Better Off: When Should Pervasive Displays be Powered Down?

Nigel Davies[1], **Sarah Clinch**[2], **Mateusz Mikusz**[1], **Oliver Bates**[1], **Helen Turner**[1] **and Adrian Friday**[1]

[1]School of Computing & Communications
Lancaster University, Lancaster, UK

[2]School of Computer Science
The University of Manchester, Manchester, UK

n.a.davies | m.mikusz | o.bates | h.m.turner | a.friday @lancaster.ac.uk[1] sarah.clinch@manchester.ac.uk[2]

ABSTRACT

Digital displays are a ubiquitous feature of our public spaces – both ever present, and "always on". In this paper we use a combination of literature survey, experimental work, and stakeholder interviews to consider if maximising the amount of time such displays are powered on is truly advantageous. We challenge existing practice by considering arguments from the perspectives of multiple stakeholders (viewers, passers-by, content creators and signage owners), and identify multiple facets for consideration including levels of attention, cognitive load, impact on social interactions, energy and financial costs, advertising revenue, perceptions of failure and the pressures of creating valuable content.

Author Keywords

pervasive displays; viewer attention; calm computing

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

Recent estimates suggest >25 million public displays are in daily use [41] in locations such as shopping malls, transport hubs and public spaces. To maximise return on investment, signage owners look to use their display network to its fullest extent, meaning that displays are usually switched on whenever they can potentially be viewed – irrespective of the number of viewers or likely value of available content. This can result in duty-cycles (i.e. the amount of time displays are on each day) of 12, 16 or even 24 hours.

In this paper we ask if maximising the amount of time displays are powered on is actually truly advantageous, considering the merits of long duty-cycles from three perspectives:

- **for viewers** we consider the impact of displays on attention, cognitive load, social interactions and content recall.
- **for display owners** we focus on issues of content production, advertising revenue and reputational impact.
- **for environmental stakeholders** we consider the energy costs of display networks with varied duty cycle length.

In considering display duty cycles we note that while displays only have two distinct states, i.e. *on* and *off*, equally important to account for are transitions between these states, i.e. the display is *transitioning from on to off* and the display is *transitioning from off to on*. These transitions may include displaying content such as "boot-sequences" and are potentially disruptive events. Transitions also tend to mark explicit actions and hence can be used to mark significant points in time and to change viewer expectations (consider for example the impact of turning on or off a television in a typical domestic setting with other family members in the same room).

We believe that this paper is *the first to explore holistically the issue of display duty-cycles and existing practices for power management*. Our discourse is backed by an extensive literature survey, experimental work, and stakeholder interviews in the context of a large-scale, long-lived display network. We hope that the initial insights presented will prompt further detailed exploration, stimulate debate and help catalyse research into optimal duty-cycles for future display networks.

IMPACT FOR VIEWERS & BYSTANDERS

Attention

Display Blindness has long been acknowledged as a key issue for pervasive display deployments, and it is generally accepted that screens receive little attention from passersby due to a lack of perceived value in the content that they show [27]. This problem has motivated the development of a body of techniques intended to attract attention, e.g., attract sequences, calls to action, leveraging behavioural urgency and Bayesian surprise [32]. However, current evidence has failed to establish the impact of such techniques on the perceived value of content, and the techniques are all fundamentally grounded in the assumption that the underlying platform is a set of displays that are "on" – the research community's working model appears to be that screens that are turned off attract no attention, show no content, and hence have no value.

