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Physical load affects duration judgments: A meta-analytic review

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ABSTRACT

This article reports a meta-analytic review of seven extant experiments, with 235 participants, concerning effects of physical workload on duration judgments. It also provides a qualitative assessment of related studies that, for specific reasons, were not includable in the quantitative meta-analysis. All analyzed experiments used the prospective duration-judgment paradigm and the production method, in which participants knew in advance that duration estimation was required. A large overall effect size reveals that increasing physical workload results in longer prospective duration productions. Physical workload effects are comparable to those of cognitive load. Implications for applied research, theory, and applications are discussed.

1. Introduction

People encounter combinations of physical and cognitive workload in many aspects of life. People attempting to cross a street while carrying a heavy basket from a supermarket must estimate their time for passage to safety. Basketball players must scan for other players while concurrently estimating the duration during which they are allowed to remain in the restricted area of the lane, as well as the maximum duration allowed to make a shot. People operating complex technologies, such as airplane pilots and automobile drivers, also encounter increasing levels of both physical and cognitive workload as they navigate crowded airways and highways. They must do this in spite of new computer-assisted interfaces that mediate multiple tasks which often demand divided attention. Computer-control systems, such as automatic-pilots, GPS devices, and other in-vehicle assistive systems can be useful. However, they often compete for limited attention- and time-constrained resources with ongoing psychomotor control demands. Firefighters and military personnel often must carry heavy physical loads while they are concurrently making operational decisions. Many people time-share and attention-share other tasks, such as using their personal electronic devices, as they are driving or walking. Increasingly, people must perform concurrent physical and cognitive tasks, and this trend will probably continue and increase.

Most researchers agree that both cognitive and physical load consume attentional resources. In both cases, concurrent duration judgment should be reduced more when workload is high than when it is low. This is explained by attentional models of prospective duration judgment (e.g., Zakay & Block, 1997), according to which duration judgment is a function of the overall number of pulses which are emitted by a pacemaker-clock and accumulated in a counter. The number of pulses that pass through to the counter in a time unit is controlled by the amount of attentional resources allocated for timing. Attentional resources, however, are competing with other concurrent tasks since they are all coming from a general pool. When cognitive or physical load is high, less attentional resources are left for timing and vice versa. This was validated regarding cognitive load (e.g., Block, Hancock, & Zakay, 2010). However, after more than a century of experimental investigations (Hancock & Block, 2012), there is surprisingly little systematic evaluation of physical load effects.

Our recent meta-analytic review reveals that cognitive load influences duration judgments in a systematic and reliable way (Block et al., 2010). Duration estimation is therefore a useful and sensitive index of information-processing load (Zakay, Block, & Tsal, 1999). In the present meta-analytic review, we report the effects of physical load on duration judgments and compare such effects to our previously reported pattern for that on cognitive load.

All usable studies included and reviewed in the present meta-analysis used the prospective duration-judgment paradigm, in which participants are aware that they will be required to estimate a time period of various tasks (Zakay & Block, 1997). This paradigm is very

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similar to procedures to estimate time-to-contact (Hancock & Manser, 1997). However, production stands in contrast to the retrospective paradigm, in which participants are initially unaware that duration estimates will subsequently be required. All reviewed experiments used a design in which high physical load and low physical load tasks were performed in either a randomized or a counterbalanced order. All used the method of production, in which participants are asked to make a response at when the experimenter-defined duration has ended. This method is sensitive and informative (Hancock, Vercruyssen, & Rodenburg, 1992; Zakay et al., 1999). It stands in contrast to verbal estimation, in which participants are asked to estimate an elapsed duration in standard time units, such as minutes and seconds. The methods of production and verbal estimation are thought to be inversely related (Horenstein & Rotter, 1969).

To manipulate physical load, the reviewed experimenters have used a wide variety of tasks. For example, Weybrew (1963) and Warm, Smith, and Caldwell (1967) used a dynamometer, with some participants told to exert near-maximum force (high load) and other participants told to exert minimal force (low load). Comparisons were made across these respective load levels. Other researchers compared performance in an airplane flight simulator, using either a difficult flight plan or an easy flight plan (e.g., Bortolussi, Kantowitz, & Hart, 1986). These researchers examined performance using either difficult or easy simulator-based tasks to investigate psychomotor demands. Still other researchers (e.g., Arlin, 1989) studied children estimating durations while carrying heavy or light pipes.

