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Taking reading comprehension exams on screen or on paper? A metacognitive analysis of learning texts under time pressure

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A B S T R A C T

People often attribute their reluctance to study texts on screen to technology-related factors rooted in hardware or software. However, previous studies have pointed to screen inferiority in the metacognitive regulation of learning. The study examined the effects of time pressure on learning texts on screen relative to paper among undergraduates who report only moderate paper preference. In Experiment 1, test scores on screen were lower than on paper under time pressure, with no difference under free regulation. In Experiment 2 the time condition was manipulated within participants to include time pressure, free regulation, and an interrupted condition where study was unexpectedly stopped after the time allotted under time pressure. No media effects were found under the interrupted study condition, although technology-related barriers should have taken their effect also in this condition. Paper learners who preferred this learning medium improved their scores when the time constraints were known in advance. No such adaptation was found on screen regardless of the medium preference. Beyond that, paper learning was more efficient and self-assessments of knowledge were better calibrated under most conditions. The results reinforce the inferiority of self-regulation of learning on screen and argue against technology-related factors as the main reason for this.

1. Introduction

It has long been recognized that getting along in the modern world requires the ability to learn from textual material (Alexander & Jetton, 2000; Kintsch, 1998). Today, people face in-depth text learning in computerized environments in many contexts, such as reading comprehension tasks in schools, distance learning in higher education, computerized selection tests, training programs in the workplace, and scientific investigations (Allen & Seaman, 2010; Economides & Roupas, 2009; Livingstone, van Couvering, & Thumim, 2005; Precel, Eshet-Alkalai, & Alberton, 2009; Sung, Chang, & Huang, 2008). However, research has repeatedly shown that when people need to study a text thoroughly, they show a strong preference to learn from print rather than from a digital display (Buzzetto-More, Sweat-Guy, & Elobaid, 2007; Dilevko & Gottlieb, 2002; Jamali, Nicholas, & Rowlands, 2009; Spencer, 2006; Woody, Daniel, & Baker, 2010).

People often attribute their reluctance to study on screen to the inconvenience associated with the screen as a display medium. Early studies documented various factors as potentially giving rise to this reluctance (see Dillon, 1992 for a review). Most of these studies attributed the found differences between screen and paper learning to display-related factors such as ocular discomfort, display orientation, or polarity, though no single factor was found to underlie differences in learning outcomes and subjective preference (e.g., Cushman, 1986; Gould et al., 1987; Wilkinson & Robinshaw, 1987).

If indeed display-related factors are the source for the reluctance to study on screen, one might expect this preference to attenuate with recent technological advances. Yet, readers who use the most up-to-date technologies still cite a large variety of technology-related factors as alienating them from learning on screen. These include hardware-related factors, such as eyestrain and limited visual angle, and some that are software-related, such as font type and size, difficulty orienting within and among pages, and the inconvenience of navigation and annotating (e.g., Annand, 2008; Jamali et al., 2009).

Researchers have put a great deal of effort into comparing various computerized presentation conditions so as to identify those that enable better learning outcomes and subjective preference (Bias, Larson, Huang, Aumer Ryan, & Montesclaros, 2010; Dyson & Haselgrove, 2001; Potelle & Rouet, 2003; Ramadan, Mohamed, & El Hariry, 2010; Sanchez & Branaghan, 2011). However, evidence is beginning to accumulate that something other than technology-related factors is at work here. This evidence suggests that

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people activate less effective reading habits on screen than on paper (Liu, 2005; Morineau, Blanche, Tobin, & Guéguen, 2005). The present paper joins a small but growing body of studies which have examined medium effects on the cognitive processes involved in learning (e.g., Eshet-Alkalai & Geri, 2007, 2010; Garland & Noyes, 2004; Jones, Pentecost, & Requena, 2005; Morineau et al., 2005; Tewksbury & Althaus, 2000). Specifically, the present study examined the effect of the medium on metacognitive regulation of learning efforts.

1.1. Indications for medium effect on metacognitive learning regulation

Liu (2005) found in a self-report study that when reading on screen, people spend a large amount of time on browsing and scanning, keyword spotting, one-time reading, non-linear reading, and reading selectively. Importantly, the participants also reported less sustained attention and less time on in-depth reading with concentration. These findings suggest that computerized learning environments generate a context in which people tend to invest less cognitive effort (Morineau et al., 2005) or activate less effective learning habits (LaRose, 2010). That is, computerized learning suffers not necessarily because the medium provides a less supportive technological environment, but because learners do not recruit enough cognitive resources to succeed in the task (e.g., attention, memorizing strategies, self-examination). Indeed, studies have pointed to self-efficacy and goal-oriented learning as key factors that determine the success of computerized learning environments (Yi & Hwang, 2003).

Metacognitive learning regulation (MLR) refers to higher-order thinking which involves active control over the cognitive processes engaged in learning toward achieving one's goals (Brown, 1987). Activities such as planning how to approach a given learning task, setting goals, and monitoring the progress of knowledge acquisition toward the completion of a task underlie MLR decisions such as whether to invest more study time, restudy difficult sections, apply learning strategies, or seek help.

Only a few studies have examined the effect of the medium on MLR. Garland and Noyes (2004) found that subjective experiences that accompany retrieval processes after studying ("know" vs. "remember") tend to differ between screen and paper learning. They concluded that paper learning allows integration of new knowledge into the semantic memory more efficiently than screen learning. Garland and Noyes suggested that technological characteristics of cathode-ray tube (CRT) monitors, such as refresh rates, fluctuating luminance, and contrast levels, underlie the found differences.

Ackerman and Goldsmith (2011) aimed to disentangle technology-related factors and cognitive factors involved in the medium's effect on MLR. They presented a methodology for generating a *Metacognitive Learning Regulation Profile* (MLRP) that allows comparison of MLR among study conditions by a set of cognitive and metacognitive measures. In their study, undergraduate students studied expository texts on screen (on-screen learning, OSL) or on paper (on-paper learning, OPL), and were then tested using the same medium on which they had studied. After studying the texts but before being tested, participants predicted their performance, thereby providing a measure of their metacognitive monitoring. For each medium, one group studied the texts under a fixed and too-short time allotment (7 min), while another group was free to regulate their study time (M = 9.6 min). No difference in test scores was found between OSL and OPL when the study time was fixed (61.0% and 60.7%, respectively). Under the free regulation condition, however, OSL participants scored lower than those learning on paper (63.2% and 72.3%, respectively), even though under both media, the participants invested more study time under free regulation.

Ackerman and Goldsmith's (2011) results seem to discount technology-related factors as the main source of learning differences between OSL and OPL, because such factors were expected to affect screen learning regardless of the time condition. The results do point to the quality of MLR as an important factor in screen inferiority: Under OPL, free regulation and longer study time allowed better test scores than under fixed time. In contrast, although OSL participants also took the opportunity to study longer when they could, their test scores did not improve, which in fact reduced their study efficiency.

Consistent with this conclusion was Ackerman and Goldsmith's finding that screen learning was accompanied by a calibration bias in the direction of overconfidence: The subjective predictions of performance of the OSL group were inflated relative to their achieved test scores by about 10 points. Paper learners showed better calibrated predictions. Overconfidence is problematic because it is expected to misguide regulatory decisions (Aleven & Koedinger, 2000; Dunlosky & Thiede, 1998; Greene & Azevedo, 2007; Palincsar & Brown, 1984; Winne, 2004). For example, people who exhibit overconfidence may expect their knowledge to be satisfactory after a too-short study time and decide to stop studying, while their knowledge level is still too low to achieve their goals.

1.2. Text learning under time pressure

Central to achieving effective regulation of learning is self-control over study efforts (Tullis & Benjamin, 2011). In light of this principle, Ackerman and Goldsmith (2011) interpreted studying under a fixed study time as entailing less freedom to regulate study relative to the free regulation condition. However, working under fixed time conditions, such that the allotted time is short but nonetheless permits gaining a reasonable level of mastery, can be perceived by the participants as engaging in challenging work under time pressure. In particular, a complex task of learning expository texts of several pages, which takes several minutes to accomplish, still allows a relatively high degree of freedom even when the overall time is restricted. People who know the time constraints in advance may strategically allocate their cognitive resources, according to their motivation, perceived skills, and perceived difficulty of the task (Moneta & Csikszentmihalyi, 1999; Pintrich, 2003; Salomon & Globerson, 1987; Schunk, 2005). Thus, it is suggested in the present study that the fixed time condition may lead learners to a psychological state of learning under time pressure.

