The Effect of Context on Small Screen and Wearable Device Users' Performance - A Systematic Review

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Small screen and wearable devices play a key role in most of our daily tasks and activities. However, depending on the context, users can easily experience situationally induced impairments and disabilities (SIIDs). Previous studies have defined SIIDs as a new type of impairment in which an able-bodied user's behaviour is impaired by the context including the characteristics of a device and the environment. This article systematically reviews the empirical studies on the effect of context on SIIDs. In particular, this review aims to answer the following two research questions: Which contextual factors have been examined in the literature that can cause SIIDs and how different contextual factors affect small screen and wearable device users' performance. This article systematically reviews 187 publications under a framework that has five factors for context analysis: physical, temporal, social, task, and technical contexts. This review shows that a significant amount of empirical studies have been conducted focusing on some factors such as mobility but there still are some factors such as social factors that need to be further considered for SIIDs. Finally, some factors have shown to have significant impact on users' performance such as multitasking but not all factors has been empirically demonstrated to have an effect on users' performance.

CCS Concepts: • **Human-centered computing → HCI design and evaluation methods**; **Empirical studies in HCI**; **Ubiquitous and mobile computing design and evaluation methods**; **Empirical studies in ubiquitous and mobile computing**; *Interaction techniques*; *Ubiquitous and mobile devices*;

Additional Key Words and Phrases: Context, small screen devices, wearable devices

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1 INTRODUCTION

Small screen and wearable devices play a significant role in our daily lives. It is expected that the number of small screen devices will increase from 1.9 billion to 5.6 billion between 2013 and 2019 [165]. Even though these predictions might not be so accurate, they still show that the number

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of small screen devices will be quite significant. Some studies also make predictions that with the evolution of Internet of Things (IoT), these numbers can even become higher.[1] These devices are not used only to communicate anymore, but they are also used to perform most of our daily tasks [13]. Small screen devices include tablets, smartphones, phablets,[2] and wearable devices such as smart watches and glasses [136]. In this article, we refer to all these devices as small screen devices. One of the common characteristics of these devices is their small screen size relative to desktop computers. Although this feature increases portability, it can also have significant impact on interaction, in particular usability [61, 199].

Unlike desktop computers which are typically used in a fixed and stable environment (*e.g.* a typical setting would be the user seated with no excessive light or weather conditions, etc.), small screen devices can be used in different environments including indoors, outdoors, noisy, quiet, crowded, and so on. Furthermore, while using small screen devices, the users might be engaged in different and parallel tasks, for example messaging while walking on a busy street [125]. In the literature, these types of temporary reductions in user performance due to context are referred to as situationally induced impairments and disabilities (SIIDs) [189]. This phenomenon was defined as "difficulty accessing computers due to the context or situation one is in, as opposed to a physical impairment" [160, 161]. There can be many factors causing SIIDs and the main observation is that both the environment and the current context can cause SIIDs. In this article, we use context to refer to environment, situation, and context, which is defined as "any information that characterises a situation related to the interaction between humans, applications, and the surrounding environment" [44].

In the literature, there has been many empirical studies on investigating the effect of different contextual factors on SIIDs with varying findings. In this article, we aim to provide a systematic review of the work that has been done and the impact it showed on the user performance. In particular, we ask the following two research questions: (1) "Which contextual factors have been examined in the literature for small screen or wearable device interaction that can cause SIIDs?" and (2) "How do different contextual factors affect small screen or wearable device users' performances?". Answering these questions would enable us and other researchers to see what has been investigated so far and what are the factors that still need to be investigated . Knowing these would be useful for building smarter applications and would also be useful for conducting usability studies or user interaction pattern mining under different contextual factors.

There are other systematic reviews in the field of mobile-device interaction. First of all, Jumisko-Pyykkö and Vainio [81] reviewed the literature surrounding mobile contexts of use. They explained the characteristics of social, physical, technical, temporal, task, and transitions contexts. Although mobility and environmental conditions were briefly mentioned in physical context, this study does not provide a deep understanding of contextual factors and situational conditions which have been examined in the literature for SIIDs. Coursaris and Kim [37] focused on mobile-usability evaluation studies in the dimensions of user, task, technology, environment, research methodology, usability dimensions, and key findings. Although they covered environment, task, and technology dimensions, they only focused on usability studies without focusing specifically on SIIDs. Motti et al. [111] reviewed touchscreen interaction techniques and input devices only with a specific group of older adults. Liu et al. [92] applied keyword analysis on the papers published between 1999 and 2013 on ubiquitous computing field. Rather than contextual factors, they focused on the evaluation of the field. In more recent reviews, Sarsenbayeva et al. [151] provided a brief overview of the factors causing SIIDs as well as approaches to detect and overcome them. In particular, they focused

[1] https://www.intel.com/content/dam/www/public/us/en/images/iot/guide-to-iot-infographic.png, Last access: 02.11.2018
[2] Devices with capabilities of both tablet and smartphones.

only on ambient temperature, mobility and encumbrance. Finally, Wobbrock [188] discussed the definition of SIID and provided a list of factors that can cause SIIDs. However, only three contextual factors were discussed in detail: walking, cold temperature, and divided attention/distraction. Unfortunately, recent reviews on SIIDs have not covered all situational context.

Compared to these, in this article, we present a much broader systematic review of the work that has been conducted to investigate the effect of contextual factors on SIIDs (see Section 2). In order to present the contextual factors, we used the context framework proposed by Jumisko-Pyykkö and Vainio [81] as the backbone of our review. This article is organised into two main parts guided by the research questions asked above: the first part explains the contextual factors that have been considered to have an effect on SIIDs and the second part presents the findings of the studies focusing on these contextual factors and their effect on the users' performance. We first present the metrics used in the performance assessment and then we present their findings.

This article systematically reviews 187 publications in Section 2 under the context framework that has five factors: physical, temporal, social, task, and technical context. This review shows that some factors such as location and mobility as part of physical context have been widely studied but some contextual factors such as interpersonal interaction and culture as part of social context have not been widely studied (see Section 3). Furthermore, in order to investigate the effect of context on SIIDs, this review also shows in Section 4 that many performance metrics have been used in the literature. Some of these metrics are very typical, such as task completion time, but quite a lot of context-specific metrics have been introduced; for example, metrics related to navigation or gait-and-posture-related metrics (see Section 4.1). Finally, this review also shows that there have been a relatively small set of studies investigating the effect of some contextual factors in user's performance (see Section 4.2). In addition, it also shows that for some popular metrics, existing studies have no consensus on some contexts having significant impact on users' performance. Therefore, this article presents the existing work in detail and shows the gaps in the literature where further studies can be conducted (see Section 6).

2 RESEARCH METHOD

We have conducted our systematic review by following the steps specified by Ghezzi-Kopel [52] and this section provides a summary of those steps.

2.1 Research Questions

In our systematic review, we mainly asked the following two research questions:

(1) "Which contextual factors have been examined in the literature for small screen or wearable device interaction that can cause SIIDs?" – This question aims to identify and bring together all the contextual factors that have been examined in the literature centred around SIIDs. This would enable us and other researchers to see what kind of factors need to be considered or the factors that have not been considered at all.

(2) "How do different contextual factors affect small screen or wearable device users' performance?" – This question aims to see the overall effect of the contextual factors on the users' performance and how user performance was articulated in the literature. There are some standard performance measures such as task completion time, error rate, and workload, but this review will enable us to see all the performance metrics used in the literature. Answering this research question would again enable us and other researchers to see the kinds of effects the contextual factors might have on the users' performance and how they can articulate the users' performance. This could be useful for people who would

like to conduct usability studies or people who would like to develop smart applications to improve users' performance in a specific context.

2.2 Inclusion and Exclusion Criteria

In our systematic review, we mainly included papers which focus on interaction with small screen devices or wearable devices under different contextual factors. We excluded desktop interaction, or large displays such as wall-mounted displays or tabletop displays. Furthermore, we excluded papers that focus on disabled users, for example, blind users. This is mainly because they have specific requirements such as specific assistive technologies used due to their disabilities. We also excluded papers if they are late-breaking results, works-in-progress, posters, student research competitions, or adjuncts. Finally, we only reviewed publications in English. We did not limit the publications with time criteria.

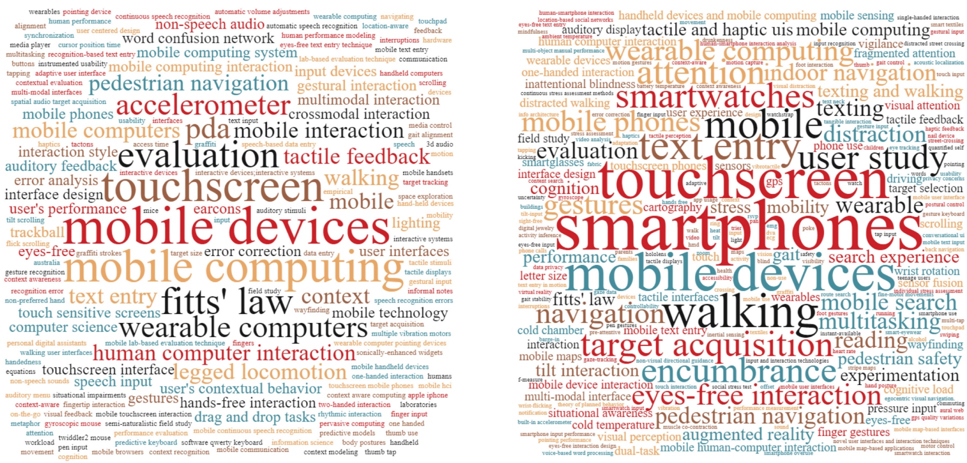
2.3 Searching for Studies

We mainly searched three sources for relevant research: (1) online libraries and search engines, (2) references and citations of the papers reviewed, and (3) publication archives of specific conferences and journals. We started our review with search queries on the following online platforms: ACM Digital Library, METUnique Search, Google Scholar, ScienceDirect, and Scopus. We mainly used the following queries with their possible combinations: "mobile, context, walk, situational impairment, cell phone, texting, typing, pointing, touchscreen, SIID, eyes-free, wearable, smartphone." For instance, we searched for "mobile and walking," "mobile and context," "situational impairment and context," and the like. These keywords were chosen because they were commonly referred in the related systematic reviews [81, 111] and they were the most relevant keywords to our research questions explained above. From these online libraries and search engines, we retrieved and reviewed 496 papers, and marked 89 papers as relevant. Then, we reviewed references of these relevant papers as well as papers that cite them. From references and citations, we reviewed 2,285 papers and marked 52 papers as relevant. Finally, we manually reviewed all the volumes/issues between 2007 and 2019 of the following key Human-Computer Interaction (HCI) venues[3]:

- Computer Human Interaction (CHI) (5,213 papers);
- ACM Conference on Pervasive and Ubiquitous Computing (UbiComp) (1,152 papers);
- International Journal of Human-Computer Studies (949 papers);
- ACM Transactions on Computer-Human Interaction (TOCHI) (364 papers);
- Behaviour & Information Technology (932 papers);
- Conference on Designing Interactive Systems (807 papers);
- Mobile HCI (740 papers);
- International Journal of Human-Computer Interaction (827 papers);
- IEEE International Symposium on Mixed and Augmented Reality (525 papers);
- ACM Transactions on Interactive Intelligent Systems (TiiS) (217 papers);
- Proc. of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (471 papers);

From these HCI conferences and journals, we reviewed 12,197 papers in total and we marked 46 as relevant. Therefore, from the three main sources ((1) online libraries and search engines, (2) references and citations of the papers reviewed, and (3) publication archives of specific conferences and journals), we reviewed in total 14,978 papers and marked 187 as relevant.

