Don't Disturb Me – Understanding Secondary Tasks on Public Displays

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ABSTRACT
A growing number of displays provide information and applications in public spaces. Most applications today are considered to pose one task to the user, such as navigating a map. In contrast to such primary tasks, secondary tasks have yet received little attention in research, despite practical relevance. For example, a secondary task might occur by displaying special ticket offers to a tourist browsing a city map for attractions. This paper investigates secondary tasks with two key-contributions: First, we describe a design space for secondary tasks on public displays, identifying dimensions of interest to application designers. Second, we present a user study with text entry and mental arithmetic tasks to assess how secondary tasks influence performance in the primary task depending on two main dimensions – difficulty and temporal integration. We report performance (completion times, error rates) and subjective user ratings, such as distraction and frustration. Analysis of gaze data suggests three main strategies of how users switch between primary and secondary tasks. Based on our findings, we conclude with recommendations for designing apps with secondary tasks on public displays.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User Interfaces—*Evaluation/Methodology*

Author Keywords
public display; secondary task performance; mental workload; parallel-task environment

INTRODUCTION
Public displays are quickly proliferating in public space. More importantly, though, an increasing number of these displays is connected to the Internet and employs sensors, hence enabling interactive applications that can be operated using touch, mid-air gestures or also the mobile phone [4]. Such applications include way-finders in large shopping malls, information displays at train stations and airports, digital bulletin boards [2], applications that shown content from social networks [33, 18, 3], and playful applications [1, 32, 47]. An overview of applications is provided by Davies et al. [11].

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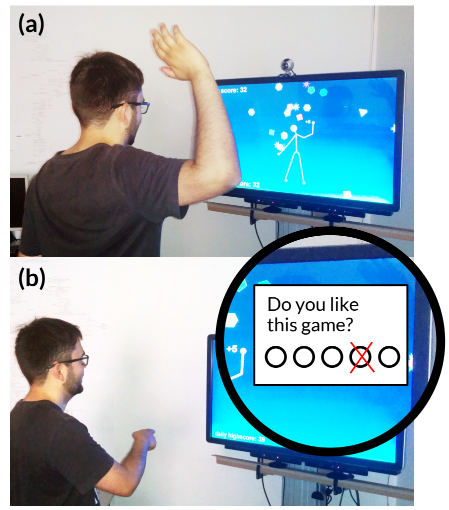


Figure 1. Example of a secondary task on a public display: (a) user interacting with the primary task, here playing a game; and (b) answering a user feedback questionnaire as a secondary task besides the display's main application.

While in the vast majority of cases applications pose only one task to the user – for example, controlling a game or browsing a store directory – there are many examples, where it would be desirable to provide additional tasks. For example, as tourists browse a city map for attractions, they could be provided the opportunity to buy discounted tickets for a particular museum or concert. Or as users are browsing the directory of a shopping mall, store owners may want to attract customers by displaying a coupon that users can retrieve using their smartphone camera. Furthermore, display owners may simply be interested in feedback from users, for example by asking, whether they found the information they were looking for quickly and easily or whether they enjoy interaction with a game (see Figure 1).

Confronting users with so-called secondary tasks infers a number of challenges: if presented while users are still deeply engaged with their primary task they may either ignore the secondary task or they may interrupt what they are currently doing, leading to a decrease in performance. If presented after having finished the primary task, users may not be motivated anymore to continue with the secondary task or they may have already left, not noticing the secondary task at all. But also the location on the display where the secondary task is presented is crucial. If presented in the periphery, users may miss it, while showing it too prominently, i.e. very close to where the primary task is performed, it may disrupt or annoy users.

The contribution of this paper is twofold. At the focus of this research, we chart a design space for secondary tasks on public displays. We identify and discuss dimensions that designers of interactive display applications need to consider when confronting users with additional tasks. Furthermore, we contribute a study, that investigates the influence of when secondary tasks are presented to users. In particular we investigate the impact on time, accuracy, and behavior.

Our results show that secondary tasks should follow directly after main user actions, instead of interrupting them. They should not be too mentally demanding, but, interestingly, very easy secondary tasks might inhibit performance in the primary task. Furthermore, we reveal that users cope with secondary tasks with different strategies, such as ”main task first” or ”shortest/easiest task first”.

BACKGROUND AND RELATED WORK

Several examples of display applications employing secondary tasks exist, both in the research literature as well as in commercial products.

Some of the most common secondary tasks on public displays is surveys, which aim to collect feedback from users. For example, the displays of the UbiOulu network [36] offer multiple applications (primary task) users can choose from as they approach the display. The platform includes a survey tool to gather in-situ feedback through questionnaires (secondary task) from the users as they engage with an application.

Another example is Digifieds, a digital bulletin board [2, 4, 30]. While users browse through the classified ads (primary task), there is the opportunity for the user to retrieve classified ads from the display (secondary task) – for example, by sending it to a personal email address or scan a QR code. To keep interruptions small, the authors implemented a shopping cart function where classified ads can first be collected through a simple button click and later be retrieved using one of the aforementioned methods.