Working under time pressure has been suggested to have two consequences. On the one hand, awareness of time constraints may distract learners from the task at hand and so reduce their working memory resources (Dunlosky & Thiede, 2004; Kellogg, Hopko, & Ashcraft, 1999). On the other hand, mild time pressure can help learners with motivation to excel and clear action implementation intentions improve their study efficiency by disengaging from failing courses of action (Henderson, Gollwitzer, & Oettingen, 2007). Indeed, it was found that mild time pressure can improve reading comprehension (Walczyk, Kelly, Meche, & Braud, 1999).

When working under time pressure, the roles of MLR become more prominent (Dunlosky & Thiede, 2004; Zimmerman, Greenberg, & Weinstein, 1994). For example, under time pressure, studying information that is on the cusp of becoming knowledge may be more effective than investing time in items that are far from being learned (Mazzoni & Cornoldi, 1993; Metcalfe & Kornell, 2005; Son & Metcalfe, 2000; Thiede & Dunlosky, 1999; Winne, 2004). As learners cannot know with certainty their actual state of knowledge, they must estimate how close the material is to being sufficiently learned on the basis of metacognitive monitoring

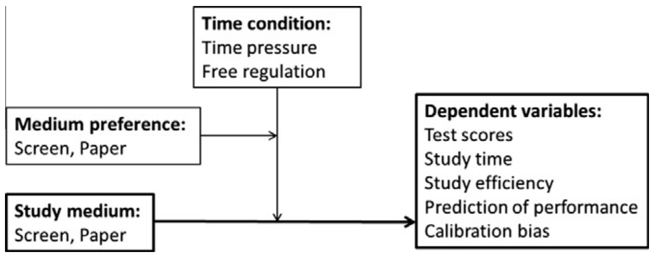

Fig. 1. The hypothesized relationships among the examined factors and the main dependent variables.

relative to their goals (Nelson & Narens, 1990). Thus, the quality of the MLR is a key factor in study efficiency, especially under time pressure.

These considerations suggest an intriguing alternative explanation for Ackerman and Goldsmith's (2011) findings. Ackerman and Goldsmith interpreted the equivalent test scores of OSL and OPL learners under the fixed time condition as reflecting similar MLR effectiveness regardless of the technological differences. However, if screen learning is perceived by learners to be more challenging because of technological barriers, and if they perceived the task as working under mild time pressure, this group may have recruited extra mental effort that allowed them to overcome these technological barriers and engage in especially efficient MLR. If this is indeed the correct interpretation, then the MLR of the OSL group was very efficient, to the extent that they brought their performance up to the level achieved by the OPL group, who did not face such technological barriers and perceived their study environment to be less challenging. The present study was designed to examine this alternative explanation.

2. Current study

2.1. Participant sample

The previous study drew its sample from students in the social sciences and humanities. At the onset of their study, Ackerman and Goldsmith (2011) had a self-report questionnaire regarding medium preference filled in by undergraduate students drawn from their target population ($N = 30$) in addition to people comprising a variety of other ages and occupations ($N = 126$ in total). The undergraduates, like the others, showed a strong paper preference: 90% regarded paper as providing a study environment that supports better comprehension. These self-reports were found to reliably predict the results of learning under free regulation. However, this sample produced no performance difference between the media under the fixed study time condition, which is interpreted as time pressure in the present study and constitutes its focus.

To maximize the likelihood of exposing recruitment of extra mental effort on screen under time pressure, the present study was performed with engineering students. This sample was expected to differ from the previous sample in several respects, including technological skills, motivation to excel, and epistemological beliefs (Jehng, Johnson, & Anderson, 1993; Paulsen & Wells, 1998; see Donald, 1999 for a review). In particular, this sample was expected to show an attenuated reluctance to study on screen, but still to show some preference for print. Indeed, a preliminary survey ($N = 42$) supported this prediction. The participants were asked to assume that they needed to thoroughly study an article that they could access only via the computer (by email or from a web site) in preparation for taking an exam or presenting a lecture. They were asked to indicate which medium they would prefer to use for studying the article (screen or paper) and explain their preference, and then to indicate whether they would expect to comprehend and remember the article better after studying it on paper, on screen, or to an equal extent on both. As expected, only 64% of this population preferred paper learning, and a similar percentage (62%) expected better learning outcomes on paper than on screen. However, the remainder of the sample (38%) expected no difference between the media, while no respondents expected an advantage for screen learning. Importantly, as in the previous study, the participants who reported preferring print over digital presentation cited technology-related factors such as eyestrain, orientation, reading angle, and the convenience of highlighting and note-taking.

2.2. Research questions

The present study examined the effects of the medium on the process of learning for an exam with and without time pressure in a population reporting only moderate paper preference. The examined factors, the hypothesized relationships among them, and the main dependent variables are depicted in Fig. 1. The central research questions are presented in Table 1.

Our first question, Q1, concerns the effect of the medium on test scores in light of the difference between the populations of Ackerman and Goldsmith (2011) and the present sample. Based on the previous study, we hypothesized that the survey answers would reliably predict natural learning outcomes, and we expected a reduced effect of the medium on freely regulated learning.

Table 1
Research questions and summary of findings.

Research question	Findings
Q1: Does the extent of reluctance to study on screen predict test score differences between the media?	Yes. The present sample, with attenuated reluctance to study on screen, achieved lower test scores on screen only under time pressure
Q2: Is the efficiency of learning on screen affected by technology-related factors?	No 1. Equivalent efficiency on paper and on screen was achieved under free regulation of study, but only when participants were interrupted before a self-decision to cease learning (Experiment 2) 2. No avoidance of highlighting and note-taking was evidenced when learning on screen
Q3: Do people activate particularly effective metacognitive learning regulation and become more efficient when facing the combined challenge of learning on screen under time pressure?	No. Although some participants became more efficient under time pressure, this was found for paper learning only, not for screen learning
Q4: Is the extent of reluctance to study on screen associated with the medium's effects on calibration bias? Is it dependent on the time condition?	Mixed results. Overall, there was a tendency for overconfidence on screen more than on paper. On screen, overconfidence was consistent across both experiments under time pressure, but under free regulation it was found only in Experiment 2. On paper, there was accurate calibration under all natural study conditions. Regardless of the time condition, overconfidence was associated with studying on the less desirable medium

In light of the reasons provided for a paper preference, Q2 deals with the role of technology-related factors in the efficiency of learning on screen. We divided the analysis of these factors into two: (1) the use of highlighting and note-taking, both suggested as important learning strategies (Kobayashi, 2007; Moos, 2009; Simpson & Nist, 1990), and (2) the effects of all other technology-related factors mentioned by participants. Highlighting and note-taking were not avoided when working on screen in the previous study (Ackerman & Goldsmith, 2011). Thus, we expected that all the more would they not be avoided among the present population. Ruling out this software-related factor allows a focus on other aspects of the subjective difficulty associated with the presentation of texts on screen.

The different patterns of medium preference can be expected to affect the balance between learners' perceptions of their own skills and of the challenges posed by studying under time pressure—a balance that is a key factor in recruitment of mental effort for concentration in learning tasks (Moneta & Csikszentmihalyi, 1999). As explained above, we hypothesized that if these motivated students can indeed recruit extra mental effort and regulate their learning effectively when faced with the combined challenge of working under time pressure on screen, they will be more efficient than those learning on paper. This is the issue raised in Q3.

With respect to the accuracy of metacognitive monitoring, Ackerman and Goldsmith (2011) found a consistent calibration bias in the direction of overconfidence among OSL participants, regardless of the time condition. Overall, people tend to be overconfident (Dunning, Heath, & Suls, 2004), and when exposed to only one study condition, they are often insensitive to external features of the task which affect their performance (Koriat, Bjork, Sheffer, & Bar, 2004). It is unknown how task characteristics such as study environment and time pressure affect the absolute level of knowledge monitoring. The present study explored whether the tendency toward overconfidence on screen depends on the extent of reluctance to study on screen and on the time condition (Q4).