Whilst the accepted view is that the more time a display is on the more attention it will garner, and the more value viewers will attribute to the content, in many areas of life attention and value are in fact determined by scarcity. For example, we attribute more financial value to naturally rare objects, we artificially create scarcity to signify that an item is high value, and we tend to have better recall of rarer events [26]. This begs the question – is the same true for the content shown on

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public displays? To date, there has been no research that has explored the impact of changing the duty cycle of displays to artificially limit their availability and hence increase scarcity. We therefore identify a number of open research questions:

1. *Can we encourage attention to displays by curating the times when they are powered on?* Research has yet to consider if limiting screen availability would actually increase the attention viewers give to a display, i.e. does a screen become more interesting (novel) because it's normally off and now it's on? There is potential risk, and this too would need further study – if viewers know that they most likely will not see a content item again, does this increase attention or simply lead to negativity towards the screens as a means of digital communication? Furthermore, do these effects increase, remain constant or reduce over time as viewers learn the behaviour of displays? How does one determine the duty cycle needed to cultivate scarcity effects in a given deployment?
2. *Does limiting screen availability alter the perceived value of displayed content?* If duty cycles can be used to garner attention through novelty, that may or may not in turn impact the value viewers attribute to content. The key question is whether we can culture an expectation that when a display is on, then there must be something of value to be communicated? What interplay does this have with content repetition? Current deployments typically aim to ensure a single viewer sees the same content item many times – is this an advantageous strategy and is there an optimal period and/or number of times for a viewer to see a content item? If items are to be repeated, should the availability of content be limited, i.e. what is the optimal time distribution for viewers to see a specific content item or campaign?

Answering these question poses significant challenges as they rely on the establishment of a general sense, amongst a population, that a display is deliberately managed in such a way that it only turns on for infrequent or short time periods (rather than, e.g., that it has simply been broken when passers-by have seen it). Furthermore, the above questions focus on the 'on' and 'off' states of a display. However, viewer attention may also be impacted or even guided by power transitions. Outside of digital signage, performances and media presentations are typically bookended with clear transition states that indicate to viewers that their attention should transition to a focal point (e.g. the dimming of lights prior to the beginning of a movie or piece of live theatre). Such cues provide direction not only to attend to the performance, but also in indicating when a show is complete or is temporarily suspended (e.g. for an interval), prompting an audience to transition their attention away to the wider environment. Transferring these concepts to the signage domain, research is needed to determine:

3. *Can we manage passer-by attention through power transitions?* We are not aware of any prior work that has considered the impact of display transitions on viewers and research is needed to establish the role of transitions in guiding attention. *Turning a display on* provides a change in light levels, colour and ambient noise – to what extent do these attract attention in themselves? Do users value an explicit signal that the owner of the display is trying to attract their attention? What interplay do power transitions have with attract sequences, calls to action, and other existing mechanisms for garnering attention? Likewise, can the act of *turning a display off* be used as a mechanism to explicitly direct attention away from the screen, for example, to direct attention to another feature of the environment or to encourage specific follow-on activity (e.g. to encourage the purchase of items following an advertisement)? What role does the hardware itself have on the degree of impact seen, e.g. could technologies such as e-ink bring more subtle transitions, and what impact would this have?

Social Interaction

Pervasive displays have a long history of fostering social interaction as both a platform for communication in themselves [1, 12, 13, 17], and as a medium for triggering interactions that occur 'out-of-band', in the physical world [28]. However, many other communication-facilitating technologies (e.g. mobile phones) have been shown to have a role in inhibiting social interactions [34, 21], and pervasive displays are often deployed into environments that already facilitate social interactions (e.g. cafes, bars, shared office spaces). To date, the tension between display engagement and social engagement has received limited attention, typically taking the form of anecdotal observations rather than being the target of explicit research. Current observations suggest that social peers can be the trigger that pauses interaction with a display [11, 16], but equally suggest that display viewers can be so strongly engaged that they became unaware of those physically close to them [33, 36].