[3] dl.acm.org, www.journals.elsevier.com, www.tandfonline.com, ieeexplore.ieee.org.



(a) Tag cloud for papers between 2002 and 2009.

(b) Tag cloud for papers between 2010 and 2019.

Fig. 1. Tag clouds for the keywords of reviewed papers.

2.4 Data Extraction

In order to systematically review all the contextual factors, we used the framework proposed by Jumisko-Pyykkö and Vainio [81] to identify contextual factors in the literature surrounding situational disabilities and impairments of the small screen or wearable device users. This framework has five main dimensions: physical, temporal, social, task, and technical context. The reviewed papers were analyzed based on these dimensions. This allowed us to systematically review all the relevant papers.

2.5 Paper Selection

During our review process, we manually checked if the paper was relevant. We started with title and abstract screening to label the papers which are clearly not related to our topic as irrelevant. We also skimmed the full text and searched for specific keywords based on our inclusion and exclusion criteria. We created a citation graph where citation relations were visually represented. Based on this graph, we applied a breadth-first search approach to analyze papers or retrieve more candidates.

Among the 14,978 publications reviewed, we selected 187 publications as relevant, which focus on different mobility or contextual conditions as well as eyes-free interaction. Figure 1 illustrates the tag clouds for the keywords of the papers published in two different periods. While walking and lighting were popular conditions studied on mobile devices and PDAs between 2002 and 2009 (Figure 1(a)); the focus has been switched to other contextual factors such as eyes-free interaction, encumbrance, stress, attention, and distraction between 2010 and 2019 (Figure 1(b)). Similarly, Figure 2 illustrates the distribution of the relevant papers published. Although this figure shows that the highest numbers of publications (18 papers) were in 2011 and 2017, it also shows that the topic is still very popular. In fact there were 17 papers published in 2018. Later in this article, we will see that the focus is still SIIDs but with different devices and interaction techniques.

In this section, we described our research methodology in conducting a systematic review of the contextual factors causing situational impairments and disabilities studied in the literature. This methodology can easily be applied to update the review presented here with the recently

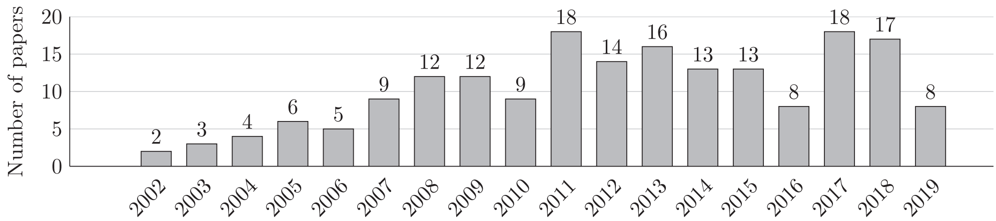


Fig. 2. Number of publications per year.

published papers. In the following sections, we present the findings of our systematic review. We organised our findings under the two research questions we asked (see Section 2.1).

3 CONTEXTUAL FACTORS EXPLORED FOR SIIDS

This section mainly investigates our first research question:

> "Which contextual factors have been examined in the literature for small screen or wearable device interaction that can cause situationally induced disabilities and impairments?"

In order to present the contextual factors studied in the literature which can cause situationally induced disabilities and impairments in a systematic way, we organised our findings based on the dimensions given by Jumisko-Pyykkö and Vainio [81]. Before we present each context review in detail, we first briefly summarise the participant characteristics in the studies we reviewed.

3.1 Participant Characteristics

In 96 papers out of 187 reviewed, participants were recruited from graduate/undergraduate students and university staff. Some authors recruited equal number of male and female participants [8, 14, 19, 25, 31, 33, 54, 55, 73, 104, 120, 130, 131, 149, 150, 152, 153, 157, 182, 187, 191, 201]. In general, participants were familiar with small screen devices; however, in some studies, participants were not familiar with wearable devices. In experiments and interviews, 46 users participated on average (minimum: 4, maximum: 3,338, standard deviation: 255.39).[4] In observational studies, the number of people observed are relatively higher than in experimental studies: 347 [76], 357 [4], 431 [60], 2,668 [23], and 4,129 [75]. Hiniker et al. [69] observed and interviewed adult caregivers. Tigwell et al. [168] applied a questionnaire to mobile content designers. Fitton et al. [50] conducted experiments with teenagers.

3.2 Physical Context

Physical context [81] is defined as:

> "The apparent features of situation in which the human-mobile computer interaction takes place, including spatial location, functional place and space, sensed environmental attributes, movements and mobility, and artifacts present."

Based on this definition, we grouped our physical context as location, mobility, artifacts, and sensed environmental attributes. Even though the definition above also refers to functional place, in our review, we did not refer to that, since most experiments have been conducted in a controlled

[4]Due to these two studies [24, 135], standard deviation is quite large as Chen et al. [24] has 1,669 and Pielot et al. [135] has 3,338 participants in their studies, which are not typical.

Table 1. Physical Contexts Investigated in the Literature (Overall Contexts Are Given in Table A.1)

Physical Context	**Types**	**Papers**
Location	Lab environment	[16, 35, 125, 138, 177, 178]
	Indoor environment	[125, 138]
	Outdoor environment	[16, 35]
	Pedestrian street or public area	[125, 177, 178]
Functional place	Home, work, outdoors, public transit, restaurant, other	[106]
Mobility	Sitting	[10, 22, 26, 27, 32, 38, 40, 42, 46, 49–51, 54, 63–66, 70, 71, 85, 90, 91, 94, 98, 99, 109, 114, 121, 122, 139, 148, 156, 173, 174, 186]
	Standing	[6, 11, 21, 32, 36, 39, 40, 45, 46, 51, 66, 82, 83, 89, 101, 108, 116, 117, 128, 155, 157, 163, 166, 192]
	Walking on a route	[6, 9, 10, 21, 26, 27, 32, 38–40, 45–47, 49, 50, 63–66, 82, 83, 85, 89, 90, 98, 101, 108, 114, 116, 117, 120–122, 128, 148, 155, 157, 173, 186, 192]
	Walking on a treadmill	[9, 11, 22, 36, 42, 63–65, 70, 85, 90, 91, 94, 102, 109, 120, 139, 146, 163, 166]
	Walking after a researcher	[51, 54]
	Walking on a straight path	[121]
	Walking through a street or public area	[99]
	Public transportation	[71]
	Walking	[156, 174]
Sensed Environmental Attributes	Lighting levels (low and high)	[9, 10, 26, 27]
	Weather (cloudy, partly cloudy, sunny)	[82]
	Vibration	[72]
	Environmental noise	[72, 152]
	Temperature (cold, warm)	[55, 149]

environment with specific interaction tasks where the function of the interaction (entertainment, work, etc.) was ignored. Table 1 presents the physical context studied in the literature. As can be seen from this table, location and mobility are more widely studied compared to other factors.

People can use their small screen devices and wearable devices in various locations and in the literature we can see that different *locations* have been studied. The most popular location for the experiments conducted related to SIIDs is the lab environment. One advantage of conducting experiments in the lab environment is that, participants and experimental conditions can be easily isolated from the external factors, such as other people or weather conditions. However, in this case, the experiments might not reflect realistic conditions. In order to address this problem, some studies were conducted outside of the laboratory, especially in public indoor environments. However, they still might not reflect the requirements of using the small screen devices and wearable devices outdoors where some other external factors such as weather conditions need to be considered. Therefore, some studies have also been conducted in outdoor locations in the literature. Our literature review revealed that there are several studies that aimed to compare lab environment to indoor or outdoor public environments.

Similar to location, the *mobility* aspect has also been widely studied in the literature and the effect of mobility was demonstrated in various ways. One way of simulating mobility in the experiments is to walk on a treadmill or on a mini-stepper. In general, when participants were walking on a treadmill, they were isolated from any other factors if the experimental design did not include artificial distractors. This mobility condition may be effective if the aim of the study is to observe the effect of walking apart from any other factors; however, it does not reflect realistic scenarios. Alternatively, many studies have examined mobility conditions where participants walked on a straight path, walked on a predefined route, and walked freely.

When we look at the sensed environmental attributes, there are very few studies that focus on conducting experiments under different *sensed environmental attributes*. Only a few studies observed contextual factors such as lighting levels [9, 10, 26, 27], temperature [55, 149], weather [82], vibration and noise levels [72]. Although they are not related to environmental attributes, some authors used various motion sensors in the experiment. These motion sensors consist of acceleration sensors, gyroscope, magnetic field sensors, motion sensors, and heart rate monitors.

There are other physical context factors that have been used as experimental conditions rather than the main focus of the studies. Table A.1 in Section A.1 in Appendix A also gives a broad overview of the physical contextual factors used in the studies. Several examples for public indoor environments include corridors [54, 82, 108, 137, 138, 143, 174, 176], stairs [196, 197], university cafeteria [68], quiet hallways [74, 114, 128, 204], an empty seminar room [45, 46], public areas [99, 138], and others [17, 122, 182]. Some studies have also been conducted in outdoor locations in the literature: quiet roads and paths [16, 35], pedestrian street [85, 132, 177, 178], both uncrowded and crowded areas in pedestrian zone [133], sports field [201], city center [95, 130], city forest [134] and others [76, 78, 82, 157, 158, 182, 193, 194]. To consider the location differences, there are also several studies that were conducted in multiple places, for example including busy street, escalator, quiet street, bus, metro platform, metro car, railway station, cafeteria, laboratory [125], different parts of a building (entrance, lift, corridor, office, meeting room, etc.) [191], train station, shopping center, university bus stop, business area and market street [60]. Besides those, there are also some unique locations studied in the literature including a warm and a cold room at an arctic medical facility [149], vehicle and public transportation [71, 72] and virtual environment [159, 164]. In the studies presented so far, at least one experimenter was present during the experiments. This experimenter was mainly monitoring or guiding people participating in the studies. There are also studies that were conducted in the wild (*in-situ* studies) [3, 135, 142, 184, 185]. In these studies, participants completed the tasks in their daily routine without having an experimenter observing their task completion.

In order to reflect realistic mobility, during the experiments in some studies, there were also physical objects around participants which might have caused collisions or attention switches. We grouped these under the *artifacts* used. Some authors intentionally placed obstacles with respect to their experimental design in the laboratory environment, such as physical obstacles or furniture in the lab environment. In some studies, on the other hand, other people or obstacles were present due to the nature of outdoor or public environments. In the studies that were conducted in virtual environments, virtual obstacles and virtual vehicles were used. Researchers placed computer monitors in front of participants to simulate pedestrian crossing behaviour while interacting with

Table 2. Temporal Contexts Investigated in the Literature
(Overall Contexts Are Given in Table A.2)

Temporal Context	**Types**	**Papers**
Duration	Multiple sessions on different days	[7, 8, 32, 79]
	Multiple experiments	[180]
Actions' relation to time	Walking speed	[34, 35, 41, 120]

mobile devices. With these experimental setups, they aimed to create a sense of experiment in real-world and eliminate possible injury risks [159, 164]. Finally, a unicycling clown was used in Hyman et al. [76] to observe inattentional blindness while talking on the phone in a natural environment.