The notification collage allowed people to post multimedia elements for their colleagues [17]. The perception of incoming elements from colleagues – as users are working, perceiving other content or posting content themselves – also constitutes a good example of a secondary task. It would have been interesting to investigate the best moment in time, when new content was presented to the user.

Secondary tasks also exist for applications that can be controlled through mid-air gestures. In ShadowGuides, hints on how to perform gestures to perform a particular (primary) task are projected onto the user's hands – processing this information can be considered a secondary task [13]. In Strike-A-Pose [47], users are taught mid-air gestures through instructions on the display (secondary task) as they interact with a game (primary task). Instructions were displayed in different ways – integrated, time-multiplexed, and space-multiplexed with the game. An interesting finding here was that in time-multiplex mode, interrupting the game led to that many users abandoned the display. This highlights the need to carefully design secondary tasks.

Another example is games (primary task) at the end of which players are asked for personal information (secondary task). In BalloonShooter players enter their name which then appears on the leaderboard [42]. In FunSquare, people select their neighbourhood and contribute to its overall score [29].

Finally, GravitySpot is an example where primary and secondary task are executed in parallel. While users are required to find the answer to a quiz (primary task), they are (subtly) guided to a particular location in front of the display (secondary task) by means of cues applied to the display context [1]. This is useful if displays employ a sensor with a narrow sensing area in which users need to be located. Note, that users here are not necessarily aware of the secondary task.

To mention one commercial example, Wayfinder[1] is an interactive touch screen map that can be deployed on kiosk systems. While it mainly allows users to find their way through a mall (primary task), it concurrently shows advertisements of stores in the mall. Secondary tasks could be simply the perception of these ads or taking a picture of a coupon code that is displayed along with the advertisement.

These examples show that there is a clear need to carefully design such secondary tasks. However, while prior research reported on some related challenges as side findings, to the best of our knowledge there is no prior work that aimed to comprehensively assess this design challenge. Hence, we close this gap by presenting a first structured investigation on the impact of secondary tasks on large displays.

PSYCHOLOGICAL FOUNDATIONS

Task performance has been extensively researched in psychology. In the following we summarize work on multitasking, interruptions, and workload and relate it to our work.

Multitasking

Of particular interest is work on multitasking. Salvucchi et al. distinguish between *concurrent multitasking* (e.g., driving and talking, listening and note-taking, etc.) and *sequential multitasking* (writing paper and reading email, cooking and reading book, etc.) [41]. In addition, multitasking can be classified based on the time required before switching tasks (seconds, minutes, or hours). In our work on public displays we primarily focus on sequential multitasking (e.g., filling in a brief questionnaire after playing a game) and on task switching times in the order of seconds or a few minutes, since interaction times with displays are in general short.

Interruptions

Closely related is also previous work on *interruptions* as one possible form of secondary tasks. As is showcased by the examples presented above, secondary tasks on public displays often take the form of interruptions, because the end of a task (such as reading content) is usually difficult to assess.

In general, interruptions lead to slower and more error-prone performance [16]. Borst et al. found that the disruptiveness of interruptions depends on three factors: interruption duration, interrupting-task complexity, and moment of interruption [8].

[1] http://www.wayfinderkiosk.com

At the same time, both the relevance (similarity) of the secondary task as well as the time of interruption is also important. In general, negative effects are less pronounced if tasks are related and if interruptions occur between subtasks [16].

For designers of display apps it is important to know when to best interrupt the user and how complex the interruption should be. Hence, these aspects are at the focus of our work.

Workload

Also of interest is the term *workload*, since it serves as a good indicator for how strong a person feels taken in by a task. While there is no generally accepted definition for the term 'workload' [35], researchers agree that workload has a strong influence on the user's performance level [24, 28, 35]. Basic principles of the construct mental workload have been summarized in [10, 26, 28, 48, 52]

Workload can be assessed by applying performance, subjective, and physiological measurement techniques. By using *performance measures* it can be determined at which level of workload the performance of the operator degrades and reaches an unacceptable level [45]. There are two distinct performance measures. Primary task measurement is used to monitor the operators actual performance on the task of interest or design choice. Changes in performance are recorded, as primary task difficulty diversifies [34, 46]. In the secondary task technique the operator has to perform a second task additionally and concurrently to the primary task which is still in focus of task process and should be completed with priority. The secondary task is only performed when the operator has enough spare capacities that are not used by the primary task [45, 46]. In case the performance of the secondary task degrades it indicates that the main task is getting more demanding [25]. In 1986, O'Donnell and Eggemeier [34] classified eight major groups of secondary tasks that have been used frequently: Choice Reaction Time, Tracking, Monitoring, Memory, Mental Mathematics, Shadowing, Simple Reaction Time, Time Estimation Paradigms.

Subjective measures gather the direct opinion and self-evaluation of the perceived amount of workload. The two most popular rating methods are the NASA Task Loading Index (TLX) [20] and the Subjective Workload Assessment Technique (SWAT) [40].

Physiological techniques record changes in the physiology of the operator caused by cognitive processing demands and are assumed to correlate with changes in mental workload [45, 46]. Common methods are assessing cardiovascular [26, 27, 34], ocular [26, 43, 51] and brain activities [14, 26, 46].