Given the current patchy and conflicting evidence, and the well-documented problems with other technologies both benefiting and inhibiting social interactions, it seems likely that screens both positively and negatively impact social interactions. Understanding these impacts in depth would potentially provide valuable grounds on which to make decisions about when displays should be powered on, and when they might perhaps better deliver value to space users by being powered down. To date, there has been no targeted research to quantify the social–digital tensions for pervasive displays, nor on the impact of altering duty cycles to promote social interaction. Open research questions in this space include:

1. *Does switching displays off (or on) impact on social interactions around the screens.* Although there is a small amount of evidence that the immersive nature of display interaction may be enough to distract people from their surroundings, research is still needed to quantify both the positive and negative effects of digital signage for passersby, viewers, and interacting users. Pervasive displays have typically been regarded as bridge for social interaction, but to what extent do they act as a social distraction (cf. the ever-present mobile phone)? Would turning off a display have a positive impact on conversation and social cohesion amongst viewers nearby?
2. *Can we better support social interactions by making informed decisions about when displays should be powered*

on or off? If research addressing the previous question indicates that digital displays do indeed both positively and negatively impact on social activity, to what extent can this be actively leveraged to maximise social cohesion? Can we quantify the cases in which effects are more likely to be positive and negative, and detect them as they arise? Are there cases in which distraction from the display is actually the preferred option – e.g. when a distracted individual would otherwise focus on a personal device (smartphone), could the display provide a shared distractor device?

Again, the above questions predominantly centre on the static power states, but the transitions themselves have clear potential to impact on nearby social interaction. Intuitively, one is inclined to hypothesise that any attention garnered by the transition of a display could easily interrupt nearby social activity and disrupt flow (in the same way that a loud noise might cause people conversing to both question the sound and then temporarily forget the previous topic of conversation). However, the explicit cues provided by power transitions are somewhat reminiscent of the subtle but well-established cues used in conversational turn taking (e.g. changes in vocal pitch, eye gaze) – perhaps transitions could be used to actively direct a viewer to engage in a nearby conversation (i.e., by moving the display to an 'off' state). We therefore ask:

3. *What impact do power transitions have on social interactions?* Does the appearance of content (as opposed to its ongoing presence) have an increased impact on nearby social interactions? Are transition effects positive (e.g. providing new topics of conversation) or negative (e.g. interrupting flow)? Can such effects be mitigated, or strengthened, through selection of display hardware (e.g. using the subtler transitions of e-ink to reduce disruption)?

Cognitive Load

Early visions for Ubicomp highlighted the challenges of absorbing information from digital devices in our environments, and set out to create 'calm' information devices that reduced cognitive load by mimicking the information transfer that occurs in more natural environments [40]. However, many current digital signs fail to reflect this vision and in fact, very closely resemble traditional computer interfaces. Our understanding of the impact of such screens on cognitive load is unclear – on the one hand, urbanisation of environments is seen to create an 'information overload' that reduces working memory capacity [5] and impairs cognitive control [3, 25]. On the other, despite (or perhaps because of) their failure to realise their potential as ambient features of the environment, digital displays are well-documented as receiving little visual attention [27]; a recent study put a typical gaze at environmental digital screens at around 300ms [10]. To date, there has been no research explicitly focused on understanding the impact of environmental displays on cognition, anxiety, affect and other factors commonly attributed to urbanisation.

A concerted study of the contribution of pervasive displays to cognitive overload is needed to inform the design of both displays and content, and of the appropriate duty cycles to be used. To this end, we therefore identify a third set of research questions, focused specifically on issues of viewer cognition:

1. *Can we improve the cognitive ability of individuals by turning off nearby pervasive digital screens?* While urbanisation may have negative effects on both cognition and mood, there is some evidence that visual media may actually act as a short-term cognitive boost [37] – how do these effects pan out for pervasive displays, an urban artefact that provides visual media stimuli? How do we design studies to establish the degree to which pervasive displays impact on (i) fundamental neurological measures (e.g. working memory capacity), and (ii) real-world task performance? To what extent can studies be carried out in real-world settings? Can we establish if turning a display on or off is likely to have a cognitive impact on nearby individuals, and any specific tasks that are impaired or facilitated? Do such effects persist over time (i.e. once a passerby has left the environment with the display)? Furthermore, given the general urbanisation of public space, would turning pervasive displays off have any meaningful impact on cognition?
2. *Do viewers perceive improvements to their enjoyment of space if digital displays are turned on, or off?* Here we consider not neuropsychological load itself, but perceptions of that load (as measured, e.g., by tests such as the NASA TLX [18]) and users' general sense of a space as one they would choose to spend time in. Are users more likely to report feeling overloaded when they occupy a space that is also populated with digital displays? Would turning displays off reduce perceived cognitive demand? To what extent is this determined by factors such as the familiarity, crowdedness, and complexity of the environment? Do duty cycle lengths have a bearing on feelings of load?

