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Information processing on smartphones in public versus private

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Abstract

People increasingly turn to news on mobile devices, often while out and about, attending to daily tasks. Yet, we know little about whether attention to and learning from information on a mobile differs by the setting of use. This study builds on Multiple Resource Theory (Wickens, 1984) and the Resource Competition Framework (Oulasvirta et al., 2005) to compare visual attention to a dynamic newsfeed, varying only the setting: private or public. We use mobile eye-tracking to evaluate the effects of setting on attention and assess correspondent learning differences after exposure to the feed, which allows us to uncover a relationship between attention and learning. Findings indicate higher visual attention to mobile newsfeed posts in public, relative to a private setting. Moreover, scrolling through news on a smartphone in public attenuates some knowledge gain but is beneficial for other learning outcomes.

Lay Summary

People increasingly get news via their smartphones by scrolling through social media newsfeeds. This often happens in public places like on trains, in cafés, or waiting rooms. These areas are typically more distracting than, for example, a quiet living room or office. It is therefore possible that people pay less attention to news on a smartphone and learn less from it when they use it in public. This study conducts an experiment where we compare attention to news on a smartphone and how much people learn from it in two different settings: A bustling student cafeteria and a quiet laboratory room. We measured attention by using eye-tracking, a technique that helps us to see where people gaze on a smartphone screen. We find that people pay more attention to a smartphone newsfeed in public. We also find that people recall less information but answer more quiz questions correctly if they saw the newsfeed on their smartphone in public compared to in private. Our study cannot fully explain this difference in learning, but we can show that paying more attention to news on a smartphone makes people learn more, regardless of the environment they are in.

Keywords: mobile devices, visual attention, news learning, public setting, mobile eye-tracking

Changes in information communication technologies structure opportunities for exposure to information, with consequences for what people learn about society (Bode, 2016; Sundar, 2008). More than any previous advancement, mobile technology has increased access to information, removing both temporal and spatial constraints (Van Damme, 2015). People can browse the news during their commute, waiting in line at a grocery store, or even 40,000 feet up in the air during a flight.

However, physical access to information via a mobile device does not equate to learning (e.g., Grabe et al., 2000; Lang, 2000). While we know media exert effects, many questions remain regarding the effects of accessing such media in public (Liebherr et al., 2020), in part because attention is nearly impossible to reliably self-report (Vraga et al., 2016), as are the circumstances of receiving information via smartphones (see Parry et al., 2021; Schnauber-Stockmann & Karnowski, 2020). This lack in research is surprising, given that a good share of smartphone usage takes place outside of common usage settings and mobility is the defining element of mobile devices (Campbell, 2019; Ross et al., 2021). Recent experimental work shows that attention to information is attenuated on mobile devices relative to computers (Dunaway et al., 2018; Ohme et al., 2022). What this research cannot tell us is whether these effects are greater outside the lab (but see Oulasvirta et al., 2005), where distractions abound, or what Liebherr (2020) calls "smartphone-related effects in situations of selective attention" (p. 3). While much work exists on the topic of mobile technology as a distraction (Meier, 2021; Vanden Abeele, 2020), we know little about how real-world distractions affect what people learn from information they access on their mobile devices. In other words, how do spatial conditions affect the way people process information accessed on mobile devices?

This dearth is due in no small part to the methodological constraints related to the study of mobile information processing, which requires researchers to trade off external validity for controllability. To address this gap, we employ a unique research design that leverages mobile eye-tracking and multiple settings to investigate how attention to and learning from information on smartphones depends on the spatial condition of exposure. Specifically, we examine differences in visual attention to the same newsfeed, on the same device, varying only the setting: private or public. We draw on Multiple Resource Theory (Wickens, 1984) and the Resource Competition Framework (Oulasvirta et al., 2005), to investigate (a) whether visual attention to newsfeed posts differs

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between public and private usage settings, (b) whether recall and recognition differs across spatial conditions, and (c), whether potential differences in attention and learning are conditional on post's content type (political, social, or news, see Bode et al., 2017). Our methodological approach balances concerns with regard to internal validity (through a controlled, experimental design), external validity (by using real news posts in a scrollable Facebook newsfeed), and ecological validity (by exposing respondents to posts directly on a smartphone while tracking their eye movements) with a level of care unprecedented for research in this area. This triangulation promises optimal insights into cognitive mechanisms, such as attention and learning, essential to understanding the unique challenges of today's information environment (Andrade, 2018).

Overall, given increasing reliance on mobile devices for news consumption (Newman et al., 2020), including via social media feeds (Anspach et al., 2019), understanding how mobile technology affects the information people learn in more realistic, daily use allows us to uncover the costs of such access and ultimately, the costs of contemporary democratic citizenship. That is, if mobile access to information in public, where most mobility occurs, leads to lower information gain then the democratic requirement of an informed citizenship (Downs, 1957) may be imperiled.

Smartphone attention to newsfeeds

Features of mobile devices, particularly their portability, add to their ubiquity. Smartphones provide users access to a wealth of information at their fingertips, wherever and whenever: People can stay connected to their friends and family, while browsing recent news headlines on their daily commute. As such scenarios suggest, mobile devices offer people the opportunity to seek information in situations where they would otherwise be unlikely to have access. With mobile devices, and notably smartphones, increasing the possibility of news consumption, for example, holds potential consequences for the information environment. This fact is underscored by two relevant mobile usage trends. First, people increasingly rely on their mobile devices for access to the Internet (Weidmann et al., 2016) and to consume information (Napoli & Obar, 2014). Second, people turn to social media for their news (Mitchell et al., 2020), and most engagement with social media happens on a smartphone (Horrigan & Duggan, 2015), though news apps are another important source of mobile news exposure (Nelson & Lei, 2018).

Of course, while smartphones make information available, such opportunities for exposure are necessary but not sufficient for learning. This is particularly true for mobile social media platforms, which purposefully feature a variety of content. In fact, Facebook's feed emphasizes social posts and more recently changed its algorithm to decrease the amount of politics and news in people's feeds (Gupta, 2021). This tracks with the work of Vraga et al. (2016), who use eye tracking to reveal different levels of visual attention by post type on Facebook. Political posts, in particular, receive less attention, with people skipping a post entirely once they come across a signal (i.e., a word) that it is political (Bode et al., 2017). Anspach et al. (2019) find evidence that people are only likely to attend to content that they interact with, making engagement with political posts all the more unlikely depending on political interest (see also Schäfer et al., 2017).

This is one reason Dunaway and Searles (2022) make a distinction between physical access to information via a mobile device and cognitive access, with the latter being structured by the features of the mobile environment. Cognitive access to information on a mobile device is affected by affordances, which uniquely shape the content and structure of mobile messages, with consequences for information processing (Lang, 2000; Sundar, 2008). In particular, the smaller screen requires more resources for encoding (Kim & Sundar, 2014).

These same affordances are also important for understanding how accessing media via mobile platforms may or may not affect exposure. Indeed, because smartphones drive most of their traffic, social media platforms pursue a mobile-first strategy, meaning changes to the platform are led by mobile users' experiences (e.g., Facebook, 2014; Reckhow, 2013). Platforms' profit focus requires people to engage, and stay engaged, with the app so that they can effectively monetize eyeballs for advertisers. Their mobile applications are thus specially designed to cater to the needs of a person accessing via smartphone. In particular, ease of scrollability promotes a steady, habitual physical engagement with the platform that immerses users in a way that is unique to mobile social media platforms. This scrollability shapes Facebook requirements for content delivery, such that mobile posts feature larger photos, larger font size, and fewer words compared to website versions. In turn, content producers—incentivized to stop the scroll—work within these parameters to increase the likelihood users will engage with their content, including the use of clickbait headlines, emotionally arousing content, and bold pictures (Feezell et al., 2022; Kilgo & Sinta, 2016). Thus, truly understanding the effects of exposure to newsfeeds on attention and learning requires considering point of access.

