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Patterns of multi-device use with the smartphone. A video-ethnographic study of young adults' multi-device use with smartphones in naturally occurring contexts

Maxi Heitmayer

Department of Psychological and Behavioural Science, London School of Economics and Political Science, WC2A 3PH, Houghton Street, London, United Kingdom

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ABSTRACT

Using multiple devices at the same time is becoming increasingly common in the daily lives of users, be it for work or for leisure. This paper presents *in situ* qualitative and quantitative evidence of multi-device use from a dataset of over 200h of first-person and interview recordings (n = 41). We discuss three different 'patterns' of multi device use (work, leisure, mixed use) and illustrate the user experience in detail with three participant journeys. We find that the smartphone was always 'in the mix'; we did not observe multi-device use without the smartphone, or isolated use of other devices. Overall, we suggest that looking at transitions between activities users engage in rather than devices they use is more effective to understand multi-device use. Based on this analysis, we highlight issues around the patterns and experiences of multi-device use in everyday life and provide recommendations for design and further research.

1. Introduction

Everyday computing devices, especially portable and 'smart' ones have become in-expendable in our daily lives, and the number of devices around us is steadily growing. In 2020 alone, 396 million wearable and 802 million smart-home devices were shipped to customers (International Data Corporation, 2020, 2021). Regardless of whether they are supporting work or facilitating personal life, devices are usually present when users engage in their everyday activities (Crabtree & Tolmie, 2016; Voit et al., 2018). Unsurprisingly, devices like the PC, smartphone, tablet, or smartwatch have been studied with various techniques, and we understand the role these devices play and how they are used relatively well now.

In the daily lives of users, however, device-use often occurs concurrently with other devices, either directly or indirectly. With smart-devices on the rise and increasing numbers of everyday tools and objects becoming connected through the internet of things (Cerf, 2015; Maamar, 2020), Weiser's often-cited, early conjecture about "hundreds of computers in a room" (Weiser, 1991, p. 98) which go unnoticed as we engage with them to accomplish our daily goals seems to be finally upon us.

However, user behavior in the wild is complex and decision-making patterns are determined by environmental factors - which are in turn sometimes shaped by participants. Consequently, how exactly users combine devices and switch between them in the flow of natural activity is not clear yet. We therefore argue that it is necessary to study the use of devices in naturally occurring contexts to see how users integrate them into their daily lives, paying specific attention to multi-device practices. *In situ* techniques are an effective means to do so, producing rich descriptions of user behavior that can help identify overlooked pain points in human-machine systems and provide a novel angle for future research (Heitmayer & Lahlou, 2021; D. McMillan et al., 2015). With this study, we seek to contextualize and ground previous findings in real-world user behavior, and to provide an ethnographic insight into multi-device use. We therefore formulate the following research questions:

- How do users engage with multiple devices at the same time in their everyday lives?
- What are their perceptions of this use and how do they integrate it into other activities?

To address these questions, we present a mixed-methods analysis of first-person, audio-visual footage of user behavior from naturally occurring contexts and in-depth interviews with participants, resulting in a dataset of over 200 h of video with N = 41 participants aged 20–30 years old. We find that the smartphone was the only device that users

E-mail address: m.a.heitmayer@lse.ac.uk.

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engaged with in isolation; for all other devices at least one other device was 'in the mix' during use, and the smartphone was present at almost all times. Based on our findings, we describe three general patterns in which multi-device use took place in our sample (work, leisure, and mixed), provide illustrations from three individual journeys of multi-device use from our participants, and discuss the findings under the light of the literature on multi-tasking.

2. Related work

2.1. Multi-tasking

Research on multi-tasking investigates how often users switch between different tasks, screens, windows, etc., and how long their attention dwells on the respective items. The two main theoretical approaches behind multitasking are dual-tasking, which focuses on two tasks being carried out at the same time (Schumacher et al., 2001), and task-switching, which focuses on performing multiple tasks step by step and sequentially (Monsell, 2003). More studies have embraced dual-tasking although recently combined approaches have gained in popularity (Jeong & Hwang, 2016; Salvucci & Taatgen, 2008; Yeykelis et al., 2014).

Multi-tasking involving the use of media has been connected to difficulties with concentrating on tasks (Baumgartner & Sumter, 2017; Cain & Mitroff, 2011; Ophir et al., 2009; Rosen et al., 2013; Shin et al., 2019; Uncapher et al., 2017) and to reductions in cognitive performance on tasks involving long-term and working memory (Jeong & Hwang, 2016; Lang & Chrzan, 2015; Sanbonmatsu et al., 2013; Uncapher et al., 2016). In this vein, it is argued that performance is not only affected by the level of demand on the attention of users, but also by its qualitative nature. Dual processing theory thus argues that tasks which share the same information processing structures can be performed less efficiently compared to tasks that use two different processing structures, e.g. seeing and hearing (Wickens, 2002). Experimental studies confirm these conjectures, demonstrating a negative effect of sensory interference on a variety of performed tasks (J. M. Bowman & Pace, 2014; L. L. Bowman et al., 2010; Fante et al., 2013; Hwang & Jeong, 2018; Jeong & Fishbein, 2007; Pool et al., 2003; Yeykelis et al., 2014).

Another factor affecting users' ability to multitask is the hierarchy of tasks performed. Studies find that cognitive performance is lower for tasks that are perceived as secondary (Lin et al., 2009; Z. Wang et al., 2015). Task hierarchy further amplifies the negative effect of sensory interferences for tasks that are perceived as secondary (Hwang & Jeong, 2018).

A final factor influencing the performance of individuals while multi-tasking is the level of control they have over the inputs they receive (Eveland & Dunwoody, 2001; S. J. McMillan & Hwang, 2002; Milheim & Martin, 1991), their ability to selectively direct their attention to specific elements, and whether they can influence the "pace and sequence" of the information they need to process (Eveland, 2003). Initial studies find that user control has an even stronger effect on cognitive processing than sensory interference (Hwang & Jeong, 2019; Jeong & Hwang, 2016).

Research into the frequency of multitasking behaviors reports an increase in switches and a reduction in time spent continuously on a single task. While users switch to their phones from work activities every four to 6 min (Rosen et al., 2013; Yan et al., 2012), numbers for general use are slightly higher (Van Berkel et al., 2016; Visuri et al., 2017). Especially with mobile devices, however, switches often do not occur randomly or through voluntary allocation of attention; instead, devices capture user attention through notifications or acquired habits (Heitmayer & Lahlou, 2021). Frequent interruptions can thus exacerbate problems with multi-tasking as users need time to return to their previous tasks or do not return to them at all (Mark et al., 2005; O'Conaill & Frohlich, 1995), make more errors completing them after having been interrupted (Borst et al., 2015), are more susceptible for further interruptions (Dabbish et al., 2011), and experience more stress, time pressure, and effort, as well as a higher workload and frustration (Mark et al., 2008, 2018). Paradoxically, strong media-multitaskers also appear to be worse at switching between tasks effectively (Ophir et al., 2009).

2.2. Multi-device use

Research has investigated multi-device use in several contexts, and many systems and design solutions to support multi-device use have been proposed. Following Weiser's groundbreaking work at the beginning of the 1990s (Weiser, 1991), initial research on multi-device use focused on early adopters, usually in the area of computer science or more broadly knowledge work (Dearman & Pierce, 2008; Fauquet-Alekhine & Lahlou, 2017; Grudin, 2001; Lahlou, 1999, 2007; Oulasvirta & Sumari, 2007; Santosa & Wigdor, 2013; Tungare & Perez-Quinones, 2008; Tungare & Pérez-Quiñones, 2009). The use of multiple screens for one computer became popular early on as a means to manage work tasks and to help users "cleanly shift attention" (Grudin, 2001, p. 463). Moreover, an early qualitative study into multi-device use at work observed three key developments: "*specialization* – the allocation of specific roles of each device; *parallelism* – the coordination of devices for simultaneous use, and *fragmentation* – the division of data across multiple devices" (Santosa & Wigdor, 2013, p. 63). In a similar vein, a more recent observational study suggests that multi-device use can be organized into sequential and parallel use, with parallel use either being related, unrelated, or exhibiting some form of resource lending, such as sharing a tablet screen onto a laptop, or using a phone as a TV remote (Jokela et al., 2015).