Whilst the above questions are unexplored, human cognition has received some attention from the pervasive displays community. To date, this understandably focused around cognition in respect only to content recall – identifying, for example, that external tasks (e.g. waiting in or transiting through a space) have little impact on memorability of displays and their content [2], or that interaction can reduce the ability of users to recall content [35]. Given this focus, we pose one further research question related to viewer cognition:

3. *To what extent is viewers recall of content impacted by limited display availability?* Pervasive displays act as a communications medium – turning displays off for large portions of time has clear potential to impact on their effectiveness in communicating a message. Would reducing the time that a display is turned on have a negative impact on cognitive recall (assuming that it is on enough for the target audience to see, and attend to, specific content items)? To what extent is content recall impacted by cognitive load (both from ongoing tasks, and other environmental features)? Is there an optimum (cumulative) period of attention after which content recall does not substantially improve, and if so could this be used to determine the duty cycle of displays?

None of the above questions explicitly pull out the issue of display transitions. However, many of the previously identified concerns may carry over – for example, establishing the extent to which transitions garner attention may, in turn, have implications for cognitive load. More generally, the three areas of *attention*, *social interaction*, and *cognitive load* are articulated as distinct topics of concern, but whilst each raises unique challenges, and may suggest different duty cycle selections, there is undoubtedly considerable interdependency.

IMPACT FOR CONTENT CREATORS & SCREEN OWNERS

Content Creation and Scheduling

While the previous section focused on the impact of a display's duty-cycle on viewers, we are also interested in how varying this cycle might impact content creators. In particular, how a reduction in the amount of time that displays are powered on might influence content production strategies. To inform thinking in this area we interviewed the team responsible for producing the most-widely shown signage content for our local network of approximately 60 displays.

Our hypothesis was that reducing the duty cycle of displays might ease the burden of content production. We begun by asking what factors influenced the number of content items produced each week (currently ~6 items). Responses indicated that the number of items produced was dominated by the "rhythm" of press stories – creators viewed signage as one of many distribution channels, and content creation was directly related to the number of stories they produced. Content creation takes up to 30 minutes per item. When asked, the team noted that they did not feel under pressure to produce more content – one of the benefits that we had hypothesised might be accrued from reducing display duty cycles.

We were also interested in what was considered to be the optimal and maximum number of times each viewer should see a piece of content, i.e. if the team thought that repeat viewings were desirable and if there was an upper bound to this. No quantified answer to these questions was given, with the team reporting that viewers should see items "as often as necessary to reenforce the message". Returning to the theme of signage as one part of an overall communications strategy, this answer reflects their desire to use digital screens to help consolidate stories rather than to necessarily break new stories.

When asked about the idea of turning displays off for periods of time, creators immediately identified that this could have "a psychological effect" and were receptive to the idea of exploring this. What is clear from our short interview is that our content creators are focused purely on ensuring that viewers engage with the messages being displayed – content duration, the power state of the display and the number of content items are all immaterial. This leads us to the general question:

1. *How can sign owners determine the correct content schedule and duty-cycle for a display?* For a given display network and its viewers, the length of the duty-cycle is inherently linked to the number and frequency of items to be shown. However, content creators and sign owners have no tools to help them understand the optimal values for these variables. Analytics can provide per-screen counts of viewers – typically used for evidencing advertising figures – but provide little or no insights into viewer reactions to repeated content items across an entire network [31]. What are appropriate scheduling strategies for content items and power-state transitions across a network of displays?