The research suggests that whether trying to better understand information seeking broadly or social media use specifically, the story is incomplete without considering mobile access. In this study, we bring together both these objectives, leveraging the realism afforded by using a Facebook newsfeed stimulus, to better understand how mobile technology structures media exposure in different settings.

Smartphone attention in public vs. private settings

The main contribution of smartphones to changing communication patterns is enabling the transition from digital information access at spatially-bound, "in-place" environments (e.g., home, office) to digital information access in public and on-the-go (Ross et al., 2021). This portability means that a great amount of digital communication can easily be affected by situational factors. A public setting is defined as a "physical location where one is out among the general public" and differs from a private setting, "where a person considers encounters with others or oneself to be personal and not anyone else's business" (Totten et al., 2015, p. 3). Three situational factors distinguish a public from a private setting: (a) noise distractions, (b) visual distractions, and (c) social presence. However, *how* attention to smartphone content differs based on the spatial conditions is still an open question.

For cognitive processes, neuroscience understands information exposure as a division of single tasks (e.g., media exposure), carried out by individuals (Kaplan & Berman, 2010; Wickens, 2008). These tasks are "assumed to demand resources for their performance and these resources are limited in their availability"

(Wickens, 1981, p. 1). In a nutshell, Multiple Resource Theory suggests that limited cognitive resources are allocated across tasks when multiple tasks are present (Wickens, 1984). If individuals only have to carry out one task, they can determine how many resources they dedicate to the specific task (e.g., close reading vs. skimming texts; see Kaplan and Berman, 2010). In cases where more than one task is present, at least dual (if not multiple) task performance is necessary. In that case, performance is hampered, as cognitive resources need to be divided across tasks. In a public setting, it is difficult to control one's cognitive processes to the same extent as in a private setting because more situational distractors exist. When on-the-move, people must constantly assess their environment (Oulasvirta et al., 2005). This orientation can include the processing of additional audible and visual stimuli as well as orienting oneself towards other people (Lechak & Leber, 2012; Ziegler et al., 2018). Using a smartphone on the go underscores the difficulty of paying attention to both the mobile device and the environment. Hence, there is reason to expect that attention to smartphones in public is lower than in a private setting.

A second strand of research suggests that when a person is in public, they are not only more approachable, but they are also subject to "threats." Accordingly, evolutionary psychology suggests a person's level of alertness in public is higher than in private (Mobbs et al., 2015). Higher alertness was found to impair "control of the focus of attention" (Nieuwenhuis & de Kleijn, 2013, p. 1797) and that "alertness reduces stimulus-encoding time." In case of smartphone usage in public, this means that when using a mobile device in public, the setting requires people to assess their environment while also attending to the device to fulfill an informational need. As such, cognitive resources are likely to be distributed across multiple tasks, diminishing attention to the content on the device. Yet, the possibility exists that situational distractors increase the need to dedicate more attention to a task, relative to a single task situation with no distractors present.

More recent research on smartphone attention has found less or equal visual attention to information on smartphones, compared to computers and tablets (Dunaway et al., 2018; Kim & Sundar, 2014; Ohme et al., 2022). In addition, studies suggest shorter exposure times to news on smartphones, either through self-reports or log-data (Molyneux, 2018; Nelson & Lei, 2018). However, these studies did not take the location of smartphone usage into account. In a seminal study that involved attention measurements via micro body cams, Oulasvirta et al. (2005) found lower attention to a mobile device in any public situation, such as a café, compared to a laboratory situation. In turn, attention switches between mobile device and the environment were less frequent in a laboratory, while they were most frequent on a busy street. Duration of smartphone chats was found to be significantly longer in inside compared to outside settings, and in cafes compared to offices (Steil et al., 2018). Based on the outlined theoretical considerations and previous research, we expect:

H1: *People pay less attention to a newsfeed on a smartphone in public, relative to a nonpublic setting.*

Learning from mobile information in public

Learning from information exposure is a core prerequisite for media effects research, in various fields, such as health communication (e.g., Jensen, 2011), advertising (e.g., Maslowska et al., 2021), or political communication (e.g., Kruikemeier et al., 2018). Long-term effects of smartphone usage on working memory have been studied extensively (see Liebherr et al., 2020 for an overview). But less is known about short-term effects on learning from smartphone exposure, especially in different spatial conditions.

Learning from information exposure fails if sufficient cognitive resources are not available for encoding, storage, and retrieval of information (Lang, 2000). Next to individual motivations, attention is a precondition for learning from a stimulus such as a news item (Eveland, 2001; Grabe et al., 2000). Research has suggested that smartphones can increase the perceptual and cognitive load of information exposure and may therefore impair learning (see Dunaway and Soroka, 2019; Ohme, 2020). The few studies that explicitly test this association, however, find mixed results: Stephens et al. (2014) did not find mobile news app usage to contribute to political knowledge. Stroud et al. (2020) reported knowledge gains from push notification in some, but not all, instances, and Ohme (2020) found no differences between low and high levels of mobile news browsing in political campaign knowledge. Andersen and Strömbäck (2021) found no relation between mobile news usage and knowledge. However, these studies relied on self-reported exposure measures. One exception is Dunaway and Searles (2022): Using experiments conducted in the lab and naturally, they find mobile users learn less from news they read, compared to computer users, although the effects are small. Still, none of these studies investigate the effects of the environment on smartphone learning.

Research on mobile learning in a public environment is sparse but we can draw on both the Limited Capacity Model (Lang, 2000) and Multiple Resource Theory (Wickens, 1984) which remain foundational to understand information processing in stimulus-rich situations. These frameworks help us to understand how the use of mobile devices *in public* shapes attention to and learning from information in public. These frameworks lead us to expect that, given the constraints of multiple task processing in public, there will be less cognitive resources dedicated to allocating attention to information on screen, likely attenuating learning relative to a nonpublic setting. Moreover, studies have shown that high ambient noise in classrooms can impair learning among students (Addison et al., 1999) and increased alertness (as we can expect in public) is connected to lower levels of stimulus encoding-time (Nieuwenhuis & de Kleijn, 2013). On the contrary, a more recent study investigated why people like to work in coffee shops, despite the noise level: A certain level of ambient noise had positive effects on creative cognition, while higher noise levels impair information processing (Mehta et al., 2012). Moreover, heightened levels of alertness have shown to increase performance in cognitive tasks (Schneider, 2020). While this work shows the setting matters, and both the Limited Capacity Model and Multiple Resource Theory suggest that processing information on a mobile is likely to be constrained in such an environment, we don't know enough about how mobile learning should be changed in a public setting. Thus, we pose a research question:

RQ1: *Do people learn less from exposure to a newsfeed on a mobile device in public, relative to a nonpublic setting?*

Method

Procedure, participants, and design

This study investigates how spatial conditions affect visual attention to a newsfeed and the ways this attention shapes subsequent learning. We expose participants to the same content on a smartphone, delivered via newsfeed, in either a public or nonpublic setting. To both operationalize the newsfeed and engender external validity, we design a stimulus that resembles a scrollable Facebook feed with actual Facebook posts. Added realism comes from the fact that research demonstrates scrolling through a newsfeed is one of the most frequent news exposure behaviors (Anspach et al., 2019). This design also has high internal validity, as both the experimental circumstances (the study was conducted under controlled conditions) as well as the content participants were exposed to (i.e., the newsfeed) were kept constant. This is one of the first studies that uses a dynamic newsfeed for studying visual attention; more details on the stimulus are provided below.

We conducted an experimental study using mobile eye-tracking. This method allowed us to use the same eye-tracker for observing eye movements of participants in two different settings, increasing comparability of the measures. Participants were assigned to browsing a simulated newsfeed on a smartphone either in a lab facility or a public setting. We only included participants for which 90% or more of eye-tracking data was available, leading to the exclusion of seven participants where less than 90% of their gaze could be recorded[1].