The 'kit' of devices users carry therefore determines what types of activities they can engage in, and have become an influencing factor for their lifestyle (Dearman & Pierce, 2008; Oulasvirta & Sumari, 2007); kit choices have been found to depend on device capabilities, screen size, and portability (Nguyen et al., 2021). Users generally hold positive attitudes towards multi-device use and describe it as driven by a desire for convenience, especially when it comes to accomplishing tasks with less effort and in simpler ways (Monge Roffarello & De Russis, 2021).

Building on a wealth of literature on concurrent activities to watching television, studies on multi-device use with the TV discuss a wide range of interaction techniques offered by broadcasters and hardware providers, as well as habits developed by viewers (Basapur et al., 2011; Cesar et al., 2008; D'Heer et al., 2012; Holz et al., 2015; Neate et al., 2017; Smith & Boyles, 2012). Importantly, *in situ* inquiries uncovered that participants tend to focus more on the smartphone than on the TV (Holz et al., 2015; Neate et al., 2017), and that while companion use, in which other devices are being used to look up additional information on the broadcast does occur (D'Heer et al., 2012; Neate et al., 2017), users often join others in front of the TV to be social, not because they are interested in what is being watched (Holz et al., 2015).

Another strand of the literature investigates interruptions and notifications in the context of multi-device use (Kim et al., 2017; Okoshi et al., 2015; Voit et al., 2018; Weber, 2017; Weber et al., 2016). A qualitative inquiry has found that while smartphones and laptops remain the most-used devices, users interact with and receive notifications from a varied mix of devices in their daily lives. Importantly, participants reported that while they only consider a fraction of the notifications they receive as important, they do not usually change the notification settings of their devices, which emphasizes the importance of careful design of default settings for devices and applications that send notifications (Voit et al., 2018). A large-scale study of notifications in multi-device environments further found that participants keep devices at a different physical distance from themselves, and that their preferences for notification delivery vary for different devices in different contexts (Weber et al., 2016). One key issue the authors identified is that multiple devices logged into the same social media or Email accounts deliver notifications multiple times: The "disruptive effects caused by notifications are therefore amplified by the increasing

number of devices around us" (Weber et al., 2016, p. 1259).

Some studies, thus, aim to improve notification delivery in multi-device settings. Okoshi and colleagues showed that software reducing the disruptiveness of notification delivery was three times as effective at reducing the perceived workload of users when taking into account multi-device use (Okoshi et al., 2015). In a similar vein, PomodoLock, a software tool enabling users to restrict access to certain websites to increase productivity that operates synchronously on multiple devices reduces reported levels of stress and self-control required during work tasks (Kim et al., 2017). Another approach is to use notifications as *shifting cues*, suggesting to users on one device that the use of another device or a multi-device interaction may be helpful and increase productivity (Nguyen et al., 2021).

Finally, multi-device use, has been identified as a source of stress and *telepressure* (Barber & Santuzzi, 2015); as people use their work hardware at home or their private hardware for work, job pressures can intrude into their private lives (Derks et al., 2014). High levels of perceived telepressure also feedback negatively into the workplace, increasing smartphone use and reducing perceived engagement (Van Laethem et al., 2018). Moreover, users high in *nomophobia*, the feeling of discomfort related to potentially missing out on information when they cannot access their devices, perceive themselves as more engaged and productive when they use the phone in work contexts, but they also experience emotional stress, exhaustion, and reduced levels of productivity when they cannot check their device (King et al., 2013; G. Wang & Suh, 2018). Looking at digital wellbeing more broadly, it has also been pointed out that research and initiatives often take a single-device angle and assume patterns of sequential use, overlooking the challenges of multi-device environments (Monge Roffarello & De Russis, 2021).

3. The gap in the literature

The literature demonstrates that multi-device use has become the default for many users in private and professional contexts. Users engage in it naturally because they feel it helps them perform tasks better and increases the affordances and choices available to them while doing so. They therefore consciously select the assemblages of devices they surround themselves with, and how they distribute devices in the physical space around themselves. The literature also shows, however, that multi-device interactions bear a significant risk of adding further distractions for users, reducing their ability to perform their professional and private tasks, and contributing to general feelings of cognitive overload. Under this light, several interventions aimed at improving the hardware and software suite available to users have been tested.

What is missing from the literature so far is a detailed description of the habits and behavioral patterns users engage in around multi-device use with the smartphone. What users actually do with their devices in naturally occurring settings is of crucial importance; developing well-founded and effective interventions to address challenges and difficulties for users is only possible with an in-depth understanding of how they use the current hardware and software suite.

First, it will be crucial to investigate whether multi-device use with the smartphone resembles more closely a multi-tasking or task-switching model (or a combination of the two), and whether these patterns are stable or vary across time, contexts, tasks performed, etc. The patterns in which users engage with these devices have not been described explicitly and across the breadth of usage. An Initial piece of research suggests that the smartphone seems to take precedence over the TV in a shared family setting (Holz et al., 2015). Within the limited scope of this paper, we will keep a focus on the smartphone, but will extend this finding to other devices and contexts. In this vein, it will also be interesting to observe how resource lending between devices plays out, and how users supplement interactions with one device with the affordances of others. Better understanding multi-device user behaviors will be crucial to determine also which functionalities are most relevant to users, and which form factors will benefit from revisions or integration.

Another question emerging from the literature is how much control over external stimuli users have in naturally occurring settings of multi-device use, and how this affects their use and their task performance. The same applies to the discussion around task hierarchy; it is unclear whether the use of multiple devices improves the ability of users to prioritize the demands they are facing, or whether the use of multiple devices adds further complexity for them.

4. Methods

Capturing situated multi-device activity is not a trivial task and previous studies have used elaborate data-logging set ups with Bluetooth beacons and sound-printing devices to monitor the complex processes taking place and the many devices involved (e.g., Holz et al., 2015). While potentially more obtrusive than software and hardware operating in the background, first-person video-ethnographic techniques offer an elegant solution for documenting situated use of multiple devices in changing contexts.

For this study, we used Subjective Evidence-Based Ethnography (SEBE), a video-based *in vivo* technique that combines qualitative and quantitative means of analysis (Lahlou, 2011; Lahlou et al., 2015). First, participants are given unobtrusive, miniature cameras worn at eye-level (*Subcams*; see Fig. 1) to gather first-person video material (*Subfilms*). This enables participants to go gather complete data on their daily experiences (wide angle video, stereo sound) without being disrupted or distracted.[1] Then, participant and researcher watch the Subfilms together in a *Replay-interview* where participants can explain and reflect on what is happening in the videos, and they can object to interpretations by the researcher and suggest alternatives as they relive their experiences. Crucially, supporting interviews with logging and trace data was found to be effective in supporting recall (Ferreira et al., 2015) and in contextualizing usage behaviors in "wider webs of activities" (Anderson et al., 2009; Rattenbury et al., 2008); videos further capitalize on this as they can be rewound, slowed down, and stopped. Similar to ethno-mining approaches (e.g., Aipperspach et al., 2006;

Fig. 1. Multi-device A researcher modeling the Subcam. The camera weighs only 7 g and can be mounted on a pair of research glasses or the participant's own (here); it has about 3 h of autonomy with the internal, and several days with an external battery.

