consensus of an assembly of experts [24]. Examples of its use include identifying software project risks [21], knowledge management [16], and assistive technology [58]. This study deployed a unique mixture of the "rating-type" and "concept-framework" variants of the Delphi method incorporating elements similar to Wentzel et al. [58]; Okoli and Pawlowski [32],Holsapple and Joshi [16], and Chen [7].

The target of 10–18 experts follows similar studies by Paliwoda [35] and Okoli and Pawlowski [32], and included both designers of mobile technology and researchers of mobile interaction to address the broadest swath of stakeholder interests. Sessions were asynchronous via email. Participants benefited from others' input through the iterative nature of the exercises. Delphi studies require multiple sessions and are known to be highly demanding. To reduce attrition, sessions were designed to be brief [32]. The process is outlined in Fig. 2 and described in detail below.

3.2.1 Pre-step: selection of experts

To assure the selection of qualified experts, a "Knowledge Resource Nomination Worksheet" was created [32]. Questionnaires followed principles established by Dillman [10]. The 20 experts (5 females/15 males, mean age 40.7) qualified for participation based on having at least one year experience designing or researching mobile interaction (mean 6.2 years). The researchers' professional network yielded 60% of the participants, some *snowballed* from that network (detailed in Table 2).

3.2.2 Step 1: orientation

Each participant watched a brief orientation video (https://youtu.be/t-iByKVzfo4) defining the themes (with examples), along with the definitions from the video and a list of draft guidelines in alphabetical order. Clarifying questions were encouraged.

3.2.3 Step 2a: narrowing down and classification of existing guidance

This step involved a minimum of two rounds. For the first round (Narrowing Down and Classification), as in Wentzel et al. [58], the expert panel was presented with the Stage 1

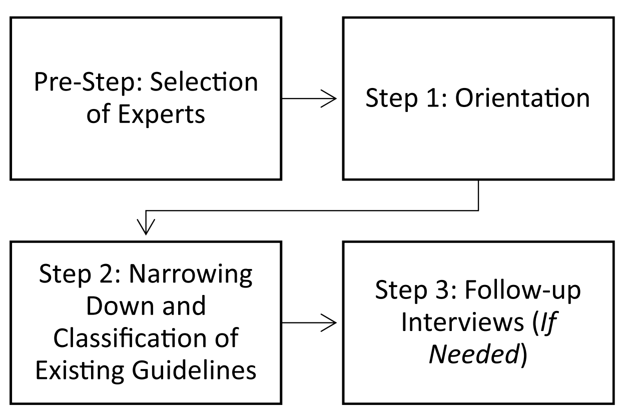

Fig. 2 The Delphi process outlined

Table 2 Participant demographics

ID	Age	Identified gender	Years of mobile interaction design/ research experience	Occupation
R1	45	M	10	Usable security researcher/freelance UX developer
R2	54	M	4	professor
R3	42	M	5	PhD student
R4	29	M	4	Assistant professor
R5	32	F	6	Doctoral researcher
R6	41	M	15	Associate professor
R7	25	F	2	student
R9	67	M	10	Professor
R10	28	M	2	PhD student
P1	53	M	18	Software engineer
P2	21	M	2.5	Student
P4	38	M	3	Software engineer
P6	48	M	10	System developer
P7	54	M	1	IT project manager
P10	49	F	3	Software engineer
R8	36	F	1	Graduate assistant
P11	61	M	7	CTO
P8	25	F	10	Student
P3	28	M	4	Software engineer
P5	38	M	7	Lead developer

guidelines in six separate email-delivered online questionnaire modules. Five modules represented one situational impairment theme from Saulynas et al. [43], with the sixth module representing Severely Constraining Situational Impairments. The order of modules in the email was different for each recipient and was determined via Latin Square to reduce order bias, and participants completed modules in the presented order. For each module, participants chose as many of the draft guidelines as they believed represented a potential solution for the addressing of that module's theme. Any of the draft guidelines (termed "items") that were selected required justification using textboxes at the bottom of each screen. The items were presented alphabetically to reduce order bias. Each module presented the same set of items. Any guideline that was selected by 50% or more of the panel was advanced to the next round [32]. The first page screen capture of the "Complexity" module appears in Fig. 3. The data captured were then analyzed and answers commuted to the participants in Round 2.

3.2.4 Step 2b: rating rounds

The objective of this step was the refinement of the list while assuring it was bound statistically [44]. Two rating rounds were conducted. After the first round, an additional round provided each participant a chance to change their response based on statistical metadata, as well as other participants' comments. This process represents one of the strongest aspects of the Delphi method. Each participant is a member of a *group*, but the asynchronous and non-co-located nature of the process allows them to remain anonymous. The possibility of bias and/or the issue of unbalanced group participation (i.e., a dominating or non-contributing member) is tremendously reduced [51].

3.2.4.1 Rating round 1 Participants received a workbook with six worksheets each representing a situational impairment theme. Each sheet contained: (1) all items chosen by 50% or more to reduce the list to a more manageable size [32], (2) theme/sub-theme definition, (3) a rating entry area, and (4) a brief rating justification area. Items were listed alphabetically to reduce the effect of order bias. Participants were asked to consider the applicability of each guideline toward the addressing of each situational impairment theme as well as their generalizability, and then asked to rate each guideline on a 5-point Likert Scale, as was done in the studies by Thangaratinam and Redman [51] and Chen [7]. Scale values were defined as follows:

5 = Essential guideline for this type of situational impairment.

4 = Important guideline for this type of situational impairment.

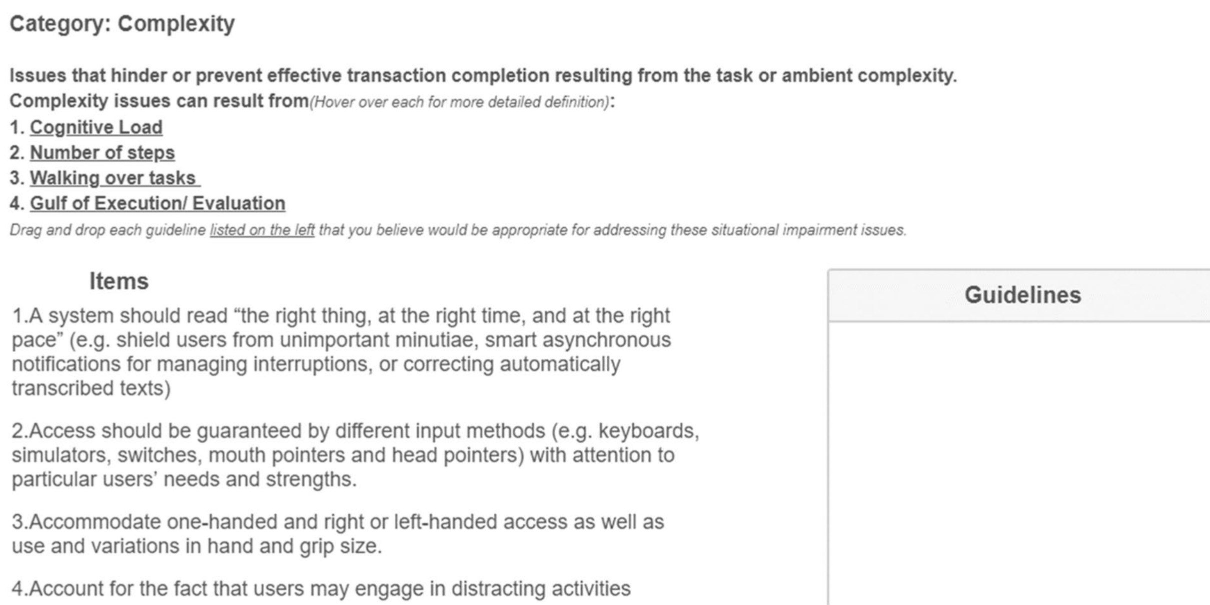

Fig. 3 Sample initial round screen

3 = Could have some value, but not essential for this type of situational impairment.
2 = May have some minimal value for this type of situational impairment if rewritten or rethought in some way.
1 = Offers no value for the addressing of this type of situational impairment and should be removed from the list.