The final sample consisted of participants that were recruited via an online participant pool of the University of Amsterdam ($N = 138$, 69% female, 1 diverse, $M_{age} = 22$, $SD_{age} = 3.8$) and data were collected between May and October 2019. The study received approval from the university's Ethical Review Board (IRB Number 2019-PC-10454).

Once participants arrived at the research location, they were asked to read the fact sheet about the study and provided informed consent for their participation. Next, respondents were asked to sit at a table in front of a smartphone docking station. We used eye tracking to measure which posts respondents attended to and for how long. Participants' eye movements were recorded by the eye-tracker that was located below a smartphone (5.0-inch screen size, 720 × 1280 resolution), at the same angle, so it was able to capture participants' eye movements when they were looking down at the phone. This setup is an improvement as it permits free head movement and normal mobile usage; similar mobile eye tracking equipment setups require the head be constrained, or special headgear. We used Tobii X2 30Hz Eye Tracker for both conditions to ensure data comparability. For the calibration of the eye-tracker, a 9-point calibration procedure was used in both conditions, meaning that respondents were asked to look at numbers on a plate to ensure that their eye movements were measured precisely. Participants were then instructed to read a short explanation on the screen and to click "next" to get to the newsfeed that they could freely scroll, without a time limit. When finished, participants took a posttest survey on a separate laptop. The whole procedure took about 30 min and participants could receive research credits or a monetary incentive (EUR 5.00).

Public vs. private conditions

The lab setting consisted of a quiet, spacious room where only the participant and a researcher were present. For the public setting, study equipment was set up in the middle of a large student cafeteria at the university. Much like in real life, participants were surrounded by neighboring tables and pedestrian traffic. A large window added to the distractions, and participants were surrounded by a noise level typical for a busy cafeteria. In both cases, the experimental equipment was set up similarly, with the administrator out of participants' sight (see Figure 1).

Stimulus

To generate a feed that resembled a Facebook newsfeed for stimuli purposes, the study applied the Newsfeed–Exposure–Observer (NEO) Framework (Ohme & Mothes, 2020). The framework can store predestined information in a database (e.g., headline, text, picture) and uses a designated stylesheet to create a responsive html website of the newsfeed to allow for optimized page display on mobile devices. Hence, we need not rely on still images to create a newsfeed, as the website automatically adjusted to the mobile screen specifications. This also produces a feed that is dynamic or scrollable. The posts were displayed in a fixed order and were not linked to the respective content, i.e., respondents could not click on the posts. We drew on the Facebook newsfeed as inspiration since it is the most used social media platform in the Netherlands, has a widely known layout, and posts usually contain more information than platforms with strong visual focus, such as Instagram. To increase external validity, we used 19 posts that had previously appeared on Facebook. One post was a commercial for a granola bar[2]. Following Vraga et al. (2016), six of the 19 posts where social posts that referred to participants' living circumstances (e.g., the city they live in, university affiliation, and daily life content, e.g., "Why you should interrogate your to-do list"). Six other posts were miscellaneous news posts, reporting on celebrities, records, and crimes (e.g., "Officials find massive cocaine shipment hidden among bananas"). The last six posts were political news posts, dealing with topics from recent political discussions about (a) melting glaciers, (b) repatriating ISIS members, and (c) plastic pollution in the sea (see all posts in Appendix B).

Measures

Visual attention was measured as dwell time and number of fixations with the help of the above-mentioned eye-tracking procedure. We recorded and analyzed people's gaze on the smartphone screen with iMotions software. The unit of analysis is a full newsfeed post, including the source, headline, picture, and description (see blue frame in Figure 2). Using dynamic content means that the full stimulus is not visible at once on the screen. We used gaze mapping to transfer a participant's unique view while scrolling to a reference picture of the stimulus, in our case a long image of the newsfeed with all 19 posts. This way, visual attention to predefined areas of interest (AOIs) was recorded and made comparable, while also allowing participants to scroll the feed at their own pace and direction. In both conditions, an extra camera above the smartphone recorded a video of participant's real-time scrolling behavior. The video contained a circle that indicated the participant's gaze, which was then mapped to the reference image. In this sense, data from individual coordinates in the form of a participant's gaze video were mapped "to a fixed reference coordinate system" (Macinnes et al., 2018). To ensure accuracy, the mapping procedure was supervised by two

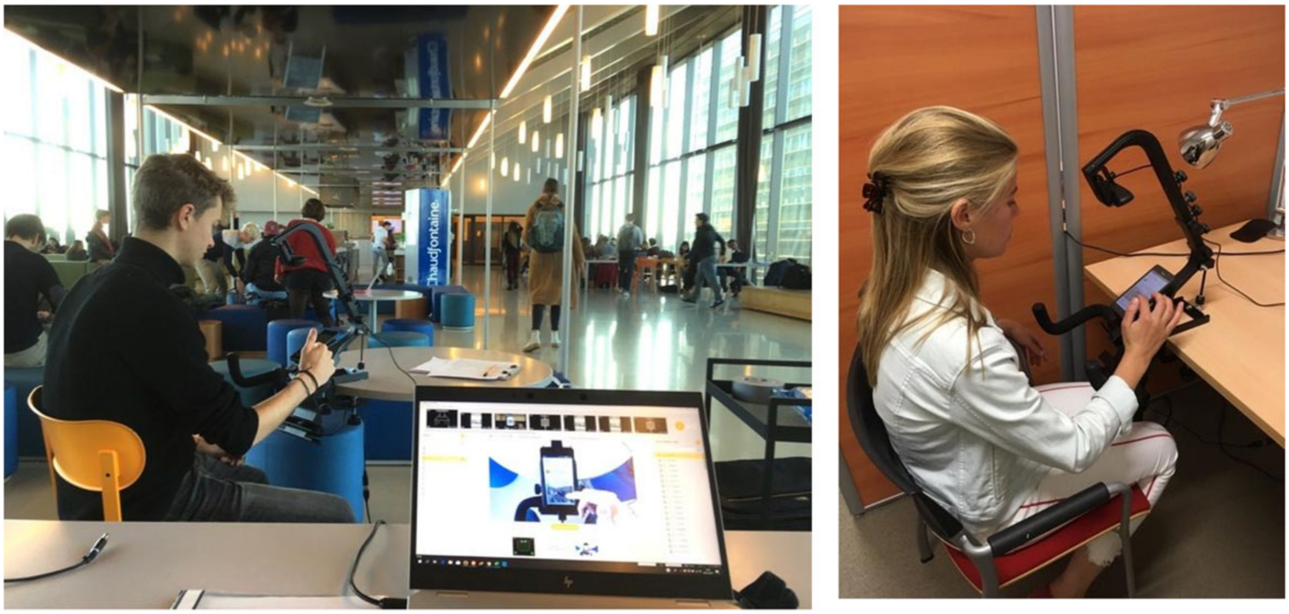

Figure 1. Experimental setting in public vs. private condition.

student assistants to make sure that recorded gaze was mapped correctly to the reference image.

In the reference image, we defined one AOI for each post (see blue frame in Figure 2) and measured the dwell time (i.e., the total amount of time in milliseconds participants spend within each AOI) and the fixations (i.e., the close occurrence of gaze on the AOI). Dwell time has been emphasized as a valid measure of visual attention in media exposure studies (e.g., Kruikemeier et al., 2018). Fixations are a standard way of measuring visual attention and assess "what objects are subject to cognitive processing at a given moment." (King et al., 2019, p. 3). Both measures are frequently used in eye-tracking research to assess systematic information processing (e.g., Bergstrom & Schall, 2014; Chou et al., 2020).