[1] We have probed participants for issues with wearing the camera during the interviews, and have given them the opportunity to withdraw from the study if they felt uncomfortable or could not forget about wearing the camera. One participant made use of this option. Participants generally reported being able to behave as they would normally within minutes of wearing the Subcam.

Anderson et al., 2009), SEBE has proven to be particularly relevant for the study of smart device use as it documents the interaction of multiple devices with the physical and the digital environments around users, as well as both their online and offline behaviors (Brown et al., 2013; Heitmayer & Lahlou, 2021; Licoppe & Figeac, 2013; D. McMillan et al., 2015, 2017).

5. Data collection

The SEBE protocol follows stringent ethical guidelines ensuring participants' full control over the data all the way they are followed (this study received approval from the Ethics Board at the London School of Economics and Political Science). Confirmation of consent was sought repeatedly throughout the research process to ensure that researchers are able to react adequately to arising issues, and that participants can adjust their initial choices (Cox et al., 2014; Everri et al., 2020; Gubrium et al., 2014). Participants were further given the opportunity to review and remove or edit unwanted passages of their recordings.

Data collection took place in the UK in 2018 and 2019 with most participants being residents of the Greater London area, generating an international, but mainly European sample of n = 41 participants.[2] Participants were recruited through mailing lists at the London School of Economics and Political Science and through snowball-sampling. Participants were aged between 21 and 29 years and the sample is roughly balanced in terms of gender (46% female). The majority or participants were university students (27), the rest were working professionals (14). Most participants used Apple iOS devices (78%), six used Android on Samsung devices (15%), with one participant each using a Sony, Motorola, or Huawei device running Android.

Participants were instructed to wear the subcam on at least three consecutive days, collecting at least 5h of video material. This has generated a data corpus spanning a breadth of recorded activities and locations with 59.6% or recordings being filmed at home, 27.8% at work, and 12.6% in mobile contexts.

The entire Subfilm footage was carefully reviewed and coded manually using an ethological approach: Every time participants used their devices we recorded the duration of the device interaction and the time elapsed since the last interaction with the device. We coded the location in which use took place, the type of interaction, where the device was in the physical space, the context participants were in (e.g., working at the office, commuting), whether there was a notification (and if so, what type), whether they were engaging in single- or multi-device use, and the nature of the activity.[3] When users switched between apps or functionalities within one continuous session of using the device, we coded this as multiple interactions. We focused our coding activities around the smartphone, firstly because of the focus of this research project, and secondly because we did not observe individual use of other devices without the smartphone being present (see discussion below). Overall, this resulted in a dataset of N = 1307 smartphone interactions, of which 789 (60.4%) took place in a multi-device use context.[4]

Replay-interviews lasted 50–90min and were conducted no more than two weeks after participants began collecting material. In the interviews, we looked at every instance in which participants interacted with their phones in the Subfilms and discussed motivations for the specific interaction, as well as device-use in general. The Replay-interview recordings have been transcribed literally and prepared for analysis using directed Qualitative Content Analysis (QCA; Mayring, 2000; Schreier, 2014). Overall, the data corpus comprises over 200h of video material.

6. Findings

We now report our observations of multi-device use in the sample. We start with a quantitative analysis of general patterns and usage habits for the various contexts and assemblages of multi-device use. We then look at the interview data and present three exemplary cases of different 'patterns' of multi-device use we have discussed with participants. It is important to note that we did not observe single use of other devices than the smartphone or multi-device use that did not involve the smartphone, which we will return to in the discussion.

6.1. Quantitative analysis of multi-device use

We investigated the relationships between single- and multi-device use with other key variables of smartphone interactions using non-parametric tests (Fisher's exact test and the Kruskal-Wallis H test where appropriate). Following the discussion in (Perneger, 1998), we have not applied Bonferroni corrections to the p-values as we do not believe the statistical significance of findings, particularly those of exploratory nature, are influence by the number of statistical tests presented in a paper. We have thus used an unadjusted value of $p < .05$ to determine the statistical significance of our findings and caution the reader to generally bear in mind the risk of type I errors that can occur in statistical testing.

Participants engaged in multi-device use with smartphones in a variety of situations and with varying assemblages of devices. Overall, 60.4% of smartphone use occurred in multi-device settings. In the remaining 39.6% of instances, the smartphone was used in isolation. Roughly three quarters of multi-device use occurred with smartphone and a computer (74%), 12.6% with smartphone and TV, and 7.5% with smartphone and tablet. On rarer occasions, participants used three devices at the same time: in 4.2% of cases participants used two phones and a computer, in 1.8% of cases, they used their phone, a TV, and a computer (see Fig. 2).

First, we tested for a relationship between the duration of smartphone interactions and multi-device use, as well as the time between smartphone interactions and multi-device use with the Kruskal-Wallis H test. We do not observe a significant difference for the duration of use for smartphone interactions in isolation and in multi-device settings (32s vs

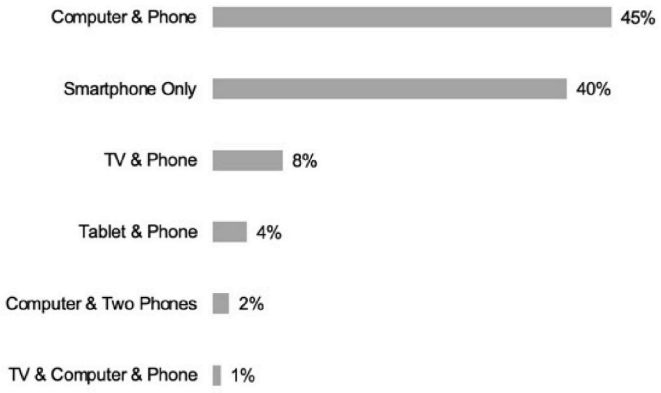

Fig. 2. Multi-device use with the smartphone as proportion of total smartphone use recorded in our sample (in %).

[2] UK (12), Italy (5), Germany (5), France (3), India (3), Latvia (3), Russia (2), USA (2), Colombia (1), Czech Republic (1), Iran (1), Netherlands (1), Singapore (1), Spain (1), Sweden (1).

[3] Data was initially recorded as categorical variables on the coding sheet and later dummy-coded to allow for easier analysis and meaningful interpretation (e.g., "home" vs "workplace" vs "public transport" into "home" vs "not home", "workplace" vs "not workplace", "public transport" vs "not public transport", etc.).

[4] The Subfilms for three participants were corrupted in the transfer process after the interview, leaving data from 38 participants only for the quantitative analyses.

34s, H (1) = 0.578, p = .447). For time between smartphone interactions, however, the results are highly significant with the average time between smartphone interactions being 27s longer for interactions that occurred in multi-device settings (148s vs 175s, H (1) = 6.457, p = .011). We further do not observe a difference in the number of apps used per smartphone use session between individual smartphone and multi-device use (1.44 vs 1.36, H (1) = 0.436, p = .509).

We then used Fisher's exact tests to investigate the relationship between further characteristics of multi-device use with the smartphone in our sample: Second, we find a significant interaction between notifications and multi-device use in our sample ($p < .001$). While 7.1% (37/518) of smartphone interactions were initiated by notifications when participants were using the device on its own, 13.3% (105/789) of smartphone interactions follow notifications when participants were using other devices as well.