Findings were analyzed and similar to York and Ertmer [62], a guideline reached consensus in this round if either met the following conditions:

1. Interquartile Range (IQR)[2] ≤ to 1 AND ≥ 75% agreement on a rating of 4 and 5 *or*
2. A > 92% frequency rating in the 3, 4, 5 categories (> 92% indicated all but 1 participant).

3.2.4.2 Rating round 2 Consensus items from the previous round were documented, as these were eligible for inclusion in the final set. A second rating round was run for the remaining items where consensus was not achieved. Participants were sent a second six sheet (theme) workbook. Each sheet displayed the theme definition and each guideline that did not achieve consensus as well as: (1) percentage of participants who rated that guideline a 4 or 5, (2) percentage of participants who rated it a 3, 4, or 5, (3) mean rating, (4) their rating, and (5) participant sample comments. A sampling of comments representing rationale of choices helps facilitate a quicker arrival at consensus (Rohrbaugh, 1979 as referenced in [32]). Participants considered the metadata, the applicability and generalizability of the guidance, and were then given the opportunity to reassess their original rating (with justification if the rating changed).

3.2.5 Step 3: follow-up interviews (if needed)

If consensus had not been reached on many of the items, follow-up interviews would have been conducted with some participants to ensure that commentary and findings truly represented their positions, opinions, and possibly additional critical themes.

4 Findings

4.1 Stage 1 findings (systematic literature review)

The search yielded 285 papers from which guidance was extracted (169 from the ACM database and 116 from the IEEE database). The domains represented were Accessibility/Assistive Technology (75%), Mobile Interaction (15%), and SIID/Situational Impairments (10%).

Next, each was analyzed and any data that might represent potential guidance toward addressing a situational impairment and/or Severely Constraining Situational

[2] The IQR is an alternative measure of variance that is the result of the subtraction of the 3rd quartile from the 1st quartile value. This measure has been used by some Delphi studies like Chen [7] that employed Likert Scale rating as an alternative measure of variance to standard deviation. IQR has an advantage over standard deviation in that it is unaffected by extreme outliers. It is for this reason that the researchers chose this measure of variance for the present study.

Impairment was extracted into a database. This resulted in 3080 extracted pieces of data from the 285 sources that were mined. The domains represented were Accessibility/Assistive Technology (1832 items, 59%), Mobile Interaction (1208 items, 39%), and SIID/Situational Impairments (40 items, 1%). Again, it is clear that Accessibility/Assistive Technology was dominant, and the paucity of guidance related to situational impairments was evidenced in only 40 extractions.

Items were obtained through one of the following ways: (1) Direct extraction from the source (unmodified or slightly modified); (2) Edited/modified version of the extraction; or (3) Editing and/or combining several extracted source items. Note that some extractions represented the same guideline in which case only the first instance in the database was used. An example of the process described in #3 above appears below:

- *Original 1* "Client-side image maps to be used instead of server-side image maps except where the regions cannot be defined with an available geometric shape." [48],
- *Original 2* "Locate functionality with high complexity on server side. Running functionality with high complexity tends to consume high resources of CPU and Memory. Allocate such functionality in S.Control." [23];
- *Original 3* "Locate functionality with a large amount of data manipulation on server side. Mobile devices have a limited secondary memory space, and computing with data on secondary memory is inefficient." [23];
- *Edited/Combined Draft Guideline* Locate Functionality with high complexity or a large amount of data manipulation on server side.

4.1.1 Mapping guidance/coding themes to situational impairment themes/ severely constraining situational impairment characteristics from Saulynas et al. [43]

Viable content was reduced from 3080 to 582. However, even if all 582 records represented valuable guidance, not all 582 necessarily represented unique guidance. Therefore, data were examined for generalized common themes present in multiple records, then coded, and themes were developed. The resulting themes were: (1) Context Aware, (2) Limited Cognitive Resources, (3) Limited Physical Resources, (4) Limited Technical Resources, and (5) Socially Acceptable. Extracted items included various interaction environments and covered the gamut of disability issues including physical (e.g., vision, hearing, motor) and cognitive challenges (e.g., memory). In addition, considerable literature addressed designing technology for older adults, as they can experience vision, hearing, motor, and memory challenges as a result of aging. The coded data were then mapped to the themes developed in Saulynas et al. [43] that are detailed in "Appendix 1". How these items were specifically mapped is discussed next.

4.1.1.1 Context aware Of the 582 remaining records, 219 were coded as "Context Aware" which focused on solutions where technology adjusts input/output conditions based on changing ambient conditions. Accuracy, adaptation, and being able to make adjustments in real time were prominent in the guidance offered. Sehic et al. [47], referring to a context-aware programming model, noted, "Context-aware applications have to be developed using dedicated programming abstractions that provide an environment-agnostic interface." The diverse papers addressing the Assistive Technology and Accessibility domains noted the need for technology to be adaptable to the user and context. For example, in a paper on designing accessible TV remote controls, Costa et al. [8] noted that buttons should be configurable for sensitivity so that users regardless of dexterity and strength will be able to interact effectively.

Some records coded as "Context Aware" refer to the need for technology to act like a human personal assistant, getting to know and continuously learn about what the user wants and needs and produce empathetic human-like results. Inostroza and Rusu [17], for example, in their paper about mapping usability heuristics note, "Like a good personal assistant, [the system should] shield people from unimportant minutiae." This human-like technological empathic need also expressed itself in papers from the AT and Accessibility domains. Sulaiman et al. [50] importantly noted that an intelligent system for blind users should ultimately be able to "…read the right thing, at the right time, and at the right pace."

4.1.1.2 Limited cognitive resources The 174 records coded as "Limited Cognitive Resources" refer to unavailability of intrinsic user resources. These mapped well to the subthemes: "Cognitive Load", "Number of Steps", and "Gulf of Execution/Evaluation" of the "Complexity Issues" theme from Saulynas et al. [43]. In design workshops conducted by Saulynas and Kuber [42], limited cognitive resources were also noted as a main differentiator of a regular situational impairment verses the more severely constraining variety for users on-the-go. Mobile devices may demand attention that can distract users from more important tasks. Okoshi et al. [33] suggest discovering "Breakpoints" ("boundary between two adjacent units of user activities") as timing potential distractions (such as perceiving and responding to notifications) to lessen cognitive load.

AT/accessibility research has noted, because assistive technology users often need separate dedicated devices, the burden of dealing with additional items in and of itself creates additional complexity. For example, Quinones et al.

[38] note that visually impaired users "…desire to carry around as few tools as possible. An open concern is how to design a technology such that it poses little burden…". Burden reduction needs could have parallels beyond the visually impaired domain. Forgetting mobile accessories (e.g., headset, charger) was among issues that appeared in the situational impairment events corpus from Saulynas et al. [43], suggesting that the added capability/functionality of mobile devices in users' everyday routine might be adding some complexity to that routine.

4.1.1.3 Limited physical resources The 109 records coded as "Limited Physical Resources" refer to issues accessing or applying the necessary physical resources needed (e.g., holding grocery bags or a mouth full of food). This theme primarily supports the "Workspace/Location Issues" theme from Saulynas et al. [43] but also secondarily the "Ambient-Environmental Issues" theme.

Solutions focused primarily on overcoming common physical limitations during mobile events, such as accounting for limited/restricted workspace [11], or body and clothing-specific affordances as alternative input spaces [25]. Also offered was guidance addressing alternatives to normal mobile task modalities. Schulze and Woerndl [45], note that alternative ways of input must be considered, as keyboard-based input on mobile devices is laborious at best and infeasible at worst. AT and accessible solutions also centered around overcoming limitations but for those users whose physical limitations are more omnipresent. Examples include single-handed interaction [36] and [56], as well as support for both left- and right-hand use and various hand sizes and grips [20].

4.1.1.4 Limited technical resources Corpus items coded as "Limited Technical Resources" (44 total), unlike "Limited Physical Resources" and "Limited Cognitive Resources", refer to issues exogenous to the user and focused on mobile technology limitations. Battery life and Internet connection were the most common issues addressed, directly mapping to the two major sub-themes of the "Technical Issues" theme from Saulynas et al. [43]. Suggestions included placing mobile data on the server side thus reducing battery-hogging phone resources [23] and differentiating connection and disconnection periods [34]. Though few records were extracted from AT/accessibility papers, some offered guidance. For example, focusing on older adults' mobile use in developing countries, Van Biljon and Renaud [55] noted the value of recharging via cradle verses plug.

