Mobilizing Cognition for Speeded Action: Try-Harder Instructions Promote Motivated Readiness in the Constant–Foreperiod Paradigm

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Abstract

We examined the effect of motivational readiness on cognitive performance. An important but still not sufficiently elaborated question is whether individuals can voluntarily increase cognitive efficiency for an impending target event, given sufficient preparation time. Within the framework of the constant-foreperiod design (comparing reaction time performance in blocks of short and long foreperiod intervals, FPs), we examined the effect of an instruction to try harder (instructional cue: standard vs. effort) in a choice-reaction task on performance speed and variability. Proceeding from previous theoretical considerations, we expected the instruction to speed-up processing irrespective of FP length, while error rate should be increased in the short-FP but decreased in the long-FP condition. Overall, the results confirmed this prediction. Importantly, the distributional (ex-Gaussian and delta plot) analysis revealed that the instruction to try harder decreased distributional skewness (i.e. longer percentiles were more affected), indicating that mobilization ensured temporal performance stability (persistence).

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Almost everyone would agree with the allegation that cognitive efficiency during mental work undergoes level changes (Langner & Eickhoff, 2013; Smallwood, 2013) which can be overcome by taking a rest (Helton & Russell, 2015; Steinborn & Huestegge, 2016) or must be overridden by mobilizing capacity (Weger & Loughnan, 2013, 2015). However, there is less agreement with regard to the underlying mechanism. In fact, the transient variations in the effort that individuals invest in a current task determine their ability to engage in something else at the same time. Kahneman (1973, p. 4) refers to this aspect as spare (monitoring) capacity and illustrates this point by an example: *"…imagine that you are conducting a conversation while driving an automobile through city traffic. As you prepare to turn into the traffic, you normally interrupt the conversation…"*. The core message of this rather simple example is that the available spare capacity serves to monitor the environment and to detect exceptional challenges. Kahneman (1973, pp. 31-38) believes that such an exceptional focus is under the control of the task but can – on principle – be attained at will, given appropriate pre-set instructions and sufficient preparation time. Since there is little evidence on this subject, we examined the effect of instructed effort on performance speed and variability within the framework of the constant–foreperiod paradigm. In this paradigm individuals are enabled to (vs. prevented from) attaining a timely state of peak readiness at the moment of target occurrence, which renders it especially suited to pinpoint optimal prerequisites for successful effort mobilization.

Temporal Preparation in the Constant–Foreperiod Paradigm

The foreperiod paradigm consists of five essential elements, the warning signal **(WS)** which starts a current trial, the foreperiod **(FP)** that follows afterwards enabling the participants to prepare for the imperative signal **(IS)** to which participants have to give a response **(R)**, and the intertrial-interval **(ITI)** that separates subsequent trials from each other. When FP length is constant within a block of trials, participants know exactly when the target will occur, and therefore, are likely to engage in a process of temporal preparation to be ready to respond at the moment of IS occurrence (i.e., the imperative moment). This goes better with short than with long FP intervals, since the imperative moment can better be anticipated with the former than with the latter. For example, consider a choice-RT experiment where the target occurs 1000 ms after the WS in one of the experimental blocks (short-FP condition), and 5000 ms after the WS in the other of the experimental blocks (long-FP condition). In this experimental setting, responses are fast in the short-FP but slow in the long-FP condition, yielding the typical upward-sloping FP–RT function in the constant-FP paradigm (Niemi & Näätänen, 1981, pp. 136-138). While a short FP interval enables to synchronize closely with the imperative moment, a long FP interval is less able to do so. Thus, the paradigm is considered a proper means to directly compare two distinct conditions, an alerted (prepared) and a relatively less-alerted (non-prepared) mental state (Langner & Eickhoff, 2013).

Posner (1976, pp. 128-137) argued that a constant-FP length does not influence the rate of build-up of information but rather the time that individuals can respond to the build-up that has taken place within a given time. If the task is such that stimulus information builds-up relatively slowly, fast responses will come up when information quality is insufficient. This should result in an increase in errors. When the task is such that stimulus information builds up quite rapidly, however, responses will come at an asymptote in quality, resulting in an increase in both response speed and accuracy, that is, in performance efficiency (Posner, Klein, Summers, & Buggie, 1973). Note that Posner's model is inconsistent with a processing-stages view, from which one would assume that stimulus information goes through a sequence of discrete stages, and that processing within a stage can only start when the previous stage is completed. Instead, he assumes that information build-up and level of preparedness increase in parallel until the participant finally responds. Since a state of peak readiness can be maintained for some (300-400 ms) time (Alegria, 1974; Steinborn, Rolke, Bratzke, & Ulrich, 2008, 2009, 2010), there is room to adjust the response threshold such that it meets with the information build-up and with the internal standards for response accuracy. In this way, FP effects might not be specific to one particular task, but rather, virtually every operating activity can be addressed by manipulating FP length (cf. Kiesel et al., 2010, pp. 854-855).

Although Posner's micro-vigilance model of FP effects assumes a parallel increase of both the information build-up and the ability to respond to that build-up, this does not imply that the rate of information build-up is by itself a constant. Time pressure that is inherent in the structure of the task seems to be capable of increasing mental focus (Kerr, 1973; Ruthruff, Johnston, & Remington, 2009). For example, a paradoxical improvement in both performance speed and accuracy as a function of constant-FP length was observed when the imperative stimulus was rapidly masked, and thus, the time to potentially process the stimulus was reduced (Klein & Kerr, 1974). According to Posner (1976, pp. 128-137), individuals are quite capable to speed-up their performance voluntarily by means of two strategies, given sufficient preparation time, by lowering response threshold or by increasing mental focus. Kleinsorge (2001) showed that participants in a choice-reaction time experiment (variable FPs: 250, 500, 750, 1000 ms) were capable to increase response speed voluntarily. In this study, an instructional cue (presented in 20% of the trials) requested them to try harder in the impending trial. Successful responding was rewarded (by a monetary bonus) only in the effort trials. As a result, responses became faster but more erroneous in the effort trials than in the standard trials, which at least indicates a change in processing strategy. However, it remains unclear whether this was due to a decreased criterion or an increased focus.