For content providers, power transitions themselves represent a distinct window for scheduling. This raises the question:

2. *What types of content should be scheduled to coincide with transitions?* Current signage content is often scheduled with no knowledge of where it will appear within the context of a display's duty-cycle (e.g. [29] selects randomly within possible content items). However, one could consider transitions as specific windows for targeted content – what, then, are the characteristics of good "transition content"? Should media be explicitly designed for transitions, e.g. as standard "start" and "end" sequences similar to the boot animations common on computers and smart-TVs?

Advertising Revenue

In common with the web, digital signage is often funded through advertising. However, while sophisticated mechanisms for measuring the effectiveness of adverts exist for the web (e.g. click-throughs), digital signage has relatively limited analytics [30] with advertising revenues often calculated based on impressions for signs with known viewer profiles.

Reducing the duty-cycle for a display necessarily reduces the number of potential content impressions for a given time frame. While in the short term this could be a significant issue for many display networks we believe that this problem could be ameliorated by the emergence of new analytics frameworks that more accurately reflect the levels of user engagement with content and hence their value to an advertiser. Such systems could eventually seek to link signage activity with real-world purchasing patterns [39]. However, even with such enhanced analytics a fundamental question remains:

1. *How can we model content value to facilitate new revenue models?* For open display networks with dynamic duty-cycles, accurately attributing value to content items and scheduling slots becomes critical. How should these values be calculated and audited to provide market confidence?

Reputation and Perception of Failure

As displays become more pervasive researchers have begun to explore how users respond to visible errors [20, 22]. However, changes to a display's duty-cycle raise fundamental questions about how users perceive displays. Viewers expect pervasive displays to be switched on; those that are turned off are often assumed to be broken or indicate that the owner has no information of value to share [38]. Such assumptions pose a significant challenge to space and screen owners because of the potential reputational impact.

1. *What is the right way to inform users that displays are intentionally switched off?* For display owners it is clearly important that viewers recognise that displays are turned off intentionally and for good reason. In the same way that public spaces sometimes leave areas of grass uncut to encourage wildlife and then feel obligated to place physical signs to indicate their motivations, will the same be true for digital signs? Are physical signs required or will users eventually become conditioned to this behaviour?

ENVIRONMENTAL CONSIDERATIONS

Having considered the potential impact of duty cycle reduction on viewers and signage owners, we now turn to the potential for environmental impact. In this section we explore the relationship between duty cycle and energy consumption, and the global consequences of changes to sign usage patterns.

Profiling a Signage Network

To understand the energy use of a typical pervasive display network we again profiled our own local display infrastructure. At the time of writing, this e-Campus display network consists of 57 large displays (40 – 50 inches), connected to Apple Mac Minis of varying vintage (models 1,1 – 8,1). Technical specifications indicate that the maximum power consumption would be ~120W for a display and ~110W for the Mac Mini. To determine actual power consumption, we instrumented two common configurations (a 2009 Mac Mini/Sony 40" display, and a 2014 Mac Mini/Iiyama 46" display) with Plugwise socket meters. Our 2009 configuration consumes an average of 22.4W for the Mac and 168.9W for the display; the 2014 configuration consumed significantly less power – 8.4W for the Mac and 96.3W for the display.

Our displays are powered on for ~9.5 hours per day, while the accompanying Mac Minis are continuously powered to enable them to respond to requests for presentation of emergency content. Approximately one third are typified by the 2009 configuration, with the remainder closer to the 2014 configuration. Daily network consumption is thus ~83 kWh, at a cost of ~£11.64 (i.e. ~30MWh and ~£4250 per year)[1].

Altering the duty cycle of displays has the potential to both reduce energy consumption and increase operational lifetime. Table 1 (cols. 2-4) shows the potential benefits of modifying the duty cycle of an installation such as e-Campus; reducing the duty cycle from 12 hours to 6 hours would result in a saving of 41.21 kWh and £5.77 energy costs per day. These energy savings may appear small, but are by no means insignificant; implications of duty cycle changes for displays and signage becomes clearer when we consider the potential for global savings.