4.1.1.5 Socially acceptable Some recommendations (28 in total) addressed issues of social acceptance for attempted transactions in the wild and mapped directly to the "Social/Cultural Issues" theme from Saulynas et al. [43]. The preponderance of guidance came from AT/accessibility research, focusing on technology for an impaired population feeling self-conscious or needing assistance (e.g., a blind user unaware of others nearby). Coventry and Bright [6] noted the importance of technology being "covert" to minimize the perception of interactions being of an assistive nature. Oh and Findlater [31] observed visually impaired participants prioritize social acceptability over ease of use, physical comfort, and discreet input locations. Piccolo et al. [37] note the importance that blind users place on knowing their input/output is secure as they may not be aware of people nearby. This could apply to any user experiencing reduced situational awareness.

4.1.2 Draft guidelines

This approach resulted in 49 draft guidelines deployed in Stage 2 (complete list in "Appendix 2"). While source domains for each draft guideline are noted, it is somewhat problematic to cite specific sources for each guideline. Domain references were often a function of what remained after several duplicate sources were removed in the process that took a corpus of 3080 items, paired down to 582, and then eventually 49. In cases where the same conceptual guidance was referenced in several discrete sources, many draft list items were created as the result of consolidation, forming a new single guideline. Even in cases where the guideline was extracted for use, it could not be determined if that source was the first or only source of that idea. For example, a draft guideline mapped to "Limited Physical Resources" ("Access guaranteed by different input methods…") was at least partially derived from a paper discussing W3C standards (common in the corpus), and another paper discussing design for people with cognitive impairments. The reason a particular W3C standard was used in their work may have been unique, but not the standard or the concept itself. It would be impractical to attempt to source all the papers with items extracted to the corpus offering the same recommendation.

4.2 Stage 2 results (Delphi)

4.2.1 Narrowing down and classification round

A total of 13 out of 20 participants completed all six modules in this round (two completed some but not all rounds). Of the 49 presented, 29 unique items met the criteria (described in Sect. 3) for carryover into the rating rounds. This yielded 43 preliminary guidelines to consider over the six themes, as several were represented in multiple tables.

Table 3 Rating round 1—guideline consensus summary

Theme	Ranked	Reached consensus	Removed due to < 50% 4/5 rating	Carry to next round
Ambient-environmental	5	3	0	2
Complexity	8	6	1	1
Social-cultural	8	3	1	4
Technical	6	5	0	1
Workspace-location	6	3	0	3
SCSI	10	3	2	5
Totals	43	23	4	16

Table 4 Rating round 2—guideline consensus summary

Theme	No consensus during rating round 1	No consensus during rating round 2	Net add to master list
Ambient-environmental	2	1	1
Complexity	1	0	1
Social-cultural	4	3	1
Technical	1	0	1
Workspace-location	3	0	3
SCSI	5	1	4
Totals	16	5	11

4.2.2 Rating round 1

All 13 participants who completed the initial round also completed this round. Based on the criteria for consensus (defined in Step 2b: Rating Rounds subsection of Methodology), 23 of 43 items (53.5%) reached consensus with a rating of 4 (important) or 5 (essential). Of the remaining 20 items not meeting consensus, 16 were selected for the second and final rating round. The four items that did not make consensus but were not considered for Round 2 were under 50% agreement on a rating of 4 and 5. The goal was guidance that experts determined to be important or essential. Therefore, guidelines where less than half ranked it as a 4 or 5 were eliminated (detailed in Table 3).

4.2.3 Rating round 2

The opportunity to reconsider based on external data and comments presented, resulted in more of the draft list meeting the criteria for consensus. Similar studies such as Chen [7] relaxed criteria in subsequent rounds, over concerns for participant attrition should the study extend too long. Participant attrition was evident (only 12 out of 13 completed this round). However, the criteria used stayed as strict as in Rating Round 1, as the results of this round showed no need to relax them. Table 4 shows that only 5 of 16 reassessed items remained without achieving consensus, resulting in a total consensus rate of 79.1%, exceeding the rate in Chen [7], even with relaxed criteria. Similar to Chen [7], with only 5 of the original 43 items not in consensus, the study terminated in this round with no need for follow-up interviews.

4.2.4 Guidance for addressing situational impairments

"Appendix 3" shows each item selected from the original draft set. In all, 26 items were employed from a total of 34 records, as some were used for more than one theme. The final preliminary guidelines, arranged by situational impairment theme along with relevant implications, are discussed next.

5 Discussion

Key take-aways and implications of this study include: (1) because little guidance exists toward addressing of situational impairments, new guidance can be created and existing guidance can be strengthened to better account for the presence of situational impairments faced by users of mobile technology (RQ1); (2) guidance can be gleaned by examining related domains, particularly Assistive Technology and Accessibility (RQ2); and (3) the Delphi method can be a valuable tool for validating guidance.[3]

[3] When referring to final set of 26 guidelines, we use the numbering applied to the original 49 of the unique draft guidelines first offered to the expert panel for review and validation.

Table 5 Ambient-environmental issues guidance

Ambient-environmental						
G#	Guideline	Mean rating	IQR	4+5%	3+4+5%	Source domain
2	Access should be guaranteed by different input methods (e.g., keyboards, simulators, switches, mouth pointers and head pointers) with attention to particular users' needs and strengths	4.3	1.0	77	92.3	Accessibility/ assistive technology
11	Avoid touch input that is too sensitive (prevent accidental presses) and tackle the fear of accidentally initiated commands	3.8	1.0	69	92.3	Accessibility
27	For any given task the design should specify which modalities are appropriate for each context and offer additional value to users that are not directly interacting with the screen	3.5	1.0	54	92.3	Mobile interaction
45	Under certain ambient conditions (e.g., extreme cold) account for reduced accuracy (e.g., offset skew) in target acquisition, particularly in one-handed interaction	4.3	1.0	85	92.3	Mobile interaction

5.1 Analysis of guidance by theme

In this subsection, using the themes of Saulynas et al. [43] as a framework, the final set was analyzed. Each theme is represented in a separate table showing the: (1) items chosen, (2) scoring that led to their inclusion, and (3) source domain(s). Also, the definition of each theme from Saulynas et al. [43] and the defined sub-categories are provided above each table as a reference. How well each of the theme issues is being addressed and whether user needs/desires are being accounted for are discussed below each table along with sample supportive commentary (where appropriate) from Stage 2. Finally, to help support the potential validity of the guidance represented here, situational impairment scenarios originally presented in design workshops conducted by Saulynas and Kuber [42] were presented as use cases demonstrating how a subset of the guidance identified could be applied. This in turn could be used to support designers in developing solutions to address the challenges faced by users.

5.1.1 Ambient-environmental issues

Definition from Saulynas et al. [43] Anything about the environmental context of the transaction space that is hindering or preventing effective transaction completion.

Subcategories

- *Meteorological conditions* Some aspect of the weather (i.e., sun, rain, heat, or cold) that is hindering or preventing effective transaction.
- *Ambient "Noise" conditions* Some non-meteorologically ambient condition is creating "noise" in the communication channel hindering or preventing effective transaction. The "noise" can be any non-meteorological input that is negatively affecting the signal-to-noise ratio of the transaction signal (not necessarily just audible noise) including another human.

Ambient-environmental issues focus on impairment events occurring due to the constant flux of ambient context. The expert panel chose four potential design solutions that focus on effective incorporation of alternative modalities (Table 5). All were from the "Limited Physical Resources" category established in Stage 1. The sources chosen were evenly split between the mobile interaction and AT/Accessibility domains. The results indicate that the mobile interaction community needs to account for diverse conditions as is demonstrated in the two mobile sourced items which point to "context" (#27) and "ambient conditions" (#45). AT/Accessibility developers need to account for diverse abilities as reflected in Guideline #2 ("Suggesting the use of alternative modalities") and Guideline #11, which offers a more general view of users' unique set of strengths and abilities. Guideline #11 also points to the need to account for adjusting touch sensitivity, which are applicable to both personal and situational conditions.