Spare–Utilized (Monitoring–Focus) Capacity Model

It is recognized across disciplines that some concept of energy is absolutely essential to sustained performance (Botvinick & Braver, 2015; Machado, 1997; Metcalfe & Mischel, 1999; Szalma & Hancock, 2011). For example, van der Molen et al. (1991) and Langner et al. (2010) conjectured that the typical compound pattern of cognitive, self-report, and psychophysiological effects may reflect mobilized effort in support of preparation rather than preparation as such. Such a view of FP effects implies the question whether and to what extent individuals can improve their performance efficiency by trying harder. Kahneman (1973) suggested that the allocation of capacity is closely linked to task characteristics such that one cannot put the same effort into an easy task as into a difficult one. Given sufficient preparation time, however, it might be possible to voluntary increase effort to impending demands. Kahneman (1973) considered capacity allocation as mobilization of mental energy to enable active mental operations. An important feature of the model is the distinction between the rate of utilized (operation) and spare (monitoring) capacity. Capacity is never fully utilized for algorithmic operations, but there is always some spare capacity left to monitor the environment in order to enable the detection of relevant changes potentially resulting in an increase in demand (Dreisbach & Fischer, 2011; Langner, Eickhoff, & Steinborn, 2011). Accordingly, deployed capacity is not constant but depends on current needs.

A spare capacity model ideally assumes that while there is a global limit on individuals' capacity to perform a task, there is some freedom to allocate this limited capacity to concurrent activities, that is, to task operations and to monitoring. Kahneman (1973) suggested that the control over the allocation policy is to merely decide whether to carry out the task in the first place. Once the global policy is set-up, the amount and allocation of effort expended to task operations and monitoring activities depends on actual demands. Many theorists in this domain hold that there is some flexibility in strategies of pre-allocating capacity, while rejecting the view that capacity can be allocated in a graded fashion. For example, Brown and Braver (2005) conducted an experiment where they manipulated the likelihood of a response error by varying discrimination difficulty. In one condition, the authors announced this event by an informative cue given in advance of a current trial. Individuals were capable to pre-allocate additional capacity to meet impending demands by upregulating the response threshold (to give more time for stimulus processing in that trial), and thus preventing the error from occurring. Note that allocating additional capacity here equals allocating additional time units to ensure the standards for performance accuracy, so that the stimulus-related information build-up has reached an advanced stage when individuals finally respond. Yet, the observed control strategy was still a long way from representing a fine-tuning of processing resources.

An energetic view on capacity relies on two principles (Kahneman, 1973). First, the amount of capacity is not fixed but depends on arousal. An increase in arousal leads to an increase in capacity for task operations at the cost of monitoring. An increased focus on task operations basically leads to performance benefits, however, it can also be harmful if the task produces outputs or side effects that must be accounted for by effective feedback mechanisms (Navon & Miller, 1987, 2002). Capacity models thus have limited explanatory value when there is outcome conflict between tasks or competing mental operations. Second, the relation of utilized versus spare capacity is under continual evaluation and re-adjustment towards sustainable performance, which means that capacity for active task operations varies over trials. According to Kahneman (1973), such variations occur because the allocation policy sometimes channels capacity to other activities (monitoring), resulting in slower responses in that trial. Such a perspective of intermittent resource allocation (to active operations vs. passive monitoring) offers a very natural way to explain the trial-by-trial RT variability that is usually observed in warned choice-RT experiments (Hohle, 1965; Leth-Steensen, 2009). At a sophisticated level, RT variability is examined by analysing RT distributions which tend to be skewed with a long tail towards longer percentiles, assumed to being composed of two discrete (focused vs. non-focused) mental states (Miller, 2006; Van Breukelen et al., 1995).

Effects of Try-Harder Instructions on Performance

In the present study, we aimed to estimate the potential for improvement of speeded performance by volitional effort mobilization. To answer this question, we need to consider at least three aspects related to experimental set-up and measurement methodology: (1) the issue of inducing a mobilization of effort, (2) the evaluation and due consideration of contextual variables that could potentially modulate (impede or promote) effort mobilization, and (3) the use of appropriate methods of performance measurement. *First*, we manipulated effort mobilization explicitly by means of instructing participants to try-harder, which is a key characteristic of our study but only rarely the case in current research. By this means, we were enabled to clearly attribute experimental effects on performance to effort mobilization, while we consider more indirect methods (e.g., using response deadlines, social presence, priming a competitive mindset, etc.) problematic with this regard. *Second*, contextual variables that are expected to either promote or to hinder the mobilization of effort should not be ignored but deeply considered with regard to theory and empirical facts. Given our aforementioned exposition of the critical role of temporal preparation on performance, and according to previous theorizing, we see the need to implement our research goals within the contextual framework of the constant-FP paradigm. Thus, we asked whether the hypothesized effect of a try-harder instruction on performance is modulated by transient states of low versus high motor readiness.

Third, the analysis of effort-related performance effects is closely linked to the analysis of performance reliability as revealed by RT distributional analysis. Notably though, the bulk of current research theorizing on effort-related issues neglected this important aspect of measurement. Whether the hypothesized improvement of performance by effort mobilization is accomplished by an increase in the speed of information processing or by mental persistence is fundamental to the analysis and understanding of effort, and in order to distinguish between both theoretical alternatives, we need to go beyond traditional measures of central tendency but instead must consider its effect at critical density zones of the RT distribution. We employed a cumulative distributive function (CDF) for each of the experimental condition, asking whether the instruction to mobilize effort makes stimulus-related information processing run more quickly, or alternatively, makes processing run more reliably albeit with the same processing speed. Consequently, we examined whether effects on RT mean originate from a global speed-up that is equally present at all CDF percentiles (parallel effect) or only from a local speed-up at slower percentiles (mixture effect). The former would indicate a true improvement in mental speed while the latter would indicate improved reliability (i.e., a stabilization of performance).

We expected to observe the constant-FP effect on RT and accuracy. That is, responses should be faster but somewhat more erroneous in short-FP as compared to long-FP blocks (Posner, 1976, pp. 128-137; Posner et al., 1973). We expected faster responses in the effort condition as compared to the standard condition, irrespective of FP length. Whether the effort instruction is differentially effective for short-FP versus long-FP conditions is an empirical question, since previous theorizing on FP effects does not provide any guidance regarding this issue (Niemi & Näätänen, 1981, pp. 136-137; Posner, 1976, pp. 128-137). In accordance with the studies of Kleinsorge (2001) and Falkenstein et al. (2003), we employed the probe-trial technique, presenting the effort instruction infrequently in 20% of the trials, while 80% were standard trials. According to Kleinsorge (2001), this set-up is aimed to ensure the effort instruction to work properly.

To examine whether a short-term mobilization of additional effort leads to a stabilization of performance, we examined both the classic parameters of RT variability and parameters of distributional skewness based on the ex-Gaussian model. Remind that from the perspective of an energetic-capacity model, it is crucial to know whether effort mobilization leads to a generic (vs. selective) speed-up of all (vs. only long) CDF percentiles. Theorizing within an energetic-capacity framework, the try-harder instruction is expected to primarily promote reliability of information-processing by reducing the probability of attentional failure.