Information learning was measured with two different variables: recall and recognition (Eveland & Dunwoody, 2001). Recall has been used by eye-tracking research before to measure political learning; for example, Kruikemeier et al. (2018). We measured unaided *recall of posts* by asking respondents to describe, in any order, the posts they remembered from the newsfeed, in 19 open text fields. Based on their responses, recall of each newsfeed post was coded as correct (1) if the level of detail in the open-ended text response was precise enough to uniquely identify the post, or as incorrect (0) if no response was given or the response was not specific enough to identify the post. A response such as "Climate Change," "ISIS," or "University" was not specific enough, given that more than one post addressed these topics. In contrast, "Whale died of plastic in stomach" or "EU strategy repatriating ISIS fighters" was specific enough to uniquely identify the post. The 19 responses from both conditions were coded by two coders to assess reliability. The intercoder reliability test (Hayes & Krippendorf, 2007) revealed strong agreement between coders (M_{Kalpha}= .85, Range_{kalpha}= .80–1.00). A mean score of the correct number of recalled posts was calculated as the measure of recall. From all 19 posts, participants could correctly recall four posts on average ($M = 3.9$, $SD = 2.5$, $Min = 0$, $Max = 11$). More specifically recall for the political posts was highest ($M = 1.5$, $SD = 1.3$, $Min = 0$, $Max = 6$), followed by correct recall of social posts ($M = 1.3$, $SD = 1.2$, $Min = 0$, $Max = 5$) posts and news posts ($M = 0.8$, $SD = 1.0$, $Min = 0$, $Max = 6$).

Recognition of information was measured by asking respondents six comprehension style multiple choice questions about each of the political news posts,[3] one question per post (e.g., "To what extent do melting glaciers contribute to the rise of the sea level?"). To allow for comparability, questions addressed information that was in the post text, not the headline. Participants were instructed that they had 20 s per question to respond and that they could select one of four answers, as well as a "don't know" option. Correct responses were coded as 1; incorrect or "don't know" responses were coded as 0. A mean score of correct responses was calculated as a measure of recognition ($M = 2.0$, $SD = 1.5$, $Min = 0$, $Max = 6$).[4]

Results

The first hypothesis (H1) predicted visual attention to a newsfeed on a smartphone would be attenuated in a public setting relative to a lab setting. To test this prediction, we ran an independent *t*-test analysis to compare mean differences of gaze time across spatial conditions. To analyze the average gaze time for the newsfeed, dwell time and number of fixations of all 19 posts were added. In the lab setting, dwell time was 179.2 s ($SD = 61.2$), compared to 192.8 s ($SD = 78.3$, $p = .134$) in public (see Figure 3). The number of fixations was again lower in the lab ($M = 469.7$, $SD = 185.9$) relative to the public ($M = 537.9$, $SD = 219.2$) condition and differed significantly. On average, participants spent about 13 s longer and showed 68 fixations more attending to the same content in the public condition; H1 is therefore not supported.

Although we do not pose a formal hypothesis to this effect, to better understand processing in each setting, we extend these analyses to include differences in attention for three different types of newsfeed posts. Recall that the newsfeed includes political, social, and miscellaneous news posts: we see that, relative to participants in the lab, participants in

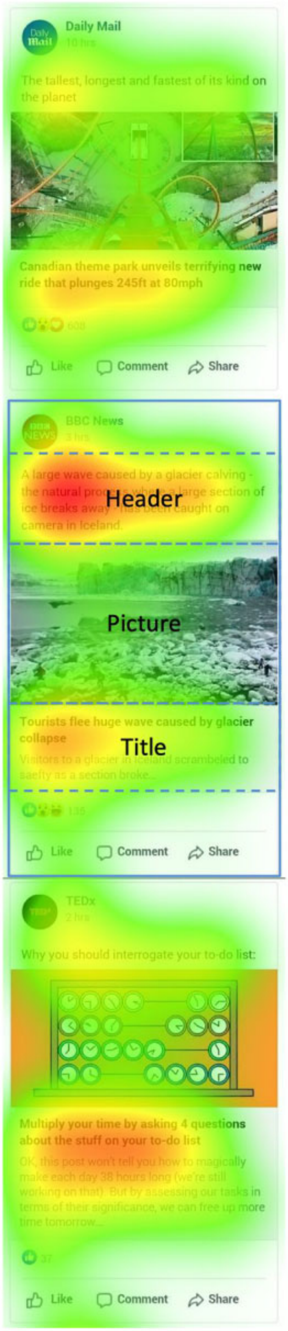

Figure 2. Representation of visual attention in mobile newsfeed.

Note: The blue frame delineates the area of interest defined as a post. Heatmap shows visual attention distribution across participants with red zones indicating highest visual attention. Zoomed-out version of newsfeed displayed. Only one full post was visible on the smartphone display at a time when scrolling. (A color version of this figure appears in the online version of this article.)

public attended to political posts on average 6.5 s longer (p = .119), social posts 6.8 s (p = .048) longer, and news posts 1.0 s less (p = .600). Similarly, relative to the lab, participants in public had an average of 29 fixations more on political posts (p = .010), 30 fixations more on social posts (p = .001), and 7 fixations more on news posts (p = .244; see Figure 4 and see Table 1 for full test statistics). As a robustness check, we analyzed whether this difference was driven by specific posts. However, this was not the case; for almost all posts, attention in the public condition was higher (see Appendix A). Moreover, we checked whether higher levels of attention were caused by a greater number of revisits to posts in the public condition or a faster scrolling speed. We do not find that participants systematically revisited posts more frequently in the public condition relative to the lab condition; nor did they—based on time to first fixation—scroll through the newsfeed more quickly (see Appendix C).

RQ1 asked whether learning from a smartphone newsfeed differed based on spatial conditions. Recall we operationalize learning in two ways: recall and recognition. First, for recall, we saw people in the public setting recall less than their peers in the lab. On average, participants in public could recall about half a post less compared to the lab setting, but the result was only marginally significant (see Table 1; first panel of Figure 5). Again, we breakdown the pattern by condition and post type to further probe these results, and the results show remarkable stability. Overall, and for each post type, recall is higher for people in the lab condition, but the difference is significant only for social posts (see Table 1; Figure 4). Looking at the results by post type, recall was higher in the lab condition for political, social, and news posts, but only differed significantly for social posts (see Figure 6).

Recognition was measured by asking respondents multiple choice questions about information contained in the political posts. In contrast to the recall results, participants browsing a mobile newsfeed in public had higher recognition rates compared to their peers in the lab and scored, on average, three-quarters of a question more correctly (see Table 1; second panel of Figure 5).

Given the differences in attention to the newsfeed across conditions, we conducted a post-hoc analysis that investigates a potential mediated relationship, whereas visual attention mediates the direct relationship between the condition and learning, by using a fully specified path model (see Kruikemeier et al., 2018 for a similar approach). The analysis confirms previous findings: being in the public condition increases dwell time, number of fixations as well as recognition, but not recall. Consequently, dwell time and fixations are also significant predictors of learning, aided (i.e., recognition) or unaided (i.e., recall). Interestingly, the results suggest that the relationship between spatial condition and learning is mediated by attention, though some estimates deviate from conventional significance thresholds. This significant mediated relationship indicates participants learned more in public *because* they attend longer to the mobile newsfeed. This mediation negates the negative relationship uncovered between the public setting and recall, as the total effect of the mediation is positive (*Coef.* = 19.2, SE = 9.7, p = .049; see full analysis in Table 2).[5] Together, these results start to paint a portrait of learning in a mobile news environment: While recall is overall harder in public on a mobile device, if the environment makes people pay enough attention, they can overcome learning deficits related to the setting.