There is little systematic research that could be included in the quantitative meta-analysis. Considering the necessities of demands such as multitasking, this is surprising. Our present meta-analysis not only summarizes what is presently known, but it also serves as a benchmark, indicating what remains to be discovered. Consequently, here we do not simply summarize extant information; our work looks to inform experimenters how much and what remains to be done in this area of growing theoretical and applied importance. Our hypothesis is that the impact of physical load on prospective duration judgment will be found to be similar to that of cognitive workload, namely, that the higher physical load is, the shorter prospective duration productions will be.

2. Method

2.1. Selection of experiments

We used the same selection strategy and meta-analytic methods as in our previous meta-analytic research on effects of cognitive load (Block et al., 2010). We searched more than 14,000 references on the psychology of time, including references from two major databases, PsycINFO (1887–2013), using the keywords *time perception* and *time estimation*, and Medline (1966–2013), using the keyword *time perception*. We also searched published bibliographies on time research, book chapters, and books; as well as each of our individual files. We searched for articles that contained such terms as *duration judgment*, *workload*, *physical load*, *cognitive load*, *attention*, *difficulty*, as well as many other similar and related terms.

We checked the reference lists of relevant articles to ascertain whether other studies might also be included. We included only experiments that manipulated physical load from which we were able to calculate an effect size from reported inferential statistics, a data table, or a figure. Our inclusion and exclusion criteria were identical to those used in our previous meta-analyses of duration judgments (e.g., Block et al., 2010). Every included experiment involved normal human participants judging durations predominantly equal to or greater than 3 s, with at least one of the independent variables involving physical load as defined earlier. Perception and estimation of durations less than about 3 s involve very different processes than of longer durations (for reviews and evidence, see Hancock, Arthur, Chrysler, & Lee, 1994; Wittmann, 1999), and thus our exclusion threshold at this value.

2.2. Effect size analyses

We independently identified effect sizes, and we resolved any disagreements by discussion. Each effect size was calculated as *g*, the sample-size-corrected difference between the mean duration judgments given by participants in each condition divided by the pooled standard deviation (Hedges, 1981; Hedges & Olkin, 1985), using Borenstein, Hedges, Higgins, and Rothstein's (2011, Version 2.2.064) Comprehensive Meta-Analysis (CMA) program. Effect sizes were defined as positive if the duration judgment ratio was larger under the high physical-load condition as compared with that under the low physical-load condition. Conversely, it was defined as negative if the duration judgment ratio was smaller under high rather than low physical load conditions. This was the case in all experiments we analyzed (see Block et al., 2010, for details, including on what negative effect sizes mean). Negative effect sizes reveal that time productions were shorter under high-workload than under low-workload conditions.

The meta-analytic procedures and calculations were the same as in Block et al. (2010). However, because of the small number of studies, we could not analyze any moderator-variable effects. Given such a limitation, we also review other relevant and important studies in a qualitative way.

3. Results

Seven includable experiments, with a total of 235 participants, manipulated physical load. All used the prospective duration-judgment paradigm and the method of production.

As shown in Table 1 and Fig. 1, each of the studies show a negative effect size, and each experiment revealed a significant (or marginally significant) effect. Many effect sizes are large, whereas others are medium (Cohen, 1988). Confidence intervals reveal the consistency across this data set. Considering the limited number of experiments for which an effect size could be calculated, a qualitative assessment follows later in the General discussion section.

Using a random-effect model, as is recommended, the overall weighted mean effect size was significant ($d_+ = -1.36$, 95% CI $= -2.06$ to -0.65, $p < .001$). This overall effect is larger than the comparable overall effect for cognitive load reported by Block et al. (2010). Because the cumulative confidence interval does not include zero (see Fig. 1), substantive and consistent effects of interest need to be explained.

4. General discussion

The present meta-analytic study concerned ongoing theoretical controversies about duration judgment processes by investigating possible effects of physical workload on prospective time estimates. In particular, we investigated whether the effect of physical workload on duration judgment is similar to the effect of cognitive load by using exactly the same meta-analytic procedures as in our previous research (Block et al., 2010). Our meta-analysis showed an overall effect size ($d_+ = -1.36$) that is comparable to and in the same direction as the effects of cognitive load on prospective duration. This reveals that high physical load demands require attention, which lengthens prospective timing (i.e., shortens time productions). It may be attributable to the fact that tasks involving high physical load, such as piloting an aircraft, demands the allocation of attention at the same time that they involve the sequencing and executing of complex physical movements. Therefore, when relatively high amounts of physical efforts and cognitive functions are combined in a dual-task situation, there are relatively fewer residual attentional resources available to allocate to timing. If both cognitive and physical loads are combined (e.g., in a car or an airplane simulator), the effect on time production is greater. This implies that even though the processes behind the two types of load are not entirely the same, the effects are interactive. This hypothesis is supported