Method

Participants. Thirty-two (91% female) volunteers (mean age = 21.5 years, *SD* = 3.0) took part in the experiment. Participants were in standard condition and had normal or corrected-to-normal vision.

Apparatus and Stimuli. The experiment was controlled by an IBM-compatible computer with color display and programmed using the Psychopy software package (2009). Participants sat about 60 cm in front of the screen. A cross (0.5° × 0.5° angle of vision) was displayed in the middle of the screen. The WS (sine tone, 1000 Hz; 70 dB) was presented binaurally via headphone. The digits “1”, “2”, “3”, “4”, “5”, “6”, “7”, and “8” (1.14° × 0.86° angle of vision) served as IS and were displayed in blue at the center of the screen.

Implementation of the Effort Instruction. Essential for a mechanism such as effort mobilization to work effectively is that at least five methodical rules are considered, which were also implemented in the current study. **(1)** Before the session, the experimenter instructed the participant in the usual manner, that is, to respond as fast and accurate as possible. Further, the instructor explained that the participant will occasionally be requested by a cue to try harder on the impending trial that is, to be exceptionally fast and accurate in these occasions. These events will be announced in advance of a trial by the German word “Anstrengen”. **(2)** During the experiment, there is time needed to implement the effort signal prior to a current trial. The instructional cue was therefore presented prior to the WS that starts the preparatory period (FP) of a current trial **(3)** Processing the instructional cue should neither interfere with timing processes during the FP interval, nor with any other processes. **(4)** The mobilization of exceptional effort is considered costly and should be requested only at rare occasions, using the probe-trial technique. **(5)** The effort instruction must the applicable to the task. This means that it must on principle be possible to improve performance by trying harder (Langner et al., 2010; Ruthruff et al., 2009; Warm & Alluisi, 1971; Warm, Kuwada, Clark, & Kanfer, 1972; Yeh & Wickens, 1988).

Design. The two-factorial within-subject design contained the factors “foreperiod” (FP: short vs. long) and “instruction” (Cue: effort vs. standard). The FP interval was either short (1000 ms) or long (4000 ms), manipulated between blocks of trials (constant-FP design), and counterbalanced over the experimental sessions. The cue instruction was either the German word “standard”, presented in 80% of the trials, or the word “anstrengen” (effort), presented in 20% of the trials. The intertrial-interval (ITI) was such that it equalized the interval between subsequent trials for both the short-FP and the long-FP condition (cf. Capizzi, Sanabria, & Correa, 2012; Meiran & Chorev, 2005; Meiran, Chorev, & Sapir, 2000; Steinborn et al., 2008, 2009; Steinborn, Rolke, et al., 2010; Thomaschke & Dreisbach, 2013, 2015; Thomaschke, Kunchulia, & Dreisbach, 2015; Vallesi, Lozano, & Correa, 2013, for a discussion of ITI effects). Note that while the intertrial interval often serves to control for sequential crosstalk between subsequent trials in the domain of cognitive-control research (Frings, Rothermund, & Wentura, 2007; Meiran et al., 2000; Soetens, Boer, & Hueting, 1985), or to provide micro rest in vigilance research (Adams, 1954; Lim, Teng, Wong, & Chee, 2016), it mainly serves to equalize tonic activation from frequent responding in the domain of temporal preparation (Killeen, Hanson, & Osborne, 1978; Vallesi et al., 2013).

Procedure. Before the experimental session, the experimenter explained the experiment and instructed the participant in the usual manner to respond quickly and accurately in general. The participants were instructed to give their best performance (to try harder) in the effort trials, both in equal measures of speed and accuracy. The experimenter requested verbal feedback from the participants, and if necessary, delivered further explanation to ensure that they have understood the instruction correctly. Globally, the design closely resembled the temporal-orienting paradigm, where a temporal cue is presented before the WS in a current trial (Coull & Nobre, 1998; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001). Yet, the instructional cue in our study holds only information about whether or not to try harder in a forthcoming trial. Any form of bias about stimuli, responses, or imperative moment (Bertelson & Barzeele, 1965; Holender & Bertelson, 1975; Thomaschke, Hoffmann, Haering, & Kiesel, 2016) was intentionally avoided.

The visual effort-instruction (1000 ms duration) was sufficiently long and presented immediately before the WS in a current trial. The auditory WS (200 ms duration) started the preparatory interval (FP), followed by the visual IS, to which participants were to respond. Trials were separated by an intertrial interval (ITI). Participants performed a two-choice RT task of moderate difficulty and were required to respond with either the left shift-key (left index finger, if either "1", "2", "3", or "4" was presented) or the right shift-key (right index finger, if "5", "6", "7", or "8" was presented). The experiment contained 481 trials overall and lasted about 50 min of testing time.

Results and Discussion

Data treatment. Responses faster than 100 ms were regarded outliers and removed from RT analysis. We only used a minimal-trimming method by removing the three slowest reactions for each of the conditions (Ulrich & Miller, 1994; Ulrich, Schroeter, Leuthold, & Birngruber, 2015). Incorrect responses were regarded response errors and used to compute an index of error rate.

Standard performance indices. For each of the experimental conditions, we computed the reaction time mean (RTM) to index average response speed and the RT coefficient of variation (RTCV) to index relative response-speed variability, according to the suggestion of Flehmig et al. (2007) and according to our previous use of this method (Flehmig, Steinborn, Westhoff, & Langner, 2010; Steinborn, Flehmig, Westhoff, & Langner, 2010; Steinborn, Langner, Flehmig, & Huestegge, 2016). Error percentage (EP) indicated the rate of incorrect responses, and served as measure of response accuracy.

Distributional analysis. To analyze the distribution of responses, we computed the vincentized cumulative distributive function (CDF) of responses with 19 percentiles for each of the experimental conditions according to the suggestion of Ulrich et al. (2007). By means of this analysis, we were to know whether the hypothesized effect of the effort instruction on mean RT is due to a generic speed-up of all responses or alternatively due to a selective speed-up of the long percentiles of the CDF. To more directly account for experimentally-induced effects of distributional shape (right-tail density accumulation effects, further referred to as skewness), we also adopted an ex-Gaussian approach but only as a descriptive model of reaction times (Heathcote, Popiel, & Mewhort, 1991; Steinhauser & Huebner, 2009) to analyzing its three parameters mean, dispersion, and shape (μ, σ and τ). We computed ex-Gaussian model parameters for each participant according to the methodical rules provided by Lacouture and Cousineau (2008). Parameters μ and σ can readily be interpreted as localization and dispersion (around μ) indicators while τ is sensitive to experimental effects on right-tail density accumulation of the distribution.