Discussion

We are left with a conundrum: In this study, we find that people pay more attention to a mobile social media newsfeed in the public setting. This runs counter to what we expected (H1). This difference is mostly driven by political and social newsfeed posts, less by news posts. We find this pattern both for dwell time and number of fixations. People recall more

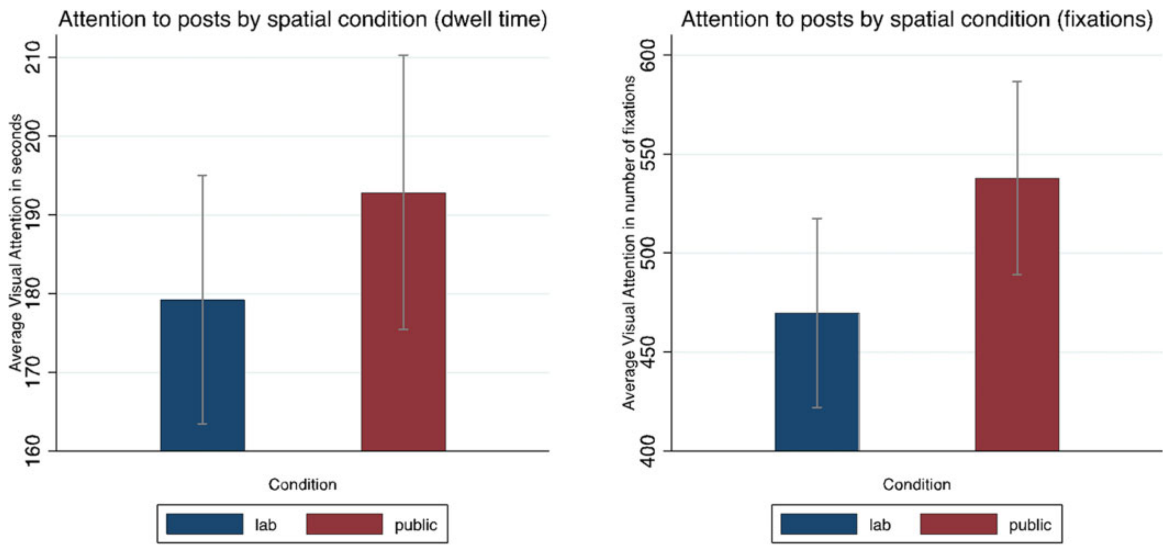

Figure 3. Differences in visual attention by spatial condition.

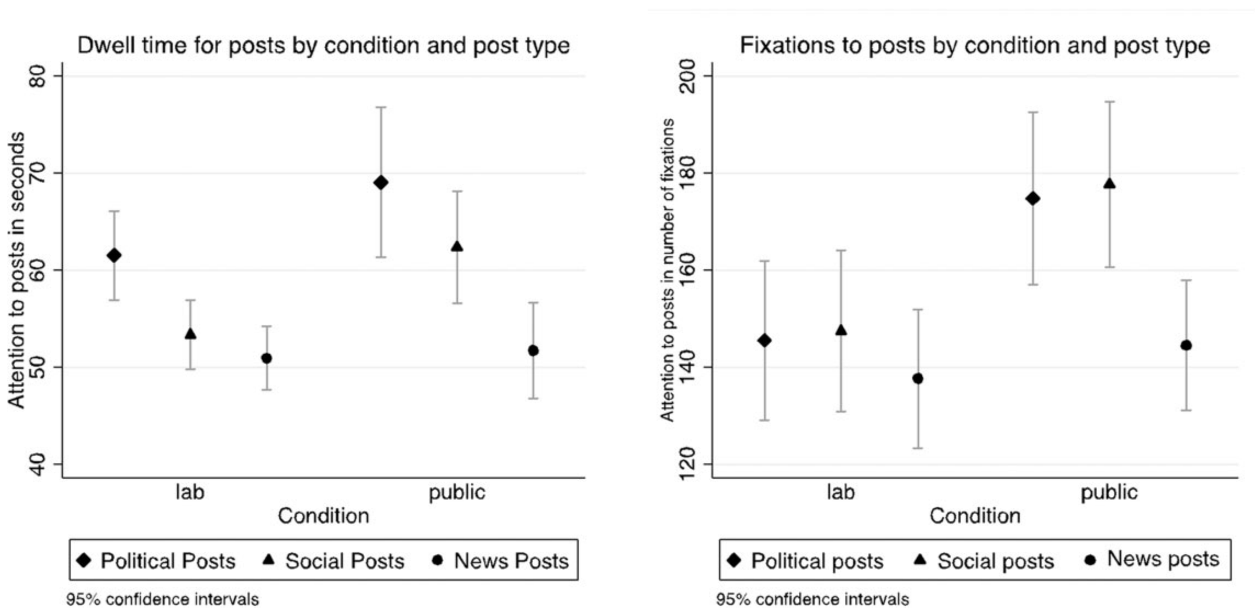

Figure 4. Differences in visual attention across spatial condition and post type.

information correctly in the lab situation, supporting H2, but they answer more knowledge questions about political posts correctly in the public condition.

How can we explain these findings? It could be that Multiple Resource Theory and the Resource Competition Framework, which claim that multiple simultaneous tasks impair cognitive performance (Oulasvirta et al., 2005; Wickens, 2008), do not apply to a mobile environment. It is possible that new models for understanding multiple task processing in a mobile setting are needed. Or it may be that, despite the difficulty of encoding information in a public setting, mobile affordances offset some of the costs of simultaneous tasks. For example, it may be the case that the mobility of smartphones permits people to take as much time as they need, ameliorating some of their cognitive load. Put another way, reading news on a smartphone in public may require more cognitive resources than performing the same task at home, however, the increased flexibility and accessibility of mobility means that people are likely to engage with their devices in settings where portability is required. And as such, it is likely that people perceive their mobile devices as characterized fundamentally by affordances which permit behaviors that otherwise would not be possible. In other words, the underlying psychology of mobile use cannot be separated from portability, which is fundamentally linked to use setting. A person's ability to access the Facebook app in public is made possible by access to a smartphone, which also means that other public use behaviors—time on page, clicks, scrolling—are also likely shaped by the psychology of mobile affordances (Ross et al., 2021). For the sake of illustration, imagine a person scrolling their Facebook app in the airport as they wait for a flight: As they are in a setting where they would be waiting with or without smartphone access, they may feel free to scroll for longer than they would otherwise. That same person may feel more pressure to attend to myriad daily activities—laundry, email, exercise—when accessing their Facebook mobile app at

Table 1. Differences in attention, recall, and recognition by spatial condition

	Private (SE)	Public (SE)	*N*	*t*	*p*
Visual attention					
Dwell time total (19 posts)	179.2 (8.80)	192.8 (7.97)	138	−1.10	.134
Dwell time political posts (6 posts)	62.6 (3.44)	69.0 (3.88)	138	−1.18	.118
Dwell time social posts (6 posts)	55.5 (2.62)	62.3 (2.90)	138	−1.67	.048
Dwell time news posts (6 posts)	52.6 (2.35)	51.7 (2.48)	138	.25	.600
Fixations total (19 posts)	469.7 (24.2)	537.9 (24.6)	138	−1.92	.028
Fixations political posts (6 posts)	145.5 (8.2)	174.7 (8.8)	138	−2.33	.010
Fixations social posts (6 posts)	147.5 (8.2)	177.6 (8.5)	138	−2.46	.001
Fixations news posts (6 posts)	137.6 (7.1)	144.5 (6.7	138	−0.69	.244
Learning					
Recall total (19 posts)	4.33 (.33)	3.68 (.28)	138	1.50	.067
Recall political posts (6 posts)	1.64 (.17)	1.39 (.14)	138	1.12	.130
Recall social posts (6 posts)	1.55 (.15)	1.17 (.12)	138	1.90	.029
Recall news posts (6 posts)	.86 (.12)	.81 (.11)	138	.32	.627
Recognition political posts (6 posts)	1.90 (.14)	1.59 (.16)	138	1.46	.073
N	59	79			

Note: Dwell time given in seconds, fixations in frequencies.