One major application area of assessing the influence of multiple tasks is evaluating its effects on driving performance in automobiles [12]. For example the influence of the use of mobile phones on mental workload, drivers speed [44], reaction time [37] and number of collisions [19] was investigated. Other application areas are aircrafts [7, 49] and learning environments [9, 50]. Also for desktop computer interfaces the impact of multiple tasks on performance has been investigated, in particular the effects of interruptions of the primary task by a secondary task [6, 21, 22, 23].

In short, evaluating the impact of multiple (parallel) tasks has been investigated in various areas with diverse influencing factors. However, for applications on public displays, this impact and the influence of different aspects has not been ascertained yet and is, hence, at the focus of our research.

SECONDARY TASKS ON PUBLIC DISPLAYS

The following section provides a definition of primary and secondary tasks, charts a design space for secondary tasks on public displays, and summarizes our research questions.

Definition

According to [38], a primary task is defined as follows: "Ergonomically speaking, when one has a multi-task assignment, the primary task is the one that takes priority. That is, it is the task that should receive the largest amount of allocated mental and physical resource. All other tasks in the assignment are dealt with in later order".

Therefore, a secondary task is subordinated or incidental to the primary task and is set to be performed just in addition to the primary task [31, 39]. Note that a secondary task is thus by definition different than multitasking: the latter implies that both tasks run in parallel and possibly without any hierarchy (i.e. equally important), while a secondary task is more generally any task conducted on the display besides its defined main application.

	Dimension	Description
D_1	Task difficulty	Determining the level of difficulty at which primary task performance degrades
D_2	Temporal integration	Determining the point in time at which primary task performance is impaired the least
D_3	Spatial integration	Determining the most appropriate location and size for showing the secondary task on (or also off) the screen
D_4	Application context	Determining application-specific aspects for optimal presentation and embedding of secondary tasks (e.g. different for games vs maps)
D_5	Situation	Situational context and relationship of display and user; e.g. passer-by vs waiting, groups of users
D_6	Number of tasks	Determining the number of tasks that users can handle in parallel without degradation of the primary task
D_7	Frequency of tasks	Determining the number of secondary tasks that users can handle one after another within a certain timeframe without degradation of the primary task

Table 1. Design Space for Secondary Tasks on Public Displays: From a literature review we identified seven dimension to be taken into account when designing applications that require the user to perform secondary tasks in addition to their main tasks.

Design Space

At the outset of our research, we conducted an extensive literature review. We searched for research articles about public display applications on Google Scholar, the ACM Digital Library, project websites as well as on personal websites of recognized experts in the field. In particular, we were interested in applications that pose several tasks at users, including ones that are considered secondary (cf. also related work). From the review we created a design space for secondary tasks on public displays. In the following, we describe several examples for deriving the identified dimensions (Table 1).

On public displays, common applications include in-situ questionnaires (e.g. [36]), which raise questions on when to display them (D_2), and how to spatially embed them (D_3) on the screen (e.g. pop-up, split screen, own application). Here, design considerations also include how many (D_6) and how often (D_7) questions should be displayed. Design choices regarding these dimensions can easily be expected to influence whether or not users will feel annoyed and seriously complete the questionnaire.

Another type of secondary tasks on public displays are instructions (e.g. teaching gestures for a game [47]). For such tasks, temporal (D_2) and spatial integrations (D_3) also need to be considered to optimise usefulness and minimise frustration on the user's part. Note, that the spatial integration may include locations off the display, as in ShadowGuide [13], where hints on how to perform gestures are projected on the users' hands. These considerations will also likely vary depending on the application context (D_4), for example gameplay instructions compared to navigation instructions. Moreover, some instructions might inherently be more difficult to process than others, raising questions along the dimension of secondary task difficulty (D_1).

Secondary tasks can also occur due to asking users to submit information other than a questionnaire, like entering a name for a highscore list in a game application [29] or to perform a crowdsourcing task [15]. For forms in general, aiming for maximal user participation and form submissions, designers will likely also consider situational contexts (D_5) – for example, whether users are expected to be mostly passers-by with short spontaneous interactions or people waiting for a bus.

Note that this example list and the discussed dimensions per example are not meant to be exhaustive. We rather aim to demonstrate that considering design questions on how to include multiple tasks on a public display leads to at least these listed aspects, which can be expected to influence performance, behavior and perception of the display user.

In this paper, we focus on investigating the first two dimensions (D_1, D_2) in detail in a lab study. We deliberately opted for a controlled setting that allowed (a) the influence of task difficulty to be assessed using a common approach (math tasks of different complexity) as well as (b) temporal integration to be investigated, which would have been difficult in a real-world study due to the need to predict when the user finishes a task.

In particular, the following question is guiding this piece of research: How difficult can a secondary task be and when is the optimal time for presenting it to minimise impact on main task performance as well as on user distraction and frustration? The following section therefore outlines hypotheses with regard to these two dimensions.