Results of the standard analysis. Complete statistical results are referred to in Table 1. Essentially, responses were significantly faster in blocks with the short-FP than with the long-FP duration (RTM = 503 vs. 569 ms), which well resembles the constant-FP effect on RTM [$F(1,31) = 58.9$, $p < .001$]. In addition, responses were faster in effort trials than in standard trials (RTM = 493 vs. 580 ms), as indicated by the main effect of CUE on RTM [$F(1,31) = 133.7$, $p < .001$]. There was no interaction of FP length and effort instruction on RTM [$F < 1$]. Overall, error rate (EP) was low (3.96%), although somewhat increased in the effort condition as compared to the standard condition (5.0% vs. 3.0%). Yet, error rate remained still to be low (beneath approximately 5%)[1].

Results of the distributional analysis. Besides effects on average response speed (RTM), responses became essentially more stable (or less variable, respectively) in the effort (vs. the standard) trials. A visual inspection of the CDFs (Figure 2) provides an indication that the stabilizing effect of effort mobilization is due to a strong reduction in distributional skewness. This is indicated by a main effect of CUE on the classic variability parameter, RTCV [$F(1,31) = 18.6$, $p < .001$], which closely corresponds to the visual pattern of skewness of a particular CDF. Since recommended by several authors (cf. Leth-Steensen, 2009; Steinhauser & Huebner, 2009), we additionally obtained parameter of skewness from an ex-Gaussian distributional model. As expected, the stabilizing effect on performance is also (even more sensitively) indicated by a main effect of the factor CUE on the ex-Gaussian τ parameter [$F(1,31) = 99.4$, $p < .001$].

Discussion

Summary. Our results revealed that an explicit instruction to mobilize effort in preparation to the impending IS improved processing speed, while error rate remained low within a range of about 5%. The improvement in response speed was roughly at the same level for each of the (short vs. long) constant-FP experimental blocks (approximately 100 ms, equivalent to 20% gain). As expected, effort differentially yielded an increase in error rate in the short-FP (not in the long-FP) condition, which delivers a clue as to the contextual limitations of voluntary mobilization of additional resources for speeded action (cf. Weger & Loughnan, 2013, 2015). Importantly, the cumulative distributive function (CDF) analysis revealed that the effort (vs. standard) instruction decreased distributional skewness, as indicated by indices of response-speed variability. This means that the instruction to mobilize effort became more effective from the fast towards the slowest CDF percentiles. This result might have important implications since our theoretical understanding of attentional mobilization by intention depends partly on whether the effort instruction influences all CDF percentiles uniformly or selectively. These results differ in some important aspect from the results of previous studies (Falkenstein et al., 2003; Kleinsorge, 2001), where the effort instruction was only effective in trials with a long (not with a short) cue–target interval. In any event, they imply an energetic-capacity mechanism that secures performance stability by counteracting low arousal.

Methodology and replicability issues. It might be important to discuss a few methodical rules to be considered in replication (or follow-up) studies. Statistically, the effects are huge, both in measures of probability and effect size, and in comparison with two prior studies (Falkenstein et al., 2003; Kleinsorge, 2001). Therefore, exact-replication studies will likely observe the same result pattern. However, there are some design features that are essential for a try-harder instruction to work and to uncover the underlying mobilization mechanisms addressed here. **(1)** A study of effort mobilization should not fail as a result of inconsequent or ambivalent cue implementation. Thus, one should consider that informative cues need at least 300 ms presentation time and additional 500 ms preparation time (Koch, 2001; Meiran, 1996; Sudevan & Taylor, 1987). Further, we recommend to orally explain the meaning of instruction signals prior to the session, and to solicit feedback from the participant as to whether he/she had understood the instruction correctly. **(2)** We also recommend to stick closely with the temporal-orienting design (Correa, Lupianez, Milliken, & Tudela, 2004; Coull & Nobre, 1998; Los & Heslenfeld, 2005), where the cue is presented before the WS in a current trial. In previous studies (Falkenstein et al., 2003; Kleinsorge, 2001), the cue occurred unpredictably before the IS and thus was ineffective in short but effective only in long intervals (this was even less effective as compared to our results). This compromises a clear-cut interpretation.

(3) There should be no interference of cue processing with preparatory processes during the FP interval. Since the cue was randomly but equiprobably presented (at pre-cueing intervals of 300, 600, 900, and 1200 ms) in the study of Kleinsorge (2001), the conditional probability of cue presentation increased towards the longest pre-cueing interval. This might have caused surprise at early critical moments where expectancy is low, but enables strong facilitation at late critical moments where expectancy is high (variable-FP effect, Klemmer, 1956, 1957; Steinborn & Langner, 2011, 2012). **(4)** The instruction to mobilize exceptional effort to the impending IS implies a context where exceptional performance is requested only infrequently. It might be reasonable either to use a probe-trial technique where 20% effort trials are set in relation to 80% standard trials, or to use the mini-block technique where effort trials and standard trials alternate in small but predictable sequences of equal probability (Strayer & Kramer, 1994), with rest given between blocks (Helton & Russell, 2015; Steinborn & Huestegge, 2016). The importance of this principle becomes clear if one considers related studies that focused on adjustments of speed–accuracy tradeoff by an instructional cue. The general problem in this situation is that having to change response criteria back and forth in a trial-by-trial manner is demanding due to inertial tendencies of the motor preparation mechanisms (Jentzsch & Dudschig, 2009; Jentzsch & Leuthold, 2006).

Strayer and Kramer (1994) have examined whether individuals are capable to shift their response criterion (by an instructional cue) in a trial-by-trial manner in a Sternberg type memory search paradigm (Exp. 4). In this task, the participants had to indicate via a speeded response whether a presented target (a five-letter word, e.g. sheep, horse, tiger, etc.) was previously included in a memory set of varying difficulty (memory load: 2, 4, and 6 words). While error rate was high under the speed instruction (90.6%), they were unable to respond less erroneous under the accuracy instruction (91.1%). The authors concluded that individuals are hardly capable to control their speed–accuracy tradeoff voluntarily. However, this interpretation might be incorrect if one considers that the participants were probably not unable to shift their response criterion but to increase accuracy. Hence, the results are likely compromised by a limitation to perform beyond a certain degree of accuracy. **(5)** The last rule concerns the applicability of the task. While a mobilization of effort might be applicable to any speeded-decision task, because an increase in the intensity of attentional processing is usually effective in routinized tasks, it might be even detrimental to performance if the task requires fine-tuned perceptual processing (Hockey, 1997; Jolicoeur, 1998, 1999), or if intensified attentional processing is likely to produce outputs that are harmful to efficient mental representations and thus to efficient performance (Navon & Miller, 1987, 2002).