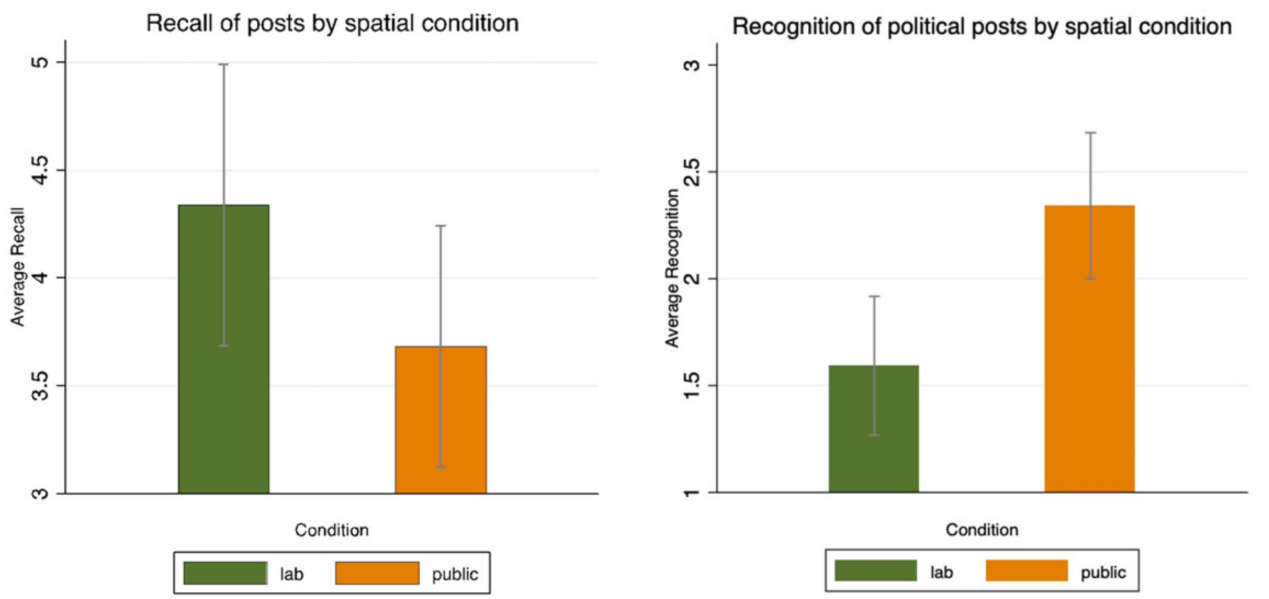

Figure 5. Recall and recognition by spatial condition.

home. These habitual use patterns which vary by setting may influence respondent behaviors in the context of our study, such that the public condition permits people to take additional time, reducing some of the burden associated with multiple simultaneous task processing. Our mediation analysis supports this possibility, as we find that participants in the public setting that spend more time attending to the mobile newsfeed had higher rates of recall and recognition. In addition, we can show that it is mostly higher attention to textual, relative to visual information, that is responsible for greater information gains.

Similarly, it may be affordances related to the platform itself that favors learning even under taxing circumstances such as in public, on a smartphone. Indeed, by their own admission, the platforms invest much of their research and development funds into user experience testing, all in efforts to increase time-in-app or attention. Designers at Facebook and other platforms have intentionally built products that capture and maintain people's attention, optimized for situations they're most likely to be used in. As people are most likely to use their smartphones to access information in public, and even more likely to access this information via social media, an information processing task on a mobile device in public may feel more familiar and thus, manageable enough to overcome any negative aspects of reading on a mobile device. Moreover, the immersive, constant nature of scrolling the newsfeed is also likely to draw people in and keep their attention (see Groot Kormelink & Costera Meijer, 2019). Given the mobile-first strategies of the platforms, and their habitual use in public, future research should disentangle what characteristics of a mobile newsfeed are responsible for the direct effects of setting being minimized by attention.

To what extent increased attention in public is sufficient for knowledge building can be seen in our results on learning. We observe different results for learning from information exposure on a mobile device by setting: Recall and recognition are two common measures of learning, yet, they differ in difficulty and their cognitive preconditions. Unaided recall proves

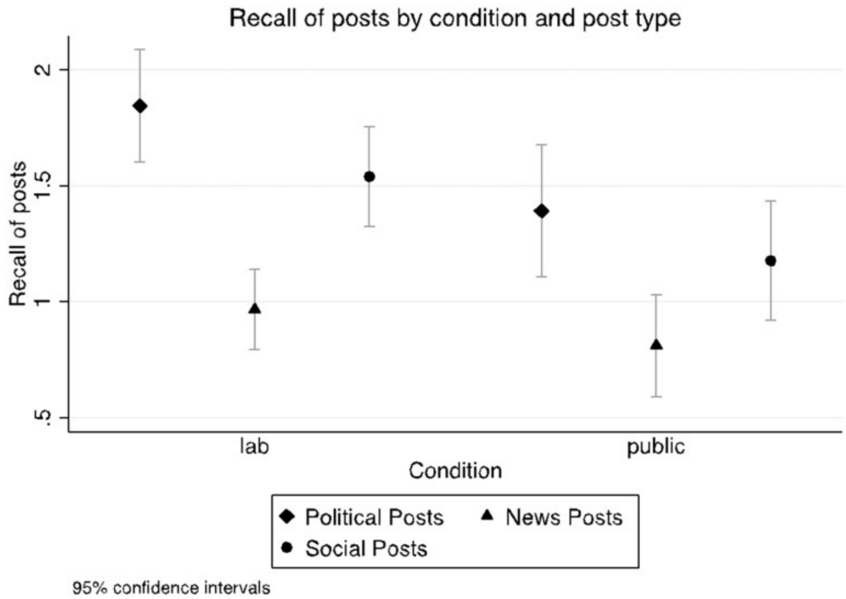

Figure 6. Differences in recall across post type by spatial condition.

Table 2. Direct and indirect effect of spatial condition on recall and recognition

	Direct effect (unstandardized)	SE	*p*	LL	UL
Condition					
Public → Dwell time	19.2	9.7	.049	.104	38.357
Public → Fixations	53.6	28.4	.060	−2.198	109.492
Public → Recall	−1.24	.343	.001	−1.915	−.571
Public →Recognition	7.542	4.22	.074	−.734	15.81
Visual attention					
Dwell time →Recall	.013	.002	.001	.008	.018
Fixations → Recall	.004	.001	.001	.003	.006
Dwell time →Recognition	.018	.002	.001	.012	.024
Fixations →Recognition	.007	.001	.001	.005	.010
Mediation through full post AOI	**Indirect effect (unstandardized)**				
Public → Visual attention → Recall					
Dwell time	.254	.137	.064	−.014	.524
Fixations	.265	.147	.073	−.024	.555
Public → Visual attention → Recognition					
Dwell time	.139	.081	.086	−.019	.298
Fixations	.182	.083	.030	.018	.347

Note: Test for indirect effects with bootstrap (5,000 resamples), LL = lower level; UL = upper level.

more difficult for people compared to aided recognition questions with the question text as well as the response categories providing aid. Indeed, this is why "Who wants to be a Millionaire" does not ask open-ended questions. The result that recall is higher in the lab condition, hence, may indeed be explained by cognitive storage being complicated through situational disturbances, such as visual and audible distractors. In a situation where no recall aid is given, attending to a newsfeed in a public situation seems to complicate learning.

However, we find higher recognition of political posts in public, relative to the lab, in curious contrast to the observed pattern for recall. We cannot say anything about the recognition of social and miscellaneous news posts, as we only measured recognition for the six political news posts. One explanation may be that a public situation, where visual and audible signals are more available, strengthens associative learning. This means it is easier for the cognitive system to retrieve stored information when it was not received in isolation but stored in concurrence with other information. Ambient noise can be one such signal and accordingly, can enhance learning (Mehta et al., 2012). Zhang et al. (2021), for example, found that babble noise enhanced learning of specific sentences, while car noise and rain noise showed to be less effective. Angwin et al. (2017) found white noise to enhance aided recall and recognition in a learning task. And yet, our interpretation of this result is post-hoc and speculative. Still, it might be worthwhile for future researchers to consider how or when a bustling environment might impair or facilitate learning.

While these results raise more questions than answers, as the first study of its kind this study takes important first steps, with implications for how we think about the challenges presented by the modern information environment. First, we find evidence that people do not necessarily attend to information less on a smartphone just because they are out in public. Previous research found attentional differences not only between private and public environments, but also between types of public contexts (Oulasvirta et al., 2005; Steil et al., 2018). It may be the case that the combination of browsing a mobile newsfeed in a bustling cafeteria is well suited to processing information, but future research should investigate whether this is also true in other public contexts, such as when on-the-go or using public transport.