5.1.2 Complexity issues

Definition from Saulynaset al. [43] Issues that hinder or prevent effective transaction completion resulting from task or ambient complexity.

Subcategories

- *Cognitive load* The cognitive resources required to effectively complete a transaction are unavailable or not easily accessible to the user as the result of having to hold aspects of the current transaction in working memory or having "other things on their mind" that are not directly related to the current transaction.
- *Number of steps* The number of steps that would be required to complete a transaction are perceived as too

Table 6 Complexity issues guidance

G#	Guideline	Mean rating	IQR	4+5%	3+4+5%	Source domain
1	A system should read “the right thing, at the right time, and at the right pace” (e.g., shield users from unimportant minutiae, smart asynchronous notifications for managing interruptions, or correcting automatically transcribed texts)	4.5	0.0	92	92.3	Assistive technology/ mobile interaction
4	Account for the fact that users may engage in distracting activities because they may not realize that their performance is degraded or overconfident in their ability to deal with distractions while engaged in the primary activity	3.8	0.0	77	92.3	Car interaction
8	Avoid distractions (i.e., blinking images) and discourage unconscious action in tasks that require vigilance	4.4	1.0	85	92.3	Accessibility
20	Design flexible limits for task completion and warnings/ feedback should stay on the screen as long as the user does not respond to them	3.9	2.0	69	92.3	Accessibility
22	Detect breakpoints(when the user is not actively manipulating the device) using additional sensors, such as GPS, accelerometer, proximity and light sensors	3.6	1.0	62	92.3	Mobile interaction
29	In highly demanding situations, the user should be saved from overload by either oppressing or delaying non-important information	4.2	1.0	77	100.0	Car interaction
36	Minimize the number of steps and consider simple movement (e.g., clicking) over complex movements (e.g., dragging, drawing certain shapes). Also, interaction based on tap length (invoking different functionality on long tap) should be avoided	4.4	1.0	77	100.0	Accessibility/ assistive technology/ mobile interaction

numerous or too cumbersome to effectively complete the transaction.

- *Walking over tasks* The transaction cannot be completed due to another transaction attempting to occupy the active transaction space (i.e., a modal pop-up that appears while attempting to type a text message) or other interruption that may or may not be technology related (i.e., children interrupting an attempt to place a call via Bluetooth).
- *Gulf of execution/evaluation* [30] The user has insufficient knowledge from personal experience or from the current context to either effectively complete a transaction or evaluate whether a transaction has been effectively completed.

When addressing mobile transaction space issues that may increase overall complexity, it is not surprising that guidance selected by the expert panel reflect solutions that either address cognitive load (#4, #8, #20, and #36) or suggest a greater technology role in assessing environmental context and making adjustments as needed (#1, #22, and #29) (Table 6). The latter role is succinctly summarized in Guideline #1, indicating that technology “should read the right thing, at the right time, and at the right pace…” and protect users from information irrelevant to the context. In one situational impairment scenario presented in the design workshops conducted by Saulynas and Kuber [42], participants were asked to envision being actively engaged in driving to an unknown location, using GPS, and having a phone call “override” the GPS directions at a critical moment. A main implication for designed gleaned from the workshops in addressing scenarios like this was, that the mobile device should act as a personal assistant: (1) recognizing the situation context, (2) assessing the best course of action, and (3) executing the steps necessary with minimal to no in situ input from the user [42]. This suggested solution is clearly supported by Guideline #1, but also Guideline #29 (“In highly demanding situations, the user should be saved from overload by either oppressing or delaying non-important information”).

Four of the seven items chosen were completely or partially sourced from the AT/Accessibility domain. Items #8 and #36, for example, reflect the importance that the panel collectively placed on recognizing the limits of human cognition and how the test of these limits is being exacerbated. One panelist noted regarding Guideline #36, “Every step is another chance for errors, bail-outs, and frustration."

Another interesting finding was that two items (#4 and #29) were sourced from mobile research specifically targeted to interaction with technology while driving. While technically catalogued as mobile interaction, these items are specifically being labeled here as “Car Interaction”. Mobile

Table 7 Social-cultural issues guidance

G#	Guideline	Mean rating	IQR	4+5%	3+4+5%	Source domain
1	A system should read "the right thing, at the right time, and at the right pace" (e.g., shield users from unimportant minutiae, smart asynchronous notifications for managing interruptions, or correcting automatically transcribed texts)	4.1	1.0	85	84.6	Assistive technology/mobile interaction
20	Design flexible limits for task completion and warnings/feedback should stay on the screen as long as the user does not respond to them	3.9	0.0	77	92.3	Accessibility
25	Ensure the AI system's language and behaviors do not reinforce undesirable and unfair stereotypes and biases	4.4	1.0	92	92.3	Mobile interaction
41	Provide subtle feedback, such as vibration from within a pocket, or personal audio, in situations where individuals are hesitant to carry their devices in public	4.3	1.0	85	92.3	Assistive technology

technology interactions while operating a vehicle (either a mobile device or embedded) are increasingly common, yet interaction with anything not supporting the driving task can test the limits of human attention. As one of the key findings of Saulynas and Kuber [42] points out that even though users know the danger that exogenous device interaction can place on themselves and others, most (if not all) do it anyway. The increased complexity in mobile interaction attempts while driving was clearly deduced by the panel with the inclusion of these two items. One panelist quipped regarding Guideline #4, "I got distracted answering this, so I guess it's the real deal."

5.1.3 Social-cultural issues

Definition from Saulynas et al. [43] These issues offer no physical barrier to transaction completion but nevertheless can hinder or prevent effective transaction completion.

Subcategories

- *Fear of reprisal from an authority* Completing the transaction may result in a violation of the law or reprimand from a boss, teacher, or other type of authority figure (i.e., texting while driving, in class, or while at work).
- *Safety* The completion of a transaction is hindered or prevented due to concern over the potential harm the attempted completion may cause (i.e., getting into an accident while texting and driving or having your device stolen while using it on the street in a "bad neighborhood").
- *Socially acceptable behavior* The social context is perceived by the user to be inappropriate within the perceived cultural norms or personal moral code for effective completion of the transaction.

The main obstacle preventing transaction completion represented in this theme is user volition (Table 7). While most of the guidance focused on addressing technical barriers and physical issues, there were four that were coded in Stage 1 as "Socially Acceptable". These four all reflected on designing technology to help the user to not stand out or be embarrassed as the result of technology use in public. Two of the four draft items coded as "Socially Acceptable" speak directly to the "Socially Acceptable Behavior" sub-category of this theme. Guideline #25 seeks to ensure that the system does not produce socially/culturally insensitive output. Guideline #41 suggests subtle feedback to account for user hesitancy to carry devices in public. This addresses "Socially Acceptable Behavior" and perhaps "Safety" in scenarios where the user is concerned that public display may lead to device theft. As one panelist noted, "[When] waiting for an important notification when in an unfamiliar/unsafe location, [the user] wouldn't have to worry about constantly checking." Some panelists also noted the value of #41 in addressing embarrassment and the "Fear of Reprisal from an Authority" sub-theme. As one panelist noted, "Better for meetings or places where discretion is needed."

The results for this group were greatly influenced by the AT/Accessibility community. Three out of the four items were fully or partially sourced from these domains, which reflects an understanding that use of assistive technology often makes users feel self-conscious. The panel clearly recognized that even users who do not have more omnipresent physical or cognitive challenges may feel stigmatized in some situations. Guideline #1 ("…right thing, at the right time, and at the right pace…"), for example, was recognized by the panel as helpful in remaining inconspicuous.

5.1.4 Technical issues

Definition from Saulynas et al. [43] A technical fault, glitch, or other non-user or environmental issue that prevents effective completion of a transaction.