Third, we looked at the influence of the location participants were in on multi-device use. Multi-device use occurred significantly less when participants were in public transport (5.8% (3/52) vs. 62.6% (786/1255), $p < .001$) or outside (13.5% (10/74) vs. 63.2% (779/1233), $p < .001$), and significantly more at work (79.9% (291/364) vs. 52.8% (498/943), $p < .001$), but we did not observe a significant difference in multi-device use when participants were at home compared to other contexts (61.7% (481/779) vs. 58.3% (308/528), p = .119). Regardless of the location, when participants were working, they were significantly more likely to use multiple devices (compared to when they were not (91.5% (482/627) vs. 39.4% (307/780), $p < .001$).

Fourth, we examined the association between the use of various smartphone apps and multi-device use. We tested for a variety of app categories, but did not find a significant difference in app use between individual smartphone interactions and smartphone use in multi-device settings: *Messaging apps* such as WhatsApp (20.8% (108/518) vs. 21.7% (171/789), p = .388), or facebook messenger (6.8% (35/518) vs. 5.8% (46/789), p = .285); *social media apps* such as facebook (5.6% (29/518) vs. 5.3% (42/789), p = .461) or Instagram (16.2% (84/518) vs. 14.4% (114/779), p = .214); as well as *Email* (4.2% (22/518) vs. 6.1% (48/789), p = .093), the *web browser* (4.4% (23/518) vs. 3% (24/789), p = .120), and *tool apps* (e.g., weather, Shazam; 3.3% (17/518) vs. 4.9% (39/789), p = .094).

Finally, we observe that brief lock screen checks of the smartphone occurred significantly more often when participants used more than one device compared to using the smartphone only (12.7% (66/518) vs. 19.6% (155/789), p = .001).

6.2. Qualitative analysis of multi-device use

We now look more closely at the situated instances of multi-device use our participants have recorded. The various complex assemblages and situations of distributed multi-device use provide a nuanced picture in terms of the role of devices, the interplay of their affordances, and how participants switch between them. Following the distinction between work and leisure contexts that is drawn in the literature, we have divided multi-device use in our sample into three general patterns based on participants' activities: *multi-device work* when participants were engaged in work activities as their main task, *multi-device leisure* when participants were not engaging in work activities at all, and *mixed use* when work and leisure activities were both present and alternating as the main activity. In the following, we present an analysis of these three patterns based on the Subfilm data and the Replay-interviews, illustrating with three individual journeys of multi-device use.

6.2.1. Multi-device work

As observed in our quantitative analysis, multi-device use occurred more frequently in our sample when participants were working. This is not surprising given that many of our participants were students or knowledge workers. Consequently, most of them used a computer or a tablet as their main tool for work, and their smartphone to supplement, or to manage other aspects of their lives. Fig. 3 shows some examples of this. Participants use the smartphone as a secondary channel to communicate with work colleagues: Messaging apps like WhatsApp and facebook messenger seem to have superseded Email for communication with close colleagues, also because they integrate the capacity to record multi-media content and share it with multiple people (see Fig. 3, top left). Beyond messaging, the phone also served as a multi-media tool (voice recorder, note pad, calendar, calculator, etc.) while participants engaged with their main work activities on another device (see Fig. 3, bottom row). Finally, participants used smartphones to take short breaks to coordinate their lives while they were working (see Fig. 3, top right). Importantly, we did not observe the phone as the locus of the main work activity with other devices being used to supplement the activity in our sample.

Fig. 4 provides a timeline and an overview of a session of multi-device work. In this sequence lasting roughly 1.5h, P12 is working on a laptop at a large co-working desk with two smartphones placed visibly and facing up, as well as several notepads and journals, a water bottle, and a tub of lip balm besides the laptop. Phone A is her private and phone B is her work phone; both devices are muted, but their screens light up when notifications arrive. In the interview, P12 mentioned that this is a typical example of how she arranges her desk space for work, and that she scatters her things widely, so nobody sits next to her and distracts her. This journey gives an excellent overview of the interplay of multiple devices, resource lending, and the differentiation between a personal and a private phone in work contexts. It also illustrates how participants used both digital and analogue tools to manage their complex schedules.

The sequence starts with P12 setting up her workspace and waking her laptop (1). She then briefly checks phone B and proceeds to her first work goal, filing receipts from a business dinner for reimbursement. To do so, she arranges the receipts on the desk and sends a photo from phone A to phone B (2). This is an interesting solution to quickly move data from her phone to her computer: rather than opening the images on phone B, she logs into WhatsApp on her computer to access them directly on the machine where she needs them (3). Unfortunately, the file does not download properly so she moves back and forth between phone A and the laptop several times, before deciding to email the photo to herself. This solves the problem, and she proceeds to file the receipts which takes about 15min (4). After filing the receipts, P12 checks phone A for notifications first and then phone B with which she is fidgeting for a while, moving around the apps on the home screen. She exhibited surprise about this in the interview:

> "I don't know why I just did that! It happens often when I've just been on my phone. So, I wasn't just using it to procrastinate, I was actually using it to do something useful, but then, there's just this feedback loop, you know, and you have to … linger a bit".

P12 then takes notes on a notepad (18) and replies to a text message on phone B (19), before reading on her laptop and taking notes for about 15min (20) and writing an Email (21). In the interview, she commented on this longer period of focus on the computer: "Here I'm focused because I'm about to go for lunch, and I want to get as much work done as I can since I'm about to leave". After 5min, P12 checks phone B for notifications, before picking up phone A (22, 23; "It's always … If I look at one [phone] it's hard not to look at the other I guess"). On her private phone she finds several messages from her friend saying that she arrived at the location. P12 responds to her friend, apologizing for being late and assuring her friend she will be there soon (23). Nevertheless, she then returns to her Email for about 5 more minutes before packing up her things and meeting her friend (26), which ends the sequence. In the interview, P12 commented:

> See, I have three messenger notifications from my friend, she's like "Where are you?" And I go, "Hi, I just typed an E-Mail, I'll be right

Fig. 3. Various instances of multi-device use during work (top left to bottom right): Sharing a photo of a document with a colleague while writing, coordinating a meeting with a friend while reading, audio-recording a video-conferencing call with a smartphone, using the phone as a calculator.

there". And then I keep on writing that E-Mail … and then I was late (laughs). It took so long, but I wanted to get this done.

Throughout the sequence P12 used WhatsApp and facebook messenger to communicate with her personal phone (A) and calls and text messages with her work phone (B). As our participants suggest, social media apps seem to constitute a more personal form of communication than traditional means using the cellular network.

6.2.2. *Multi-device leisure*

We also observed participants using multiple devices for entertainment and other non-work activities. This usually occurred when they were in their or someone else's home. Like for multi-device work, participants often use the phone for brief moments but in regular intervals in these situations while a computer or TV provided the main source of entertainment and was in the focus of their attention. In these cases, the phone was often used for communication, for example to get feedback on a potential purchase the participant wanted to make (see Fig. 5, top right), or it provided distraction or additional information: one of our participants used his phone to look up further information on a sports segment of a show he was watching for example (see Fig. 5, bottom left).

However, the smartphone sometimes also was the main focus of attention during multi-device leisure, with another device playing video or music in the background. In the bottom right panel of Fig. 5, the participant watches cartoons with her son, both to spend time with him and to monitor the content he consumes. As the show itself did not interest her, she mainly focused on her phone on which she was scrolling through Instagram.

Fig. 6 depicts a sequence of multi-device use for leisure. In this sequence lasting just under 2h, P15 is having dinner while watching Netflix on a laptop at his desk at home, using his smartphone to access social media and to play games at the same time. The smartphone is muted but has a flashing light displaying new notifications and is sometimes placed on the desk, but mostly held in hand by the participant. This journey depicts a 'TV dinner' setting where the participant is alone and uses his devices for distraction and to keep him company. This sequence nicely depicts the hierarchy between devices that are in the focus and in the background, and how switches between focal points and devices occur during multi-device leisure. It also shows the varied use of the smartphone for active distraction and entertainment, as well as to connect with others while being physically alone.