2.3. Overview of the experiments

The study includes two experiments. Experiment 1 used a between-participants design and replicated the procedure of Ackerman and Goldsmith (2011), allowing a comparison between the populations of the two studies. Experiment 2 delved more deeply into the regulatory process required for learning efficiently under time pressure, and used a within-participant manipulation of the time condition. While in Experiment 1 medium preference was derived from the preliminary survey mentioned above, and so served in the study as a characteristic of the population, in Experiment 2 the participants filled in the self-report questionnaire in addition to performing the learning task. This made it possible to examine at the individual level whether a person's subjective preference is associated with the medium's effects on learning.

The dependent variables were study time, predictions of performance (POP) provided immediately after learning each text, and test scores. These direct measures enabled the derivation of two more important measures: study efficiency and calibration bias. *Study efficiency* was derived from test scores and study time, and reflected the average number of points gained per minute of studying. *Calibration bias* was measured as the difference between the POPs and test scores, and so reflected under- or overconfidence.

POPs also allowed the derivation of participants' learning goals, at least under the free regulation condition. This is because—according to the Discrepancy Reduction Model for the regulation of study time—people study until their subjective assessment of their knowledge reaches a satisfactory level (Dunlosky & Hertzog, 1998; Nelson & Narens, 1990; see graphical illustration in Ackerman & Goldsmith, 2011). Since under freely regulated learning POPs were provided when the participant decided to cease the learning process, these ratings can be seen as reflecting the participant's subjective assessment that his or her knowledge had reached the desired level, because otherwise he/she would have continued studying. Overall, participants set goals according to their perceived skills and the task content (Elliott & Dweck, 1988; Pintrich & Schunk, 2002; Winne, 1996), and these did not differ between the media. Indeed, Ackerman and Goldsmith (2011) found no difference between the goals set on screen and on paper. We expected no difference either, but used this interpretation of POP to control for the possibility that different goals might underlie performance differences, if any are found.

3. Experiment 1

The purpose of Experiment 1 was to examine the medium's effect on MLR under time pressure. Each participant studied two texts out of a pool of five texts used by Ackerman and Goldsmith (2011) (in that study, the results of the first two texts for each participant showed a pattern highly similar to that for the whole set of texts). Half of the participants studied under time pressure. The time allowed for studying each text was 7 min, as in Ackerman and Goldsmith (2011). This time frame was verified in a pilot study with the present population to be significantly shorter than the time allotted under a free study time schedule ($N = 10$; $M = 10.1$ min, $SD = 1.5$; $t(9) = 6.51$, $p < .0001$, $d = 6.66$). It was sufficient to permit reading the whole text and mastering some, but not all, of the material, and was therefore expected to introduce mild time pressure.

The remaining half of the participants were allowed to regulate their study time freely, with no time limit per text, though the instructions to participants defined a recommended time frame for each text (15 min). This recommendation ensured that all participants would be burdened to some extent by awareness of a time frame, and thereby controlled for the possible effects of such awareness, as distinct from pressure to complete the assigned task in a short time (Dunlosky & Thiede, 2004; Kellogg et al., 1999). The free regulation condition thus allowed exposure of unique aspects of learning under time pressure.

3.1. Method

3.1.1. Participants

Eighty undergraduate students in the department of Industrial Engineering at the Technion-Israel Institute of Technology ($M_{age} = 25.5$ years, 34% females) participated in the study. All participants reported having no learning disabilities. They were randomly assigned to one of four groups identified by the medium, OSL ($N = 40$) or OPL ($N = 40$), and time condition, time pressure ($N = 41$) or free regulation ($N = 39$; $N = 18–22$ in each group).

3.1.2. Materials

The five texts, 1000–1200 words (2–4 pages) each, dealt with various topics (e.g., the advantages of coal-based power compared to other energy sources; adult initiation ceremonies in various cultures). An additional, shorter, text (200 words) was used for practice. The texts were taken from web sites intended for reading on screen. Each text formed the basis for a multiple-choice test in which five questions tested recognition of details and five questions tested comprehension. An example of a question requiring recognition of details: In which decade did the "coal period" start in Israel? (a) 1960s; (b) 1970s; (c) 1980s; (d) 1990s. The answer (1980s) was explicitly mentioned in the text. An example of a comprehension question: The electricity production process involves a fast rotating rotor. What is the direct power source for this rotation? (a) gas exhaust generated by coal combustion; (b) fast flowing water; (c) steam; (d) hot air. The text explains that a high-temperature vapor is produced by coal combustion, which at high pressure then pushes a turbine that rotates the rotor (answer c).

3.1.3. Procedure

The experiment was administered in groups of up to eight participants in a small computer lab. All participants in each group worked on the same medium, and each participant studied and was tested on two texts.

The procedure for each text was identical to that used by Ackerman and Goldsmith (2011). The participants read the general instructions from a printed booklet. They were told that they would be asked to study for a multiple-choice test that would assess both their comprehension and their memory for details. The instructions for the OSL groups included explicit permission to edit the file and to use any highlighting or note-taking tool desired (e.g., boldface, underlining, highlighting, font color, marginal comments). A brief guidance regarding the use of such tools in Microsoft Word was given, even though participants were already familiar with these tools. Paper participants were provided with a yellow highlighter and a pen for note-taking.

For both media, the experiment was administered by a computer program. For the OSL groups, when the "Start" button was pressed, the program opened the relevant text in Microsoft Word, in an edit mode. Once participants finished learning they saved the file and closed the program. For the OPL groups, pressing the "Start" button opened a window on the screen indicating the title of the text to be studied. The participants took the printed text from the pile at their station and began reading. When they finished learning, they turned the text face down. Text learning in both media was ended by pressing the "Continue" button on the screen. Study time was measured as the time elapsed between the two button presses.

Two predictions of performance (POPs) were collected on screen immediately after the participant studied each text. Participants were asked to drag arrows along continuous 25–100% scales to indicate how well they thought they would do on test questions that involved (1) memory for details and (2) comprehension.

The procedure for the test was similar to that of the study phase. For the OSL group, the test form was opened in Microsoft Word. The participants marked their chosen option for each question using the yellow marker tool and saved the file. The OPL group marked their answers using a yellow marker on paper.

The experiment began with a run of the entire task (study, POP, and test) on the target medium, using the shorter practice text. Then the participants who worked under time pressure were informed that they would be given 7 min to study each text and 5 min for each test. The experimenter announced the time remaining when half the time had elapsed, and again 1 min before the time limit. The participants who worked under free regulation were informed in advance that they were free to allocate their study time across the texts, but they were advised that the time allotted for the whole experiment would allow about 15 min per text, including studying and taking the tests. This time frame was not strictly enforced.

3.2. Results

Several manipulation checks were performed. The first set dealt with the time investment. For the participants who worked under time pressure, a validation test assured that the mean test taking time ($M = 4.2$ min, $SD = 0.7$) was shorter than the 5 min allowed, $t(40) = 7.96$, $p < .0001$, $d = 1.24$, suggesting that participants did not fully exploit the time allotted for the test. The free regulation learners indeed invested more study time than the 7 min allotted under the time pressure condition ($M = 9.9$ min, $SD = 1.7$; $t(38) = 10.54$, $p < .0001$, $d = 1.69$). An additional manipulation check verified that under free regulation, for both the OSL and the OPL groups, the study and test phases together took less than 15 min per text ($M = 13.8$ min, $SD = 1.7$; $t(38) = 4.35$, $p < .0001$, $d = 0.70$), meaning that the participants complied with the overall time frame.

Test scores were calculated as the percentage of correctly answered questions out of ten. The scores were significantly higher than chance level (25%) and lower than perfect performance (100%) for each of the five texts (61–74%), all $ps < .0001$, assuring sufficient variability and allowing enough margins for POPs to show under- or overconfidence. The mean of the two POP ratings elicited for each studied text, one for memory for details and one for comprehension, was taken as the POP, reflecting the balance between the question types within the tests. Fig. 2 presents the mean test scores and POPs. Overall, the range of values in this study was similar to Ackerman and Goldsmith's (2011) results. This manipulation check indicates that the two populations are not qualitatively different in their overall learning skills, and allows focusing on the sensitivity of their learning processes to the media and to time pressure.