Research Questions

Based on the related work and the psychological foundations seven hypotheses were formulated, subdivided in respect of secondary task difficulty and temporal inclusion mode.

Secondary Task Difficulty

By adding an additional task, to a main task the overall workload for the operator increases which can lead to a degradation of primary task performance [45]. By varying the difficulty of the secondary task, impacts on the operator's performance (task completion time, error rate) as well as on the operators perception of satisfaction, level of frustration and mental workload are expected. The difficulty of the secondary task is segmented in three levels: easy, medium, and hard.

- H1: The higher the difficulty of the secondary task, the longer the task completion time of the primary task.
- H2: The higher the difficulty of the secondary task, the more errors are made in the primary task.
- H3: The higher the task difficulty of the secondary task, the higher the frustration level of the user.

Integration Mode

In addition to secondary task difficulty we vary the point in time of integration. Three different modes were distinguished. The first conceivable mode is to display the subsidiary task together with the main task right from the beginning (t_1). Second, the secondary task can appear during primary task procession, meaning while the operator is working on the main task (t_2). Finally, the secondary task can be shown just after the primary task has been completed (t_3). In particular, the anticipated distraction of the secondary task in condition t_2 is expected to have an impact on user performance (task completion time, error rate) and perceived level of frustration.

- H4: Embedding the secondary task at t_2 leads to a higher distraction than embedding at t_1 or t_3.
- H5: Embedding the secondary task at t_2 leads to a higher task completion time of the primary task than embedding at t_1 or t_3.
- H6: Embedding the secondary task at t_2 leads to a higher error rate in the primary task than embedding at t_1 or t_3.
- H7: Embedding the secondary task at t_2 leads to a higher frustration level of the user than embedding at t_3.

APPARATUS

In order to evaluate our research questions, an interactive public display application was developed that shows one main and one secondary task to the user. Again, we opted for a lab experiment since we needed a highly controllable environment where users were not subject to any interruptions, such as other people in the display vicinity, in order to not influence our measurements. This also enabled us to deploy an eye-tracker. In summary, our evaluation is based on three types of measurements: performance data, subjective ratings through questionnaires, and the gaze path of the user.

Tasks

Primary task: We chose text transcription as the primary task. More precisely, users had to enter a given sentence shown on the screen into a text-box, using an on-screen keyboard on the public display (see Figure 2). To ensure that text input was comparable between subjects, short sentences with 56 to 58 characters were created by adapting tweets and ads from eBay classifieds.

Secondary task: We chose mental arithmetic problems as the secondary task. These tasks were segmented in three categories, namely easy, medium and hard math problems. Easy problems consist of addition/subtraction with 1-digit numbers, medium problems use addition/subtraction with 2-digit or 3-digit numbers, and the most difficult category contains multiplications and divisions of 2-digit or 3-digit numbers. These three categories allow the difficulty of the secondary task to be varied in a controlled manner.

Data Logging

Performance measures include the tracking of completion times and error rates of primary and secondary tasks, as well as text input speed. Hence, our application logged the starting time of the tasks (i.e. moment of appearance of the given sentence), and the end point, when a submit button was pressed.

Furthermore, all key presses were logged to determine the number of errors made during typing and the total number of keystrokes. We also logged the current number of characters of the primary task text field to be able to display the math task after half of the characters of the presented sentence were entered (for t_2).

Finally, the gaze-path of the users during the task completion was recorded so that we could analyze visual scanning behavior post-hoc. For this, we used a pupil eye tracker[2].

Implementation Details

The prototype was implemented as a web application using HTML, CSS, JavaScript, JQuery, PHP and MySQL. Figure 2 shows the graphical user interface of the application.

The sentence for the primary task was shown to the left, above the text entry filed and the on-screen keyboard. The math task was displayed on the right side. In case of t_1, the arithmetic problem was shown right from the beginning, whereas in conditions t_2 and t_3 the space was initially blank.

Both text and math task had a ‘submit’ button. The final solution (entered text, result of equation) was stored in the database upon pressing these buttons. The final number of errors in the entered sentence, compared to the original sentence was calculated by applying the Levenshtein (edit) distance[3].

[2]Pupil Website: http://pupil-labs.com
[3]Levenshtein distance: http://xlinux.nist.gov/dads//HTML/Levenshtein.html

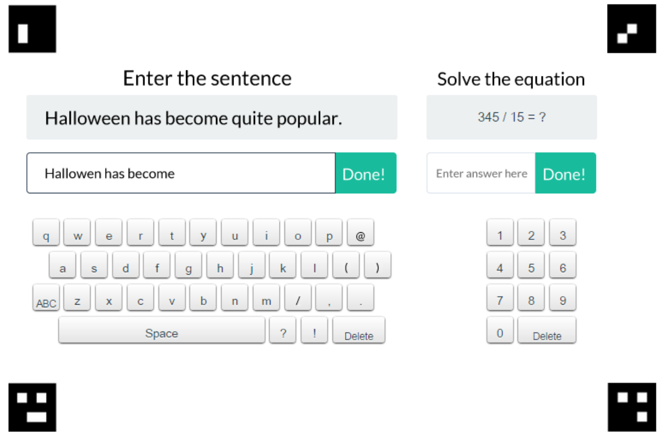


Figure 2. Graphical user interface of the public display application. The primary task was display to the left, the secondary task to the right.