The sequence starts with P15 finishing working on his laptop (1). He then opens Netflix on the laptop and begins watching a show while eating dinner for roughly 9min (2). After washing his hands (3), he picks up the phone and checks his Emails and WhatsApp messages with Netflix playing in the background before proceeding to play various games on his smartphone (4, 5). P15 continues to play games for about 35min with multiple episodes of the show playing on the laptop in the background before eating a bit more (6) and smoking his vape. When he returns to his phone, he turns to Instagram for about 8min, watching stories first and then scrolling through the feed after answering a brief phone call with his brother (7). He then puts the phone away and vapes while watching Netflix on his laptop. Interestingly, he uses the phone to look up an experiment that is mentioned in the show he watches (8; "The Big Bang Theory" which revolves around the lives of several physicists). After that, he switches between replying to messages from his friends (10), watching the show (11), and vaping for about 15min. Finally, he plays games on his phone for about 6 more minutes (12) before switching to facebook and watching videos (13): "Facebook is a lot of sports for me. I recently have become into snooker, and since then I've been sort of expanding my knowledge of it. Football is very common, too, especially here in the UK." This is where the recorded sequence ends.

6.2.3. *Mixed multi-device use*

Finally, we also observed instances of multi-device use in which some devices served work, and some served leisure purposes. During mixed use, the work device usually was the focus of attention with another device providing entertainment or distraction in the background. Typical situations include using the phone to play music (see Fig. 7, bottom left), or a TV to playing a film (bottom right), while working. In contrast to multi-device work, we did observe the use of the phone as the main work tool in mixed settings: Fig. 7 shows a participant answering work Emails while watching TV on his sofa (top left), and another participant browsing a music streaming service on his laptop during a work call, intermittently muting his microphone to preview songs (top right). The intensity of work during mixed-use tended to be lower compared to multi-device work, with mixed use often occurring when participants were working after hours or from home.

Fig. 8 depicts a 1h sequence of mixed multi-device use. In this sequence P40 is working on her sofa in her living room in the evening. She uses a laptop for work, a TV for entertainment, and a smartphone for both work and entertainment. The smartphone is muted ("I think it's 11 p.m., it automatically goes into do not disturb mode"). When asked about the use of three devices at the same time, P40 commented:

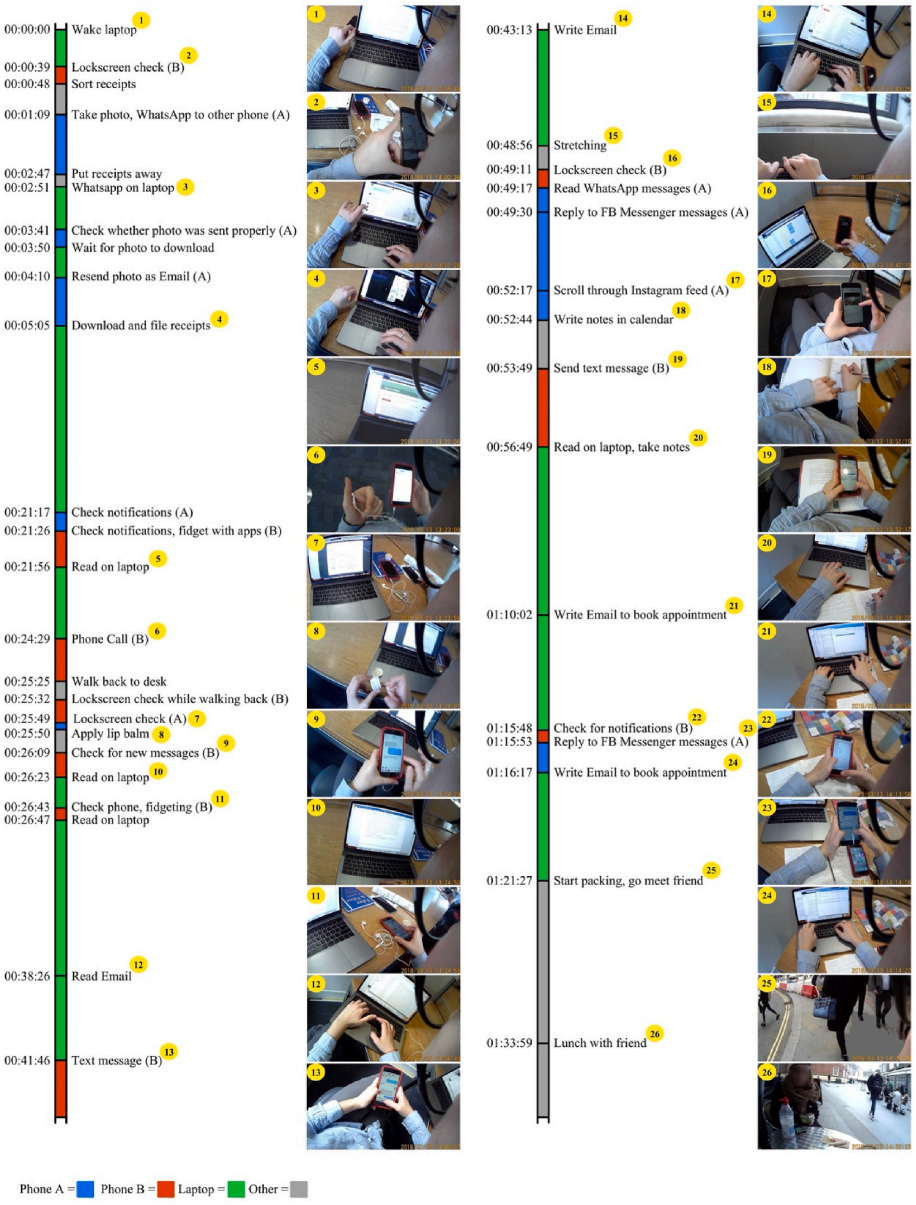

Fig. 4. Timeline of a 1.5h session of multi-device work at an office. Length of events on the timeline has been square-root transformed for legibility and represents actual duration.

> I do it to supplement the news and other stuff that's going on. That's what usually happens because I find it extremely hard to focus on one thing. I find myself more comfortable when I sort of distribute my attention. I don't know if that makes sense, but that really contributes to my productivity somehow.

The final journey depicts an 'end of day' setting where the participant catches up on some work that was not finished during working hours in a slightly more relaxed setting. This sequence gives an insight into the complex push and pull between devices and between private and professional demands that users experience when they engage with their devices. It also illustrates how smartphone is used as a transitional device between activities; P40 moves from housekeeping to watching TV, to working on the laptop with the smartphone being used intermittently. It also illustrates the differences between multi-tasking and task-switching.

The sequence starts with P40 hanging up her laundry (1) and sitting down on her sofa where her phone was lying. She then picks up the smartphone and watches Instagram stories for about 2min, before turning to a news app (2). After about 11min, she turns on the television and tunes into the news:

> This is where I get really deep into the news. It's the end of the day, I'm trying to see what has happened today in the world. And there was this thing that happened with a journalist in Iran today, I don't know why I was so obsessed with this, but I found it quite interesting and had to see everything.

P40 continues to watch the news on her TV for about 5min with two short interruptions of using the phone to read a news article and to look at photos (3) for about 1min each. In the interview, she commented:

> I'm actually looking at pictures of the document I'm working on at the moment. I sent the first draft to my father to ask for his opinion as a general reader. And what he did was that, well, he's from another generation. So, he actually printed out the document and made some edits with a pen and sent me photos of it. Which is a bit funny, but I mean I can't really - he's from another generation.