Pashler (1998, chap. 8) argued that the utility of effort mobilization as a theoretical concept is restricted to an experimental set-up (1) where trials of a task are carried out one after the other (cf. Pieters, 1983, 1985; Van Breukelen et al., 1995), (2) where individuals have acquired a relatively pronounced level of skill as is the case in most of the cultural techniques: reading writing, and arithmetic, (3) where reward and intrinsic value is usually low, and consequently, (4) where performance is essentially limited not by structural constraints of the attentional system but by motivational factors (cf. Hancock & Warm, 1989; Humphreys & Revelle, 1984; Warm et al., 1972; Warm, Parasuraman, & Matthews, 2008). Pashler (1998) believed that at a microscopic scale, there are structural limitations (imposed by an attentional bottleneck) that cannot simply be overcome by trying harder. For example, Ruthruff et al. (2009) asked whether parallel central processing is possible with greater effort as induced by using a variant of the psychological-refractory period (PRP) paradigm. This modified paradigm relies on the application of game-design elements (gamification), meaningfulness of task goals (semantic content), and feedback (knowledge of results) as basic principles, using tasks that have natural, inherent time deadlines (cf. Los, Hoorn, Grin, & Van der Burg, 2013). The complex result pattern obtained in 5 experiments led the authors to conclude that there is no evidence that participants could perform central operations on two tasks in parallel.

Mechanism of Effort Mobilization. The description of an intention as simple as those of obeying an instruction in choice-RT experiments is usually not included in most performance models (Ruthruff et al., 2009; Van der Molen, 1996), though sufficient motivation is considered important with respect to test reliability (Miles & Proctor, 2012; Miller & Ulrich, 2013, p. 824). Within the theoretical framework of a spare capacity model, a short-term mobilization of effort serves to fetch back control by re-utilizing the fluctuating spare (monitoring) capacity for the active mental operations required. This directly implies that mobilized effort invested in a given task reflects the proportion of the time (or trials) during which a mental operation is carried out effectively across a series of trials. In this formulation, effort directly corresponds to RT variability. This exactly has been observed in the present study. Although the try-harder instruction resulted in a global speed-up of responses, while error rate remained remarkably low (Figure 1), the distributional analysis indicates that this was mainly driven by the slowest percentiles of the CDF (Figure 2, 3). Thus, notwithstanding the stimulating explorations of prior studies (Falkenstein et al., 2003; Kleinsorge, 2001), our experimental set-up enabled us to more directly test the prediction that the ratio of spare and utilized capacity can be corrected by voluntary mobilization. These results suggest an increase of capacity by means of stabilizing information throughput (Humphreys & Revelle, 1984; Thorne, 2006).

It becomes evident from Figure 2 that the experimental conditions (standard vs. effort) are not very different at the shortest percentiles of the CDF while the difference increases substantially towards the longest percentiles. Figure 3 displays a delta plot of the try-harder instruction effect, comparably for the short-FP and the long-FP condition (De Jong, Liang, & Lauber, 1994; Ridderinkhof, 2002). A delta plot is obtained by calculating the RT difference as induced by an experimental manipulation (e.g., standard vs.

effort) against the mean of the experimental condition for each of the percentiles. By means of this analysis, the beneficial effects of a mobilization of effort can be evaluated relative to the mean of level of performance. This analysis indicates that the individuals in the effort condition were not particularly going faster overall but especially became more persistent, as indicated by a smaller proportion of overly long responses in the effort than in the standard experimental condition. In this way, delta plots might provide a convenient simplification of the relatively complex information present in the CDFs (e.g., Schwarz & Miller, 2012; Steinborn & Huestegge, 2016; Steinborn et al., 2016; Ulrich et al., 2015). Thus, the mechanism underlying effort is not in any way mystical (cf. Inzlicht & Gutsell, 2007; Inzlicht & Schmeichel, 2012) nor easily accounted for by using muscle metaphors (cf. Muraven & Baumeister, 2000), but simply serves the purpose of conveying processing stability (Humphreys & Revelle, 1984).

Broadly, mobilization in terms of non-specific attention control might have three qualitatively different effects in the domain of speeded action: an enhancement of performance effectiveness through focusing, a stabilization of information processing through maintenance control, and a more effective use of strategies. First, given that high arousal relates to an increased tendency to focus on few relevant aspects at the expense of irrelevant ones, an increased focus is predicted to result in improved performance. In this way, focus might be seen as a task-tailored optimization of attentional selection. Yet, the effectiveness of attentional selection is likely to deteriorate with high arousal particularly if the selection requires fine discrimination with regard to concurrent (Easterbrook, 1959; Hockey, 1997) and consecutive stimulus processing (Jolicoeur, 1998, 1999). Second, attaining effort might stabilize performance but is unlikely to be maintained for long (Pieters, 1983, 1985). To maintain performance, regulatory-control strategies might sometimes be more important than sole energization (Fernandez-Duque, Baird, & Posner, 2000; Lupker, Brown, & Colombo, 1997). Third, crucial to all successful performance is an effective way to mentally represent elements of a task with regard to the timing and sequencing of its constituent operations, thus dominance and potential confusability of mental representations (Navon & Miller, 1987, 2002) or cognitive codes (Hommel, 1998a, 1998b; Huestegge & Koch, 2009, 2013) must be taken into account.

Taken together, the prototypical scenario to study effort mobilization is the constant-FP paradigm, since individuals in this paradigm can be compared at different levels of (motor) readiness at the imperative moment corresponding to different FP durations that are administered between separate blocks of trials (Jennings & van der Molen, 2002, 2005). When asking questions of how effort is attained in anticipation of an impending target event, therefore, the FP task will be the design of choice. When asking questions of how effort is maintained over a certain period of time, however, the paced-task paradigm will be the best option, with demand (workload) and run length (length of successively performed trials) as principal factors determining performance. Kahneman (2013, chap. 2) recently provided an impressive description of this paradigm, and his view on capacity is mainly based on results with the paced-task paradigm. Having said this, we have severe concerns of studying effort mobilization within the microscopic framework of the PRP paradigm (Pashler, 1994). We see no possibility to reasonably assume that increased effort (corresponding to increased capacity) enables parallel processing (cf. Luria & Meiran, 2005; Ruthruff et al., 2009). Quite the contrary, from a spare-utilized capacity view, effort is assumed to foster increased focus on task operations (at the cost of monitoring), which does not necessarily include (but might even prevent) parallel attentional processing or concurrent preparation of multiple actions (Easterbrook, 1959; Hockey, 1997).