3.2.1. Test scores

To examine the combined effect of the Medium (screen vs. paper) and the Time Condition (time pressure vs. free regulation) on test scores, a two-way Analysis of Variance (ANOVA) was performed. The results showed a significant main effect of the medium, $F(1,76) = 4.06$, $MSE = 146.70$, $p < .05$, η_p^2(partial eta square) $= .05$, and a significant main effect of the time condition, $F(1,76) = 9.17$, $MSE = 146.70$, $p < .01$, $\eta_p^2 = .11$. The interactive effect was also significant, $F(1,76) = 5.33$, $MSE = 146.70$, $p < .05$, $\eta_p^2 = .07$. An analysis of the simple effects revealed no difference between the

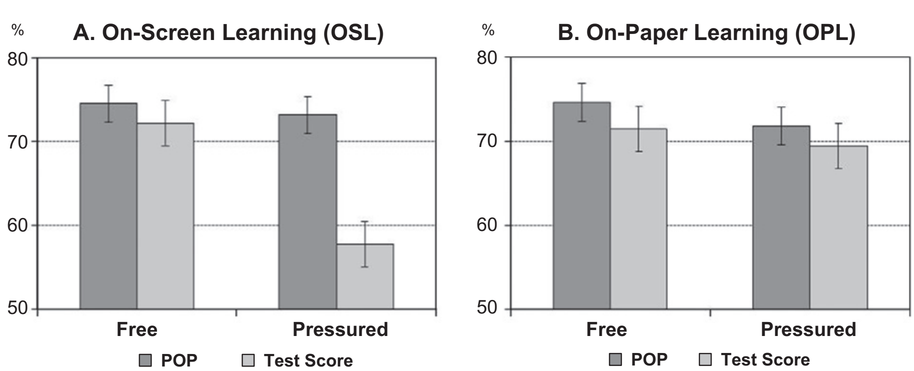

Fig. 2. Mean test scores and predictions of performance (POP) for the two time conditions in Experiment 1 for screen and paper learning. Error bars represent the standard errors of the mean.

media under free regulation conditions, $t < 1$. Under time pressure, in contrast, the OSL group achieved lower test scores than the OPL group, $t(39) = 3.81$, $p < .0001$, $d = 1.23$, despite facing the same task characteristics.

The use of highlighting and note-taking tools was analyzed to examine whether the subjective experience of difficulty in using such tools on screen, as reported in the survey, indeed leads to less utilization of these in-depth processing strategies. Overall, half of the participants used highlighting and note-taking for both texts (50%), a large proportion did not use them at all (35%), and the rest used them for one text. Under time pressure the participants used those tools less frequently on screen (0.7) than on paper (1.4), Mann–Whitney $U = 121.5$, $p < .05$. Under free regulation, in contrast, they tended to use them more on screen (1.6) than on paper (1.1), $U = 130.5$, $p = .10$. Although some association can be found between test scores and the use of highlighting tools, there is clearly no general avoidance of using these tools on screen.

3.2.2. Study time

Study time under the time pressure condition was fixed at 7 min. Study time under the free regulation condition was significantly longer overall, $t(38) = 10.54$, $p < .0001$, $d = 5.83$, with no difference between the media (OSL: $M = 9.8$ min, $SD = 1.6$; OPL: $M = 9.9$, $SD = 1.8$, $t < 1$).

3.2.3. Study efficiency

The study efficiency measure summarizes the relative differences in test scores and in times. It was calculated by dividing the test score by the study time. An ANOVA as above yielded a marginal main effect of the medium, $F(1,76) = 3.34$, $MSE = 3.06$, $p = .07$, $\eta_p^2 = .04$, a significant main effect of the time condition, $F(1,76) = 16.16$, $MSE = 3.06$, $p < .0001$, $\eta_p^2 = .18$, and a significant interaction, $F(1,76) = 6.00$, $MSE = 3.06$, $p < .05$, $\eta_p^2 = .07$. Under the free regulation condition, similar efficiency was found for the two media (OSL: $M = 7.6$, $SD = 2.5$; OPL: $M = 7.4$, $SD = 1.6$), $t < 1$. However, time pressure led to less efficient learning on screen ($M = 8.3$ points per minute, $SD = 1.2$) than on paper ($M = 9.9$, $SD = 1.6$; $t(39) = 3.81$, $p < .0001$, $d = 1.23$). A comparison of the time conditions within each medium revealed that under OSL, studying under time pressure was not accompanied by enhancement of efficiency, $t = 1.04$, while under OPL the difference between the time conditions was substantial, $t(38) = 4.94$, $p < .0001$, $d = 1.60$. Thus, studying on paper under time pressure was the most efficient condition, while OSL participants did not adjust their efficiency in light of the time constraints.

3.2.4. POP

As can be seen in Fig. 2, the differences in test scores were not reflected in POPs. ANOVA as above revealed no differences, all $Fs < 1$.

3.2.5. Calibration bias

The calibration bias was calculated as the discrepancy between mean POP and mean test score across the studied texts. An ANOVA on the calibration bias revealed a marginal main effect of the medium, $F(1,76) = 3.52$, $MSE = 183.82$, $p = .06$, $\eta_p^2 = .05$, a marginal main effect of the time condition, $F(1,76) = 3.63$, $MSE = 183.82$, $p = .06$, $\eta_p^2 = .05$, and an interactive effect, $F(1,76) = 4.68$, $MSE = 183.82$, $p < .05$, $\eta_p^2 = .06$. Overall, overconfidence characterized OSL ($M = 9.09$, $SD = 16.10$; $t(39) = 3.57$, $p = .001$, $d = 0.57$ for the difference from zero), but was negligible in OPL ($M = 2.79$, $SD = 11.73$; $t(39) = 1.51$, $p = .14$, $d = 0.24$). However, clearly the OSL calibration bias stems mainly from learning under time pressure ($M = 14.7$, $SD = 15.7$; $t(21) = 4.38$, $p < .0001$, $d = 0.94$). The overconfidence for OSL under time pressure was significantly greater than that found for the three other conditions (2.3–3.2; all insignificantly larger than zero, $t \leqslant 1$), all $ps \leqslant .001$.

3.3. Discussion

As expected, when allowed free regulation of their learning, the present sample showed no difference between the media. This finding is in accordance with the attenuated reluctance of the present sample to study on screen relative to the sample of Ackerman and Goldsmith (2011). It thus offers an answer for Q1 (see Table 1). This finding also rules out the possibility that the burden imposed by mere awareness of a time frame is associated with an effect of the medium. In addition, participants in both free-regulation conditions (OSL and OPL) had equivalent POPs, assuring us that no difference in goal setting underlies the found differences between the media.

However, under time pressure, the results show screen inferiority. Thus, although the less screen-wary participants of the current study can achieve similar results on screen and on paper under certain circumstances, paper learning still offers an advantage. This finding completes the answer to Q1. Interestingly, the POPs per text did not reflect acknowledgement of this difference, which resulted in overconfidence for OSL in general, and under time pressure in particular. This provides an answer for Q4.

Regarding Q3, the results suggest that the current population of students is generally capable of working highly efficiently under time pressure. However, the findings in this respect are surprising, as greater efficiency under time pressure was not found for screen learning, as expected, but for paper learning. Why should this be so? This question—which corresponds also to Q2—remains open, as it is not yet clear whether the difference between the media under time pressure stems from technological factors or from the particular effectiveness of the MLR on paper. The findings reduce the likelihood of technological factors as the main source for the difference under time pressure, because such factors were expected to take their effect in both time conditions, and because no consistent difference was found between the media in the use of highlighting and note-taking. Nevertheless, it is possible that learners are distracted by technological factors, but when allowed free regulation they can effectively overcome these distractions. Experiment 2 was designed to adjudicate between these two explanations.