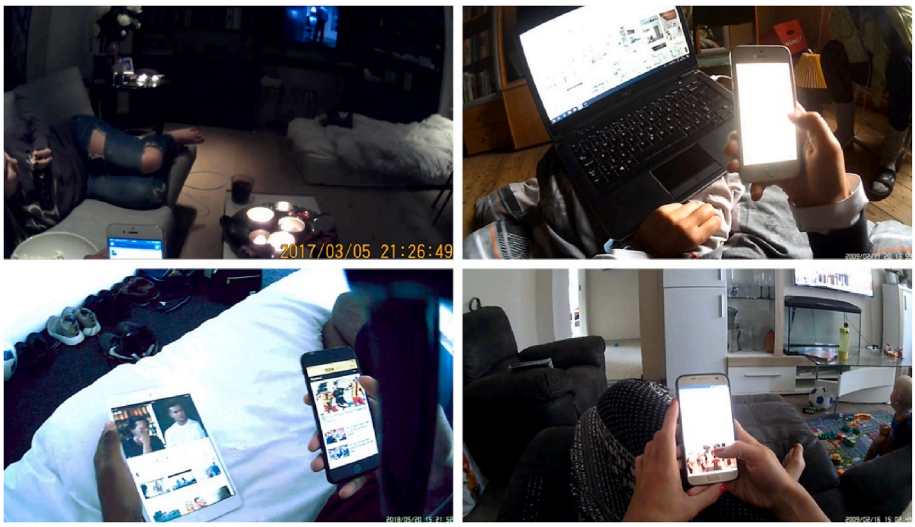

Fig. 5. Various instances of multi-device use for leisure (top left to bottom right): Scrolling through facebook while watching a movie, replying to messages while doing online-shopping on a computer, reading the news on a phone while watching a video on a tablet, scrolling through Instagram while watching TV with a child.

After this, she focuses on the TV for about 10 min. She then picks up her laptop and begins to work on a document with the TV playing in the background (5). After about 8min of working, she replies to some WhatsApp messages and puts the phone down next to herself with the photo application opened (6):

> Here I'm a little bit tired, but don't want to finish work yet. I just need a few minutes. If I put down the laptop and get up, it's going to be a longer break than I intend for it to be. So, I'm not going to get up. I just need like a few minutes break. And what's there for a few minutes break? My phone is there.

This continues for about 15min before the sequence ends with P40 taking a deep breath and picking up the smartphone to reply to more messages on WhatsApp, and to watch stories on Instagram (8):

> I think I'm finished with editing the document. So if you hear me do that [breathing], that's definitely the cue that I need a break, which is why I reach out to get my phone and go to Instagram.

7. Discussion

Our quantitative data show that smartphone interactions do not differ in length between single- and multi-device use. We further do not find a difference in the frequency of use of different apps, or the use of the phone as a tool between single- and multi-device interactions. This suggests that the actions and activities people engage in with their phone remain largely the same whether participants use the phone on its own or in combination with other devices. The smartphone's utility to users and its contribution to the kit they carry seems to stay invariable across different assemblages of devices and contexts of use. This is important for the idea of resource lending discussed previously (see section 2.2; Jokela et al., 2015; Monge Roffarello & De Russis, 2021). The smartphone appears to be the key tool lending resources to other devices and increasing the capability of assemblages for users. But although the smartphone is a versatile tool, and often portrayed as such, it appears that the resources the smartphone lends to other devices are relatively static and represent a core functionality of the form factor.

We do observe, however, that intervals between instances of smartphone use are significantly longer when participants use other devices at the same time. In conjunction with the finding that multi-device use occurs more when participants were working and significantly less when they were on the move, this points to the fact that most of our participants were knowledge workers or students. Participants use the phone to manage their schedules and other parts of their life during short breaks of their main work activity. Consequently, longer intervals between smartphone use in contexts of multi-device activity can be attributed to situations in which participants were using their phone intermittently while focusing on their work on a computer or tablet.

In this context, it is also not surprising that we observed more locked smartphone use when participants were engaging with more than one device, and that notifications were more likely to lead to smartphone interactions in multi-device settings. Again, participants use lock screen checks and notifications to stay up to date on incoming information on their phones while being engaged in another activity. When working on another device (e.g. computer, tablet), but also when watching TV, participants usually place their smartphone visibly and accessibly to them, which increases the likelihood of notifications to be noticed, and the ability to engage with the phone during an opportune moment in the flow of their activity (Heitmayer & Lahlou, 2021). During multi-device use in leisure or mixed contexts, we further observed the strength of the smartphone as a cognitive attractor (Lahlou, 2005), where it usually captured the full attention of participants until they had exhausted their interest *in*, and returned to a pattern of intermittent interactions *with* it. Other devices only provided 'background' ambience until participants finished using the phone, and we observed several instances in which participants had to rewind a movie or show because they had not followed the action.

One challenge for future research will be to investigate whether monitoring the phone at a higher frequency in multi-device settings is warranted (e.g., since there is a higher demand on users because they are working with or distracted by the other devices), or whether this can be incidentally attributed to habitual patterns of switching in which they engage more (e.g., to procrastinate from an undesired task), or users noticing notifications more frequently as they keep their phone close and unmuted, etc.

7.1. Single vs. multi-device use

Strikingly, we did not observe single device use of other devices than the smartphone. The important distinction to be drawn here is between leaving the phone out of reach and sight (e.g., in a bag, a drawer, another room), and placing it next to oneself so it can fulfil a monitoring function (e.g., Banovic et al., 2014; Heitmayer and Lahlou, 2021). While we have observed a variety of activities during which the phone was inaccessible to participants (e.g., cooking, cleaning, conversations,