Subcategories

Table 8 Technical issues guidance

G#	Guideline	Mean rating	IQR	4+5%	3+4+5%	Source domain
13	Connect with different communications and data networks to ensure high availability of services	4.8	0.0	100	100.0	Mobile interaction
14	Connectivity and power issues should be transparent for the end-user. Use automatic logging as an efficient way to obtain continuous battery information and highlight/educate the user regarding their battery life limitations and performance improvements	4.6	0.0	85	100.0	Accessibility/ mobile interaction
23	Device should be easy to recharge via a cradle rather than a plug	3.8	1.0	62	92.3	Accessibility
24	Employ a simple and universal external mechanism to provide power for phone (e.g., implemented in a carry bag or in a coat pocket) making it accessible	3.7	2.0	54	92.3	Mobile interaction
26	Explicitly distinguish between periods of active use and passive use, then use the passive periods to conduct power and data intensive operations	4.2	1.0	85	100.0	Mobile interaction
33	Low energy consuming localization methods should be used as substitute for power hungry localization techniques (e.g., GPS)	3.9	1.0	69	100.0	Mobile interaction

- *Connection* Something technical prevents connecting to an information source (i.e., bad cell or no Wi-Fi).
- *Power* There is no, or insufficient, electrical power (i.e., low battery) to effectively complete the transaction.
- *Other technical* A technical issue other than connection or power that prevents effective transaction.

These results shown in Table 8 were straightforward and predictable. Technical issues are not the result of any user physical/cognitive limitation, any user choice, or any limitations brought about by the external environment. The inability to effectively complete a mobile transaction as a result of situational impairments from this category stems from limitations of mobile technology, in particular needing a constant data source connection and adequate power for operation. While Internet connection and access to a power source are necessary to interact with any information appliance, because mobile devices are usually used while on-the-go, these issues can often be exacerbated.

In addressing the sub-theme "Connection", the panel recognized the importance of having an omnipresent source of data. For Guideline #13 ("Connect with different communications and data networks"), the entire panel scored this as "4" or "5" (mean 4.8/IQR of 0.0). The panel deemed Guideline #24 ("Simple universal mechanism for power") valuable because, as one panelist noted, it "… helps users not worry about switching phones or asking others for a charger or trying to charge the phone in a public place." Guideline #26 ("Distinguishing between periods of active/passive use") was deemed valuable for both connection and power issues. As one panelist noted, "Reduced 'cognitive load' is good for electronics as well."

5.1.5 Workspace-location issues

Definition from Saulynas et al. [43] Issues that hinder or prevent the ability to effectively complete a transaction that are geospatial in nature. Either the workspace area is of insufficient size or the resources required are not within sufficient proximity to permit the effective completion of the transaction.

Subcategories

- *Inaccessible location* The information appliance is within reach but in a space that cannot be easily accessed in sufficient time to complete the transaction effectively (i.e., in a jacket/pants pocket or bag).
- *Workspace size* Some aspect of the workspace is affecting movement of resources required in the transaction and therefore hindering or preventing effective transaction (i.e., not big enough to effectively negotiate the input space).
- *Relative location* The relative location of the user and information appliance is such that interaction cannot effectively take place.
- *Unavailable resources* The resources needed to assist in the completion of the interaction are unavailable (i.e., hands full, phone powered off or on silent).

Workspace and location issues refer to the inability to access devices due to: (1) user and device being in different locations, (2) resources needed to access the device are unavailable, or (3) the workspace makeup is inhibiting access. It was expected that most guidance would come from items coded "Limited Physical Resources". In fact, only three of the six selected were coded "Limited Physical Resources" (Table 9). Others were items coded "Limited Cognitive Resources" (2) and "Context Aware" (1). All six

Table 9 Workspace-location issues guidance

Workspace-location						
G#	Guideline	Mean rating	IQR	4+5%	3+4+5%	Source domain
2	Access should be guaranteed by different input methods (e.g., keyboards, simulators, switches, mouth pointers and head pointers) with attention to particular users' needs and strengths	4.5	0.0	85	92.3	Accessibility/assistive technology
9	Avoid gestures needing precision, large areas to perform, or cause physical pain after prolonged use	4.5	1.0	85	100.0	Assistive technology
12	Avoid two-handed, multiple-finger interaction	3.9	1.0	77	92.3	Accessibility
21	Design technology such that it poses little burden/encumbrance (i.e., reducing the need for resources such as hands or storage areas like a coat pocket)	4.1	1.0	77	84.6	Assistive technology
36	Minimize the number of steps and consider simple movement (e.g., clicking) over complex movements (e.g., dragging, drawing certain shapes). Also, interaction based on tap length (invoking different functionality on long tap) should be avoided	4.0	0.0	77	100.0	Accessibility/ assistive technology/ mobile interaction
48	When in motion, user can query the system using voice, when not in motion, users can interact with the system using tabs and gestures	4.1	2.0	69	100.0	Assistive technology

were sourced, all or in part, from AT/Accessibility domains demonstrating a strong connection with research on mobility or motion issues. The fact that the panel found these to be of value with issues of space shows the strength of incorporating AT/Accessibility research. This impairment type (issues with tremors) was the focus of Nicolau's [29] research that first explored the possibility of an SIID-AT/Accessibility connection.

Item #2 ("Access via different input methods…") also appeared in the Ambient-Environmental Issues results, perhaps reflecting the common thread of non-stable interaction context existing in both themes. Guideline #36 ("Minimize the number of steps…") was also chosen for the "Complexity" theme. At first it did not seem intuitive to include a guideline coded as "Limited Cognitive Resources" for this theme, but rationales provided by the participants proved interesting in addressing "Workspace Size" and, possibly, "Inaccessible Location". For example, "This guideline would be great for speeding up interaction when it might be cumbersome in certain workspace locations, and where it might be too noisy for voice input."

The other guideline coded as "Limited Cognitive Resources" chosen for this theme was Guideline #21 ("Design technology such that it poses little/burden encumbrance…"), supporting the addressing of "Unavailable Resources". Guideline #9 ("Avoid gestures needing precision, large areas…") had justification reflecting value for "Inaccessible Locations" and "Workspace Size": "…if user is using the device in a small area like car, the space may not be enough for user to use gesture interaction to complete the task." Only Guideline #48 ("When in motion, user can query system using voice…") addressed the sub-theme "Relative Location" but could also support "Workspace Size" and "Unavailable Resources".

5.1.6 Severely Constraining Situational Impairments (SCSI)

Definition from Saulynas et al. [43] An occurrence of a situational impairment where a workaround is not available/easily obtained, or where a technological solution was found that only led to the introduction of a new situational impairment and disability.

SCSI characteristics/types

- *"Super" situational impairment event* Multiple impairment events combined in a single transaction. (E.g., "Thought of something I wanted to search the web for while I was cutting grass, but couldn't use phone because it was too bright out and couldn't use Siri because it was too noisy—By the time I reached a shady area, I ended up forgetting what the task was.")
- *Expiration of transaction "Half-Life"* The value of a transaction becomes zero before conditions conducive to transaction completion can be achieved. (E.g., A SMS is received (and unattended) while in a store. The text is read upon returning from the store and was a request from the spouse to purchase an item.)
- *Solution to One SIID Produces New SIID* An existing design solution to an SIID creates a new and different SIID. (E.g., voice input can overcome hand encumbrance, but not necessarily if that input contains information that cannot be disseminated in public.)

Table 10 Severely Constraining Situational Impairments (SCSI) guidance

G#	Guideline	Mean rating	IQR	4+5%	3+4+5%	Source domain
1	A system should read "the right thing, at the right time, and at the right pace" (e.g., shield users from unimportant minutiae, smart asynchronous notifications for managing interruptions, or correcting automatically transcribed texts)	4.5	1.0	77	100.0	Assistive technology/mobile interaction
2	Access should be guaranteed by different input methods (e.g., keyboards, simulators, switches, mouth pointers and head pointers) with attention to particular users' needs and strengths	4.4	1.0	85	92.3	Accessibility/assistive technology
5	Any function designed for the adaptation to the variable contexts and environments must function in real-time and as a background task without altering the normal operation and use	4.5	1.0	92	92.3	Assistive technology/mobile interaction
19	Design features to reduce contextual stress (e.g., facilitate the ease of safety check-ins, users locating one another, and compensate for lack of communication synchronicity)	3.8	1.0	62	92.3	Accessibility
20	Design flexible limits for task completion and warnings/feedback should stay on the screen as long as the user does not respond to them	3.8	1.0	69	100.0	Accessibility
29	In highly demanding situations, the user should be saved from overload by either oppressing or delaying non-important information	4.5	1.0	85	100.0	Car interaction
39	Passively identify potential situational impairment events so that the device can react independently of users' direct feedback	3.9	1.0	77	92.3	Mobile interaction

- *Competing modal transactions* Common communication channel needed for competing modal transactions. (E.g., "GPS navigation in car interrupted by telephone call.")
- *Pre-abandonment* Transaction voluntarily terminated due to [a] concern over the violation of certain contextual social/cultural norms, or [b] past history leads user to not make transaction attempt. (E.g., "Operation to get files from a secured 'cloud' service, download them to my phone with an app, then upload them to a web service is simply too cumbersome to do on the phone… If even possible at all…")

Severely Constraining Situational Impairments (SCSI) represent severe cases or amalgamated collections of different themes. It was not surprising that four of the seven guidelines chosen also were selected to combat one or more of the other themes (Table 10). Five were coded as "Context Aware", supporting findings in Saulynas and Kuber [42] that having technology be more context aware (e.g., like a personal assistant) was desirable in addressing these more severely constraining events. Significantly, five of seven items were sourced in part from the AT/Accessibility domain.