3.2.1 Summary and Discussion. One of the most significant discussions in physical context has been on location. Chamberlain and Kalawsky [21] states that the environmental conditions for each participant would be unique when the experiments were conducted outside; therefore, the environment must be controlled to ensure a uniform set of experiences. Many other researchers have conducted experiments in a controlled lab environment. On the other hand, many researchers have drawn attention to the unrealistic environmental settings in the lab environments [138, 169]. A lab environment might not reflect real-world cases due to lack of various lighting levels [50], complex obstacles or disruptions [5, 15, 32, 87, 108, 128, 143], environmental noise [173], pedestrians [108] and any factor that requires attentional resources for safety reasons [16]. Similarly, Stavrinos et al. [164] argued that using a real world setting might result differently than using a virtual environment for the experiments. Kane et al. [82] highlighted the challenges of conducting experiments outside; such as weather conditions, unexpected interruptions and distractions, and safety concerns; however, they stated that those experiments conducted outside are more realistic. Suggested open research areas are conducting experiments in dynamically changing paths [5], crossing roads [143] and music concerts to observe the effect of vibration and noise levels [72].

Another debate in physical context has been on mobility. Barnard et al. [9] and Ng et al. [120] stated that, using treadmill to simulate walking was simpler to control and maintain walking speed. On the other hand, Ng et al. [120] highlighted the possible input problems about treadmills with safety bars when conducting experiments with encumbrance. Barnard et al. [9] indicates that ground walking is more realistic than using a treadmill. Crossan et al. [40] argued that resting, sitting, standing, and walking postures in a lab environment do not reflect real-world cases such as walking on a busy street. Kane et al. [82] suggested transitions between mobility conditions as a research area, such as starting the experiment with standing and continuing with walking.

3.3 Temporal Context

Temporal context [81] is defined as:

> "The user's interaction with the mobile computer in relation to time in multiple ways such as duration, from time of day to years, the situation before and after use, actions in relation to time, and synchronism."

Table 2 presents the studies that investigated the effect of temporal context. As can be seen from this table, only the effect of the session and walking speed have been investigated in the experiments. The experiment session was used to observe performance changes across different sessions. Moreover, some authors aimed to observe how walking speed affected participants' performance in walking conditions. Compared to these though, synchronism aspect, different time of day to years and other action relation to time aspects have not been so widely studied.

The majority of temporal context factors have been used as experimental conditions. Table A.2 in Section A.2 of Appendix A also summarises the factors that have been used related to temporal context. The length of the interaction session depends on the task to be completed, the number of sessions, and the experimental settings. The *duration* of the overall experiments ranges from 15 minutes [33] to 90 minutes [119, 133, 149]. The length of a single session also varies from 3 minutes [1, 98, 114] to 40 minutes [79] or 45 minutes [54]. On the other hand, Jongil et al. [80] limited the length of a single trial to 1 minute. In some studies, multiple sessions were arranged with the participants. For example, Banovic et al. [8] conducted 16 sessions which took around 40 minutes; whereas Clawson et al. [32] completed 15 sessions where each session took 20 minutes. Conradi et al. [36] arranged four sessions in consecutive days. Unlike others, Reyal et al. [142] conducted experiments for four weeks in the wild, and asked participants to complete corresponding tasks 10 times in a day. The same experimental settings may also take different amounts of time. For instance, indoor sessions took around 30 minutes in [82]; while outdoor sessions took 90 minutes. On the other hand, in [182], indoor sessions took 50–60 minutes where outdoor sessions lasted in 20 minutes. Finally, experiments in stationary condition took 15 minutes and walking condition in 90 minutes in [166]. These intervals give ideas about the duration of the overall experiments. Task completion time for a single task, on the other hand, has been used to compare performance of the participants within various conditions or approaches.

For most of the studies, authors did not mention the *time of day, week, and year* of the experiments especially if they conducted the experiments in the lab environment. This may be due to the fact that, the same experimental conditions may be repeated regardless of the time. On the other hand, it may be challenging to conduct two experiments with similar parameters in outdoor environments since weather conditions or number of people around the participants change. To address this challenge, Pielot and Boll [130] repeated the experiments on Saturdays in May. Similarly, Kane et al. [82] conducted experiments in the afternoons. On the other hand, Harper et al. [60] conducted their observations at different hours of a day; so that they could see the changes with respect to time. Finally, some authors aimed to prepare experimental setups in which participants also deal with pedestrians on their route. For this purpose, Wenig et al. [182] and Pielot et al. [133] conducted their experiments in summer, when many tourists visited the city. MacKay et al. [99] also set their experiment time to busiest time of the day (11:00 a.m. to 4:00 p.m.).

In terms of *events before or after the experiments*, in [142], participants were sent periodic notifications which asked them to complete text entry tasks. These notifications were sent 10 times a day. Similarly, Aliannejadi et al. [3] sent search tasks to participants based on a pre-defined schedule. There is no experimental setup in the remaining studies if they were conducted in the wild.

Regarding the *actions' relation to time*, along with multitasking, some studies aimed to put more pressure on the participants during the experiments. These studies aimed to simulate cases such that a user is late for a meeting and has to send a text message to a colleague while he/she is walking to his/her office. In some studies, participants were asked to walk in different walking speeds [34, 35, 41, 90, 118, 120]. Similarly, Oulasvirta et al. [125] simulated hurrying, normal, and waiting conditions in their experiments. Finally, Conradi [34] changed presentation time in the experiments to analyze minimum time for users to perceive short words on the phone screen.

Regarding the *synchronism*, generally, participants were asked to complete the tasks individually and synchronously in existing studies in the literature. There are several exceptions for this condition. In some experiments, participants talked on the phone with an experimenter [88, 164]; while some experimental setup consisted of both talking on the phone and texting with an experimenter [159, 169, 201]. Harper et al. [60] observed people while they were texting and walking in the wild. Similarly, Hyman et al. [76] checked whether people paid attention to their surroundings

Table 3. Task Contexts Investigated in the Literature (Overall Contexts Are Given in Table A.3)

Task Context	Types	Papers
Multitasking	Walking	[6, 9–11, 21, 22, 26, 27, 32, 36, 38–40, 42, 45, 46, 49–51, 54, 63, 64, 66, 70, 82, 83, 85, 89–91, 94, 98, 99, 101, 102, 108, 109, 114, 116, 117, 120–122, 128, 139, 146, 155–157, 166, 173, 174, 186, 192]
	Encumbrance	[45, 116–120, 163]
	Collision/hazard avoidance	[28]
	Distraction or cognitive tasks	[15, 150]
	Presence of dual task while walking	[1, 25, 28, 41, 47, 80, 87, 93, 95, 104, 138, 154, 167, 169]
	Presence of dual task while crossing street	[24, 159, 164]
Interruptions	Eyes-free interaction	[56]
	Stressor tasks	[150]
	Distraction tasks	[79, 102]
	Visual disruptions	[43]
	Incoming phone calls	[14]

while they were walking and talking on the phone. In synchronism context, talking on the phone is a synchronous task; while texting is asynchronous.

3.3.1 Summary and Discussion. As can be seen from Table A.2, durations widely studied can be considered short given the amount of time people spend with their small screen and wearable devices these days. Therefore, one criticism about temporal context is that, some interaction techniques may require longer learning curves; however, in experiments, participants had limited time to learn and perform the tasks [48]. Therefore, some people argue that such as Arif et al. [5] longitudinal studies should be conducted to give time to participants to be familiar with the input device or interaction technique during the experiments. Furthermore, in real world, people do have actions related to time and also do use their devices in different times of the day and year. Even though there are a few studies focusing on these, there can be still many more studies with varying factors to better understand the effect of the temporal context.

3.4 Task Context

Task context is defined as follows [81]:

> "The surrounding tasks in relation to user's task of interacting with mobile computer containing the sub-components of multitasking, interruptions and task domain. Task context is related to the demands of the entire situation upon one's attention."

Table 3 presents the studies that investigated the effect of task context. As can be seen from this table, walking is the most widely studied multitasking aspect. Table A.3 in Section A.3 of Appendix A provides a summary of the task context used in the literature under three factors: multitasking, interruptions, and task domain. According to this table, navigation, reading, text entry, and target selection are the most popular task domains studied. However, as presented in this table, there are many other domains which are not widely studied and of course there may be many others that can be studied in the future.

Multitasking has been considered as an effective way of fragmenting attentional or cognitive resources during small screen and wearable device interaction. This is considered to be one of the major causes of SIIDs. In experimental studies, one of the most common techniques used in the literature is to ask participants to walk while completing a set of predefined tasks. Mobility conditions that have been used to achieve this are presented in Section 3.2. In different mobility conditions, a user needs to maintain her walking speed, check for route in order not to get lost and watch for obstacles, vehicles and other pedestrians to avoid collisions. As a result both mental and physical workload increase in such conditions. Another multitasking condition is encumbrance. In the literature, participants were asked to hold an object (box, bag, etc.) during some experiments [116–120]. Alternatively, Oulasvirta and Bergstrom-Lehtovirta [124] simulated several conditions such as use of non-prefered hand and occupation of whole or some parts of hand by asking participants to hold objects with different sizes (such as a box, basketball, coffee mug, tongs, or scissors) while they were entering text on mobile devices. Moreover, users' attention to the possible risks while interacting with a small screen or wearable device was also examined. In these studies, different cases were simulated including artificial hazard notifications [38, 97], injury risk in virtual environment [164] and collision cases with obstacles and other pedestrians [68]. In such experiments, participant safety is critical; as a result, such experiments were conducted in virtual or controlled environments. Similarly, Conradi et al. [36] and Jongil et al. [80] asked participants to watch for environmental changes while they were interacting with small screen or wearable devices. Kjeldskov and Stage [85] asked participants to play the Jungle Book Groove Party game. Although talking on the phone has been used as the main task in most studies, in [88], participants were asked to complete several tasks such as numeric text entry or calendar checking while they were talking on the phone and playing a driving game. This experimental condition illustrates the cases in which users interact with a cell phone in an eyes-free fashion. Finally, cognitive tasks such as note recalling [42], attention-saturating tasks [15], and mathematical calculations [104] have also been used in the literature.

Temporary *interruptions* that break users' attention have been covered with different methods in the literature. One of these methods is to place obstacles in the participants' walking paths. Similarly, conducting the experiments in a public area in which other people were present causes interruptions in the interaction with small screen and wearable device. In both cases, participants need to divide their attention between completing the current task and avoiding collisions. The studies designed to include obstacles or other people in their experimental settings are provided in Section 3.2. In [38] and [97], participants were asked to check for artificial hazard notifications. Unlike a normal walking path, going up or down the stairs may also interrupt participants [196, 197]. Using virtual objects such as vehicles is another technique to interrupt participants [159, 164]. Jain and Balakrishnan [79] used visual distractions in forms of changing numbers, while Yang et al. [195] placed stop signs on the route to interrupt participants' attention on the tasks. We considered eyes-free interaction in which participants complete a set of tasks without looking at the device screen as an interruption condition. Such case of interaction was also covered in the literature [8, 31, 33, 51, 56, 73, 86, 88, 107, 115, 123, 126, 134, 170, 171, 180, 184, 198].