4. Experiment 2

The purpose of Experiment 2 was to further examine the source for screen inferiority under time pressure. In this experiment, the time condition was manipulated within participants. Each participant studied five texts under three time conditions: time pressure, free regulation, and interrupted study. The time pressure and free regulation conditions were as in Experiment 1. In the interrupted study condition, participants began studying one text under free regulation instructions, and were interrupted after 7 min – the time allotted under the time pressure condition. Thus, the only difference between the time pressure and the interrupted study conditions was participants' knowledge of the time constraint in advance of studying under time pressure, but not under the interrupted study condition. The interrupted study condition took place between the other two conditions, for the third study text, while the order of the other two conditions was counterbalanced across participants. Fig. 3 presents the timeline of the experiment for the two orders. Within each order, the tasks were given either on screen or on paper.

If strategically improved MLR was responsible for the performance superiority achieved on paper under time pressure in Experiment 1, knowing the time constraint in advance should allow better scores than when study is planned for free regulation and then interrupted. If the two groups perform similarly under interrupted study, this will support the MLR effectiveness explana-

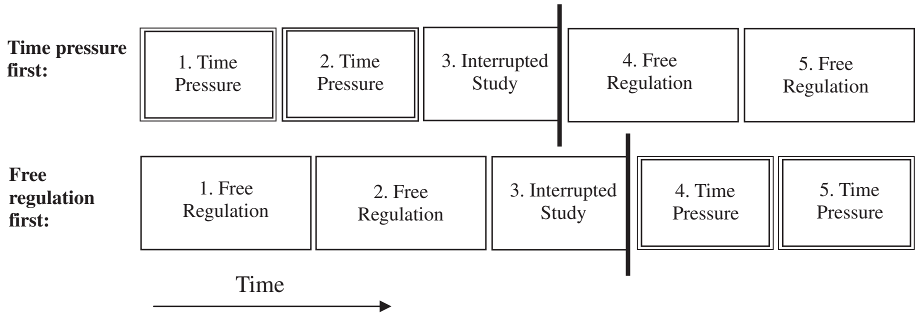

Fig. 3. Timeline of the within-participant manipulation for the two condition orders of Experiment 2.

tion for screen inferiority under time pressure. If, on the other hand, lower scores are found under this condition on screen, technology-related factors that might have been remedied at a later stage cannot be ruled out as the source for the test scores equality found under free regulation in Experiment 1. In order to allow examination of the relationship between medium preference and the differences between screen and paper on an individual basis, the self-report questionnaire described above was filled in at the conclusion of the experimental session.

4.1. Method

4.1.1. Participants

Seventy-six students (M_{age} = 25.4 years; 42% females) were drawn from the same population used for Experiment 1. The participants were randomly assigned to OSL and OPL groups (N = 38 in each group). The order of the time conditions was counterbalanced within each group.

4.1.2. Materials

The materials were the five texts which served as the pool of texts for Experiment 1. Each participant studied all five texts. The texts were randomly assigned to their position in the study list for each participant.

The self-report questionnaire was printed on one page. After providing a few personal details, respondents were asked about their preferred medium, paper or screen, and about their perceptions of study effectiveness. Possible answers were paper, screen, or no difference.

4.1.3. Procedure

The specific procedure for each text (study, POP, and test) was identical to that used in Experiment 1. All groups began with the short practice text on the target medium of the group. The procedure then varied based on the within-participant manipulation of the time conditions. Groups that began with the time pressure condition (upper timeline in Fig. 3) were told that they would be given 7 min to study each text and 5 min to complete the relevant test. As they were working on the second test, participants were asked to wait before going on to the third text. At that point, they were told that they would be free to allocate as much time as they needed for each of the three remaining texts, within a global time frame of 45 min, which allows a mean of 15 min per text. After 7 min, the experimenter interrupted the study, and the participants were required to provide their POPs and take the third test. The experimenter then reassured participants that they would not be stopped unexpectedly again, and the experiment proceeded through the fourth and fifth texts with a global time frame of 30 min.

Groups that began with the free regulation condition (lower timeline in Fig. 3) were told that they were free to allocate their time across the five texts, within a global study time of 75 min; they were advised to keep in mind that this would average out to 15 min per text. During their work on the second text, participants were asked to wait before going on to the third text. They started the third text at the same time, without special instructions, and were interrupted by the experimenter after 7 min. When the third test was completed, the experimenter explained the procedure for the time pressure condition.

The participants filled in the self-report questionnaire after completing the experimental procedure. The whole procedure, including instructions and the practice text, took about 90 min.

4.2. Results

First, to confirm that the data could be used for within-participant analyses, the effect of time condition order was examined. In a set of two-way ANOVAs of Order (time pressure first vs. free regulation first) $\times$ Medium (screen vs. paper) on all dependent variables, no significant main effects for order, all $ps > .20$, or interactive effects with the medium were found, all $ps > .15$. Thus, the following analyses were conducted across the two orders.

In the self-report, 58% of the participants stated that they would print the article for thorough learning. They attributed their paper preference to similar technology-related factors as mentioned in the preliminary survey. As for comprehension and memory of the article's content, 51% of the participants thought that paper would produce better outcomes, 3% (N = 2) thought that screen was preferable, and 43% expected no effect of the medium on their comprehension and memory (two participants did not answer this question). Importantly, no difference in medium preference was found between participants who were assigned to OPL and OSL prior to filling out the questionnaire, $\chi^2(3) = 4.13$, $p = .25$.

Test scores and POPs per medium and time condition are presented in Fig. 4. Overall, the main results of Experiment 1 regarding OSL inferiority under time pressure were replicated in the within-participant manipulation. Thus, the results report focuses on a comparison of the interrupted study condition with the time pressure and free regulation conditions.

4.2.1. Test scores

The role of mental effort regulation was examined by comparing the interrupted study condition with the other two conditions to see in which medium, if either, participants benefited from knowing the time constraint in advance. A two-way ANOVA of Medium $\times$ Time condition (3) on test scores revealed a main effect of the medium, $F(1,74) = 5.72$, $MSE = 294.76$, $p < .05$, $\eta_p^2 = .07$, a main effect of the time condition, $F(2,148) = 11.14$, $MSE = 157.84$, $p < .0001$, $\eta_p^2 = .13$, and a significant interactive effect, $F(2,148) = 4.29$, $MSE = 157.84$, $p < .05$, $\eta_p^2 = .06$. Comparisons between the media in the three time conditions yielded a significant difference in test scores only in the time pressure condition, $t(74) = 3.91$, $p < .0001$, $d = 0.91$. A one-way

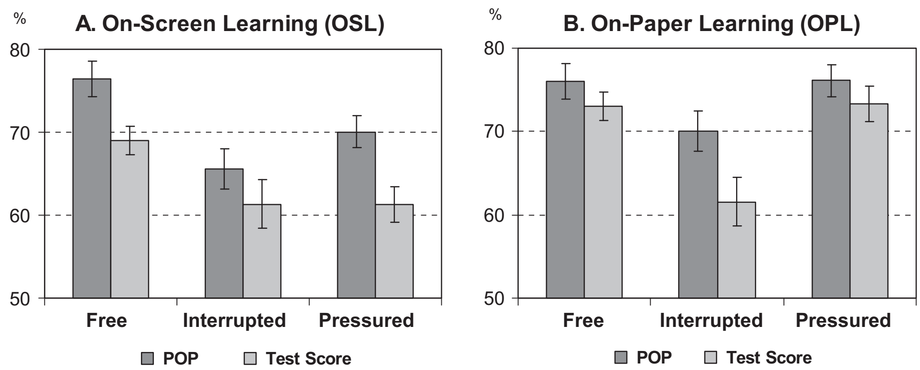

Fig. 4. Mean test scores and predictions of performance (POP) for the three time conditions in Experiment 2 for screen and paper learning. Error bars represent the standard errors of the mean.

ANOVA was then performed for each medium separately to examine the pattern of differences between the three time conditions. For both media the effect was significant, $F(2,74) = 4.39$, $MSE = 168.13$, $p < .05$, $\eta_p^2 = .11$ for OSL and $F(2,74) = 11.51$, $MSE = 147.55$, $p < .0001$, $\eta_p^2 = .24$ for OPL. For OSL, a post hoc analysis by LSD pairwise comparisons showed absolutely no difference between the interrupted study and time pressure conditions, $p = 1.0$, and significant differences between the free regulation and both other conditions, $p < .05$ and $p = .001$ for the interrupted study and time pressure conditions, respectively. For OPL, in contrast, significant differences were found between the interrupted study condition and the other two conditions, both $ps < .0001$, with no difference between the time pressure and free regulation conditions, $p = .91$. Importantly, the results indicate that for both groups the time pressure was mild, as it did not reduce study effectiveness relative to the natural learning process that took place under the interrupted study condition.