Guideline #1 reflected its almost universal applicability as well as its value in addressing the characteristic of "Expiration of Transaction Half-Life". Guideline #2 is also universal in nature with relevance addressing the characteristic "Competing Modal Transactions". Some panelists viewed Guideline #29 as helping address the characteristics of "Pre-abandonment" and "Competing Modal Transactions". Items chosen only for this category reflect strongly on solutions suggested from Saulynas and Kuber [42] to address the unique severity aspects of SCSI events. Guideline #5 ("Relating to the technology adapting in real-time") really accents the importance of context awareness in addressing the added load of a SCSI event. Guideline #39 refers to passive identification of situational impairment events identified by the panel for these reasons:

> Supports [the] situation by reducing the need for identifying what modality is better for the interaction or how things should be modified to support that situational impairment.
> Anything that saves the user from fixing the problem is a good thing.
> This is technology that helps produce calm.

In one situational impairment scenario presented in the design workshops conducted by Saulynas and Kuber [42], participants were asked to envision being in a crowded theater. During this time, their phone vibrates in their trouser pocket. They are expecting an important message and they believe checking cannot wait until the end of the show, but do not wish to bother anyone and even the act of leaving their seat would create a disturbance. Participants suggested potential ways to address this, through the use of a secondary device (smartwatch) to receive/reply to the message. This solution recognized the cultural affordance associated with the use of a wristwatch, mainly that it is currently culturally acceptable to look at one's watch during a movie or live performance without the user drawing much attention to themselves, unlike the more challenging scenario of removing the phone from the trouser pocket while seated, and then viewing the display [42]. This suggested solution is clearly supported by Guideline #1 ("…right thing, at the right time…"), Guideline #2 ("Access should be guaranteed by different input methods…with attention to particular users' needs…"), Guideline #19 ("Design features to reduce contextual stress"), Guideline #29 ("In highly demanding situations, the user should be saved from overload by either oppressing or delaying non-important information"), and Guideline #39 ("Passively identify potential situational impairment events so that the device can react independently of users' direct feedback.").

The final list of guidance (also in "Appendix 3") provides potential value for mobile design when addressing situational impairments (RQ1). The volume and normality of mobile device use requires addressing various challenges and new complexity brought about within this still nascent interaction space. The experts identified this potential source of centralized guidance as applicable to addressing situational impairment events in support of maximizing mobile user experience.

5.2 The value in examining guidance from parallel domains

The preponderance of expert validated guidance came all or partly from the Assistive Technology or Accessibility domains. Of the 34 final records, 20 (58.8%) were at least partially sourced from Assistive Technology/Accessibility research, further supporting that situational impairment guidance can begin to be addressed by examining how more permanent impairments are supported (RQ2). Individuals with health-induced impairments may have very different mental models of using technologies, but these results suggest that the challenges may be similar to individuals who are experiencing situationally induced impairments.

This is not to say that addressing situational impairment events from a UI perspective did not prove valuable. Since about two-thirds of the results were from AT/Accessibility domains, then about one-third was gleaned from research specifically focused on mobile device UI. However, the fact that most solutions did not come from the mobile domain illustrates the need for a more holistic solution.

5.3 The value of the two-step approach and Delphi and what the second round added

Through the Delphi process, researchers and practitioners achieved consensus determining guidance applicability and generalizability in this problem space. The two-step approach adopted was an effective structured method to determine the applicability of guidance, validated through a panel. Other methods have been used to evaluate design guidance such as focus groups [22] or interviews and affinity diagramming [27]. However, the value of using this novel Delphi method approach to the context of situational impairments was evident in the results, particularly in the rating rounds. The ability of the experts to offer their ratings anonymously in the first round allowed opinions to be recorded without the influence of other opinions. This can be a tremendous advantage of Delphi studies over focus groups, where participation may not be equally distributed and ideas subject to exogenous influence. No participant knew the others in this study thus alleviating concern over what other people felt about their choices.

The influence of others, however, can be valuable in shaping ultimate solutions to problems and this study also benefited from additional opinions in a subsequent rating round. Participants benefited from seeing group metadata comparing their scores and unstructured opinion statements in support of positions taken. The second round influenced the outcome as the process of showing participants different ratings influenced nearly all to change some of their scores.

6 Limitations and future work

6.1 Reducing participant workload

The Delphi method required participants to invest considerable time and cognitive effort. For example, each participant examined 49 items and then mapped them to one of six themes, justified mappings, then repeated the process five times before even being granted the privilege of advancing to the next round for *more* work. Instead of alpha order, perhaps presenting the draft list in a random order may offer a way to reduce order effect. However, there was no evidence that items at the end of the list were not being fully considered, as some of the later list items (e.g., 41, 45, and 48) made the final cut. Indeed, the distribution of list items by number appears to be quite evenly dispersed. Note also using the same alpha order for each participant allowed each guideline to retain a common ID number (i.e., Guideline #1 was always Guideline #1 for all participants). Because of the volume of data sought, while participants could have suggested additional guidance and free response comments at the end of each module, few did. To obtain deeper and richer insights from valuable experts, future studies could conduct interviews or more open-ended questioning at the time of the initial survey. The anonymous and asynchronous nature of the method reduced issues of dominance or passivity. However, the final round (where participants were allowed to see the overall group statistics and others anonymous comments) may have not prevented the issue of social conformity, where individuals change opinions/behavior to conform with an opposing majority's expectations. While studied extensively in face-to-face interaction, its effect on online groups is not yet completely understood [59].

6.2 Next steps: a targeted approach, testing with prototypes, and/or additional Delphi panels

Selections were made by humans, not an unbiased algorithm. Therefore, it is difficult to conclude that all bias was eliminated. The researchers knew what they were looking for, which might have led them to favor excerpts fitting the framework outlined in Saulynas et al. [43] and implications for design from Saulynas and Kuber [42].

The outcome of this research represents a first step. Designers and researchers can select the guidance from the list ("Appendix 3") and address this when developing interfaces to minimize the challenges from situational impairments. Future studies could offer a more targeted approach. Using these preliminary guidelines, the next logical application would be to develop prototypes to test their utility. For example, a prototype mobile app might be developed incorporating the items for addressing Ambient-Environmental issues. Tests *in the wild* could see how well the preliminary guidelines address this impairment type and possibly discover aspects not effectively being addressed. Also note that situational impairments can impact users with disabilities [1], so future work should address diverse needs and abilities. Should testing determine that guidance gleaned from these results prove of practical value, future studies could extend to handhelds (e.g., tablets) and wearables (e.g., smartwatches). Mobile technology innovation is proceeding at a rapid pace, and the guidance from this research will likely prove mobile device agnostic as new devices are created.

6.3 Cautions regarding designing to address situational impairments

Lastly, there may be a danger in designing to overcome situational impairments. As noted in Saulynas and Kuber [42], all their study participants openly admitted in interviews that they have attempted to complete a touch transaction on their mobile devices while driving, completely aware of the dangers. The possibility of *always available/always on* information search/retrieval leading to potentially addictive behavior has led to the creation of the term "nomophobia" described by Wang and Suh [57] as anxiety/discomfort resulting from being unable to use a smartphone. Perhaps mobile design should mirror the medical profession and be cognizant of the potential dark side to mobile interaction and ensure solutions to situational impairments *do no harm*.