A considerable amount of the studies in the literature aim to compare the performance of the user under various *task* domains. As a result, majority of the tasks are highly goal-oriented. In these tasks, participants were given instructions and asked to complete the tasks by considering several performance metrics such as task completion time or accuracy. One popular task domain is text entry. In this domain, participants were presented a set of phrases and asked to type it as it is. As a result, in the text entry domain, participants did not type free text or have conversation with another person. Another popular task domain is target selection. The participants were shown several targets and asked to select them by using different techniques or under different conditions. Reading is another popular task domain. Along with reading, scrolling and searching tasks were also used. In recent years, gesture-based interaction and navigation have been popular task domains. Some task domains consist of multiple realistic tasks such as entering numeric text, recording a phone number, checking your calendar [88], reading messages, replying with message templates, answering calls, sharing fitness information online [201]. Other goal-oriented task domains are tapping on buttons [16], visual acuity [35], visual search [89], web search [63, 64, 78, 125], zooming [176], RSS reading [184], cognitive tasks [114], cross-modal icon identification [70], dealing with incoming notifications [95], drag and drop tasks [204], remembering symbols [162], responding to alerts [6], sliding [33], speech-based text entry [97, 139], sports tracking [158], menu navigation [107], and menu selection [17, 132]. Although the original framework categorises mobile-gaming as an action oriented task domain, we considered game playing tasks in [68] and [185] as goal oriented since the main purposes of both studies were to compare efficiency and effectiveness of different approaches. As a result, performance and preference had higher priority than entertainment in these studies. The studies reviewed so far in this section took specified tasks as the main task domain and compared participants' performance under different factors. There are also studies that investigated the effect of small screen device usage on walking or posture. In these studies, the following task domains have been used: talking on the phone [87, 159, 164, 169], texting [1, 87, 93, 104, 159], listening to music [159], reading [154, 169] and text entry [80, 138, 154, 169]. It is important to note that, in text entry task domain, participants retyped given phrases; while in texting task domain, they had conversation with experimenters by sending or receiving text messages. We consider these tasks as goal oriented; since performance-related metrics such as task completion time and accuracy were still important during the experiments.

3.4.1 Summary and Discussion. When we look at the literature, in the majority of the studies, participants have interacted with experimental applications which were developed to simulate a particular interaction method. However, these are much more simplistic than real-world applications and tasks [91]. Realistic tasks that require continuous attention [125] or are cognitively demanding [99] may reflect real-world use cases. In text-entry tasks, participants have been asked to type predefined sets of phrases. In the majority of the studies, the text phrases have been in English. The effect of other languages may be examined in text-entry task domain. Moreover, instead of typing standard text, Vadas et al. [173] argued that user performance may be affected if they type content in which they are interested, such as personal emails. Lucero and Vetek [95], on the other hand, stated that, using participants' online accounts may cause privacy concerns and participants may have different experiences due to various content lengths. Finally, people normally use their devices with autocorrect/autofill functions enabled. Plummer et al. [138] stated that the experimental setups that disable these functions may not reflect real-world usage.

3.5 Social Context

Jumisko-Pyykkö and Vainio [81] defines social context as follows:

> "The other persons present, their characteristics and roles, the interpersonal interactions and the surrounding culture that influence the user's interaction with a mobile computer."

Based on this definition, we group the contextual factors under this dimension under the following categories: persons present shows if there is another person during the experiment, interpersonal interaction shows if there is an interpersonal interaction during the experiment and culture

Table 4. Social Contexts Investigated in the Literature (Overall Contexts are Given in Table A.4)

Social Context	Types	Papers
Persons present	Self	[60, 76, 106, 125]
	Accompanied	[60, 76]
	Other pedestrians	[60]
Culture	Users from UK and India	[185]

shows if specific culture elements have been considered or not during the experiment. Table 4 presents the social factors considered in the literature for causing SIIDs. Table A.4 in Section A.4 of Appendix A also provides a summary of the social factors used in the literature. As can be seen from this table, most studies were conducted with individuals, and interpersonal communication aspects were mainly considered one-to-one.

Our review shows that experiments were typically conducted individually in separate sessions. Only Hoggan et al. [72] conducted an experiment in which all participants completed tasks together in the same environment. The reason for this was to ensure that participants interacted with device under the same vibration and noise levels. However, participants did not interact with each other. In two observational studies, some observed people were in pairs or groups, while some of them were individuals [60, 76]. In order to simulate conditions that require interpersonal interaction such as talking on the phone or texting with someone, the participants interacted with an experimenter [1, 88, 159, 164, 169, 201]. On the other hand, Harper et al. [60] suggested that, presence of the experimenter with the participants may affect their behaviour. Hyman et al. [76] used a unicycling clown in the experiments and observed whether people could recognise him while they were talking on the phone and walking. Finally, although there were no interaction, other people and pedestrians were also present in the environmental settings of some studies conducted in public areas [60, 68, 82, 95, 130, 133, 138].

Regarding the *interpersonal interaction*, in the majority of studies in the literature, participants were given instructions to complete a set of tasks individually. This type of interaction can be categorised in the framework as one-to-myself; since participants only interact with the device. On the other hand, experimenters interacted with participants in several studies that include tasks on talking on the phone or texting. In these one-to-one interactions, conversation topic was predefined [1, 88, 159, 164, 169, 201]. We have not encountered any work in the literature that examined one-to-many or many-to-many interactions.

Culture has not been one of the major social factors considered in studies that investigated the effect of SIIDs. Only Williamson et al. [185] conducted experiments with two specific user groups from the UK and India. Moreover, other attitudes of culture, such as work and organisational culture have been ignored in the research field.

3.5.1 Summary and Discussion. Research around the social context has been mostly restricted to single participants interacting with a small screen or wearable device, and only a few studies consisted of interpersonal interaction or other people around the interaction. In our literature review, we identified three open research areas related with social context. First, some task domains require interpersonal interaction due to their asynchronous nature such as talking on the phone or texting. Stavrinos et al. [164] argued that, they could have different results if participants had interacted with someone who they are familiar with instead of researchers during the experiments. Chen et al. [24] also suggested that, participants may ignore messages or phone calls from strangers; as a result, they asked participants to bring a friend to the experiments. They could

Table 5. Technical Contexts Investigated in the Literature (Overall Contexts Are Given in Table A.5)

Technical Context	Types	Papers
Device	Smartphone with touchscreen	[63, 64, 130, 153, 162]
	Tablet	[63, 64]
	Wearable device	[18, 21, 131]
	Smartwatch	[162]
	Smartphone with physical keyboard	[38]
	Smartphone with touchscreen and physical keyboard	[124]
	UMPC	[173]
	Others: Twiddler, trackball, gyroscopic mouse and touchpad [204], head-mounted display, e-book reader [173]	

conduct experiments that reflect real world interactions if they had not restricted the conversation topic. Moreover, the studies that aim to observe user interaction in public areas or in the wild may ask participants to take videos during interaction. However, McMillan et al. [106] stated that, ethical concerns may arise from this since permission from those people around the experimenter is not taken. Although they asked participants to turn off video recording in inappropriate situations; a more effective solution may be proposed to prevent such cases from affecting experiment. The final open research area related with the social context is social acceptance [39, 85, 185], especially for gesture-based interaction [40] and kick-based interaction [2, 58]. Any unusual device or interaction technique during experiments may engage other people's attention, and as a result, participants' performances may be affected [95].

3.6 Technical Context

Technical context is defined as [81]:

> "Relation of other relevant systems and services including devices, applications and networks, their interoperability, informational artifacts or access, and mixed reality to the user's interaction with the mobile computer."

Table 5 presents the studies that are conducted addressing SIIDs related to this context. Table A.5 in Section A.5 in Appendix A also provides a broad overview of the technical factors used in the studies that addressed SIIDs. Based on the definition given by Jumisko-Pyykkö and Vainio [81], we group the technical factors in four categories: devices used, information artifacts, interoperability, and mixed reality systems. As can be seen from this table, based on the maturity of the devices, there are more studies around them. For example, there are quite a lot of studies centred around smartphones with touchscreen but not many studies around wristband/smart bracelet. Other factors compared to devices are less explored in the field. A variety of *device* types have been examined in the literature including Personal Digital Assistants (PDA), Ultra-Mobile PCs (UMPC), wearable devices, smartphones, smartwatches, media devices, tablets, and head-mounted displays. These device types have different characteristics and modalities. For example, some smartphones have either a touchscreen or a physical keyboard whereas some of them have both. Figure 3 shows the devices used in the literature with respect to years. Although PDAs had been used widely in early studies; smartphones, smartwatches, and tablets have been very popular recently.

Interopeability between devices has been used for two main purposes. One of the reasons is to provide participants a user interface during the interaction. For example, when participants

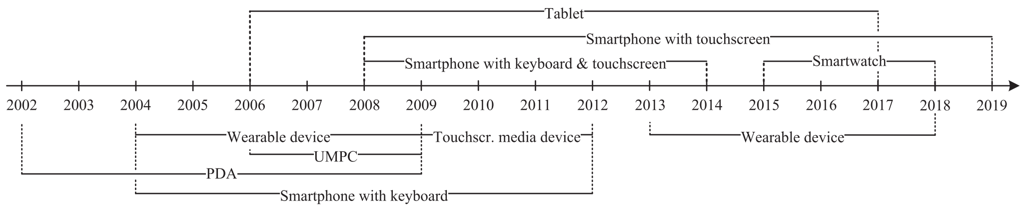


Fig. 3. Distribution over the years of the surveyed papers according to the device type used

interact with a wearable device which does not have a user interface, another connected device for representing tasks and feedback is required. For this purpose, wearable devices have been connected with PDA [17], laptop computer [22], desktop computer [66], and Google Glass [46]. In some studies, on the other hand, interoperability helped to represent tasks and feedback if experimental design required eyes-free interaction. Such kind of interoperability was achieved with different devices, including PDA/Twiddler and desktop computer [31], smartphone and laptop computer [51, 170, 198], smartphone and headphone [123], and wearable device/smartphone and external monitor [56]. All interoperability cases in the literature are between unequal resources. As an example for interoperability between applications, Zhang and Rau [201] asked participants to share their fitness information on a social media platform. Accessibility on different platforms has not been studied in the context of SIIDs.

We haven't encountered any work in the literature which used multiple devices accessing to the same content. However, in some studies, some *informational artifacts* have been used to represent tasks, including projection screen [98, 139], computer display [66, 124], external monitor [8, 56], LCD display [114], wall display [66, 104] and tablet [33]. In one study by Bragdon et al. [15], a large monitor was used for distraction tasks.

In order to simulate the experiment scenarios in which participants had injury risks, *virtual reality systems* have been used [159, 164]. Crease et al. [38] and Lumsden and Drost [97], on the other hand, used projection screens to indicate hazards. Conradi et al. [36] also used virtual reality to examine participants' attention to distractors in the virtual environment. Similarly, Jongil et al. [80] aimed to simulate environmental changes by using a projection floor and a monitor.

3.6.1 Summary and Discussion. Our literature review revealed that, not only different types of devices, but also different models of these devices have been used in the experiments. As manufacturers launched new small screen and wearable devices, researchers continued to experiment with these devices. Technological advances also enabled researches to simulate various use case scenarios by using different informational artifacts, interoperability between devices and virtual systems. As a research challenge, Wiliamson et al. [184] highlighted the importance of charging and correct placement of the wearable devices for *in-situ* studies. Moreover, they stated that, some participants may require customisation on the devices and there is a trade-off between participant frustration and equally prepared experimental conditions. They suggested that, an *in-situ* study must be flexible to handle such kind of customisation while the study continues. As an open research area, Zhang and Rau [201] suggested to study attractiveness of wearable devices for different genders.

4 THE EFFECT OF CONTEXTUAL FACTORS ON USERS' PERFORMANCE

This section investigates our second research question:

> "How do different contextual factors affect small screen or wearable device users' performance?"