The content of the text field was saved to the database via an AJAX request after each keystroke. This allowed us to later assess error rate and text entry speed as well as to analyze any task switches without loss of information.

The four markers around the interaction space were needed for the mobile eye tracker. They define a surface that is automatically detected by the eye tracker to record the gazepath.

LAB STUDY

To evaluate the constructed research questions with the developed prototype, a lab study was conducted. In the following we describe study design, procedure, and recruiting.

Study Design

In total, 18 text and math tasks had to be solved. The independent variables were the secondary task difficulty (easy, medium, difficult) and the temporal integration mode (t_1, t_2, t_3). The order of the text tasks was always the same, while the math task difficulty was varied in a counterbalanced manner. By using a latin square design, we ensured that each text task was combined with math tasks from all difficulty levels during the course of the study. The temporal modes were counterbalanced in such a way that throughout the study all sets of math tasks provide all possible permutations of the temporal inclusion types (t_1, t_2, t_3).

The dependent variables were performance data (task completion time and error rate of primary and secondary task, logged by the web app) as well as subjective ratings of frustration, mental effort, satisfaction with own performance, physical effort, distraction and preferred temporal embedding mode. Statements were assessed with questionnaires, using 5-point Likert scales (1=don’t agree at all, 5=totally agree).

Study Setting & Procedure

The user study was conducted in a university laboratory, where the application was deployed on a 46” landscape LCD monitor. Furthermore, the mobile eye tracker allowed participants to move their arms and hands freely without obscuring their eyes. In addition, we installed a second camera behind the users, so as not to distract them, but still to be able and

Figure 3. User Study: The participants are solving a sequence of main and secondary tasks on an interactive multi-touch display.

capture all comments and movements through video recordings for later analysis. Figure 3 illustrates the study setting.

After participants arrived at the lab, a brief introduction to the application was provided. To not influence the participants, they were not told the actual goal of this study. Rather we simply told them that the screen would display two different tasks which needed to be completed. After that we calibrated the eye tracker with the participants before they were given a sample task to get used to the virtual keyboard.

For the text task, we asked them to enter the whole sentence correctly, with upper and lower cases and all attendant punctuation characters. We also told them that there was no time limit. In total 36 tasks needed to be completed by them, of which 18 were text tasks and 18 were math tasks. Moreover, they were told that after 6 tasks the application pauses and that a questionnaire would be handed out to them that they would need to fill in immediately. In the final questionnaire the subjects were asked to rank their preferred temporal integration mode and to provide their demographic information.

After the study, we conducted semi-structured interviews, asking participants to comment on the perceived physical workload. We were also interested in their personal opinion, criticism and the perceived experience with the application.

Recruiting

We recruited people via University mailing lists and through social networks.

RESULTS

18 people between 24 and 28 years participated in the study. Of these, 10 were female and 8 were male. The majority of the participants (11) were university students (of which 5 are currently studying computer science), and 7 were working people. Moreover, all subjects owned a technical device that uses a virtual keyboard for text input via touch.

Quantitative Findings

The quantitative findings result from the evaluation of performance data and questionnaire items. The collected performance data were analyzed by using one-way repeated measures ANOVA tests and the questionnaire items by applying a Friedman test and in case of significance a subsequent Wilcoxon Signed-Rank Test. In respect of the eye tracker videos, only 15 out of 18 videos were analyzed due to hardware problems while recording.

The outcomes are described in the following, separated by the two categories of the study's conditions: difficulty and temporal integration mode of the secondary task.

Difficulty of Secondary Task

In this section we report on the influence of secondary task difficulty with regard to the three hypotheses.

H1: The higher the difficulty of the secondary task, the longer the task completion time of primary task.

No significantly higher task completion time of the primary task with increasing math difficulty in context of performance data could be noted. For the easiest math assignment it took on average 15 seconds to complete one text task, for the medium ones 13 seconds, and for the hardest category on average 29 seconds. No significant differences in the text entry speed could be observed.

From the questionnaire statements it was noted that the subjects had the feeling to be significantly faster in solving the text task when the secondary task was easy in comparison to the medium ($Z=-2.111$, $P=0.035$) or hard ($Z=-2.311$, $P=0.021$) level problems. In accordance with this finding, the participants felt significantly more time pressure in the medium ($Z=-2.070$, $P=0.038$) and hard ($Z=-0.741$, $P=0.458$) math tasks compared to the easy ones.

In short, the hypothesis can not be confirmed in respect of performance data, but the subjective assessment shows that the task completion time is perceived as shortest in the easy condition. As the medium and the hard math assignment put time pressure on the participants as well, the easy math mode performs best.

H2: The higher the difficulty of the secondary task, the more errors are made in the primary task.

By raising the math difficulty no significantly higher error rate in the final submitted sentences could be found. On the other hand, while typing significantly more errors were made in the easy math condition compared to the medium setting ($P=0.037$). No significant differences could be noted between the other conditions.