7 Conclusions

Technology exists to make lives easier. As needs become more complex, users require technology to alleviate complexity. The variable interaction context at the center of the mobile interaction problem space is a nascent example of such complexity. To effectively account for various factors contributing to mobile interaction discord, designers would benefit from generalized holistic guidance for situational impairments. This support is lacking a centralized home. This study offers practical assistance in addressing situational impairment events. Specifically, this study proposes an approach (two-step method) which when applied offers promise in identifying the merits of this guidance.

Appendix 1

See Table 11.

Table 11 Situational impairment themes and SCSI characteristics from [43]

Category	Description	Subcategories
Technical issues	A technical fault, glitch, or other non-user or environmental issue that prevents effective completion of a transaction	*Connection* Something technical prevents connecting to an information source (i.e., bad cell or no Wi-Fi)
		Power There is no, or insufficient, electrical power (i.e., low battery) to effectively complete the transaction
		Other technical A technical issue other than connection or power that prevents effective transaction
Ambient-environmental issues	Anything about the environmental context of the transaction space that is hindering or preventing effective transaction completion	*Meteorological conditions* Some aspect of the weather (i.e., sun, rain, heat, or cold) that is hindering or preventing effective transaction
		Ambient "noise" conditions Some non-meteorically ambient condition is creating "noise" in the communication channel hindering or preventing effective transaction. The "noise" can be any non-meteorological input that is negatively affecting the signal-to-noise ratio of the transaction signal (not necessarily just audible noise) including another human
Workspace/location issues	Issues that hinder or prevent the ability to effectively complete a transaction that are geospatial in nature. Either the workspace area is of insufficient size or the resources required are not within sufficient proximity to permit the effective completion of the transaction	*Inaccessible location* The information appliance is within reach but in a space that cannot be easily accessed in sufficient time to complete the transaction effectively (i.e., in a jacket/pants pocket or bag)
		Workspace size Some aspect of the workspace is affecting movement of resources required in the transaction and therefore hindering or preventing effective transaction (i.e., not big enough to effectively negotiate the input space)
		Relative location The relative location of the user and information appliance is such that interaction cannot effectively take place
		Unavailable resources The resources needed to assist in the completion of the interaction are unavailable (i.e., hands full, phone powered off or on silent)
Complexity issues	Issues that hinder or prevent effective transaction completion resulting from task or ambient complexity	*Cognitive load* The cognitive resources required to effectively complete a transaction are unavailable or not easily accessible to the user as the result of having to hold aspects of the current transaction in working memory or having "other things on their mind" that are not directly related to the current transaction
		Number of steps The number of steps that would be required to complete a transaction are perceived as too numerous or too cumbersome to effectively complete the transaction
		Walking over tasks The transaction cannot be completed do to another transaction attempting to occupy the active transaction space (i.e., a modal pop-up that appears while attempting to type a text message) or other interruption that may or may not be technology related (i.e., children interrupting an attempt to place a call via Bluetooth)
		Gulf of execution/evaluation (Norman, 1988) The user has insufficient knowledge from personal experience or from the current context to either effectively complete a transaction or evaluate whether a transaction has been effectively completed

Table 11 (continued)

Category	Description	Subcategories
Social/cultural issues	These issues offer no physical barrier to transaction completion but nevertheless can hinder or prevent effective transaction completion	*Fear of reprisal from an authority* Completing the transaction may result in a violation of the law or reprimand from a boss, teacher, or other type of authority figure (i.e., texting while driving, in class, or while at work)
		Safety The completion of a transaction is hindered or prevented due to concern over the potential harm the attempted completion may cause (i.e., getting into an accident while texting and driving or having your device stolen while using it on the street in a "bad neighborhood")
		Socially acceptable behavior The social context is perceived by the user to be inappropriate within the perceived cultural norms or personal moral code for effective completion of the transaction

Severely Constraining Situational Impairments (SCSI) An occurrence of a situational impairment where a workaround is not available/easily obtained, or where a technological solution was found that only led to the introduction of a new situational impairment and disability.

Characteristics/types of SCSI

"Super" situational impairment event Multiple impairment events combined in a single transaction (e.g., "Thought of something I wanted to search the web for while I was cutting grass, but couldn't use phone because it was too bright out and couldn't use Siri because it was too noisy- By the time I reached a shady area, I ended up forgetting what the task was.")

Expiration of transaction "Half-Life" The value of a transaction becomes zero before conditions conducive to transaction completion can be achieved. (e.g., A SMS is received (and unattended) while in a store. The text is read upon returning from the store and was a request from the spouse to purchase an item.)

Solution to one SIID produces new SIID An existing design solution to an SIID creates a new and different SIID (e.g., voice input can overcome hand encumbrance, but not necessarily if that input contains information that cannot be disseminated in public)

Competing modal transactions Common communication channel needed for competing modal transactions (e.g., "GPS navigation in car interrupted by telephone call.")

Pre-abandonment Transaction voluntarily terminated due to [a] concern over the violation of certain contextual social/cultural norms, or [b] past history leads user to not make transaction attempt (e.g., "Operation to get files from a secured 'cloud' service, download them to my phone with an app, then upload them to a web service is simply too cumbersome to do on the phone... If even possible at all…")

Appendix 2

See Table 12.

Table 12 Draft guidelines (by coding theme)

Article category	Limited technical resource guidelines
Mobile	Connect with different communications and data networks to ensure high availability of services
Mobile	Employ a simple and universal external mechanism to provide power for the phone (e.g., implemented in a carry bag or in a coat pocket) making it accessible
Mobile	Explicitly distinguish between periods of active use and passive use, then use the passive periods to conduct power and data intensive operations
Acc	Device should be easy to recharge via a cradle rather than a plug
Mobile	Locate functionality requiring a large amount of data manipulation or complexity on the web server (as opposed to the device)
Mobile	Low energy consuming localization methods should be used as substitute for power hungry localization techniques (e.g., GPS)
Mobile/Acc mobile	Connectivity and power issues should be transparent for the end-user. Use automatic logging as an efficient way to obtain continuous battery information and highlight/educate the user regarding their battery life limitations and performance improvements
Article category	**Context-aware guidelines**
Mobile/AT	Any function designed for the adaptation to the variable contexts and environments must function in real-time and as a background task without altering the normal operation and use
Mobile	In unfamiliar/new environments, automatic discovery of device/data services should distinguish between services that interact with applications and those that interact with users
Acc	Design buttons with configurable sensitivity to adapt to the user's own dexterity and strength
Mobile	Define in advance the semantic locations (e.g., park, car, street or office) where the user will likely interact with the application then conduct context analysis of the environment factors influencing each location
Acc	Design features to reduce contextual stress. (e.g., facilitate the ease of safety check-ins, users locating one another, and compensate for lack of communication synchronicity)
Mobile	Push notifications after phone calls and text messages rather than random times
Mobile	Passively identify potential situational impairment events so that the device can react independently of users' direct feedback
AT	When in motion, user can query the system using voice, when not in motion, users can interact with the system using tabs and gestures
AT/mobile/mobile/AT	A system should read "the right thing, at the right time, and at the right pace" (e.g., shield users from unimportant minutiae, smart asynchronous notifications for managing interruptions, or correcting automatically transcribed texts)
Mobile	Detect breakpoints (when the user is not actively manipulating the device) using additional sensors, such as GPS, accelerometer, proximity and light sensors
Mobile	Sensing the user's attention state must be performed all day long as long as the user's notification system is available
Mobile	Notification settings should leverage users' existing contact info metadata in order to select when, where and how to be notified by certain people
Acc	Assign task weights through either micro or macro factors: Micro factors refer to the application or condition of use (e.g., sit, walk); whereas macro factors refer to the most-used input method for each individual user and different personal touch screen behavior
Car	In highly demanding situations, the user should be saved from overload by either oppressing or delaying non-important information
Article category	**Limited cognitive resources guidelines**
AT	Design technology such that it poses little burden/encumbrance (i.e., reducing the need for resources such as hands or storage areas like a coat pocket)
Acc/AT/mobile/mobile	Minimize the number of steps and consider simple movement (e.g., clicking) over complex movements (e.g., dragging, drawing certain shapes). Also, interaction based on tap length (invoking different functionality on long tap) should be avoided
AT	Use horizontal navigation structures as they are more easily understood than vertical navigational structures when no assistance is provided
Mobile	Associate pitch and amplitude of output to the severity of the situation (e.g., unsafe temperatures, presence of a hazard) rather than a continual increase in intensity which may be ignored after a period of time
Mobile/Acc AT	Implement hard keys for often used tasks and an easily discernible tactile "home" that ensures one key on any tactile control pad can be used to orientate users within the interface. Provide tactile exploration with a haptic groove or gentle directed motion toward the target element