Table 6. Evaluation Metrics

Metric	Papers
Task completion time	[9, 10, 14, 15, 17, 18, 20–22, 26, 27, 33, 36, 38–40, 45, 46, 48–50, 56, 66, 68, 71, 73, 74, 82, 83, 85, 86, 88–91, 94, 96, 99, 101, 107, 112, 114–120, 127, 128, 130–134, 137, 143, 144, 147, 149, 150, 152, 155–158, 163, 166, 172–176, 180, 182, 183, 186, 191–195, 198, 202, 203, 204]
Error rate / accuracy	[5–11, 15, 17, 20–22, 26–29, 31, 32, 36, 38–40, 42, 45–51, 53–55, 58, 65, 67, 68, 70, 71, 73, 79, 80, 82, 83, 85, 86, 88–90, 94, 97, 98, 101, 108, 109, 112, 114–123, 126–128, 130, 132–134, 137–139, 142, 143, 146, 147, 149, 150, 152, 155–158, 163, 166, 170, 171, 173, 174, 176–178, 180, 182, 183, 186, 195–198, 202–204]
Workload	[7–10, 14, 16, 17, 19–21, 26, 27, 38, 42, 48, 49, 63, 64, 71, 74, 85, 89, 90, 96–98, 101, 102, 107, 130, 133, 139, 143, 157, 162, 173, 175, 176, 182, 183, 186, 195–197, 201]
Walking speed	[5, 17, 48, 49, 93, 96, 97, 108, 114, 131–133, 137, 138, 143, 154]
Text entry speed	[5, 7, 8, 16, 31, 32, 42, 47, 51, 54, 72, 79, 108, 121, 122, 138, 142, 150, 170, 171, 177, 178, 196, 197]
Subjective evaluation	[5, 12, 20, 33, 43, 53, 56, 74, 78, 83, 88, 99, 100, 109, 110, 131, 141, 147, 157, 172, 174–176, 191, 192, 201]
Interaction-related metrics	[6, 26, 27, 29, 33, 71, 72, 74, 78, 105–107, 109, 115, 127, 132, 133, 169–171, 184, 195]
Gait and posture-rel. metrics	[1, 25, 41, 47, 74, 80, 82, 87, 104, 113, 114, 154, 162, 167, 169]
Navigation metrics	[12, 19, 110, 112, 131, 133–135, 179, 187, 193, 194]
Usability metrics	[18, 50, 85, 96, 99, 126, 132, 134, 182, 201]
Attention-related metrics	[5, 43, 60, 68, 76, 80, 82, 125, 134, 195]
Gesture-related metrics	[67, 96, 145, 172, 185]
Pedestrian variables	[24, 76, 159, 164]
Others: reaction/response time [80, 146], point of subjective equality [34, 35], just noticeable difference [35], manual Multitasking Index [124], multimodal flexibility index [123], search-related metrics [63, 64], cost of error correction [5], system performance [193, 194], heart-rate classification accuracy [59], finger and battery temperature [153], reading speed [102], valence, energy, stress [29, 30], user interviews [60, 69], social reactions [95, 184], gaze behaviour [77].	

In the literature, different metrics have been used to assess the users' performance. In order to explain the impact of the context, in this section, we first present the metrics used in the literature and then we explain how these metrics are used to show the impact of context on users' performance.

4.1 Performance Metrics

Majority of the studies reviewed in this document aim to observe the main effect of an interaction technique or contextual factor on how users interact with the system or how they behave. For this purpose, they used one or more evaluation metrics for measuring users' performance. Table 6 provides a summary of the performance metrics used. As can be seen from this table, performance metrics in terms of task completion time and error rate, and perceived workload in terms of NASA TLX [62] have been widely used. For text entry tasks, another popular performance metric is text entry speed in terms of words per minute [5, 8, 31, 32, 54, 72, 79, 121, 122, 142, 170, 171, 177, 178], characters per second [7, 108], characters per minute [51], or number of codes entered [16].

Besides those metrics, some other metrics are also used that focus on the effects of contextual factors on user behaviour. These can be summarised as follows:

- *Gait and Posture-Related Metrics:* Spatio-temporal parameters, ankle and knee kinematics [1], minimum margin of stability [104] velocity, lateral deviation, linear distance [87], stride length [41, 154, 167], stride frequency, abs path lateral direction, delta right-foot position [154], maximum displacement, interference duration, maximum deviation from normal movement during right steps [162], synchronisation of gait [113], toe clearance, toe velocity, step length, foot position, foot contact [169], dynamic walking stability [80], walking deviations [82], average walking speed, total walking distance, total steps, strides per minute [74], gait speed [25, 41, 47, 167], stride time [167], error steps [114], head flexion angle [57].
- *Attention-Related Metrics:* Accurate change detection, response time, detection rate [43], attentional resources, attention switched, switch back duration [125], number of attention switches [60], noticing unicycling clown [76], field-of-regard loss [80], number of glances [82], number of slow-downs and head-ups [68], collisions [5], wrong turns [5], secondary task performance, duration and subjective distraction [134], number of stop-signs missed and step-outs, unnecessary stop-time [195], situational awareness [47].
- *Pedestrian Variables:* Looks away, looks left and right [159], missed opportunities, attention to traffic, hits/close calls [164], time left to spare [159, 164], head turning frequency, unsafe crossing behaviour [24], crossing time [24, 76].
- *Navigation Metrics:* Number of references to route directions, number of self-position references [179], traveled distance, time looking at the map, disorientation events [131, 134], navigation performance [135], arrive time, position accuracy, orientation accuracy [110], distance [144], walking time [12], step and time differences [19], number and length of sessions [187], orientation loss, number of targets found, orientation phases [133], stationary time, time and distance for incorrect route, portion of time in which participants paid attention to the display [193, 194], number of steps [112].
- *Interaction-Related Metrics:* Number of swipes on menu [109], total time in which fingers were in contact with touchscreen [33], time looking at the phone [105], amount of interaction, time device was held in the hand, scanning, time the screen was turned off [135], number and duration of fixations on the phone [169], interaction type (touch vs no touch), interaction time, application, length of interaction [106], interactions per minute [184], list navigation time [127], tap features [29], amount of interaction [133], number of operations [78], field change error, incorrect field error, drawing time [74], scrolls [26, 27], number of commands [115], number of pages viewed [195], average swiping time [107], answer time, access time, pocket time [6], reading time [26, 27], reading speed and text comprehension [148], number of breakdowns when participants take device out of their pockets [132], keystrokes per character [71, 72, 170, 171].
- *Gesture-Related Metrics:* Number of incorrect nods, accuracy of gestures, number of gestures aborted [96], gesture mode and technique [185], character recognition rate [145], distribution of pseudo impulse [67], articulation time, gesture size, aperture, corner shape distance, angular difference, shape distance [172].

- *Usability Metrics:* Ability to answer questions [18], usability problems identified [85], ease of use [99, 201], usefulness [201], efficiency [50], System Usability Scale [182], subjective usability [132], pleasantness [126], difficulty [126], comfort [96], confidence [134].

This section has reviewed a comprehensive set of evaluation metrics surrounding SIIDs. The following section will focus on how contextual factors given in Section 3 affect these evaluation metrics.

4.2 The Effect of Contextual Factors on Users' Performance

In order to present the effects in a systematic way, we again use the five contextual factors as the backbone for our discussion. In Sections 4.2.1–4.2.5, we present quantitative results of the papers which give the significance of the results explicitly (either significant or insignificant) or provide a p-value for the statistical tests presented. Then, in Section 4.2.6, we outline qualitative findings.

4.2.1 Physical Context. Table 7 and Table 8 present the effect of physical factors on the performance metrics discussed above. Environment has been used to compare indoor and outdoor environments or public and private places in terms of user performance and attentional metrics. While Brewster [16] showed the main effects of indoor and outdoor environment on text entry performance in terms of speed and error rate, a more recent study by Plummer et al. [138] did not reveal significant difference in terms of texting speed and accuracy between private and public environments. The effect of different mobility conditions on user performance has been widely investigated for different task models. Although the literature agrees on the influence of the mobility on perceived workload, there are contradicting results on task completion time and error rate. In traveling condition, on the other hand, Hoggan et al. [71] compared sitting conditions in laboratory environment and subway train; and showed that mobility condition affected task completion time; however, it had no main effect on either error rate or workload. When it comes to sensed environmental variables, there are relatively few studies in the literature which investigate their effects on user performance. According to Kane et al. [82], weather condition has no effect on target selection time. Sarsenbayeva et al. [152] clearly indicated that different types of ambient noise influenced target selection, visual search, and text entry time. Similarly, Sarsenbayeva et al. [149] and Goncalves et al. [55] showed the effect of environmental temperature and finger temperature on target selection time. The studies comparing low- and high-lighting levels for reading and searching tasks have indicated that the lighting level has a significant effect on task completion time and workload but not on error rate.

4.2.2 Temporal Context. Table 9 presents the effect of temporal factors on the performance metrics discussed before. There is a relatively small body of literature that investigated the effect of session or temporal tensions on user performance. Session was used to observe the changes in user performance through overall experimental process if it contains multiple sessions. So far, a number of studies have reported that error rate, task completion time and perceived workload decrease as the experiment progresses [7, 8, 32, 79, 180]. Different levels of walking speed have also been used to simulate temporal tensions like hurrying. Several lines of evidence suggest that users make more errors when they walk at a higher speed [11, 120]. Taken together, these studies demonstrate the effect of session and walking speed on user performance. Unfortunately, we encountered no studies that compared different times of day, week, and year, or synchronism conditions.

4.2.3 Task Context. Table 10 summarises the effect of task context on the performance metrics. The effect of walking as a multitask was given in Section 4.2.1. Böhmer et al. [14] reported that task completion time increased in the case of phone call interruptions during question answering tasks. Similarly, Mariakakis et al. [102] suggested that perceived workload increased with the

Table 7. The Effect of Physical Context (Mobility) (SD: Significant Difference, ID: Insignificant Difference)

Physical Context	Task Domain	Evaluation Metric	SD	ID
Mobility (stationary, walking on a treadmill)	Target selection	Task completion time	[36, 94, 166]	[22, 91]
		Error rate / accuracy	[11, 22, 36, 94, 166]	
	Other tasks	Task completion time	[163]	
		Error rate / accuracy	[42, 109, 139, 163]	[70, 146]
		Workload	[42, 102]	
Mobility (stationary, walking on a treadmill, walking on a route)	Target selection	Task comp. time & err. rate	[90]	
	Text entry	Task comp. time & err. rate		[85]
		Workload	[85]	
	Reading, search.	Workload	[63, 64]	
	Searching	Hits per query & errors	[65]	
Mobility (sitting in lab, sitting in subway train)	Text entry	Task completion time	[71]	
		Error rate & workload		[71]
Mobility (stationary, walking on a route)	Target selection	Task completion time	[21, 39, 40, 45, 46, 66, 99, 101, 116, 117, 186]	[82, 83, 128, 155, 156]
		Error rate / accuracy	[39, 40, 45, 46, 83, 101, 116, 155, 156, 186]	[21, 82, 128]
		Workload	[21, 101, 186]	
	Text entry	Task completion time	[38, 50]	
		Error rate / accuracy	[38, 47, 50, 54, 108, 122]	[32, 51, 121]
		Text entry speed	[32, 47, 54, 121]	[51, 108, 122]
		Workload	[38, 98]	
	Reading	Task completion time	[10, 157, 192]	[26, 27, 49, 173]
		Error rate / accuracy	[10, 26, 27, 173]	[49, 157]
		Workload	[10, 26, 27, 157, 173]	
		Reading speed	[148]	
	Other tasks	Task completion time	[10, 89, 114, 157]	
		Error rate / accuracy	[10, 114, 157, 174]	[6, 89]
		Workload	[10, 89, 157]	
Mobility (walking on a treadmill, walking on a route)	Target selection	Task comp. time & err. rate	[120]	
	Reading	Task comp. time & err. rate		[9]
		Workload	[9]	
	Searching	Task comp. time, workload	[9]	
		Error rate / accuracy		[9]

Table 8. The Effect of Physical Context (Environment and Sensed Environmental Attributes) (SD: Significant Difference, ID: Insignificant Difference)