Design to study effort mobilization. We used the constant-FP design as contextual background, comparing performance at two hypothetical distinct mental states, a state of readiness and a state of non-readiness. Responses slow down monotonously (not linearly) with FP length, being fast with short FPs (>500 ms) but become (asymptotically) slower with the lengthening of FP (although a further lengthening beyond 5000 ms does not result in further slowing). It is assumed that individual track the time flow but engage in actual response preparation only immediately before the expected imperative moment (Drazin, 1961; Grosjean, Rosenbaum, & Elsinger, 2001; Karlin, 1959). Individuals occasionally fail to timely engage in preparatory processing which results in particularly slow responses in these trials (with these "lapses" contributing to RT distributional skewness). The probability of such failure-to-engage trials increases with FP length, resulting in a more skewed RT distribution in long-FP versus short-FP blocks

(Hohle, 1965; Kornblum, 1973). Crucially, the instruction to try harder mainly reduced distributional skewness (Figure 2), which was somewhat more pronounced in short-FP than in the long-FP blocks. Moreover, the faster responses in the effort trials were accompanied by an increase in error rate, which was observed only in the short-FP but not in the long-FP condition. Therefore, our results revealed a contextual limitation of effort mobilization that might be relevant for its effective implementation in future studies.

A further point relates to effort mobilization as a (non-specific) compensatory-control process (Hockey, 1997). It has often been argued both by earlier (Düker, 1929; Hillgruber, 1912) and contemporary authors with affinity to energetic issues such as Sturm and Willmes (2001), Hommel et al. (2012), Boot et al. (2008), Fischer et al. (2010, 2012), or Colzato et al. (2013), that tasks providing minimal environmental support through kinds of stimulation (e.g., phasic and tonic stimulation, gamification) deliver more room to be compensated by effortful processing as compared to their counterparts. Kleinsorge (2001) but also Bratzke et al. (2009; 2012) positioned themselves as advocators of such a view which implies that effort mobilization will be more effective under adverse than under favorable conditions because there is more to compensate in the former than in the latter case (Falkenstein et al., 2003; Folkard & Greeman, 1974; Yeh & Wickens, 1988). With regard to our study, one could reasonably expect a more pronounced compensatory effect of effort mobilization in long-FP than in short-FP blocks. However, this was not the case, since the benefits of effort mobilization were fairly additive (Figure 1). The extended RT distributional analyses even revealed a more pronounced effect of effort mobilization in the short-FP (vs. long-FP) condition (Figure 2, 3). This is supported by a supplemental sequence analysis (Figure 4, 5) where a critical condition (the effort trial) is directly compared with its preceding standard trial (cf. Brewer & Smith, 1984).

Another issue concerns the use of the probe-trial technique to study short-term mobilization by instruction. Posner and and Boies (1971) refer to several empirical studies where it was found that a probe task implemented in this way had little effect on the primary task. While this might basically be the case (since costs might be relatively low and are therefore tolerable), this claim is certainly a bit exaggerated, given recent work where these costs are measured more explicitly (cf. Miller & Durst, 2014, 2015). Hence, we have to tackle the issue of what effectively is manipulated by having an effort-instruction trials mixed into a design with standard trials. In fact, if participants know that they will be requested to perform better in the effort-instruction trials, this could lead them to put less effort into the standard trials. One could argue, therefore, that the observed effect of mobilization might not be to decrease variability in the try-harder condition, but could be to increase variability in the standard trials. We tested this possibility via a supplemental sequence analysis comparing RT performance in standard–standard versus effort–standard sequences. According to such a loafing hypothesis (cf. Kurzban, Duckworth, Kable, & Myers, 2013), a performance decrement after effort trials is expected (i.e., post-effort slowing), but conversely, the opposite was found (i.e., post-effort speeding). Responses became faster (not slower) after effort-instruction trials[2].

Final conclusion. Posner (1976, pp. 128-137) assumed two independent components as determinants of the constant-FP effect, to know (the correct response) and to be ready (to respond). More formally, he assumed a parallel increase of both the information build-up and the readiness to respond, with the latter being earlier at its peak in the short-FP (vs. long-FP) condition, resulting in a higher error rate. The results of our study imply that a short-term mobilization of effort increases the (average) rate of information build-up by a mechanism of stabilizing performance. We suggest that although the higher temporal precision in the short-FP (vs. long-FP) condition enabled an earlier start-up of stimulus analysis (information build-up), it simultaneously hampered the precise control of the motor-system components that are decisive for performance. In this way, the exact adjustment of response threshold to optimally meet the moment of sufficient information build-up might be the crucial determinant of a successful implementation of effort in choice-RT situations. Given the idea of an intermittent exchange between the capacities for operating processes versus monitoring across trials (Craik, 1948; Thomaschke, Hopkins, & Miall, 2012), our results imply that short-term mobilization changes the spare–utilized ratio by increasing capacity for operating processes at the cost of monitoring, resulting in a (short-term) reduction of response-speed variability and by this means increasing average response speed (or mental efficiency, respectively).

The key contribution that our study delivers to the community embraces two aspects, (1) knowledge in terms of novel, theoretically important insights into the prerequisites and specific effects of effort mobilization, (2) methodology of design and experimental set-up, (3) and advanced measurement technology. *First*, despite prior studies (Falkenstein et al., 2003; Kleinsorge, 2001; Schmidt, Kleinbeck, & Brockmann, 1984; Yeh & Wickens, 1988), our results provide new knowledge since we are the first to exactly determine the size of potential benefits of mobilizing additional capacity. *Second*, we provide a methodical advancement to study effort mobilization within the realm of mental chronometry. In the foreground of our research project thereby stand the goals of manipulating effort mobilization directly and measuring its effects with high precision by analyzing the entire RT distribution instead of only analyzing RT means. This is an advancement to previous studies in this domain. We must once again remind that most studies manipulated standard variables and attributed their effects on RT mean to effort mobilization. We demonstrated that there is a reserve of about 20% (100 ms) available, which can be released to an equal amount at both short-FP and long-FP conditions. Crucially, the benefits on RT mean are not interpretable by itself since they originate from a selective speed-up of responses at long CDF percentiles. Therefore, the main conclusion our study provides is that try-harder instructions do not globally speed-up information processing. In effect, a short-term mobilization of capacity makes individuals more reliable by protecting the system against attention failure. In this way, it ensures stability of information-processing throughput.

Ethical Statements

Informed consent was obtained from the participants regarding their agreement with their participation in this research. Our study was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All authors declare that there are no conflict of interests.