The use of highlighting and note-taking tended to characterize all three conditions consistently for each participant. Thirty-five percent used these tools for all five texts (24%) or for all but one (11%), while 58% used them for only one text (15%) or not at all (43%), making the comparison between the time conditions not meaningful. A comparison between the media revealed that the OSL group used these tools ($M = 2.9$ texts, $SD = 2.1$) more often than the OPL group ($M = 1.1$ texts, $SD = 1.8$), $U = 386.5$, $p < .0001$. Thus, as in Experiment 1, the OSL participants clearly did not avoid highlighting and note-taking on screen.

The question arises whether medium preference, as reflected in the self-reports, was associated with the achieved test scores. To resolve this question, a three-way ANOVA of Medium preference (screen vs. paper) × Study medium (2) × Time condition (3) was conducted. Beyond the above-mentioned effects, the triple interaction was significant, $F(2,140) = 3.24$, $MSE = 156.04$, $p < .05$, $\eta_p^2 = .04$. Analysis of the interaction revealed that among those who preferred studying from the computer screen, no significant differences were found between OSL and OPL, all $ps > .15$, but the trends under all time conditions were in the direction of lower scores for OSL than for OPL. Among those who preferred studying from a printed text, significant differences were found between OSL and OPL under time pressure (OSL: $M = 59.4$, $SD = 14.3$; OPL: $M = 74.0$, $SD = 12.0$; $t(42) = 3.63$, $p = .001$, $d = 1.12$), and also under free regulation (OSL: $M = 68.8$, $SD = 9.0$; OPL: $M = 74.8$, $SD = 11.2$; $t(42) = 1.98$, $p = .05$, $d = 0.63$). Thus, only participants who preferred studying on paper studied effectively on paper under time pressure. In addition, those participants scored higher than those who studied on screen even when they could freely regulate their learning.

4.2.2. Time

Study time in the interrupted study and time pressure conditions was fixed. Under free regulation, participants tended to invest longer on screen ($M = 9.1$ min, $SD = 1.9$) than on paper ($M = 8.3$ min, $SD = 2.0$). An ANOVA of the effects of Medium preference (screen vs. paper) × Study medium (OSL vs. OPL) yielded only a marginal main effect of the study medium, $F(1,70) = 3.13$, $MSE = 3.76$, $p = .08$, $\eta_p^2 = .04$, with no interactive effect, $F < 1$. Thus, medium preference did not affect time investment.

4.2.3. Study efficiency

The marginal difference between the media in the time invested under free regulation along with the difference in test scores between the media under the time pressure condition highlights the importance of the study efficiency measure. An ANOVA of Medium × Time condition (3) on study efficiency yielded a main effect of the medium, $F(1,148) = 1.58$, $MSE = 9.55$, $p = .01$, $\eta_p^2 = .08$, a main effect of the time condition, $F(1,148) = 6.25$, $MSE = 3.74$, $p < .01$, $\eta_p^2 = .08$, and an interactive effect, $F(1,148) = 3.96$, $MSE = 3.74$, $p < .05$, $\eta_p^2 = .05$. A comparison between the media for each time condition yielded no difference under the interrupted study condition ($M = 8.8$ in both media), $t < 1$, but lower efficiency on screen under both other conditions. Under time pressure, efficiency on screen was the same as under the interrupted study condition ($M = 8.8$, $SD = 1.9$), while on paper it was significantly higher ($M = 10.5$, $SD = 1.9$; $t(74) = 3.91$, $p < .0001$, $d = 0.9$). Importantly, there was also a significant difference under the free regulation conditions, with efficiency on screen ($M = 7.9$, $SD = 2.3$) lower than on paper ($M = 9.3$, $SD = 2.9$; $t(74) = 2.28$, $p < .05$, $d = 0.6$). One-way comparisons of study efficiency between the time conditions for each medium yielded a marginal effect for OSL, $F(2,74) = 2.89$, $MSE = 3.38$, $p = .06$, $\eta_p^2 = .07$, and a significant effect for OPL, $F(2,74) = 3.92$, $MSE = 4.11$, $p < .01$, $\eta_p^2 = .16$. Post hoc comparisons revealed that on screen, study under free regulation was significantly less efficient than under time pressure, $p < .01$, but, importantly, it was also less efficient than under the interrupted study condition, $p < .05$, suggesting that the additional time invested under free regulation was not efficiently used for test score improvement. As clearly evidenced by the test scores, absolutely no difference in efficiency was found between the interrupted study and time pressure conditions, $p = 1$. On paper, in contrast, free regulation and the interrupted study condition did not differ significantly, $p = .31$, and efficiency under the time pressure condition was higher than for both, $p < .05$ and $p < .0001$ for the free regulation and interrupted study conditions, respectively. Examination of the effect of medium preference on this finding yielded no main effect and no interactive effect, both $Fs < 1$. These findings expose an important efficiency difference between the media. See the Discussion.

4.2.4. POP

In contrast to Experiment 1, POPs showed variability across the time conditions, as can be seen in Fig. 4. A two-way ANOVA for the effect of Medium × Time condition (3) revealed a main effect of time condition, $F(2,148) = 22.99$, $MSE = 59.53$, $p < .0001$, $\eta_p^2 = .24$, and a significant interactive effect, $F(2,148) = 3.56$, $MSE = 59.53$, $p < .05$, $\eta_p^2 = .05$. The main effect of the time condition indicates an overall sensitivity to task characteristics. The difference between the media was significant only for the time pressure condition. POPs were lower for OSL than for OPL, $t(74) = 2.23$, $p < .05$, $d = 0.52$. Both media yielded significant effects in one-way ANOVAs comparing the three time conditions, $F(2,74) = 25.05$, $MSE = 44.49$, $p < .0001$, $\eta_p^2 = .40$ for OSL and $F(2,74) = 6.25$, $MSE = 74.57$, $p < .01$, $\eta_p^2 = .15$ for OPL. For OSL, all pairwise comparisons between the three time conditions yielded significant differences, all $ps \leqslant .01$. For OPL, in contrast, the analysis showed significant differences in POP between the interrupted study and the other two time conditions, both $ps < .01$, but absolutely no difference between the time pressure and free regulation conditions, $p = .96$. Thus, while for the OPL group the differences in test scores were reliably reflected by differences in POP, for OSL, the difference in POP between the interrupted study and time pressure conditions was not matched by an equivalent difference in test scores.

Examination of the role of medium preference by a three-way ANOVA as above yielded, beyond the effects reported above, a two-way interaction between medium preference and study medium, $F(1,70) = 5.51$, $MSE = 398.41$, $p < .05$, $\eta_p^2 = .07$. Regardless of the time condition, those who preferred learning on screen provided lower POPs for OSL ($M = 69.2$, $SD = 11.4$) than for OPL ($M = 79.4$, $SD = 7.9$; $t(28) = 2.92$, $p < .01$, $d = 1.10$), while those who preferred paper provided similar POPs for both media (OSL: $M = 72.8$, $SD = 10.7$; OPL: $M = 71.0$, $SD = 14.1$; $t < 1$). Thus, interestingly, those who preferred studying on screen provided relatively high POPs when facing the task on paper. However, it is difficult to interpret this result without reference to the test scores, to which we turn next.