Physical Context	Task Domain	Evaluation Metric	SD	ID
Environment (indoor, outdoor)	Visual acuity	Psychophysical metrics		[35]
	Tapping on buttons	Workload	[16]	
	Text entry	Error rate & text ent. speed	[177, 178]	
Environment (lab., in-door real-world setting)	Text entry	Gait speed	[138]	
		Texting speed & accuracy		[138]
Environment (indoor, outdoor, transport.)	Web search	Attention metrics	[125]	
		Switch-back duration		[125]
Functional place	Smartwatch use	Length of interaction		[106]
Ambient Noise (music: fast, slow, silence)	Target acquisition	Task comp. time & err. rate	[152]	
	Visual search	Task completion time	[152]	
Ambient Noise (urban noise: indoor, outdoor)	Target selection	Task completion time	[152]	
	Visual search	Task comp. time & err. rate	[152]	
	Text entry	Task completion time	[152]	
		Error rate		[152]
Ambient Noise (speech: meaningful/meaningless)	Target selection, visual search, text entry	Task completion time	[152]	
		Error rate		[152]
Weather (cloudy, sunny)	Target selection	Task completion time		[82]
Vibration level /Noise level	Text entry	Text entry speed	[72]	
		Keystrokes per char.	[72]	
Temperature (cold, warm)	Target selection	Task completion time	[149]	
		Error rate		[149]
Thumb finger temp.	Target selection	Movement time & err. rate	[55]	
Index finger temp.	Target selection	Movement time	[55]	
		Error rate		[55]
Lighting level (low, high)	Reading	Task comp. time, workload	[9, 10, 26, 27]	
		Error rate		[9, 10, 26, 27]
	Searching words	Task completion time	[9, 10]	
		Error rate		[9, 10]
		Workload	[9]	[10]

presence of distraction tasks. Jain and Balakrishnan [79] conducted experiments with three levels of distraction including no distraction, low distraction, and high distraction. They reported that there was a significant difference in terms of text entry speed between no distraction, low distraction, and high distraction. Moreover, the highest text entry speed was observed in high distraction condition. They commented that, text entry speed increased due to the attention demand of high distraction condition. Sarsenbayeva et al. [150] showed that, stress decreased target selection time and increased touch offset size; however, it did not have effect on text entry in terms of texting speed and error rate. According to Gustafson et al. [56], task completion time increased when participants were blindfolded. Unfortunately, there is not a consensus among scientists on the effect of encumbrance on user performance. Finally, it is now well established from a variety of studies that interacting with a small device or wearable device has a significant effect on gait and attention metrics. Overall, these studies highlight that such dual tasks reduce walking speed [76, 87, 93, 138,

Table 9. The Effect of Temporal Context (SD: Significant Difference, ID: Insignificant Difference)

Temporal Context	Task Domain	Evaluation Metric	SD	ID
Task length	Speech based text entry	Error rate	[139]	
Session	Text entry	Text entry speed	[7, 8, 32, 79]	
		Error rate / Accuracy	[7, 32, 79]	[8]
		Workload	[8]	
	Sight-free text entry	Text entry speed, accuracy & workload	[8]	
	Target selection	Task comp. time & error rate	[180]	
Walking speed	Reading/Visual acuity	Point of subjective equality	[34]	[35]
		Just noticeable difference	[35]	
	Texting, talking on phone	Gait parameters	[41]	
	Target selection	Error rate	[11, 120]	
		Task comp. time & accuracy	[120]	

154, 167, 169] and cause divided attention [87] or inattentional blindness [76]. As a result, they introduce pedestrian safety problems [24, 87, 159, 164].

4.2.4 Social Context. Table 11 presents the effect of social factors on the performance metrics. Similar to temporal context, there are relatively few studies in the literature which investigate the effect of social context on attentional metrics and interaction techniques. Overall, there seems to be some evidence to indicate that presence of others has a main effect on how people interact with smartwatches. On the other hand, one study by Harper et al. [60] indicated that other people do not affect the number of attention switches; while Oulasvirta et al. [125] showed that users attended to the environment significantly more when the environment was crowded. Culture was only used to compare gesture mode preferences of users from UK and India; according to Williamson et al. [185], it does not have a main effect on user interaction.

4.2.5 Technical Context. In previous studies which included factors related to technical context, either the effect of using various device types or use of a wearable device has been compared on user performance. Table 12 presents the effect of technical context on evaluation metrics. The majority of the studies indicate that user performance is influenced by device; however, several lines of evidence suggest that device has no significant effect on some of the user performance metrics. Using a wearable device improves user performance in terms of task completion time for information retrieval [18] and target selection [21] tasks; but does not have a main effect for navigation task [130, 131]. On the other hand, it increases target selection errors [21] and navigation errors [130]. Pielot et al. [131] reported that, using a wearable device for navigation purpose decreased traveled distance, walking speed, and distraction compared to using only a map.

Finally, Table 13 represents the interactions between contextual factors. As can be seen in the table, there are both significant and insignificant interactions on performance metrics depending on the task domain.

Table 10. The Effect of Task Context (SD: Significant Difference, ID: Insignificant Difference)

Task Context	Task Domain	Evaluation Metric	SD	ID
Multitasking (encumbrance)	Target selection	Accuracy	[116–118, 120]	
		Speed	[117]	
		Task completion time	[118, 120]	[116]
	Gestures based int.†	Task comp. time & error rate	[45, 119, 163]	[45, 119]
Presence of interruption	Question answering	Task completion time	[14]	
Presence of visual disruption	Target detection	Accurate change detection	[43]	
Presence of distraction	Reading	Workload	[102]	
	Text entry	Text entry speed	[79]	
		Accuracy		[79]
Presence of motor act. and dist.	Gesture based int.	Task comp. time & accuracy	[15]	
Object negotiation	Texting	Game score	[28]	
Sightedness (sight. vs blind.)	Target searching	Task completion time	[56]	
Presence of dual task while walking	Texting	Spatio-temporal parameters	[1]	
		Ankle and knee kinematics		[1]
		Gait parameters	[25, 28, 47, 87, 93, 104, 138]	
	Talking on the phone	Velocity	[87]	
		Lateral dev. & linear dist.		[87]
	Texting & visual task	Resp. rate, field of regard loss	[80]	
		Dyn. walk. stab., resp. time		[80]
	Texting & talking on the phone	Time & fixations	[169]	
		Gait parameters	[41, 169]	
	Texting & reading	Walking speed	[154]	
	Dealing with notif.	Time	[95]	
	Other	Gait parameters	[167]	
Presence of dual task while crossing street	Texting	Time, head turning freq.	[24]	
	Talking on the phone	Attention parameters	[164]	
	Texting, talking on phone, listen. to music	Looks away	[159]	
		Time to spare, looks left-right		[159]
Presence of stress task	Target selection	Task comp. time & accuracy	[150]	
	Visual search	Time to memorise item	[150]	
		Time to find item		[150]
	Text entry	Texting speed, error rate		[150]
Task type (working memory tasks, vigilance task)	Cognitive tasks	Task comp. time, walking speed, error steps	[114]	

† Ng et al. [119] found significant differences in terms of error rate for all gestures. They also found significant difference in the terms of task completion times for tapping and dragging gestures but not for spreading, pinching, or rotating gestures. Dobbelstein et al. [45] found significant differences in terms of task completion time and error rate for tapping and wrist-flicking gestures but not for the swiping gesture.

Table 11. The Effect of Social Context (SD: Significant Difference, ID: Insignificant Difference)

Social Context	Task Domain	Evaluation Metric	SD	ID
Persons present	Text entry	Number of attention switches		[60]
	Talking on the phone	Time to cross	[76]	
	Smartwatch usage	Interaction type & length	[106]	
	Web search	Duration of continuous attention to the phone	[125]	
Culture	Playing a game	Gesture mode		[185]

Table 12. The Effect of Technical Context (SD: Significant Difference, ID: Insignificant Difference)

Technical Context	Task Domain	Evaluation Metric	SD	ID
Device (wearable, smartphone)	Cognitive task	Workload & gait parameters	[162]	
Device (head-mounted display, e-book reader, UMPC)	Reading	Task comp. time & workload	[173]	
		Error rate		[173]
Device (Trackball, mouse, touchpad)	Drag and drop	Task comp. time & error rate	[204]	
Device (different smartphone types)	Target selection	Battery temperature	[153]	
	Text entry	Manual Multitasking Index	[124]	
		Task comp. time & workload	[38]	
		Accuracy		[38]
Device (wearable device)	Information retrieval	Task completion time	[18]	
		Ability to answer questions	[18]	
	Target selection	Task comp. time, err. rate, workload	[21]	
	Navigation	Task comp. time & subj. eval.		[131]
		Walk. speed & navigation param.	[131]	
Device (personal navigation device, wearable device & smartphone)	Navigation	Task comp. time & workload		[130]
		Navigation errors	[130]	
Device (tablet, smartphone)	Web searching	Workload	[63, 64]	
		Number of hits per query		[63, 64]

Table 13. Interactions between Contextual Factors (SD: Significant Difference, ID: Insignificant Difference)

Interaction	Task Domain	Time / Speed		Error / Accuracy		Workload	
		SD	ID	SD	ID	SD	ID
Mobility x Lighting level	Reading		[9, 10, 26, 27]		[9, 10, 26, 27]		[10, 26, 27]
Mobility x Lighting level	Word search	[9, 10]			[9, 10]	[10]	
Mobility x Device	Target selection		[21]		[21]		[21]
Mobility x Encumbrance	Tapping		[45]	[45]			
Mobility x Encumbrance	Target selection	[117]		[117]			
Mobility x Task	Cognitive tasks	[114]		[114]			
Mobility x Task	Reading	[102]					
Environment x Task	Text entry		[138]		[138]		

4.2.6 Qualitative Results. One-third of the studies conducted subjective evaluations to investigate participants' preference on their proposed interaction mechanism over existing methods. Lucero and Vetek [95], Williamson et al. [185], and McMillan et al. [106] focused on the social acceptibility of gesture-based interactions. According to Lucero and Vetek [95], participants had problems with gesture- and speech-based interactions while using smartglasses in public. Similarly, Williamson et al. [185] reported that some participants felt uncomfortable due to social reactions while they were playing a game on their mobile phone with gestures. McMillan et al. [106] gave examples about how smartwatch notifications affect social context when users are in conversations with others. Sarsenbayeva et al. [150] stated that presence of a stress task psychologically and physically affected participants' perceived task performance. Oulasvirta et al. [125] observed participants' strategies to reduce fragmented attentional resources. Ranasinghe et al. [140] questioned users' trust on GPS-based navigation apps while they are having GPS problems. Participants indicated a distrust for such cases and provided strategies to overcome the problem. Ioannidou et al. [77] reported that, although a considerable number of participants had at least one fall from stairs, a majority of them continued to use their phone while walking down or up stairs. Most of the participants commented that light conditions affected mobility. Applying a questionnaire, Piazza et al. [129] investigated the intentions of participants to cross a street while using a mobile phone. Hiniker et al. [69] observed and interviewed adult caregivers. They investigated the apps caregivers used while they were parenting and strategies to reduce phone absorption. Although some caregivers thought that it is acceptable to use a mobile phone while parenting if the children are safe; others thought that mobile phone use should be minimised. However, most caregivers agreed that using a mobile phone makes it more difficult to pay attention to the children. Tigwell et al. [168] interviewed mobile content designers and reported that majority of them did not consider situational visual impairments in their designs due to several reasons including limited resources, restricted design scope, or unawareness of situational impairments. Finally, Mäntyjärvi and

Seppänen [100] stated that, adaptive behaviour is acceptable for participants; however, participants highlighted the importance of accuracy and control over adaptations.