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Footnotes

Footnote 1. One reviewer had some questions regarding error rate in short-FP blocks. It may sometimes be of theoretical importance to show that an effect on RT occurs robustly, irrespective of (even small) differences in error rate across individuals (Jentzsch & Dudschig, 2009; Notebaert et al., 2009; Steinborn, Flehmig, Bratzke, & Schroeter, 2012). However, this should explicitly be demonstrated. To this end, we divided the sample into three parts according to the individual overall error rate and selected one third (the most accurate) of the sample for further analysis. In fact, similar results were obtained both visually and statistically. Responses were faster in blocks with the short-FP than with long-FP duration, as indicated by a main effect of FP length on RTM [$F(1,10) = 34.8$, $p < .001$]. Responses were also faster in effort trials than in standard trials, as indicated by the main effect of CUE on RTM [$F(1,10) = 38.0$, $p < .001$]. No FP × CUE interaction on RTM occurred [$F < 1.7$].

Footnote 2. One reviewer asked whether the exercising of effort and the resulting benefit in a current trial yielded costs in the subsequent trial. This issue is certainly important particularly with respect to recent findings and theorizing in the domain of vigilance-detection performance (Helton & Russell, 2011; Matthews et al., 2002; Thomson, Besner, & Smilek, 2015; Warm et al., 2008). In response to this request, we performed an extensional GLM analysis, comparing RT performance in standard–standard versus effort–standard sequences. The result of this extensional analysis is that individuals become slightly faster (not slower) after the effort trial as compared to after a standard trial ($p > .05$). There was no interaction with foreperiod length ($F < 1$). This indicates that attentional control settings are affected by short-term effort mobilization, although the precise mechanism underlying this aftereffect cannot be determined here. We therefore will not further expand on this issue at this point. Notably, our results are consistent with a recent finding of Ralph et al. (2016), who observed that vigilance-detection performance immediately improved after the arousing experience of exercising a car game.

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Appendices

Table 1. Results of the experimental effects on standard performance indices.

Source			RTM			EP			RTCV		
		df	*F*	*p*	η^2	*F*	*p*	η^2	*F*	*p*	η^2
1	FP	1,31	58.9	.000	.66	21.9	.000	.41	0.7	.395	.02
2	CUE	1,31	133.7	.000	.81	1.7	.208	.05	18.6	.000	.38
3	FP × CUE	1,31	0.9	.351	.04	6.5	.016	.17	4.2	.049	.12

Note. Effect size: partial η^2; Experimental factors: Constant Foreperiod (FP: short vs. long), Effort Instruction (CUE: effort vs. standard). RTM = reaction time mean; EP = error percentage (%); RTCV = reaction time coefficient of variation.

Table 2. Results of the experimental effects on ex-Gaussian parameters

Source			μ (Mean)			σ (Variability)			τ (Skewness)		
		df	*F*	*p*	η^2	*F*	*p*	η^2	*F*	*p*	η^2
1	FP	1,31	39.2	.000	.56	4.7	.038	.13	6.2	.018	.17
2	CUE	1,31	8.1	.008	.21	0.0	.974	.00	99.4	.000	.76
3	FP × CUE	1,31	0.1	.906	.00	0.8	.384	.03	0.7	.397	.02

Note. Effect size: partial η^2; Experimental factors: Constant Foreperiod (FP: short vs. long), Effort Instruction (CUE: effort vs. standard).

Figure Captions

Figure 1. Reaction time mean and error rate (RTM, EP) as a function of the factors foreperiod (FP: 1000 vs. 4000 ms) and instruction (Cue: standard vs. effort) in the speeded choice-reaction task.

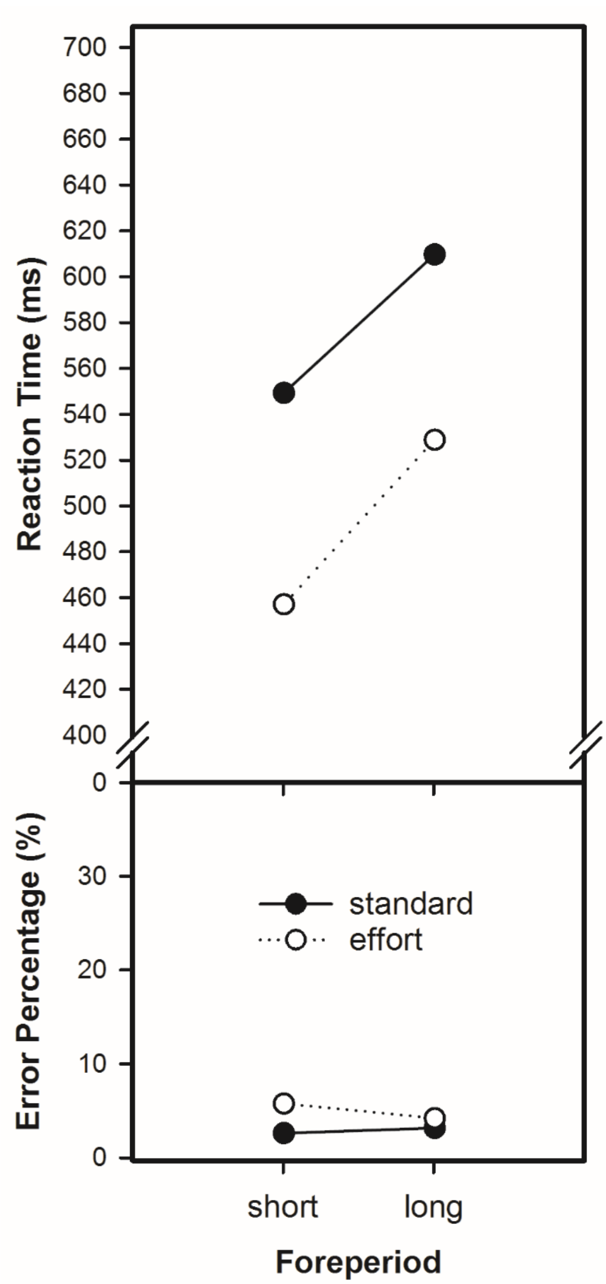
Figure 2. Vincentized cumulative distributive function (CDFs) of reaction times for each combination of the factors foreperiod (FP: 1000 vs. 4000 ms) and the instruction to try harder (Cue: standard vs. effort).

Figure 3. Delta plots of the mobilization effect for each of the short-FP (vs. long-FP) condition. For each percentile, the RT difference between the experimental conditions (standard vs. effort) is plotted against the mean of the conditions in that percentile.

Figure 4. Vincentized cumulative distributive function (CDFs) of reaction times for each combination of the factors foreperiod (FP: 1000 vs. 4000 ms) and the instruction to try harder (Cue: standard vs. effort), comparing sequence pairings of effort with its preceding standard trials.