In the questionnaires the participants were asked whether the difficulty of the primary task always stayed the same throughout one set of tasks (6 tasks) which is one set of math difficulty. In the hard math condition all text tasks are perceived to be of a similar level of difficulty, in comparison to the medium ($Z=-2.332$, $P=0.020$) and easy math rounds ($Z=-2.021$, $P=0.043$).

To conclude, the final submitted sentences did not differ in the conditions, but while typing the least mistakes were made during the medium set. Hence, regarding this hypothesis the medium math tasks are superior to the easy math problems. A possible explanation for this result is the potential "safety" of the very easy tasks, luring some participants into jumping to the easy task first (see qualitative findings and eye-tracker results below), or into speeding up in the main task to get to the easy one, whereas a medium task may facilitate concentration.

H3: The higher the task difficulty of the secondary task, the higher the frustration level of the user.

The study's questionnaires contained items that indicate frustration, namely the perceived level of stress, annoyance, and discouragement. The latter did not indicate any significances, but the analysis revealed that with growing math difficulty the subjects felt significantly more stressed in all three conditions. In the easy math condition no one felt stressed (mean level 4 and 5 on the Likert scales), compared to 2 people in the medium setting (Z=−2.310, P=0.021). In the hard math rounds, 7 out of 18 people felt stressed, which is significantly more than in the medium (Z=−2.754, P=0.006) and the easy rounds (Z=−3.482, P<0.0005).

Furthermore, participants were significantly more annoyed during solving the hard math problems than solving easy (Z=−3.334, P=0.001) or medium (Z=−3.176, P=0.001) ones. When clustering all three items that indicate frustration (stress, annoyance and discouragement) and taking the maximum value of all three aspects, it can be seen that the harder to solve the math task, the more frustration was perceived by the test persons. With regard to the hard arithmetic problems, a total number of 9 persons (50%) reported to feel at least one of these aspects, while only 2 felt frustrated in the medium (Z=−3.115, P=0.002) and 1 in the easy math condition (Z=−3.488, P<0.0005). Even between the easy and the medium assignments a significant difference was found (Z=−2.179, P=0.029).

Hence, the hypothesis can be confirmed, meaning that with growing math difficulty the frustration level of users raises. This outcome is particularly important when a display is installed in public space, because all negative factors that could result in users leaving the display need to be averted.

Temporal Integration

Next, we report on the influence of temporal integration of the secondary task with regard to the founr hypotheses.

H4: Embedding the secondary task at t_2 leads to a higher distraction than embedding at t_1 or t_3.

This hypothesis states that in contrast to an integration of the math problem right from the beginning or after primary task completion, an embedding in the middle of text task completion process leads to a higher distraction from the primary task. The results reveal thats few participants felt distracted (only 11.11%), none disrupted (0%), and few felt the need to complete the math task first when it appears (only 5.56%). A total of 83.32% of the participants preferred to solve the tasks sequentially, meaning that they did not like to interrupt the text assignment for solving the arithmetic problem first. Nevertheless, one participants noted that the t_2 mode did not distract him and that he actually liked this mode, because it helped him to think about the math problem, while still typing the sentence of the primary task. From the recordings of the eye tracker videos, it can be noted that 7 out of 15 participants (46.67%) noticed that the math task was appearing during working on the primary task in condition t_2, but only 4 of them (26.67%) interrupted their primary task process in order to start solving the math assignment.

In conclusion, the secondary task was noticed by the participants, but not perceived as disturbing or disruptive.

H5: Embedding the secondary task at t_2 leads to a higher task completion time of the primary task than embedding at t_1 / t_3.

No significantly higher task completion time could be found in any of the temporal embedding conditions. In t_1 users needed on average 00:53 seconds per sentence, in t_2 00:52 seconds and the least time in t_3 with 00:48 seconds. Hence, the hypothesis cannot be accepted.

H6: Embedding the secondary task at t_2 leads to a higher error rate in the primary task than embedding at t_1 or t_3.

Analyzing the number of errors in the submitted sentences, no significant difference could be found between the temporal conditions. However, by comparing the number of submitted sentences that contained errors, it could be observed that significantly more sentences contained errors in t_2 (83.33%) than in t_3 (44.44%) (P=0.013).

The hypothesis can be partially confirmed due to the difference between t_2 and t_3. t_3 is the superior mode, as it leads to a higher chance of entering sentences correctly.

H7: Embedding the secondary task at t_2 leads to a higher frustration level of the user than embedding it at t_3.

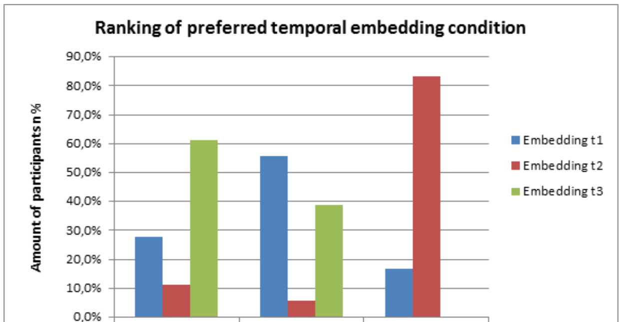
With regard to frustration, the expected higher level of stress and discouragement in condition t_2 compared to t_3 could not be confirmed. Yet, when integrating the secondary task at t_3, participants felt significantly more annoyed than at t_2 (Z=−2.299, P=0.022). Moreover, when clustering all three aspects indicating frustration, the results show that subjects felt significantly more frustrated at t_2 than at t_3 (P=0.041).

