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Time-on-task effects in digital reading are non-linear and moderated by persons' skills and tasks' demands

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ABSTRACT

Time-on-task effects on response accuracy in digital reading tasks were examined using PISA 2009 data ($N =$ 34,062, 19 countries/economies). As a baseline, task responses were explained by time on task, tasks' easiness, and persons' digital reading skill (Model 1). Model 2 added a quadratic time-on-task effect, persons' comprehension skill and tasks' navigation demands as predictors. In each country, linear and quadratic time-on-task effects were moderated by person and task characteristics. Strongly positive linear time-on-task effects were found for persons being poor digital readers (Model 1) and poor comprehenders (Model 2), which decreased with increasing skill. Positive linear time-on-task effects were found for hard tasks (Model 1) and tasks high in navigation demands (Model 2). For easy tasks and tasks low in navigation demands, the time-on-task effects were negative, or close to zero, respectively. A negative quadratic component of the time-on-task effect was more pronounced for strong comprehenders, while the linear component was weaker. Correspondingly, for tasks high in navigation demands the negative quadratic component to the time-on-task effect was weaker, and the linear component was stronger. These results are in line with a dual-processing account of digital reading that distinguishes automatic reading components from resource-demanding regulation and navigation processes.

1. Introduction

Reading digital text is one key competency for participation in 21st century knowledge societies. At the same time, significant proportions of today's youths, deemed “digital natives”, in fact do not master digital reading, meaning they reach only very basic levels of competency in this domain. For individual countries, these figures may be as high as 32% in OECD countries, and >50% in non-OECD countries (OECD, 2014). The question thus stands what precedes successful performance on digital reading tasks. One angle from which to address this issue is to ask what kind of cognitive processes are required to perform well on a digital reading task. In the following, we briefly sketch a very general approach to describe human cognitive performance, dual processing theory, and this theory's application to reading. From these perspectives we derive predictions on how time on task, as one fundamental variable in human behavior, predicts accuracy in digital reading. We test these predictions using log file data from a large scale assessment of digital reading, the PISA 2009 Digital Reading Assessment (see OECD, 2011).

2. Dual processing theory

Cognitive science over the last four decades has accumulated overwhelming evidence for a dichotomy between two basic kinds of cognitive processes, automatic and controlled (see Schneider & Chein, 2003, for a review). Controlled processes are slow and sequential, and interfere with each other: Typically, a person can only accommodate for a single controlled cognitive process at the same time. At the same time, controlled processes are very flexible, and can both be acquired and un-learned (in the sense that it is learned that the process must not be executed at a given point in time) in one trial. Automatic processes in contrast are fast, and become active upon encountering a well-defined configuration of mental input without the necessity of active mental control (see Schneider & Shiffrin, 1977). Automatic processes do not interfere with controlled processes, or with other automatic processes that are carried simultaneously (Schneider & Chein, 2003). At the same time, they need a consistent learning environment and a long

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[1] Parts of this research emerged while Johannes Naumann worked at Goethe-University, while other parts emerged while he worked at DIPF.

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time be learned. Consistent means that the same pattern of input in each learning trial requires the same kind of response. Controlled processes, once acquired, can thus become automatic over time. In such a learning sequence, first a production system is set up to solve a task, that is, a set of rules that "fire" and generate a specific output, once a condition is met (see Anderson, 1992; Anderson & Lebiere, 1998). Through repeated activation, these rules become more and more likely to be activated automatically.

3. Dual processing theory and reading

Reading is an activity that draws on both automatic and controlled processes. In skilled readers, processes such as letter and word recognition, the retrieval of word meanings from long-term memory, or the syntactic parsing of sentences will be automatic (Perfetti, 1994). However, the degree to which word and sentence level processes are automatic might vary not only in beginning, but also in adult readers. Specifically, the quality of lexical representations, meaning the degree to which context-dependent word meanings become automatically available upon encounter, varies across individuals, and is a strong predictor of comprehension (Perfetti, 2007).

Not all processes in reading are amenable to become automatic alike, especially in "task-oriented" reading situations, where a specific goal is being pursued, using multiple sources. In such situations, students need (a) to identify those parts of the text(s) that are relevant to their task. (b) They need to switch back and forth between the task and the text(s) to evaluate whether the information accumulated is sufficient to complete the task (Vidal-Abarca, Mañá, & Gil, 2010). Depending on the number, length, semantic and syntactic complexity of the text(s), and the difficulty to match the task to the text(s), these processes will require cognitive resources and are unlikely to be accomplished in a purely automatic processing mode. For example, Cerdán, Gilabert, and Vidal-Abarca (2011) had students answer questions with text, where some questions contained misleading word matches between the question and a passage of the text (i.e., the passage was in fact irrelevant to the question, but contained words that were also part of the question). In this scenario, successful comprehenders differed from unsuccessful comprehenders in that they discarded the irrelevant passages *after* they had initially considered them. While the initial attendance to the passage might well have occurred in an automatic mode, discarding it will have required controlled processing (in a fashion quite similar to identifying a letter as a distractor which previously had been learned to be a target, Shiffrin & Schneider, 1977).