4.2.5. Calibration bias

The correspondence of POPs to test scores was further examined by a two-way ANOVA on the calibration bias. This analysis yielded no main effects, but a significant interactive effect, $F(2,148) = 4.03$, $MSE = 145.07$, $p < .05$, $\eta_p^2 = .05$. A one-way ANOVA for each medium did not yield significant effects. The interactive effect stemmed from the fact that the patterns for OSL and OPL were in opposite directions. As can be seen in Fig. 4, when the participants were allowed free regulation of their study, in comparison to the interrupted study condition, the calibration bias tended to increase for OSL: There was significant overconfidence under time pressure and under free regulation, both $ps \leqslant .001$, $d > 0.55$ for the difference from zero, but the calibration bias did not reach significance under the interrupted study condition, $p = .09$, $d = .28$. For OPL, in contrast, significant overconfidence was found under the interrupted study condition, $p < .0001$, $d = 0.66$, but not in the other conditions, both $ps > .18$, $d < 0.22$. Thus, in both natural learning conditions the OPL group was well calibrated.

As with POP, examination of the role of medium preference by a three-way ANOVA yielded a two-way interaction between medium preference and study medium, $F(1,70) = 7.92$, $MSE = 248.33$, $p < .01$, $\eta_p^2 = .10$, which was not associated with the time condition. Delving into this interactive effect revealed that those who preferred screen learning were marginally more calibrated when assigned to the OSL group ($M = 3.8$, $SD = 7.6$; $t(12) = 1.79$, $p = .10$, $d = 0.50$ for the difference from zero) than when assigned to the OPL group ($M = 8.5$, $SD = 7.2$; $t(16) = 4.88$, $p < .0001$, $d = 1.18$), $t(28) = 1.73$, $p = .09$, $d = 0.64$. Those who preferred paper showed a calibration bias when they were assigned to the OSL group ($M = 9.2$, $SD = 11.2$; $t(23) = 4.02$, $p = .001$, $d = 0.82$ for the different from zero), but were absolutely calibrated when assigned to the OPL group ($M = -0.23$, $SD = 9.6$; $t < 1$), and this difference was significant, $t(42) = 2.96$, $p < .01$, $d = 0.92$. Thus, the participants in both groups were well calibrated when they studied on their preferred medium, but suffered from overconfidence when facing the task on the less desirable medium.

4.3. Discussion

Experiment 2 replicated in a within-participant design the finding of screen inferiority under time pressure. Although, unlike in Experiment 1, in this experiment the OSL group studied more efficiently under time pressure than under free regulation, their test scores under time pressure were nonetheless much lower than achieved by the OPL group. Importantly, their efficiency under time pressure was not higher than in the interrupted study condition. On paper, there was full replication of the high efficiency under time pressure found in Experiment 1, which led participants to score as well under pressure as under free regulation, but using significantly less time. The results for the free regulation and interrupted study conditions suggest that for the OSL group, learning efficiency fell over time, meaning their learning was less efficient during the later stages. In contrast, on paper the participants kept their efficiency constant throughout the learning process.

The results support the predictive power of respondents' general medium preference (Q1). Indeed, this finding is strengthened by the fact that in the time pressure condition, participants who expressed a preference for paper, and who were assigned to the OPL group, scored more than 10 (!) points higher than participants assigned to learn on screen. Moreover, a paper preference within the OPL group was also associated with higher scores and better calibration of POPs (Q4) when free regulation was allowed. By most measures, those who preferred screen learning did not benefit from studying on their preferred medium, though they did have a marginally reduced calibration bias when they studied on screen relative to studying on paper (Q4).

The main purpose of this experiment was to help adjudicate between two possible explanations for the finding of screen inferiority under time pressure by adding the interrupted study condition. No differences were found between OSL and OPL in this condition. In addition, the intensive use of highlighting and note-taking on screen points away from a problem in applying these strategies as the source of screen inferiority. Both of these findings discount the role of technological factors as the cause for screen inferiority under time pressure and provide an answer for Q2. As for the MLR effectiveness, the results provide decisive evidence that OSL participants did not take advantage of the opportunity to plan ahead when they knew the time constraints in advance, as OPL participants did (Q3). In addition, a calibration bias was found for OSL under natural learning conditions, while accurate monitoring was found under these conditions for OPL (Q4). Thus, the results support the explanation suggesting that OSL is characterized by inferior MLR.

5. General discussion

The starting point of the present study was the fact that while screen inferiority is commonly attributed to technology-related factors associated with both hardware and software, evidence has begun to emerge pointing to differences between screen and paper learning in cognitive factors that are related to MLR. The study was conducted with a population in which the reluctance to study on screen is not strong. Although more participants reported that they preferred learning on paper, a significant percentage indicated that they would not print out material for study but would learn it on screen. Importantly, those who did not expect a paper advantage in learning outcomes also did not expect a screen advantage, but expected to acquire equivalent levels of knowledge on the two media. Indeed, no advantage was found for screen learning in any of the examined measures.

The answers to the research questions are summarized in Table 1. The results suggest that the participants were correct in expecting no medium effect on their test scores when they could regulate their study freely. But they were also correct that differences between the media still exist, despite the attenuated reluctance to study on screen (Q1), because in both experiments, when participants had to study under time pressure, they studied more efficiently on paper than on screen. The findings of Experiment 2 strengthen this finding by showing that medium preference has a strong predictive value not only on test scores with and without time pressure, but also on calibration bias (Q4). Overall, the findings support the hypothesized model presented in Fig. 1, and highlight the contribution of MLR to the inferiority of learning on screen.

5.1. Dissociating technology-related factors and metacognitive learning regulation

The finding of screen inferiority when studying under time pressure could have stemmed from several sources. The present study examined three possibilities: (1) the extra cognitive effort devoted to awareness of the time during learning; (2) the effect of technology-related barriers (Q2); and (3) the effectiveness of MLR (Q3). The first possibility was ruled out as a cause for this inferiority by the finding that test scores were similar for the two media when a global time frame was defined but the instructions directed participants to a free regulation mode of learning (under both the free regulation and the interrupted study conditions).

The results also argue against technology-related barriers as the main source for screen inferiority under time pressure (Q2). If technology-related factors were responsible for this inferiority, they should have taken their effect under all conditions, either by generating consistent differences in test scores or by revealing evidence for compensatory actions. Several findings suggest that this is improbable. First, if OSL participants had recruited more mental effort to compensate for technological barriers under time pressure than under free regulation, this should have emerged via differences when the learning was interrupted unexpectedly (Experiment 2), while in fact absolutely no difference was found. It is possible that the chosen interruption point came too late in the process to matter, but in the absence of any other supporting evidence and given the pronounced differences between the media under time pressure, this possibility seems to be implausible. Second, in contrast to the common perception (e.g., Jamali et al., 2009; Liu, 2005), OSL participants used highlighting and note-taking more often than the OPL group in most conditions over the two experiments. Thus, media differences cannot be attributed to the level of technological support available during active learning. Overall, it appears that the reluctance people express regarding highlighting and note-taking on screen constitutes a misleading subjective perception which they do not follow in practice.

The results do point to the effectiveness of MLR as the main source for screen inferiority under time pressure (Q3). The strongest evidence in support of this conclusion is that for OSL, no significant difference was found in Experiment 2 between learning under time pressure and learning that started under free regulation instructions and was then interrupted after the same amount of study time. Looking at the same comparison for OPL, participants achieved markedly higher test scores when the time constraints were known in advance, suggesting that strategic recruitment of mental effort allowed an improvement in study effectiveness. Indeed, this strategic regulation allowed OPL participants who studied under time pressure to perform about as well as when they were allowed to study freely (Experiments 1 and 2). Importantly, the results of Experiment 2 associate this finding with medium preference—those who scored highest on paper under time pressure were those who preferred print as a medium for studying texts thoroughly (Q1).

Looking at the present study together with Ackerman and Goldsmith (2011), the findings of the two studies suggest that learning on screen yields inferior MLR relative to paper learning. In Ackerman and Goldsmith's study, screen inferiority was revealed under free regulation. The present study's population could overcome this limitation, but participants' performance was still inferior when learning on screen under time pressure. Moreover, in Experiment 2, although test scores were not lower under the free regulation condition, time management was less effective and led to lower study efficiency on screen than on paper. Particularly striking is the finding that under the interrupted study condition, learner efficiency was equivalent for both media. This finding suggests that the later stages of the learning process were less efficient on screen than on paper, meaning that OSL participants wasted some of their learning time. Thus, the present study provides evidence that even when people are capable of achieving similar test scores on both media, and also of engaging in efficient learning when facing time pressure on paper, screen learning hinders the MLR.