This verifies the hypothesis and leads to the conclusion that a secondary task which is displayed while users work on their primary task has a higher frustration potential than embedding the task just after completing the primary task.

At the end, subjects were asked to rank the temporal embedding conditions. The outcome is illustrated in Figure 4. Most participants favored integration at t_3 (61.1% for rank 1) which is displaying the secondary task after primary task completion. The second most popular mode is integration at t_1 that is presenting both tasks simultaneously (55.6% for rank 2). Least popular is integration at t_2 – displaying the secondary task during primary task completion (88.1% for rank 3).

Further Findings

In addition to the statements regarding the constructed hypotheses, the participants were asked to rate their expended physical effort. The results show that assignments were significantly different with regard to the required physical effort (P=0.004). For easy tasks the physical effort was considered significantly higher than for medium tasks (Z=−2 − 658, P=0.008) and hard tasks (Z=−2.191, P=0.028). This difference could not be observed between the medium and hard tasks (P=0.834). In contrast to the easy tasks, 6 out of 18 people (33.33%) stated that the set was physically highly exertive. Only 2 people felt a high physical effort during the medium and hard tasks (11.11%).



	Rank 1	Rank 2	Rank 3
Embedding t1	27,8%	55,6%	16,7%
Embedding t2	11,1%	5,6%	83,3%
Embedding t3	61,1%	38,9%	0,0%

Figure 4. Ranking of preferred temporal embedding mode.

From the videos we found that since the task completion time for the math tasks was considerably higher in the medium and the hard conditions, the users had more time to take down their arms, while solving the mental arithmetic. During this mental calculation they could relax their arms, before lifting them again to complete the math task before proceeding with the next text task. Easy math tasks were solved so quickly that users had to proceed with the text tasks instantly. Thus, there was no time for resting the arms.

From this we learn that, if deploying a primary task on a public display that can be physically exertive, a secondary task that allows the user to take down their arms is beneficial.

Qualitative Findings

Analysis of video and eye-tracking data revealed three different strategies of processing the two tasks.

Strategy 1: Main task first

Several users chose to perform the assignments always in the same sequence. 6 participants completed the text task and after submitting their sentence, they started to process the math task independently from its difficulty or temporal embedding.

Strategy 2: Shortest/easiest task first

The second strategy occurred in condition t_2 and is displayed in Figure 5. Four participants chose to interrupt their primary task once the secondary one appeared, to solve the math problem first. One participant even claimed that he liked easy tasks that he could solve quickly, because "it's fun to finish tasks rapidly". In this strategy, the math task was only performed prior to the text tasks when the difficulty level was easy (or medium for one person). For more difficult tasks, participants adapted their strategy: When the math task appeared, they suspended their primary task to look at the math problem. Was it a hard task, they decided that it was too difficult to solve rapidly, and resumed the text task first.

Strategy 3: Secondary tasks first

The last observed strategy occurred after users finished one pair of text and math tasks. In case the subsequent math task was displayed right from the start (t_1), 5 participants decided to solve the math task prior to the text tasks (see Figure 6).

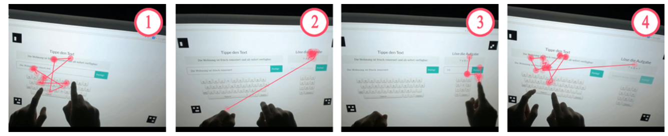


Figure 5. Strategy 2: A participant enters the text of the primary task (1). When the secondary task appears he disrupts his current activity, looks to the math problem (2) and solves it (3). After submission the user proceeds with the primary task (4).

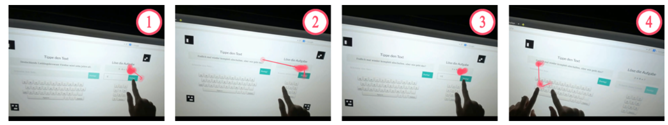


Figure 6. Strategy 3: A participant finishes a math task (1), and when the next math problem appears with condition t_1, the user has a look at both questions (2) and chooses to solve the math question first (3), before processing the text task (4).

Limitations

We acknowledge that our study is limited through the lab setting as well as the artificial tasks. While this allowed us to obtain results of high internal validity [5], it is not clear how well they generalize to a public setting with realistic tasks – for example as a playful or informative public display application is being interlaced with a short survey. We plan to investigate this in the future.

Another limitation is the fact that our secondary task was unrelated to the primary task. This is similar, for example, to showing a user a coupon for take-away during or after playing a game. At the same time, there may be cases where primary and secondary tasks are connected, for example, answering a question on the user experience with the game currently being played. This could have been reflected in our study by making participants count words, syllabi or letters. Future work could investigate the influence of the relationship between primary and secondary task in depth.