Global Implications

Communications and IT are beginning to form an important component of global energy demand. In 2012, communication networks contributed 1.8% of global energy use (350 TWh), and this energy demand grows by 10% annually [23]. Digital signage also continues to grow, reaching 25 million globally at the end of 2014 and predicted to grow by 18.7% per year to reach ~70 million by 2020 [41].

The rightmost columns of Table 1 provide an illustrative example of the energy and costs of a global digital signage network. This example assumes that all global signage has a mix of hardware similar to our e-Campus deployment. This is likely to be conservative for two reasons: (i) signage on the global scale is often larger than our 40 – 50 inch displays, consuming more energy; and, (ii) outdoor displays need to be weatherproof and brighter which leads to larger consumption. Based on our illustrative calculations, global signage could currently be consuming 29.25 TWh of energy per year, growing to 68.8 TWh by 2020 (assuming all displays are similar to our 2014 configuration and running a 100% duty cycle).

Reducing display duty cycles also extends operational lifetime. Given an operational lifetime of approximately 60,000 hours [14] and a global network of 70m displays, reducing the duty cycle of displays from 100% to 50% means that 5m fewer displays will need to be replaced each year.

1. *How will new technologies impact on optimal duty-cycles for displays?* Our energy estimates assume conventional technology but developments such as e-ink could change this picture significantly. What would be the right mix of e-ink and conventional displays given their different characteristics? Will the emergence of e-ink displays with low refresh rates change the way viewers perceive displays, leading to increasing or decreasing rates of display blindness?

RELATED WORK

While there has, to the best of our knowledge, been no work that has directly addressed the issue of duty cycles for pervasive displays there has been considerable attention given to the impact of displays themselves on a wide range of stakeholders. For example, observations about the low levels of attention given to displays were first made by Huang et al. in 2008, with social effects such as the Honeypot observed in 2003 [6]. More recently, viewer attention and cognition has been explored through consideration of factors that effect the memorability of content shown on a public displays, with recall levels of up to 20% in naturalistic settings [2], and as much as 77% when participants were explicitly instructed to remember as many items as possible whilst watching or interacting with a large display [35].

The above research has focused on the presence of displays as a permanent ("always on") feature of the environment. Closer to our own consideration of displays that transition to being 'on' and 'off' is the work of Hardy who explored the use of projection to create "transient displays" [15]. The core idea is that though use of projection, displays can appear and disappear as needed without creating a sense of a missing or malfunctioning display. Despite this attractive feature of projected displays their cost and visibility issues mean that most signage networks use conventional display technology.

Finally, our consideration of the energy implications of altering display duty cycles is reminiscent of research in the wider ubicomp community. Energy and environmental impacts have been explored primarily in the area of domestic energy (and surrounding practices) [8, 9, 19], with some focus on mobile devices [4, 7, 24]. To date we know of no works considering the specific role of displays and ubiquitous computing deployments in shared non-domestic environments (e.g. workplaces, shopping malls), nor any that attend to the role of energy in pervasive display system design.

[1] Assuming a flat energy tariff of £0.14/kWH (based on the cost of Cooperative Energy: https://www.cooperativeenergy.coop/siteassets/tils/pioneer-variable-2/til---pioneer-variable---region-16.pdf in January 2016).

Duty Cycle	e-Campus deployment (57 Displays) Daily Running Costs	Energy Use	Daily Lifetime Hours Gained	Illustrative Deployment (25 million displays) Daily Running Costs	Energy Use	Displays Replaced Annually
100% (24 hrs/day)	£25.58	182.72 kWh	-	£11.22 million	80.14 GWh	3.7 million
75% (18 hrs/day)	£19.81	141.51 kWh	6	£8.69 million	62.07 GWh	2.4 million
50% (12 hrs/day)	£14.04	100.30 kWh	12	£6.16 million	43.99 GWh	1.8 million
25% (6 hrs/day)	£8.27	59.09 kWh	18	£3.63 million	25.92 GWh	1.2 million

Table 1. A summary of the cost and energy consumption impact when altering the duty cycle of our 57 e-Campus displays *[columns 2-4]* , and a deployment consisting of 25 million displays per day assuming a mix of display hardware *[columns 5-7]*. In both cases we assume the computers driving the displays are powered on 24 hrs/day.