In Ackerman and Goldsmith's (2011) study, the participants did not recruit extra mental effort on paper under time pressure despite their clear paper preference. They only performed better when they had control over their study time, an advantage that was not achieved on screen. This difference between the two studies may reflect differences in learning styles between the two populations (Donald, 1999; Jehng et al., 1993; Paulsen & Wells, 1998). It thus appears that the alternative explanation for Ackerman and Goldsmith's results, which suggested that studying on screen under time pressure led to recruitment of extra mental effort (Q3), is not plausible. A direct examination of this question with a population that shows a strong paper preference would go farther toward confirming this.

In both studies, people's degree of reluctance to study on screen was predictive of the medium's actual effect on learning under free regulation (Q1). The reliability of the self-reports suggests that participants' attitudes are key to interpreting the results. This emphasis is in agreement with recent calls to bridge research and application by examining relevant learner characteristics for developing personalized learning environments (Vandewaetere, Desmet, & Clarebout, 2011). Of course, additional learner characteristics should be explored as possible factors leading to the present findings.

Generally, it is known that people tend to be overconfident in many domains of life (Dunning et al., 2004). In the present study, OPL allowed accurate calibration in most conditions. This finding emphasizes the inferiority of MLR when learning on screen, as POP ratings of the OSL group tended to be inflated in relation to their achievement (though not in all conditions), even though the materials allowed good calibration. Interestingly, an association between the preferred learning environment and the accuracy of metacognitive monitoring was found (Q4). The participants who reported a preference for learning on paper showed consistent overconfidence on screen, regardless of the time condition, across both populations. However, in Experiment 2 those who preferred learning on screen showed accurate calibration when they indeed faced the learning task on screen. Of course this finding calls for further examination, but a challenge for future studies is to determine whether people able to monitor the quality of their metacognitive processes and derive their medium preference on this basis.

5.2. Goal setting and pursuit under time pressure

The present study aimed to investigate the effect of the medium—paper vs. screen—on learning under time pressure. However, the cognitive and metacognitive measures collected, along with the measurement of study time, also allow a theoretical analysis of learning under time pressure from a more general perspective. An effective use of time is a central component in effortful cognitive processes that is deemed to facilitate productivity and alleviate stress (Wirth, Künsting, & Leutner, 2009; see Zempetakis, Bouranta, & Moustakis, 2010 for a review). It is widely accepted that goal setting is a key factor in such processes (Schunk, 1990). As explained above, according to the Discrepancy Reduction Model, people learn until they assess their knowledge level as sufficient to achieve their goal (Dunlosky & Hertzog, 1998; Nelson & Narens, 1990), and POP under the free regulation condition can provide information in this regard. According to this analysis, the equivalence of the POPs provided under free regulation suggests that goal setting was similar in both media in both experiments.

When facing learning under mild time pressure, the derivation of the goal is less straightforward than under free regulation. The POP in this case reflects an assessment of the knowledge level achieved by a learning process that was halted, probably too early. However, we suggest that this POP can inform us that the goal was probably higher than this level; otherwise the learner would have stopped studying earlier. Following this logic, when OSL participants produced lower POPs for the time pressure condition than for the free regulation condition (Experiment 2), it is unclear whether the difference stems from lower goal setting under known time pressure or from lower assessment of the knowledge level achieved in the allotted time. In contrast, facing text learning under mild time pressure on paper in both experiments and on screen in Experiment 1 resulted in similar POP levels to those associated with learning under free regulation. This finding suggests that the participants aimed to achieve a knowledge level under time pressure at least as high as they would have aimed for under free regulation. This finding contrasts with the conclusions drawn in metacognitive studies using rote learning of very short stimuli, like word pairs. In those studies, researchers have concluded that learning under time pressure leads people to set low goals, and to strategically waive the most difficult items (Thiede & Dunlosky, 1999). One obvious explanation for the contrasting findings here is the extent of the time pressure (Walczyk et al., 1999). It is reasonable that severe time pressure would reduce the goals set for texts as well. However, beyond that, it is possible that lengthy text learning allows flexibility that is appreciated by learners. For example, studies of self control in other contexts suggest that people sometimes acknowledge that deadlines help their performance (Ariely & Wertenbroch, 2002). It seems, then, that in the multi-phase task of lengthy text learning, learners have the opportunity to recruit extra mental effort and increase learning efficiency without compromising the desired level of performance.

When considering actual scores at test, the participants who studied under time pressure on paper, but not on screen, indeed achieved test scores as high as when they faced the same task under unconstrained conditions. In light of the two possible reasons for the effects of time pressure raised in the Introduction, the findings provide no indication that time pressure reduced the resources available to working memory. In contrast, the findings for paper learning support the conjecture that time pressure helps learners to improve their study efficiency. Together these findings question the classic speed-accuracy tradeoff per se and point to the quality of strategic MLR as key to task performance under time pressure (see Förster, Higgins, & Bianco, 2003; Peters, O'Connor, Pooyan, & Quick, 1984; Walczyk et al., 1999). The different effects of time pressure on goal setting and learning efficiency for the two media call for future research to examine factors that take effect under time pressure, other than the characteristics of the learners and task per se.

6. Conclusions and directions for future research

It has been known for a long time that the reading process is affected by the medium of presentation (e.g., Dillon, 1992). Many stakeholders in the process—educators, designers of educational material, and students—have hoped that advances in hardware and software would overcome the factors that prevent computerized learning from being as pleasant and effective as paper learning. However, numerous studies along the years, including many that are quite recent, have questioned the effectiveness of computerized environments for learning, and pointed to a variety of factors that may limit their value (for reviews, see Bennett, Maton, & Kervin, 2008; Brown, 2000; Dillon & Gabbard, 1998; Sancho, 2009).

The present study suggests that psychological factors affect screen learning, and points to metacognitive processes as important factors in explaining differences between the two presentation media. It seems that computerized study environments generate contextual cues that hinder cognitive processes, while paper tends to facilitate more effective learning (Morineau et al., 2005). However, it is also possible that effective MLR for in-depth learning of texts is a context-dependent habit acquired in the early years at school (see LaRose, 2010). In this case, the contextual cues associated with computerized study environments may be different for individuals who, as schoolchildren, acquired their learning skills on screen in the first place. An examination of media habits as a potential factor underlying the findings is therefore called for.

It should also be noted that the direction of causality is not clear. Is it that people are reluctant to study on screen, and therefore their MLR on screen is less effective? Or is it the other way around: people recognize that their MLR is less effective on screen via some high-order meta-metacognitive monitoring, and therefore, when thorough learning is required, they prefer to study from a printed text as a metacognitive regulatory decision. This question awaits further investigation.

The finding of screen inferiority under time pressure is especially relevant for computerized testing environments that include reading comprehension sections under strict time constraints (e.g., the Test of English as a Foreign Language, or TOEFL, which is administered via the Internet). On which medium should the test taker prefer to take the exam? According to the present study, those who generally prefer learning texts on paper should strongly prefer taking the exam on paper. For those who prefer learning lengthy texts on screen, there is in general no reason to choose one medium over the other, but the time pressure is expected to result in lower scores than more relaxed work. Beyond that, some computer-adapted selection tests, such as the Graduate Management Admission Test (GMAT), challenge candidates with reading tasks under time pressure, and the results are standardized to score each individual relative to other test takers. In such cases, policy makers should consider the possibility, suggested by the present study, that the effect of the medium on final scores is not consistent for all populations. Such differences in susceptibility to the medium effect may bias test-takers' relative success.

As computerized reading is already a fact in study and work environments, researchers have discussed tools and strategies to assist text learning. For example, researchers have developed computerized environments designed to facilitate learning, or, alternatively, to develop users' MLR (e.g., Azevedo, 2005; Burleson, 2005; Kramarski & Michalsky, 2010; Narciss, Proske, & Koerndle, 2007; Roll, Aleven, McLaren, & Koedinger, 2007; Winne, 2004). Future research might examine whether this type of assistance could help increase any benefits accrued from knowing in advance the characteristics of a task, such as time constraints. From a theoretical point of view, it would be interesting to examine

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whether such improvements are mediated by more accurate metacognitive monitoring and more effective MLR.

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