We believe that our findings revealed interesting direction for future research. For example, researchers could investigate how to make tasks less physically demanding through smartly embedding secondary tasks. Or displays could learn the strategy of the user when it comes to responding to secondary tasks and adapt the embedding strategy accordingly.

DISCUSSION

Regarding the level of difficulty of secondary tasks, both easy and medium difficulty conditions showed benefits and drawbacks: With easy math problems, the text task was perceived as most rapidly solvable and as evoking no time pressure. Moreover, easy tasks did not evoke frustration, while medium difficulty tasks indicated slight frustration, followed by hard tasks with the highest level of frustration. This needs to be accounted for on public displays. For example, a survey on the screen where users are required to simply select checkboxes may be preferable over open-ended questions that require users to both formulate an answer and enter it using an onscreen keyboard.

In contrast, the number of errors during typing was smaller in the medium difficulty condition compared to the easy set of tasks. Furthermore, the physical effort was rated to be lower in the medium and hard difficulty conditions. This suggests that secondary tasks should not be too simplistic. An example to account for this could be to slightly increase the number of available answer options (e.g., a 5-Point or 7-Point Likert scale in comparison to only 3 answer options). Despite being counter-intuitive this could both lead to more fine-grained results while at the same time positively affecting primary task performance. Difficult tasks led to the worst performance and should hence be avoided.

Based on our results, a clear recommendation with respect to the best temporal integration can be given: Although the distraction through the appearing secondary task in t_2 was less severe as previously expected, t_3 is the most preferred mode of temporal integration. Here, users showed the tendency to complete their primary tasks faster and submitted the most number of entirely correct texts as well. Moreover, the subjects felt less frustrated in condition t_3 compared to condition t_2. The results also showed that users preferred processing tasks sequentially, which is supported by embedding secondary tasks at t_3. Thus, temporal integration at t_3 is the most appropriate and recommended mode, as it showed good performance with little frustration. Note, however, that determining t_3 is not always straight-forward. Whereas the secondary tasks could be shown immediately after the end of a game level, after the user finished a transaction, or after he purchased a train ticket, additional means such as eye trackers may be required in cases where the user simply perceives content, for example, reading text on the screen or searching a particular location on a map.

IMPLICATIONS

We evaluated effects of the secondary task's difficulty and temporal integration on primary task performance, user perceptions and behavior. Based on our results, we derive the following implications for secondary tasks on public displays:

- *To minimize error rate and physical effort, secondary tasks of medium difficulty should be selected.* We explain this with a potential feeling of "safety" for the very easy tasks, which tempts some users to switch to the easy task first (as revealed with the eye-tracker), or letting them speed up in the main task to get to the easy one, whereas a task of medium difficulty may instead facilitate concentration.

- *Secondary tasks should ideally be displayed after natural break-points in the users' primary task.* This implies, that the primary task should be designed in such a way as to include multiple "natural" breakpoints or steps. For example, navigating an interactive shopping mall map could be structured by 1) selecting a wing, 2) then a floor level, 3) then browsing the map, until 4) selecting a point of interest.

- *Secondary tasks should not be too mentally demanding.* This implication is of high practical relevance and has not been shown before for secondary tasks on public displays. Interestingly, the reasons behind this implication are less straight-forward than one might expect: Subjectively, participants felt significantly more time pressure when presented with hard secondary tasks. Quantitatively, they also took longer to complete their primary task with hard secondary tasks, but not significantly so.

- *To minimize task completion time and frustration, easy secondary tasks should be selected.* While this may seem trivial, it should be seen in the light of the first implication; just "as easy as possible" may not always be the best choice.

In summary, these seemingly contradicting implications suggest that designers face a tradeoff: in cases where it is important that users finish their tasks quickly, easy secondary tasks are advisable. However, if it is more important that users make a minimum number of errors, then slightly more demanding secondary tasks may be employed.

CONCLUSION

We first charted a design space for secondary tasks on public displays, useful for designers of interactive display applications that confront users with additional tasks. We then investigated the influence of secondary task difficulty and temporal integration, measuring effects on task completion time, error rates, and perceived subjective qualities. Our results show that a secondary task should be embedded at the end of primary tasks, if possible, to mitigate distraction and annoyance. We have revealed that users handle switches between primary and secondary tasks with different strategies. We believe these insights to be useful for design and further research on applications of secondary tasks on public displays.

FUTURE WORK

The presented design space yields many opportunities to investigate further dimensions of secondary tasks, such as spatial integration. Moreover, a field study could investigate difficulty and temporal integration for comparison with our lab results. Finally, our findings suggest to integrate secondary tasks at the end of primary tasks, or natural breakpoints therein, such as submitting a form. However, such breakpoints might not always exist and users might leave the display based on their own internal reasoning (e.g. found desired information), rather than clear interaction steps. Hence, a promising direction for future work is investigating endpoint detection of public display interactions – for example by observing body movements and gaze to detect when users have finished their main task and are about to leave.

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