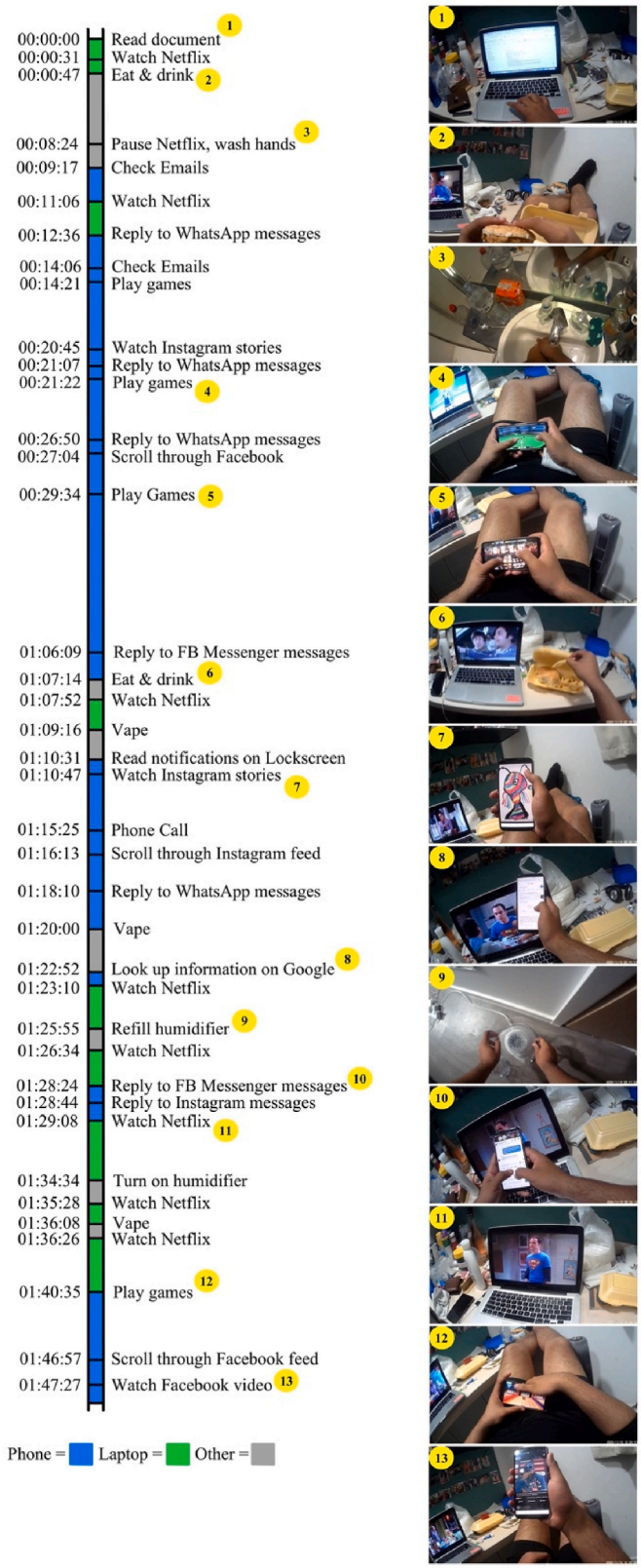

Fig. 6. Timeline of a 2h session of multi-device leisure at home. Length of events on the timeline has been square-root transformed for legibility and represents actual duration.

viewing a gallery), we did not observe this for activities that involved other devices. As a minimum during any session of device use, participants kept smartphones in their immediate vicinity and used them briefly in longer intervals to check for notifications.

This opens up an interesting discussion of what constitutes 'using a single device' specifically the smartphone, or the minimum-threshold for multi-device use. We believe that even if the phone is used once or twice only during the use of another device this should be considered multi-device use because the smartphone nevertheless remains salient through its mere presence. In this vein, it has been argued previously that "carrying a phone" can be classified as parallel use (Jokela et al., 2015, p. 3909). The possibility of notifications being delivered constitutes a key use of the phone, i.e., monitoring incoming information. This analysis has, thus, not only shown that smartphones are always 'in the mix', but also that in contexts of multi-device use, not using the smartphone (in a physical sense) can still constitute using the smartphone (in an abstract sense), and often this is precisely its use for participants.

7.2. *Multitasking vs dual-tasking in different contexts*

Typical assemblages of devices during multi-device work are a computer or a tablet on a desk with a smartphone next to it plus other notebooks or relevant tools. It is to be noted, however, that we did not observe the phone as the locus of the main work activity with other devices being used to supplement in work contexts in our sample, only during instances of mixed use. Discussions from the Replay-interviews suggest that this may be attributed to hardware factors; contemporary smartphones tend to have a smaller screen, less powerful information input technology, as well as less storage and computing power than computers or tablets. Consequently, when participants want to fully engage in work, they do so on a device they consider more capable than the smartphone and supplement it with the phone's capacities where needed ("resource lending"; Jokela et al., 2015; Monge Roffarello & De Russis, 2021). However, this may also be associated with the learned and embodied way of using the device, either because the phone is not perceived as a capable work tool per se, or because users believe they cannot accomplish as much with it as on a computer ('I need a real keyboard'). Whether this resistance to using the phone as a work tool is due to technological shortcomings of the device, or only stems from mental representations requires further investigation and could be a route for design to further integrate form factors. Since the phone has already found widespread use as a work tool in other professions (e.g., medicine, delivery), comparison with those groups may be instructive.

Our observations also suggest that focusing on the transition patterns between activities that participants are engaged in (dual-tasking vs task-switching) is more useful than distinguishing between concurrent or sequential use of devices, as lines between the latter are often blurry and transitions from one to the other smooth (see Fig. 8). Multi-device work tends to go along with task-switching between different threads of activity that participants pick up, leave, and return to intermittently (Yeykelis et al., 2014, 2018). In this pattern, devices attract the attention of users (e.g., through a notification), but also the context and break points in the flow of activity can lead to switches between activities and devices (see Fig. 4; 15). Further illustrations of this can be found in Fig. 4 between (6) and (11), where P12 is trying to figure out who called her, or between (14) and (20).

Multi-device leisure, on the other hand, tends to be associated with dual-tasking patterns and one medium taking slight precedence over the other, but can also entail task-switching. Unsurprisingly, participants tend to focus more on interactive devices like smartphones and tablets while other devices play media for passive consumption. In this vein, we also observe that the first interaction with the phone after entering a leisure pattern is often long and participants tend to 'exhaust' all apps they can check or engage with. Fig. 6 illustrates this pattern, with P15 using the smartphone for just under 1h in one intensive usage session (5)

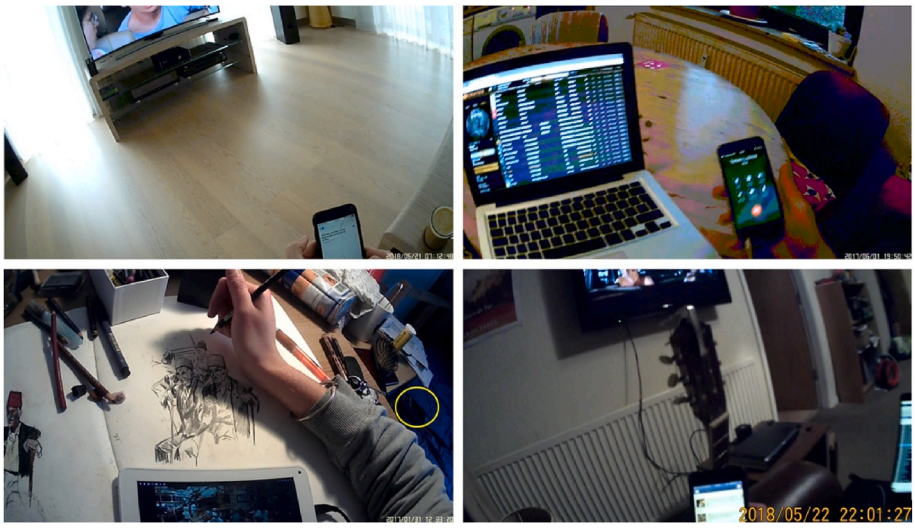

Fig. 7. Various instances of mixed multi-device use (top left to bottom right): Replying to Emails while watching TV, business call while browsing music, listening to music on the phone while copying images from a tablet, replying to messages on the phone while working on a laptop and watching a film on the TV.