Thus, in task-oriented reading scenarios that require the goal-directed selection of information, some processes will be consumptive of cognitive resources even in relatively skilled readers. This is not to say that in a *very* experienced reader, the strategies that govern decisions such as to discard initially-accessed materials as non-relevant cannot become automatic themselves (see Pressley & Afflerbach, 1995). It is however safe to say that in an average reader, a task-oriented reading situation that requires *more* decisions as to what information to access, or to discard, requires *more* controlled processing than a reading situation that requires *less* such decisions.

3.1. The Compensatory Encoding Model

Given that the degree of automaticity of word-level reading processes (Perfetti, 1994, 2007) impacts comprehension, the question stands how readers with less automatic reading processes at the word level might comprehend texts. Walczyk, 1995, 2000 introduced the compensatory-encoding model, claiming that readers with less automatized and thus less efficient routines at the word level might compensate for this lack of efficiency. For example, readers with less automatized word-level reading processes need to carry these processes out in a controlled mode, which burdens their working memory. As a consequence, they are less able to store incoming textual information. In line with this, Walczyk and Taylor (1996) found that readers with a low quality of meaning representations (as measured through long latencies in a semantic categorization task) had more look-backs while reading a passage. Also in line with this reasoning, Walczyk (1995) showed that the quality of meaning representations was more predictive of comprehension in a condition with time pressure than in a condition without time pressure. This result is consistent with the assumption that in the condition without time pressure, readers could compensate for lesser verbal efficiency, from which they were prevented in the time-pressure condition.

3.2. The time-on-task effect in reading

The considerations in Sections 3 and 3.1 have implications for how time-on-task effects in reading are shaped by tasks and readers. From the distinction of tasks that require processes amenable to automatization to different degrees, it follows that tasks where processes *non*-amenable to automatization are prevalent will require more time to be accomplished accordingly. Readers not willing, or not able to invest this time will likely fail, meaning that in these tasks time-on-task effects will be positive. In contrast, in tasks where processes dominate that are amenable to automatization, readers with better automatized (i.e. fast and reliable) reading processes will have a better chance to succeed. Thus, in these tasks, time-on-task effects will be negative. Correspondingly, the time-on-task effect in reading will vary across person skill. Following the Compensatory Encoding Model, it should be especially lesser skilled readers that exhibit positive time-on-task effects (and vice versa): Weak readers should have a higher probability of solving a task when taking more time because of their need to compensate for lesser automatized reading processes.

A systematic investigation of time-on-task effects in reading was introduced by Goldhammer et al. (2014). Using field trial data from the OECD Programme for the International Assessment of Adult Competencies (PIAAC), these authors compared time-on-task effects in reading across tasks of varying difficulty, and readers of varying skill. They also compared these effects to those they found within the domain of "problem solving in technology-rich environments". In accordance with the considerations above, they found strong negative time-on-task effects especially in easy reading tasks. In contrast to this, in problem solving, strong positive time-on-task effects were found for hard tasks. Correspondingly, weak problem solvers showed strong positive time-on-task effects. In reading in contrast, the time-on-task effects became zero for unskilled readers, and was strongly negative for skilled readers.

Goldhammer and colleagues explained this set of findings in a dual processing framework. According to their reasoning, problem solving tasks are by definition resource-dependent, thus prompting strong positive time-on-task effects, in hard tasks and weak problem solvers. In contrast, the reading tasks that were used in the PIAAC assessment required only little cognitive regulation. The texts used were short, linear and of little complexity, so that automatic processes might have accounted for a large proportion of the task solution process.

4. Digital reading, problem solving, and navigation

Digital reading can be conceived as a domain where reading and problem solving intersect (e.g. Brand-Gruwel, Wopereis, & Walraven, 2009; Rouet & Le Bigot, 2007). Specifically, digital reading tasks, when they imply information search, frequently cannot be solved on the basis of pre-existing cognitive schemas, so that a barrier exists between the given and the goal state of a readers' cognitive system (see Greiff, Kretzschmar, & Leutner, 2014; Naumann, Goldhammer, Rölke, & Stelter, 2014). This is because digital texts frequently come as hypertexts. Thus, it is left to the reader to find a task-appropriate selection of text contents (e.g. Nielsen, 1991), and a reading sequence that befits both the task and the reader's cognitive resources (see e.g. Salmerón, Cañas, Kintsch, & Fajardo, 2005). This process of selecting and