A few studies aimed to investigate the effect of context on attentional and gait walking behaviour by using observational data. Hyman et al. [76] placed a unicycling clown on a pedestrian walking path to illustrate inattentional blindness and observed that cell phone users were less likely to see the clown. Similarly, Chen and Pai [23] evaluated situational blindness, situational deafness, and situational awareness with a clown walking in the opposite direction of the pedestrians and playing the national anthem. They concluded that pedestrians who were using their smartphones for the tasks such as playing a game or listening to music failed to see the clown or hear the anthem more than non-smartphone users. Harper et al. [60] observed that, small device users who were standing or sitting had less attention switches than small device users who were walking. Alsaleh et al. [4] suggested that pedestrians who were distracted with smartphones had slower walking speeds than non-distracted pedestrians. Finally, Horberry et al. [75] observed pedestrians crossing streets and revealed that pedestrian smartphone users had higher risk of colliding with another pedestrian or vehicle, and crossing at the wrong time or place than non-smartphone users.

4.3 Summary and Discussion

Mobility has been a popular contextual factor in the literature and there are two research trends on mobility. One group of researchers considers interacting with a small screen device or a wearable device as the main task and walking as a secondary task that may affect user performance. These researchers have asked participants to complete goal-oriented tasks under various mobility conditions. The others consider walking as the main task and interacting with a small screen device or a wearable device as a dual task that may affect gait or distract users. These researchers asked participants to walk on a treadmill or cross a street in virtual environment while either completing action-oriented tasks or without using a device. Previous research findings on the effect of walking on user performance have been inconsistent and contradictory. On the other hand, there is a consensus among scientists that interacting with a small screen device or a wearable device affects how we walk or pay attention to our surroundings.

Most of the previous research on the effect of contextual factors on SIIDs have focused on mobility conditions, while a relatively small body of literature has covered other contextual factors. This may be explained by the fact that different mobility conditions can be easily simulated by ensuring identical experimental settings across all sessions. On the other hand, other contextual factors such as lighting level, temperature, ambient noise, or people around the interaction are hard to control and they can easily differ between sessions. However, a more comprehensive study would include all the contextual factors that may cause SIIDs.

There are several *in-situ* studies that have been conducted in the users' own environment. However, such studies remain narrow in focus, dealing only with interaction techniques. Unfortunately, our systematic review did not reveal any studies that have collected context and performance data in the wild and had drawn some implications on the interaction between context and user performance.

The researchers have faced several problems with automatic data collection mechanisms. Yatani and Truong [197] argued that, additional sensors such as accelerometers to observe physical workload might cause disruption during the experiments. Agostini et al. [1] suggested that, recording eye movements might give insights about when participants looked at screen or path in walking experiments. Kjeldskov and Stage [85] highlighted the difficulty of screen capturing while participants are walking. Finally, Reyal et al. [142] stated that collecting data from participants' devices outside of the experiment scope might cause privacy concerns.

5 DISCUSSION

Our systematic review shows that there is significant research on investigating the contextual factors for SIIDs and also investigating the effect of contextual factors on users' performance. In our systematic review, we investigated 14,978 publications and we identified as 187 relevant. Our review also revealed that SIIDs were first discussed in the literature around 2000 and, after 20 years, there are still a significant number of publications about this phenomenon. In fact, our review shows that although the devices and interaction styles studied changes over time, we still do not have a good understanding of SIID itself and contextual factors (see Figure 2). Our review has also shown that the early studies tended to focus on walking and the effect of light conditions, but the recent studies focus on larger contextual factors as discussed in our article. In fact, in Figure 1, we show two different tag clouds for papers published in 2000s and 2010s which clearly show the trends in the papers we reviewed. Our review also shows that most of the user studies are conducted with students at universities and staff, and also they are mainly done in controlled, indoor, lab environments. It is quite understandable that finding participants for studies is not easy; therefore, it is quite normal that participants are chosen from close proximity. However, more studies can be conducted with users from different backgrounds. Furthermore, our review also shows that more studies can be conducted in the *wild* to better reflect the context and cause of SIIDs. With the recent developments in sensors and small screen devices and their capabilities, we expect that more studies will be conducted in the wild.

When we look at contextual factors, our review shows that mobility and location are the key contextual factors that are studied as the physical context dimensions. However, there are fewer studies considering functional place and also the sensed environmental attributes such as lighting levels, vibration levels, temperature, and the like. Therefore, in the future, more studies can focus on these contextual dimensions. Regarding temporal context, our review also shows that experiments designed in the literature tend to be shorter studies and longitudinal studies are rare. This can easily be explained by the fact that it is much easier to control shorter studies. However, with the new technological advances, we are hoping that more longitudinal studies can be conducted to investigate SIIDs. Furthermore, our review also reveals that aspects such as synchronisation and the time of the day or year are not so widely investigated. In the literature, the focus so far has been on walking speed and multitasking. In fact, as a task context, multitasking is widely studied. However, interruptions of users including stressor tasks and the like are not investigated frequently. Further studies can be conducted to better understand the impact of such task-based contextual factors on SIIDs. Our review also shows that many of the studies investigating contextual factors were conducted in very controlled environments with simplified tasks. Therefore, in the future, more studies can be conducted in the wild with more complex tasks which will, of course, require different systematic methods for collecting and analysing data. Compared to physical, task, and temporal contexts, our review shows that social context is the least studied context in the literature. Most of the studies focus on investigating SIIDs when people are alone. However, further studies can be conducted to investigate the SIIDs experienced when people are in different social environments. Of course, such studies would require better merging and combination of social science methods and technical user studies.

Our systematic review reveals that many metrics are used to investigate SIIDs. These metrics range from very well known ones, such as task completion time to very custom metrics such as metrics to assess stress-level. When we look at effect of the context on SIIDs, we can see that in the literature we have studies confirming the findings and studies that contradict each other. For example, the effect of walking on user performance has been inconsistent. However, it is consistently shown in the literature that the presence of a dual task while walking is an important cause of SIIDs. Our review fully shows all the effects presented in the literature which are summarised in Tables 7–12.

In brief, our systematic review shows that SIID is an important phenomenon with a significant number of publications surrounding the context and the effect of context. Overall, this review shows that ability-based design could be a good approach to design applications for small screen and wearable devices that take into account users' context better and could cause less SIIDs. Ability-based design is described as identifying and exploiting users' abilities rather than their disabilities to enhance interaction by using available resources. It recommends systems to sense context that may affect users' abilities [189]. Further research is needed to show what would be the actual effect of ability-based designed applications to the users' performance.

6 CONCLUSION

In this article, we conducted a systematic review of the literature on investigating the effect of different contextual factors on SIIDs. For this purpose, we reviewed a wide range of articles from online platforms, popular HCI conferences, and journals.

Our first research question targeted the contextual factors that have been examined in the literature for small screen or wearable device interaction that may cause SIIDs. We classified the factors used in the literature under the context framework that has five main dimensions: physical, temporal, social, task and technical context. Our review has shown that, physical context has been widely studied to observe the effect of mobility or location. On the other hand, further studies regarding the effect of social or temporal factors would be worthwhile.

The other research question was related to the effect of contextual factors on small screen or wearable device users' performance. For this purpose, we first identified the evaluation metrics which helped researchers compare different contextual factors. Then, we reviewed the literature to see whether contextual factors have significantly affected corresponding evaluation metrics. Our results have shown that, there is no consensus among the scientists who have worked on popular contextual factors such as mobility or encumbrance. On the other hand, there are relatively few studies considering each of the other contextual factors. Further experiments using a broader range of contextual factors could help us understand how we interact with small screen or wearable devices under SIIDs. Technological advances in these devices enable collecting more precise and functional data with the help of available sensors.

Small screen and wearable devices have an important role in our everyday lives. As they transform into new forms and provide new functionalities, we start to use them for new purposes in different environments. Our study has not only shown that researchers have made great progress in understanding SIIDs and the factors that may cause them, it has also shown that we have yet a lot to learn on the effect of context on users' performance.

APPENDICES

A SUMMARY OF THE CONTEXTUAL FACTORS

This appendix summarises the contextual factors studied in the literature.

A.1 Physical Context Summary

This section summarises the literature related to physical context.

Table A.1. Overall Physical Contexts in the Literature

Physical Context	Types	Papers
Location	Lab environment	[1, 2, 5–11, 14–16, 21, 22, 26, 27, 28, 31–36, 38–40, 42, 48–51, 53, 56, 58, 59, 63–66, 70, 71, 73, 79, 80, 83, 85, 86, 88–91, 93, 94, 97, 98, 101–105, 107–109, 115–121, 123–127, 137–139, 142, 145, 148, 150, 152, 155, 156, 162, 163, 166, 169–173, 175–178, 180, 186, 190, 192, 195–198, 202, 203]
	Indoor environment	[17, 19, 41, 43, 45–47, 54, 55, 67, 68, 74, 77, 82, 96, 99, 100, 108, 110, 112, 114, 122, 125, 128, 137, 138, 143, 146, 147, 149, 153, 167, 174, 176, 182, 183, 191, 204]
	Outdoor environment	[4, 12, 16, 18, 20, 23–25, 35, 57, 75, 76, 78, 82, 84, 100, 131, 134, 140, 144, 157, 158, 179, 181, 182, 187, 193, 194, 201]
	Pedestrian street or public area	[60, 85, 95, 125, 130, 132, 133, 177, 178]
	Virtual environment	[28, 36, 159, 164]
	Stairs in a building	[196, 197]
	Public transportation	[71, 72]
	In the wild	[3, 14, 29, 30, 106, 135, 141, 142, 184, 185]
Mobility	Sitting	[3, 5, 7, 8, 10, 15, 16, 18, 22, 26, 27, 29–33, 38, 40, 42, 46, 48–51, 54, 56, 59, 63–66, 70–73, 79, 85, 90, 91, 94, 98, 99, 105, 109, 114, 115, 121–123, 125, 139, 148, 150, 156, 170–178, 186, 190, 196–198, 202, 203]
	Standing	[6, 11, 18, 21, 32, 34–36, 39, 40, 45, 46, 51, 55, 66, 82, 83, 86, 89, 101, 108, 116, 117, 124, 125, 128, 138, 149, 152, 153, 155, 157, 163, 166, 167, 192, 203, 204]
	Walking on a route	[5, 6, 9, 10, 12, 17, 19–21, 26, 27, 32, 34, 35, 38–40, 45–50, 57, 63–68, 74, 82–85, 87, 89, 90, 95–98, 101, 108, 110, 112, 114–122, 125, 128, 130, 131, 133, 134, 137, 140, 143, 144, 147, 148, 155, 157, 158, 167, 169, 172, 173, 175, 177–179, 181–183, 186, 187, 191–197, 201, 203, 204]
	Walking on a treadmill	[9, 11, 15, 22, 28, 35, 36, 42, 63–65, 70, 80, 85, 90, 91, 94, 102, 104, 109, 120, 139, 146, 162, 163, 166, 190]
	Walking on a mini-stepper	[137]
	Walking after a researcher	[51, 54]
	Walking on a straight path	[1, 16, 25, 41, 121, 154]
	Walking through a street or public area	[4, 23, 24, 60, 75, 76, 99]
	Going up or down stairs	[77, 196, 197]
	Public transportation	[3, 71, 125]
	Jogging or running	[100, 201]
	Walking	[3, 18, 53, 93, 100, 113, 132, 135, 138, 156, 159, 164, 174, 176]

(Continued)

Table A.1 Continued

Physical Context	Types	Papers
Artifacts	Physical obstacles	[17, 21, 25, 60, 68, 82, 84, 90, 95, 96, 98, 121, 130, 133, 143, 169, 181, 193, 194]
	Furniture	[5, 9, 10, 26, 27, 48, 63–65, 89, 99, 173]
	Pedestrians	[4, 24, 47, 60, 68, 82, 95, 130, 133, 138, 147, 181]
	Vehicles	[4, 181]
	Virtual vehicles or obstacles	[28, 159, 164]
	Unicycling clown	[76]
Sensed Environmental Attributes	Lighting levels (low and high)	[9, 10, 26, 27, 100]
	Weather (cloudy, partly cloudy, sunny)	[82]
	Vibration	[72]
	Environmental noise	[72, 100, 141, 152, 200]
	Temperature (cold, warm)	[55, 149, 153]
	Acceleration sensors	[3, 18, 19, 54, 113, 174, 175, 192]
	Gyroscope	[3, 113, 174]
	Magnetic field sensors	[22, 113]
	Motion sensors	[32, 166]
	Heart rate	[59, 166]
	GPS	[18, 20]

A.2 Temporal Context Summary

This section summarises the literature related to temporal context.