Second, the study supports the eye-mind hypothesis by showing that visual attention and learning are closely connected (Just & Carpenter, 1980). Previous research suggests mobile devices sometimes impair learning (see Kruikemeier et al., 2018; Ohme et al., 2022). We also offer evidence for the eye-mind hypothesis across different spatial conditions and further specify it by showing that the relationship between location and learning is mediated by attention.

Third, we find that different types of posts attract different levels of attention. Contrasting Bode et al.'s (2017) work in the U.S., participants attended more closely to newsfeed posts dealing with political topics and social themes that relate to their everyday reality. Miscellaneous news posts were attended to less. This pattern became more evident in the public condition. While research on attention to specific types of content across locations is sparse, a potential explanation may be "social utility bias," in which a strong social presence in public functions as an indicator of importance. Being embedded in a particular social context (such as a public environment) may lead to stronger identification with others as well as status-seeking or desire for social interaction, which can influence information-seeking behavior (O'Brien et al., 2014). Chaffee and McLeod (1973) offer a distinction between individual and social predictors of information seeking, which was confirmed by Ohme and Mothes (2020) in a newsfeed environment, where social utility cues drove selective exposure. Moreover, O'Brien et al. (2014) found social utility exerted significant influence on the selection of online information in a social setting. This motivation to select information with higher social utility is one potential explanation for our findings. Future research should investigate more systematically whether social utility better explains the effects of setting on visual attention to information in a social media app.

Limitations

These observations lead us to a number of limitations of this study. *First*, the differentiation between political, social, and news posts was determined by researchers, closely following research by Vraga et al. (2016). However, we have to keep in mind that whether a post is perceived as political or whether it refers to participants' daily life might differ person to person (see Bode et al., 2017). Future research pursuing this path should therefore test differences between post type more carefully. *Second*, we rely on a convenience sample. We cannot rule out that the higher education of the sample and potential prior knowledge on topics have reduced processing time and increased the average responses to knowledge questions. Although these same characteristics make for a conservative test; it is likely that a nonstudent sample would show even more dramatic differences by setting. Additionally, while our sample size is substantially larger than most eye-tracking studies (see e.g., Bode et al., 2017, or Dunaway et al., 2018), a Bayes Factor of .80 indicates that based on our sample, we have an increased likelihood of observing the null (Lee and Wagenmakers, 2013). Thus, results likely present a more conservative test. Future research should test whether results hold among larger samples with lower technological skills or older people, for whom smaller screens may pose greater difficulties (Hwangbo et al., 2013). *Third*, although we tried to increase ecological validity of our experiment by using a dynamic newsfeed design, the internal validity of the controlled study setting comes at the expense of external validity. Eye-tracking is not fully unobtrusive, since people were informed about this procedure extensively when giving informed consent and during calibration. Although they could move their head freely and did not need to wear any technical equipment, it is still likely that this situation has altered the realism of how respondents would normally use a newsfeed. Moreover, although controllability was high, conducting an experimental study in public bears risk for comparability of data collected. The number of people in the cafeteria differed across daytime, as did the lighting, and the level of noise. Balancing ecological validity and experimental control is a delicate matter here and we need to keep in mind that control over external factors is reduced in the public setting. Although these setting characteristics suggest distraction is higher in the public setting compared to the lab setting, we do not measure actual or perceived levels of distraction. *Fourth*, this study is one of the first that applies dynamic content in a mobile eye-tracking experiment in different locations. Our scrollable newsfeed resembles Facebook's feed, which is the best-known social media platform in the country of study. By including genuine posts (especially from the city and university of participants), we tried to increase the realism of the stimulus. However, the newsfeed is still artificial and not personalized. We also used a conservative approach to measure recall, where users had to be sufficiently precise in their responses to identify a unique post. Hence, this measure is strict and future studies should test whether it is sufficient so mention a single keyword or topic.

Exposure to information on smartphones often takes place in public locations. This study presents the first scholarly insights into how far attention to and learning from exposure to information on a smartphone differs in public, relative to a private setting. We show that attention may indeed be different in public but also find these differences do not necessarily extend to learning from a mobile device in public. Both findings point to the importance of considering both device- and location-specific effects of media exposure. Moreover, our innovative methodological approach, including the use of eye-tracking in public, may present a roadmap for much-needed additional research in the field of mobile information learning.

Notes

1. The calibration of an eye-tracker is known to be a complex procedure. Although the calibration was overall unproblematic, for some participants it was difficult to collect enough gaze information to allow for a meaningful analysis (see King et al., 2019 for a discussion on calibration issues).
2. The current study is part of a larger data collection effort. The sponsored post is not analyzed in this study but was included in another study that focuses specifically on the attention to commercial posts on mobile devices.
3. To keep post-test time reasonable, we only asked six recognition questions about political news specifically as they were deemed most relevant to learning from the news.

4. Both recognition and recall measures are commonly used in learning research because they capture different levels of learning, with recognition being the less cognitively taxing measure of the two. It bears noting that we cannot rule out that recognition measures facilitate guessing, however, the chance of guessing is randomly distributed diminishing the likelihood of systematic error. To lend confidence to these results, we also collect recall measures.
5. To investigate whether this pattern—learning through visual attention—holds for different elements of a post, we analyzed the effect of condition on visual attention to three post elements containing relevant information: the header (i.e., text above the picture), title (i.e., headline and text below the picture), and/or the picture. We focus on these three elements (see Figure 1 for an example). On average, participants spent 4.5 s longer on the header, 7.1 s less on the picture, and 8.3 s longer on the title in public, relative to the private condition. The direct effect of the public condition of visual attention to the header (*Coef.* $= 16078.0$, *SE* $= 3780.2$, $p = .001$), the picture (*Coef.* $= -12100.73$, *SE* $= 3028.6$, $p = .001$), and the title (*Coef.* $= 14070.34$, *SE* $= 3587.1$, $p = .001$) across all posts suggests that visual attention in the public condition is higher for textual information and lower for pictures. This pattern is largely the same for the six political posts used for the analysis of recognition. Turning to the indirect effects for recall of all posts, the public condition increased attention to the header and thereby contributed to higher recall of posts. With some statistical uncertainty, there is also evidence that people paid less attention to the picture in the public condition and as a result, recalled less posts. There was no indirect relationship between condition and recall via visual attention to the title. For the recognition of the six political posts, we find that the public condition contributed to higher attention to a post's title and thereby to higher recognition. We did not find an indirect relationship via attention to the header and the picture (see Appendix D).

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Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

Conflicts of interest: None declared.