CONCLUDING REMARKS

This paper represents the first exploration of power duty-cycles for pervasive displays. Analysis of the questions raised reveals a common theme, i.e. what is the interrelationship between content scheduling and power-states in pervasive display networks? At present the two concepts are treated as being entirely discrete – decisions are made about when displays are turned on and off and then content is scheduled (manually or automatically) within these time windows. In this paper we reveal a more complex landscape in which content and power state scheduling are intimately linked.

For example, as pervasive display networks continue to scale, and manual scheduling becomes increasingly difficult, we will need to develop entirely new scheduling algorithms that are able to factor in display power state as part of network-wide scheduling decisions. However, to do so at present would pose considerable challenge because we simply do not understand the details of the relationship between power state (and associated transitions) and other variables. For example, we can hypothesise that power transitions may impact on viewer attention and could therefore be used as part of a scheduling algorithm that tries to maximise attention for specific content. But, how do we test this hypothesis? How long after a transition does the effect on viewer attention persist? What is the knock-on effect for other content items? To help us begin to explore these issues we conducted a small-scale study in the context of the e-Campus signage network.

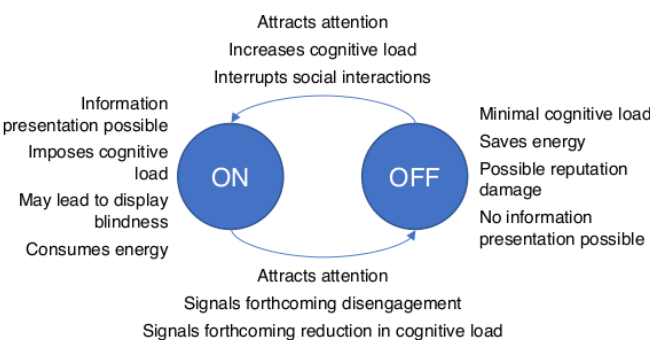

Figure 1. Potential Implications of Changes in Power State

Our in-the-wild exploratory study involved 33 participants (largely students, ~58% male), who were recruited through opportunity sampling. Participants were seated at a table in a popular study space 3 metres from a display (either side-on, or directly facing the screen). They were then given 15 minutes to tackle a paper-based cognitive test composed of 35 questions ordered in increasing level of difficulty (10 each of verbal, numeric and visual-spatial reasoning, plus 5 logic questions). Participants were assigned to one of three conditions in which, whilst they completed the test, the nearby public display was either powered on and continuously showing content [condition `ON`], was powered off and did not show any content [condition `OFF`], or one in which the display would show a single content item and then power off for a period of time before powering on to show the next item [condition `ONOFF`]. Once the 15 minutes had elapsed, participants were asked to rate their test experience using a NASA TLX [18], and were then given a recognition test in which they indicated how certain they were that specific items of content had or had not appeared on the nearby public display.

Our results did not show any clear relationship between condition and NASA TLX scores, performance in the cognitive tests or content recall. Poorest performance in the cognitive tests occurred when the screen was `ON` (median 30 questions answered with a 28% error rate, compared to 33.5 and 23% `OFF`, and 31 and 22% `ONOFF`), but this was accompanied by slightly lower reported mental demand (median 13.00 `ON`, 14.25 `OFF`, 11.50 `ONOFF`). Overall we observed that few participants appeared to glance at the display at all, and the majority reported that they could not say whether a content item had been shown on the screen or not. The mean number of correctly identified shown items was zero in all conditions.

Our initial study highlighted the challenge of developing a detailed understanding of the impact of duty-cycles on viewers. Prior to this paper we believed that existing practices to setting display duty-cycles warranted scrutiny, and our research has revealed that the implications of changes to duty-cycles could be far-reaching – impacting content creators, display owners, viewers and environmental stakeholders. Advancing understanding of the details of these implications will enable entirely new forms of content scheduling and represents an exciting new area of research for the community.

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