Table 12 (continued)

Article category	Limited cognitive resources guidelines
Acc	Phone must have an obvious top and bottom
AT/Acc mobile/Acc	Users should be able to identify the exact position of the input device (e.g., finger, stylus) and start devices in any position on the touch screen; and the user should be able to "snap back" to the start position or any other known location. Features should be in the same location to help the user's sense of orientation
Car	Account for the fact that users may engage in distracting activities because they may not realize that their performance is degraded or overconfident in their ability to deal with distractions while engaged in the primary activity
Acc	Avoid distractions (i.e., blinking images) and discourage unconscious action in tasks that require vigilance
Acc	Information should be concentrated mainly in the center
Acc	Design flexible limits for task completion and warnings/feedback should stay in the screen as long as the user does not respond to them
Article category	Limited physical resources guidelines
Acc/AT	Accommodate one-handed and right or left-handed access as well as use and variations in hand and grip size
AT	Avoid gestures needing precision, large areas to perform, or cause physical pain after prolonged use
Acc	Avoid pull down menus and scroll bars
Acc	Avoid touch input that is too sensitive (prevent accidental presses) and tackle the fear of accidentally initiated commands
Acc	Avoid two-handed, multiple-finger interaction
Mobile	Consider clothing-specific affordances for wearable placement or attachment (e.g., a clip that can attach to different clothing straps, folds, or loops)
AT	Minimize the necessity to look down on the display
Car/AT	No part of the system should obstruct user's ability to perceive the external environment
Mobile	Stability is important for both users experiencing shakes or quivers as well as on-the-go users experiencing vibration
Mobile	Under certain ambient conditions (e.g., extreme cold) account for reduced accuracy (e.g., offset skew) in target acquisition, particularly in one-handed interaction
Acc/AT	Access guaranteed by different input methods (e.g., keyboards, simulators, switches, mouth pointers and head pointers) with attention to particular users' needs and strengths
Mobile	For any given task the design should specify which modalities are appropriate for each context and offer additional value to users that are not directly interacting with the screen
AT	When visually impaired, support body input
Article category	Socially acceptable guidelines
AT	Provide subtle feedback, such as vibration from within a pocket, or personal audio, in situations where individuals are hesitant to carry their devices in public
AT	Covert technological capability to minimize perception of use. Designers should consider how their device design would impact how the user is perceived in public
AT	Make sure that gesture interactions do not involve offensive or culturally inappropriate action from the user
Mobile	Ensure the AI system's language and behaviors do not reinforce undesirable and unfair stereotypes and biases

Appendix 3

The table below displays 26 final guidelines validated by the expert panel. The topic areas of the sources primarily used to create the guideline are shown in the third column. The last column shows the theme(s) from Saulynas et al. [43] that each guideline was mapped to.

Original numbering for guidelines	Guideline	Source topic area(s)	Mapped theme(s) from Saulynas et al. [43]
1	A system should read "the right thing, at the right time, and at the right pace" (e.g., shield users from unimportant minutiae, smart asynchronous notifications for managing interruptions, or correcting automatically transcribed texts)	Mobile visual display/visual impairments	Complexity/social- cultural/SCSI
2	Access should be guaranteed by different input methods (e.g., keyboards, simulators, switches, mouth pointers and head pointers) with attention to particular users' needs and strengths	Cognitive impairments/web accessibility	Ambient-environmental/workspace-location/SCSI
4	Account for the fact that users may engage in distracting activities because they may not realize that their performance is degraded or overconfident in their ability to deal with distractions while engaged in the primary activity	Distractive driving	Complexity

Original numbering for guidelines	Guideline	Source topic area(s)	Mapped theme(s) from Saulynas et al. [43]
5	Any function designed for the adaptation to the variable contexts and environments must function in real-time and as a background task without altering the normal operation and use	Visual impairments/SIID in cold environments	SCSI
8	Avoid distractions (i.e., blinking images) and discourage unconscious action in tasks that require vigilance	UD and designing for older adults	Complexity
9	Avoid gestures needing precision, large areas to perform, or cause physical pain after prolonged use	Motor impairments/hearing impairments	Workspace-location
11	Avoid touch input that is too sensitive (prevent accidental presses) and tackle the fear of accidentally initiated commands	Designing for older adults	Ambient-environmental
12	Avoid two-handed, multiple-finger interaction	Accessibility	Workspace-location
13	Connect with different communications and data networks to ensure high availability of services	Mobile services in unstable environments	Technical

Original numbering for guidelines	Guideline	Source topic area(s)	Mapped theme(s) from Saulynas et al. [43]
14	Connectivity and power issues should be transparent for the end-user. Use automatic logging as an efficient way to obtain continuous battery information and highlight/educate the user regarding their battery life limitations and performance improvements	Shared workspace accessibility/smartphone energy efficiency	Technical
19	Design features to reduce contextual stress. (e.g., facilitate the ease of safety check-ins, users locating one another, and compensate for lack of communication synchronicity)	Cognitive impairments	SCSI
20	Design flexible limits for task completion and warnings/feedback should stay on the screen as long as the user does not respond to them	Accessibility	Complexity/social-cultural/SCSI
21	Design technology such that it poses little burden/encumbrance (i.e., reducing the need for resources such as hands or storage areas like a coat pocket)	Visual impairments	Workspace-location
22	Detect breakpoints (when the user is not actively manipulating the device) using additional sensors, such as GPS, accelerometer, proximity and light sensors	Interruption notification on smartphones	Complexity
23	Device should be easy to recharge via a cradle rather than a plug	Designing for older adults	Technical
24	Employ a simple and universal external mechanism to provide power for phone (e.g., implemented in a carry bag or in a coat pocket) making it accessible	Capacitive touch input on clothing	Technical
25	Ensure the AI system's language and behaviors do not reinforce undesirable and unfair stereotypes and biases	Human-AI interaction	Social-cultural
26	Explicitly distinguish between periods of active use and passive use, then use the passive periods to conduct power and data intensive operations	Communication in constrained computing environments	Technical

Original numbering for guidelines	Guideline	Source topic area(s)	Mapped theme(s) from Saulynas et al. [43]
27	For any given task the design should specify which modalities are appropriate for each context and offer additional value to users that are not directly interacting with the screen	Adaptive multi-modal mobile input	Ambient-environmental
29	In highly demanding situations, the user should be saved from overload by either oppressing or delaying non-important information	In-Vehicle device interaction	Complexity/SCSI
33	Low energy consuming localization methods should be used as substitute for power hungry localization techniques (e.g., GPS)	Smartphone energy efficiency	Technical
36	Minimize the number of steps and consider simple movement (e.g., clicking) over complex movements (e.g., dragging, drawing certain shapes). Also, interaction based on tap length (invoking different functionality on long tap) should be avoided	Accessible mouse-based widgets/designing for older adults/nose-based interaction	Complexity/workspace-location
39	Passively identify potential situational impairment events so that the device can react independently of users' direct feedback	SIID in cold environments	SCSI
41	Provide subtle feedback, such as vibration from within a pocket, or personal audio, in situations where individuals are hesitant to carry their devices in public	Visual impairments	Social-cultural
45	Under certain ambient conditions (e.g., extreme cold) account for reduced accuracy (e.g., offset skew) in target acquisition, particularly in one-handed interaction	SIID in cold environments	Ambient-environmental
48	When in motion, users can query the system using voice, when not in motion, users can interact with the system using tabs and gestures	Visual impairments	Workspace-location

Final 26 guidelines selected

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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