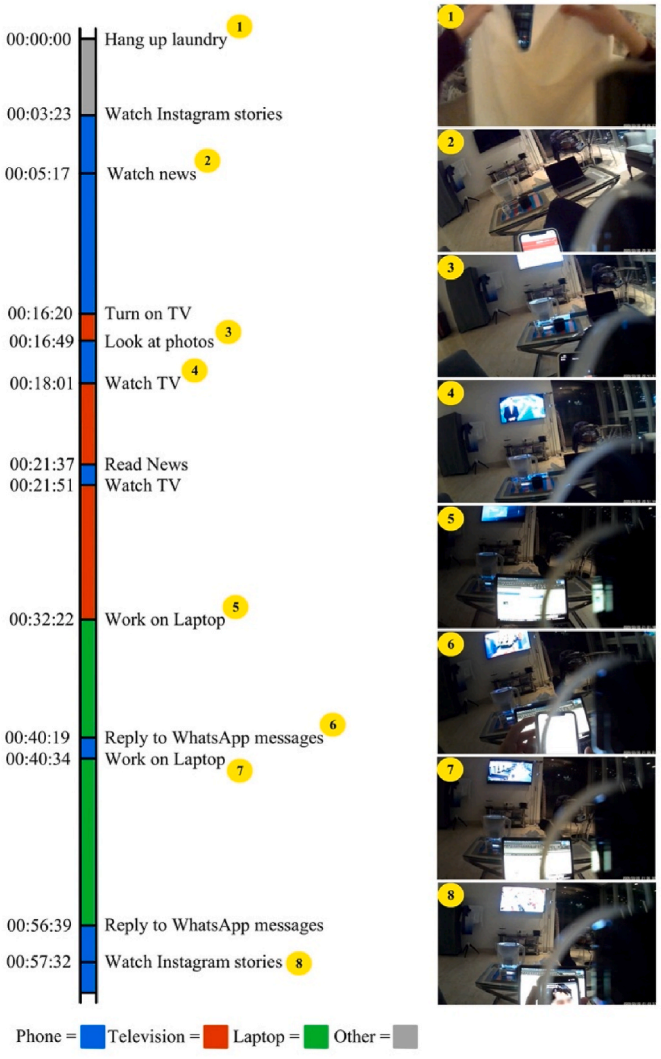

Fig. 8. Timeline of a 1h session of mixed multi-device use at home. Length of events on the timeline has been square-root transformed for legibility and represents actual duration.

before focusing on the laptop again and returning to alternating between activities and devices, which more closely resembles task-switching (6ff). Note that in this situation Netflix is playing on the laptop throughout the sequence, and the phone and other objects and activities come in and out of the participant's focus. This finding of the phone being used until both novelty and entertainment have been exhausted echoes participant sentiments of the phone as a "vice" they indulge in (P19), and the positive anticipation of "having access to what's on the phone" (P24).

Mixed use patterns are equally associated with task-switching between threads of activities and dual-tasking, depending on the specific context. The 'entertainment' device usually plays media for passive consumption as a secondary focus, occasionally drawing in users with passages of interest (e.g., a song or news segment).

Overall, we find that multi-device use, and particularly the smartphone, plays an important role in helping users transition between different activities. In Fig. 8, P40 is doing laundry (1), then uses the phone and the TV for entertainment (2, 4), but also has a look at her WhatsApp messages which contain images relevant to her work (3). At this point she begins to transition from entertainment with the television and the smartphone to working with the phone and the laptop (5). Commenting on this moment in the interview, P40 said:

> I'm not sure why I pick it up exactly, but yeah, I basically use it as a transition phase from leisure mode to work mode here.

Similarly, P12 uses her phone when she switches from filing receipts to reading (see Fig. 4; 4, 5), and from writing an Email back to reading again (14, 20). Combining different devices and their affordances (resource lending) also enables users to perform more complex work tasks involving analogue and digital activities and materials (e.g., filing receipts, see Fig. 4, receiving physical notes, see Fig. 8), but also to get smaller tasks done on the go and in non-work contexts (see Fig. 7).

7.3. Breaks

Multi-device use also allows users to take a break from a work screen with another screen, which may seem paradoxical at first:

> I really enjoy having multiple screens on, because every now and then I can take a break from what I'm doing. I sometimes have the TV on and take short breaks from the screen that I'm working on. Sometimes I take a break from it with my phone, sometimes it's with the TV, really depends. (P25)

> It's 11p.m. already, but I wanted to get some more work done. Usually by midnight I'm going to bed. So, I thought walking around might help because I was tired, and I went to my iPad for a bit to read. (P4)

It, thus, appears that the notion of 'needing a break from the screen', which has been mentioned by most of our participants, and has entered everyday language use, may be more complex than it initially appears: As participants were usually happy to engage with another device during that time, the narrative of 'relaxing the eyes' or 'getting away from the machine' may not be applicable to many of those screen breaks. Instead, work takes place on the computer and is perceived to be located within the machine; the 'screen' seems to have become synonymous with work for our participants. This has interesting implications in turn for how they think about taking breaks: Rather than *taking* a break *from work*, because one does not want to work or is tired of it, one *must* take a break to *get away from the screen*; almost as a biological necessity. In this way, it is much easier to justify taking breaks during work, to cope with cognitive dissonance around achieving work targets, and even to rationalize procrastination. Clearly, however, this does not seem to be the case, as participants are able to engage with another device's screen during these breaks without problems. This finding around 'needing a break from the screen' holds many relevant opportunities for design and further investigation, for example when it comes to smartphone overuse based on habitual engagement, or reduced work productivity.

8. Limitations

We have used a mixed-methods approach to triangulate our findings, but this study is ultimately based on data from 41 participants. Our sample only includes young adults, and two thirds of participants in the sample are university students. This study therefore presents a snapshot of device-use of a group of users who tend to be tech-savvier on average compared to older generations, but also distinctly differ in their usage patterns from younger users. It is therefore unclear how well the findings in this paper apply to different age cohorts.

Another issue is that the SEBE technique is heavy and labor-intensive for participants and researchers. Particularly the Replay-interviews require a lot of time and focus, and it was sometimes not possible to fully explore everything that was recorded in the Subfilms. A second limitation of the technique is that Subcams do not always record data as logging applications would, and that participants may consciously and unconsciously bias what they record. A third issue is related to the coding of the data. At present, it is not possible to automate the coding of Subfilm data, and manual coding of data bears the risk of human error. Because of the volume of video material generated by SEBE, only partial double-coding of data will usually be possible, which can render it superfluous for certain variables, and some variables are easier to double-code than others (e.g., Heitmayer, 2021). To address these shortcomings, more elaborate setups for data collection aimed specifically at multi-device use should combine first-person and third-person video with logging techniques to both capture the richness and complexity of interactions, and to continuously monitor the various devices users engage with and the spaces they are in (see Holz et al., 2015; Lahlou, 2005 as a starting point).

Finally, this paper has put a focus on the smartphone as is seems to be the most versatile device for users, and the one they interact with the most. Validating this finding and the role of the smartphone is crucial for the conceptualization of multi-device use, which has emerged as 'smartphone + x' from our observations. Furthermore, regardless of the prevalence of the smartphone, further examining multi-device use in contexts where the smartphone is not present will be important as well.

9. Conclusion

Multi-device use made up about 60% of all instances of device use participants engaged in our sample. Much more than a specific use case, or an activity confined to the realms of certain professions, engaging with multiple devices at the same time appears to have become the norm for users. The situated, first-person recordings our participants have collected show that the role individual devices play in different situations varies greatly.

Overall, we observe multi-device use as complex, habitualised usage patterns with participants engaging with varying assemblages of devices throughout their daily lives. The three main patterns we observed (multi-device work, multi-device leisure, mixed use) depict three archetypical ways in which users engage with their devices to fulfil the professional and personal demands they face. While TVs were used exclusively for entertainment and mostly in the background, computers, tablets, and smartphones fulfilled a variety of work and leisure functions. The smartphone was the only device that participants used without other devices 'in the mix', and it was present in the lives of users in most situations. We further find that, rather than focusing on the devices that participants use, looking at their behavioral patterns, that is, the activities they engage in, how they switch or transition between them, and how this is supported by various devices is more useful for the analysis of multi-device use, and ultimately for making design recommendations.

Future work on multi-device use should consolidate the usage patterns described in this paper. It should also consider the increasing number of devices beyond phone, computer, or television that become 'smart' and connected via the internet of things and investigate how they are incorporated into the behavioral patterns of users. Moreover, initial work on multi-device use with virtual and particularly augmented reality (e.g., Baillard et al., 2017; Horak, 2019) suggests that the multi-device assemblages we engage with may soon influence the physical spaces around us in a new and potentially much more profound way, which is why understanding the human factors in these interactions is of the highest importance.

Declaration of competing interest

X All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

X This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

X The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

Data availability

The data that has been used is confidential.

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