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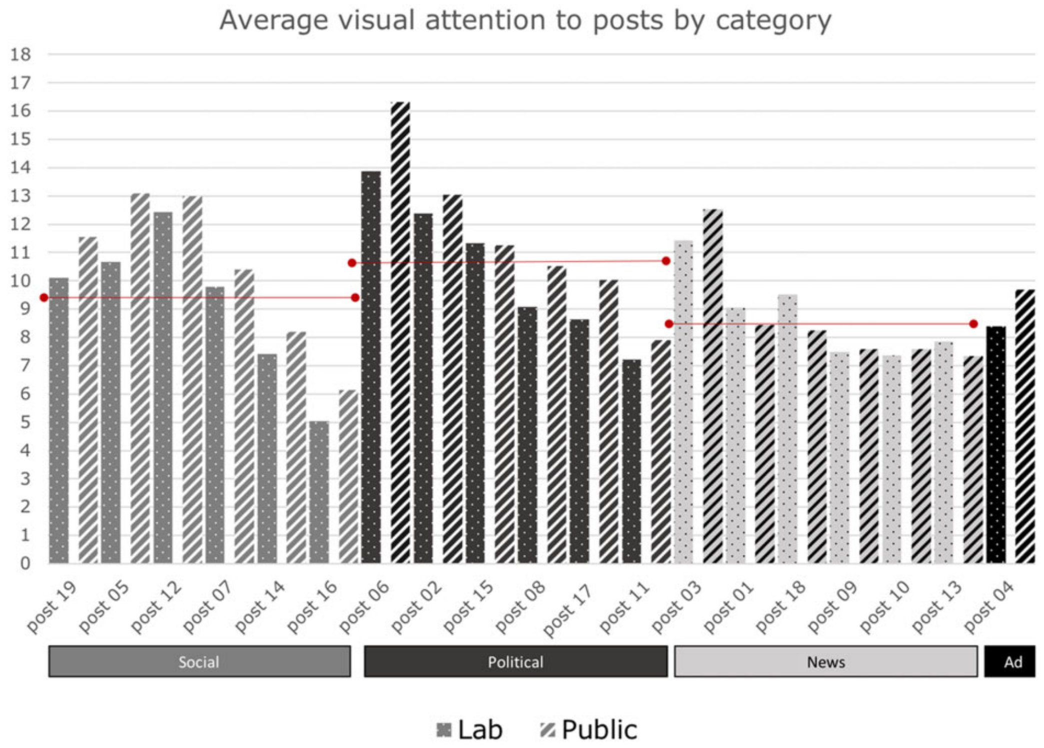
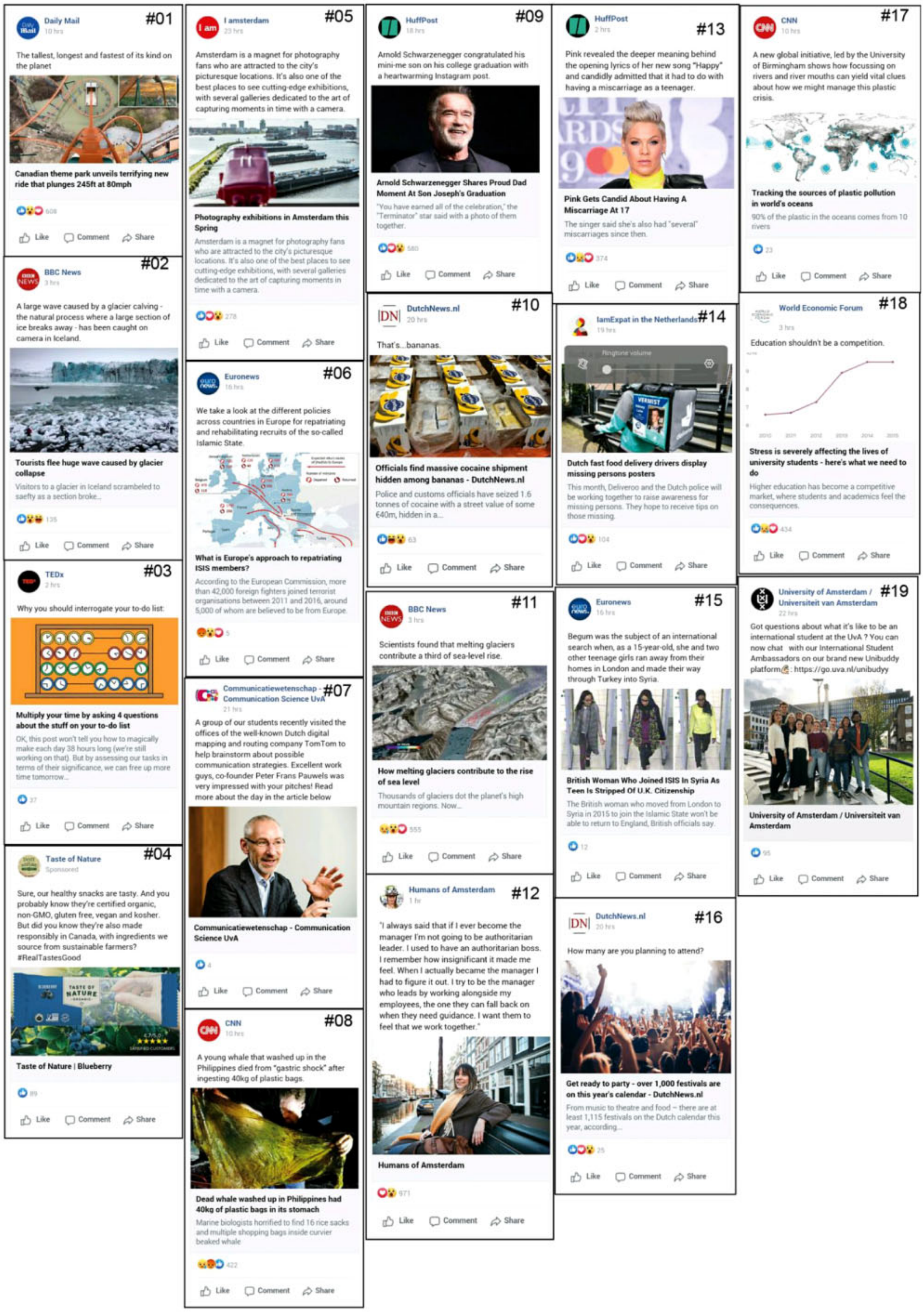
Appendix A: Attention to single posts by condition



Appendix B: Posts numbered by order of appearance in the newsfeed



Appendix C: Comparison of revisits and time to first fixation to posts based on fixations between conditions

	N	Private	Public	*t*	*p*	Private	Public	*t*	*p*
		Revisits to posts				Time to first fixation (ms)			
Post 1	138	1.00	.93	1.98	.024	209	3,342	−0.87	.809
Post 2	138	.98	.98	−0.20	.581	7,469	7,986	−0.68	.753
Post 3	138	.94	.98	−1.32	.905	24,014	21,510	0.93	.176
Post 4	138	.98	.98	−0.20	.581	31,988	33,908	−0.77	.780
Post 5	138	1.00	.97	1.22	.110	40,662	42,853	−0.68	.753
Post 6	138	1.00	.97	1.22	.110	51,522	57,762	−1.47	.928
Post 7	138	.93	.94	−0.42	.663	65,264	72,855	−1.492	.931
Post 8	138	.94	.96	−0.36	.641	77,633	82,710	−0.883	.810
Post 9	138	.96	.92	1.042	.149	86,498	93,267	−1.05	.852
Post 10	138	.94	.93	0.30	.371	90,490	100,729	−1.51	.934
Post 11	138	.94	.93	0.30	.379	99,988	105,117	−0.70	.759
Post 12	138	.96	.96	0.12	.450	106,294	115,350	−1.20	.884
Post 13	138	.96	.93	0.77	.220	117,233	127,851	−1.28	.899
Post 14	138	.96	.91	1.28	.100	124,841	135,401	−1.20	.885
Post 15	138	.94	.92	.58	.279	131,587	142,229	−1.16	.876
Post 16	138	.93	.89	0.68	.246	143,945	153,189	−0.90	.816
Post 17	138	.93	.92	0.18	.428	148,285	158,362	−0.95	.830
Post 18	138	.93	.94	−0.42	.663	155,553	166,831	−1.01	.845
Post 19	138	.98	.94	1.04	.149	163,862	174,633	−0.92	.821
N		59	79			59	79		

Note: Revisits based on fixations; 1 = revisit, 0 = no revisit to post; mean given; Time to first fixation of each post in milliseconds (ms).

Appendix D—Predicting learning through visual attention to post elements

Mediation through post element AOI	Indirect effect (unstandardized)	SE	*p*	LL	UL
Public → Visual attention → Recall					
Header	.321	.165	.052	−.003	.646
Picture	−.217	.130	.094	−.472	.036
Title	−.009	.149	.948	−.302	.283
Public → Visual attention → Recognition					
Header	−.004	.073	.953	−.148	.140
Picture	−.068	.044	.124	−.155	.018
Title	.244	.098	.013	.051	.437

Note: Mediation analysis for post elements includes all other respective post elements as controls and is based on dwell time.