Table A.2. Overall Temporal Contexts in the Literature

Temporal Context	Types	Papers
Duration	Single session for less than 10 minutes	[1, 65, 80, 98, 115, 193, 194]
	Single session for 10–30 minutes	[33, 50, 59, 69, 84, 114, 143, 144]
	Single session for 30–60 minutes	[14, 22, 29, 30, 45, 46, 54, 63, 64, 68, 102, 104, 109, 112, 113, 128, 134, 167, 171, 173, 183, 195]
	Single session for 70–90 minutes	[20, 86, 95, 119, 125, 133, 148, 150, 152, 202]
	Single session for more than 90 minutes	[19, 140, 146, 162, 177, 178]

(Continued)

Table A.2 Continued

Temporal Context	Types	Papers
	Single session with unknown duration	[6, 9–11, 15, 21, 25–28, 34, 39–41, 47–49, 53, 57, 72–74, 77, 78, 87, 89–91, 93, 94, 97, 99, 101, 105, 107, 108, 116–118, 121–123, 126, 130–132, 138, 139, 154–159, 169, 170, 174–176, 187, 191, 192, 196, 197, 201, 203]
	Multiple sessions within a single day	[5, 55, 142, 149, 153]
	Multiple sessions on different days	[7, 8, 12, 31, 32, 35, 36, 51, 79, 103, 120, 129, 147, 166, 172, 179, 182, 186]
	Multiple experiments	[2, 16–18, 38, 42, 43, 56, 58, 66, 67, 70, 71, 76, 82, 83, 85, 88, 96, 110, 124, 127, 137, 145, 163, 164, 180, 190, 198, 204]
	Longitudinal study	[3, 14, 29, 135, 141, 184, 185]
Before, during, after	ESM	[3, 29, 30, 142]
Synchronous / Asynchronous	Synchronous	[76, 88, 159, 164, 169, 201]
	Asynchronous	[159, 169, 201]
Actions' relation to time	Hurrying, normal and waiting	[125]
	Presentation time	[34]
	Walking speed	[34, 35, 41, 90, 118, 120]
Time of day, week and year	Afternoon	[82]
	Busiest time of the day	[24, 99]
	Different hours of a day	[24, 60, 106]
	Spring	[4, 69, 84, 130]
	Summer	[23, 69, 133, 182]

A.3 Task Context Summary

This section summarises the literature related to task context.

Table A.3. Overall Task Contexts in the Literature

Task Context	Types	Papers
Multitasking	Walking	[1, 5, 6, 9–12, 15–17, 19–22, 24, 26, 27, 32, 34–36, 38–40, 42, 45, 46, 48–51, 54, 60, 63, 64, 66–68, 70, 74, 76, 80, 82, 83, 85, 87, 89–91, 93–95, 97–99, 101, 102, 104, 108–110, 112–122, 125, 128, 130–135, 137–139, 143, 144, 146, 147, 154–159, 162, 164, 166, 169, 172–179, 182, 183, 186, 187, 191–197, 201, 203, 204]
	Encumbrance	[45, 116–120, 163]
	Exercising, jogging or running	[106, 109, 146, 201]
	Collision/hazard avoidance	[28, 38, 68, 97, 164]
	Playing a game	[41, 67, 85, 88, 190]

(Continued)

Table A.3. Continued

Task Context	Types	Papers
	Distraction or cognitive tasks	[12, 15, 42, 104, 150]
	Conversation or social interaction	[105, 106]
	Monitoring environment	[36, 80]
	Others: parenting [69], talking on the phone [88], holding objects with different sizes [124], working, eating, relax. and traveling [106]	
Interruptions	Obstacles	[4, 5, 9, 10, 17, 21, 24, 26, 27, 48, 60, 63, 64, 68, 82, 89, 90, 95, 98, 99, 99, 121, 130, 133, 138, 143, 147, 169, 173, 181, 193, 194]
	Eyes-free interaction	[7, 8, 31, 33, 51, 53, 56, 73, 86, 88, 107, 115, 123, 126, 127, 134, 145, 170, 171, 180, 184, 198, 202]
	Hands-free interaction	[2, 53, 58]
	Stressor tasks	[29, 30, 150]
	Hazard checks	[38, 97]
	Distraction tasks	[79, 102]
	Stairs	[196, 197]
	Virtual objects or vehicles	[159, 164]
	Others: stop signs [195], visual disruptions [43], alcohol usage [103], interruptions from children [69], incoming phone calls [14]	
Task domain	Texting or talk. on the phone (Act. or.)	[24, 141]
	Playing a game (Action oriented)	[59, 185]
	Media control (Action oriented)	[141]
	Navigation (Goal oriented)	[12, 19, 20, 74, 110, 112, 130, 131, 133–135, 140, 144, 147, 174, 175, 179, 182, 183, 187, 191, 193–195]
	Target selection (Goal oriented)	[11, 16, 21, 22, 36, 40, 43, 45, 46, 55, 56, 66, 67, 73, 82, 83, 90, 91, 94, 99, 116–118, 120, 127, 128, 137, 143, 149, 150, 152, 153, 155–157, 166, 180, 186]
	Text entry (Goal oriented)	[5, 7, 8, 25, 29–32, 38, 41, 42, 47, 50, 51, 54, 57, 60, 71, 72, 77, 79, 80, 85, 88, 98, 103, 108, 121–124, 126, 138, 142, 150, 152, 154, 169–171, 177, 178, 196–198]
	Gesture based interaction (Goal or.)	[15, 33, 86, 96, 115, 119, 163, 172, 176, 203, 204]
	Reading (Goal oriented)	[9, 10, 26, 27, 34, 48, 49, 84, 102, 148, 154, 157, 169, 173, 184, 192, 201]
	Searching (Goal oriented)	[3, 9, 10, 29, 30, 57, 63–65, 78, 89, 109, 125, 150, 152, 192]
	Talking on the phone (Goal oriented)	[41, 76, 87, 113, 159, 164, 169, 201]
	Texting (Goal oriented)	[1, 87, 93, 104, 159, 201]
	Playing a game (Goal oriented)	[28, 43, 68]
	Menu related tasks (Goal oriented)	[17, 107, 132, 202]
	Other goal-oriented tasks	[2, 6, 14, 18, 35, 39, 53, 58, 70, 88, 95, 97, 100, 101, 103, 105, 114, 139, 145, 146, 158, 159, 162, 201]

Other goal-oriented tasks include audio target acquisition [101], cognitive tasks [114], cross-modal icon identification [70], dealing with incoming notifications or alerts [6, 95, 146], foot-gesture-based interaction [2, 58], gesture recognition [145], head-gesture-based target selection [39], recording phone number, checking calendar [88], question answering [14], remembering symbols shown [162], speech-based text entry [53, 97, 139], sports tracking [158, 201], listening to music [159], information retrieval [18], browsing bus timetable [100], declining incoming calls [105], heart rate balancing, simple and choice reaction[103], and visual acuity [35].

A.4 Social Context Summary

This section summarises the literature related to social context.

Table A.4. Overall Social Contexts in the Literature

Social Context	Types	Papers
Persons present	Self	[1–3, 5–12, 14–36, 38–43, 45–51, 53–60, 63–71, 73–80, 82, 84–91, 93–104, 106–110, 112, 114–128, 130–135, 137–150, 152–159, 162–164, 166, 167, 169–187, 190–198, 201–204]
	Other pedestrians	[4, 24, 47, 60, 68, 82, 95, 130, 133, 138, 147, 181]
	Accompanied	[24, 60, 72, 76, 105, 113]
	At least one child	[69]
	Experimenter	[88]
Interpersonal interaction	One to one	[1, 24, 88, 105, 113, 159, 164, 169, 201]
Culture	Users from UK and India	[185]

A.5 Technical Context Summary

This section summarises the literature related to technical context.

Table A.5. Overall Technical Contexts in the Literature

Technical Context	Types	Papers
Device	Smartphone with touchscreen	[5–8, 11, 12, 14, 19, 20, 24, 26–30, 34, 36, 43, 47, 49, 51, 53–57, 59, 63–65, 67, 71, 78–80, 95, 102, 103, 105, 107, 109, 110, 112, 115, 117–123, 126, 130, 132–134, 138, 140, 142, 149, 150, 152, 153, 157, 162, 167, 170–172, 174, 176, 180, 181, 185, 187, 190, 195, 198, 201]
	PDA	[9, 10, 16, 17, 31, 42, 72, 83, 85, 90, 91, 96, 99, 108, 113, 128, 137, 139, 192, 196, 197]
	Tablet	[33, 50, 58, 63, 64, 68, 73, 74, 97, 145, 155, 156, 177, 178, 191, 193, 194]
	Wearable device	[17, 18, 21, 22, 46, 56, 66, 70, 73, 88, 95, 96, 98, 131, 146, 158, 191, 203]
	Smartwatch	[45, 86, 106, 109, 127, 147, 158, 162, 163, 166, 182, 183, 201]
	Participants' own devices	[1, 3, 4, 23, 75, 77, 93, 135, 142, 154, 159, 169]
	Smartphone with physical keyboard	[38–40, 71, 87, 88, 116, 123, 125, 144]
	Smartphone with touch. & phys. keyboard	[15, 32, 83, 89, 94, 124, 175]

(Continued)

Table A.5. Continued

Technical Context	Types	Papers
	UMPC	[82, 143, 173, 184, 186]
	Media device with touchscreen	[35, 48, 49, 195, 202]
	Mobile phone with physical keyboard	[85, 113, 164]
	Smart glasses	[147, 148]
	Smart bracelet/Wristband	[127, 201]
	Others: Twiddler [31, 204], Trackball, gyroscopic mouse and touchpad [204], handheld device [100], Protractor3D recognizer with acceler. [2], actuators on shoe, eye tracker [12], head-mounted display [114, 173], MT-9B orientation trackers [101], e-book reader [173], Microsoft Xbox Kinect [2, 58]	
Informational artefacts	Laptop computer	[22, 51, 123, 124, 170, 171, 198]
	Projection screen or floor	[38, 80, 80, 97, 98, 139]
	Large monitor or wall display	[15, 66, 104]
	External screen or LCD displays	[8, 56, 114]
	Desktop computer	[31, 66]
	Tablet	[33]
Interoperability	Smartphone - Smartphone	[110]
	Google Glass - PocketThumb	[46]
	PDA - wearable device	[17]
	PDA/Twiddler - Desktop computer	[31]
	Smartphone - Smart glasses & smartwatch	[147]
	Smartphone - Headphone	[53, 123]
	Smartphone - Laptop computer	[51, 170, 198]
	Wearable device - Desktop computer	[66]
	Laptop computer - PDA	[113]
	Wearable device - Laptop computer	[22]
	Wear. device - Smartphone - Ext. monitor	[56]
	Actuators on shoe, smartphone, eye tracker	[12]
Mixed reality systems	Virtual reality	[36, 159, 164]

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