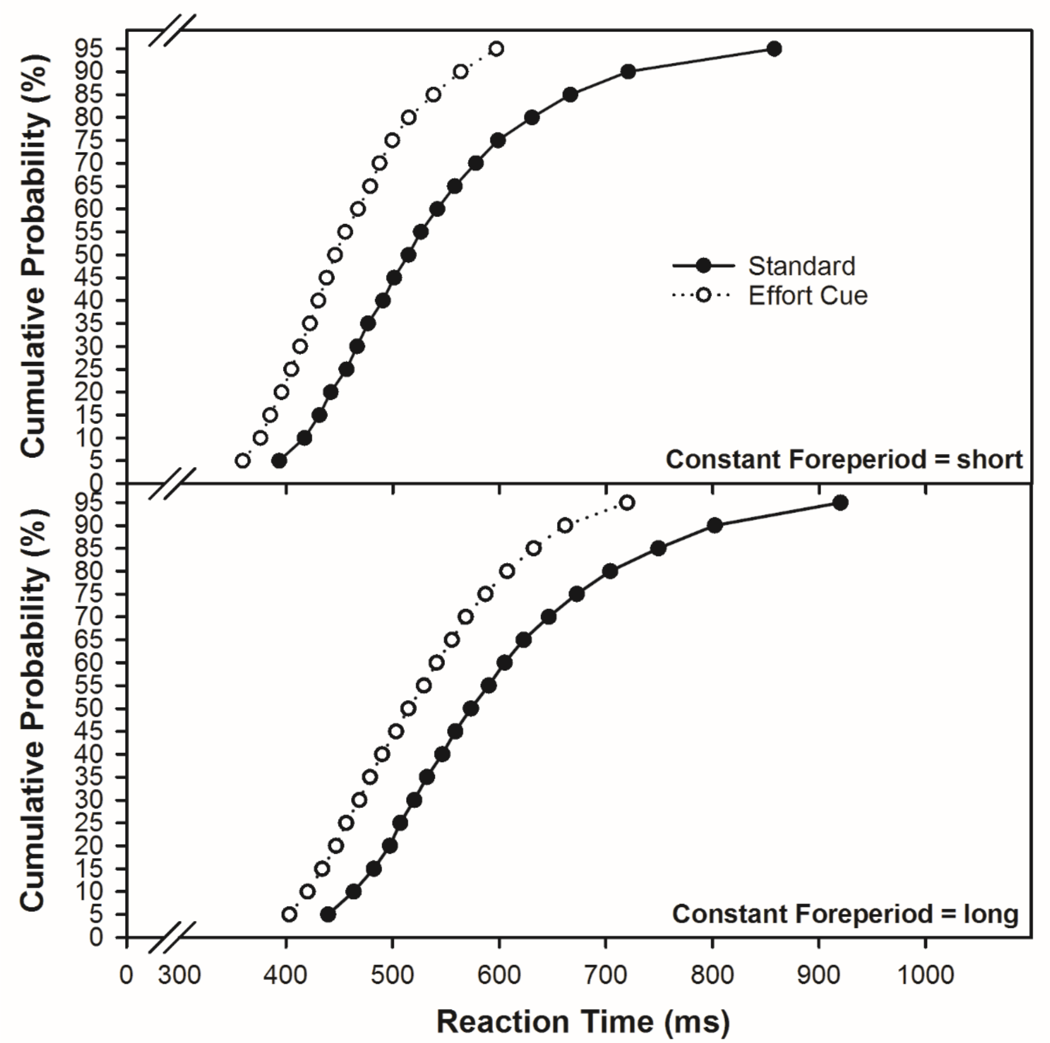
Figure 5. Delta plots of the mobilization effect for each of the short-FP (vs. long-FP) condition. For each percentile, the RT difference between the experimental conditions (standard vs. effort) is plotted against the mean of the conditions in that percentile, comparing sequence pairings of effort with its preceding standard trials.

Figure 1



Reaction Time (ms)
700
680
660
640
620
600
580
560
540
520
500
480
460
440
420
400
0
Error Percentage (%)
30
20
10
0
standard
effort
short
long
Foreperiod

Figure 2



Cumulative Probability (%)
Standard
Effort Cue
Constant Foreperiod = short
Cumulative Probability (%)
Constant Foreperiod = long
0 300 400 500 600 700 800 900 1000
Reaction Time (ms)

Figure 4

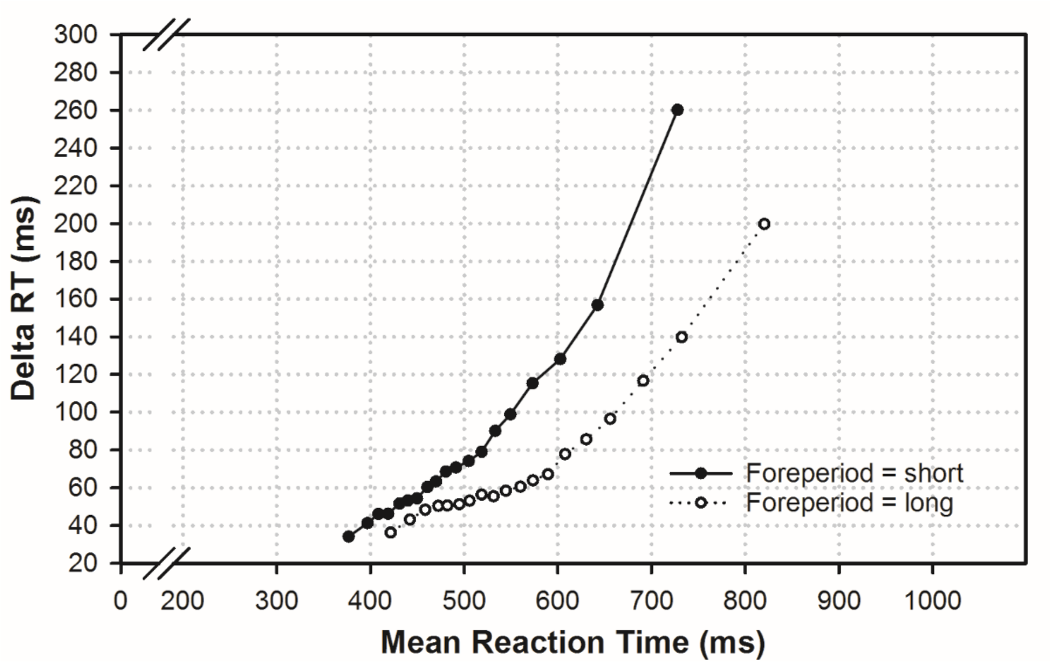

Delta RT (ms)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
200
300
400
500
600
700
800
900
1000
Mean Reaction Time (ms)
Foreperiod = short
Foreperiod = long

Figure 5

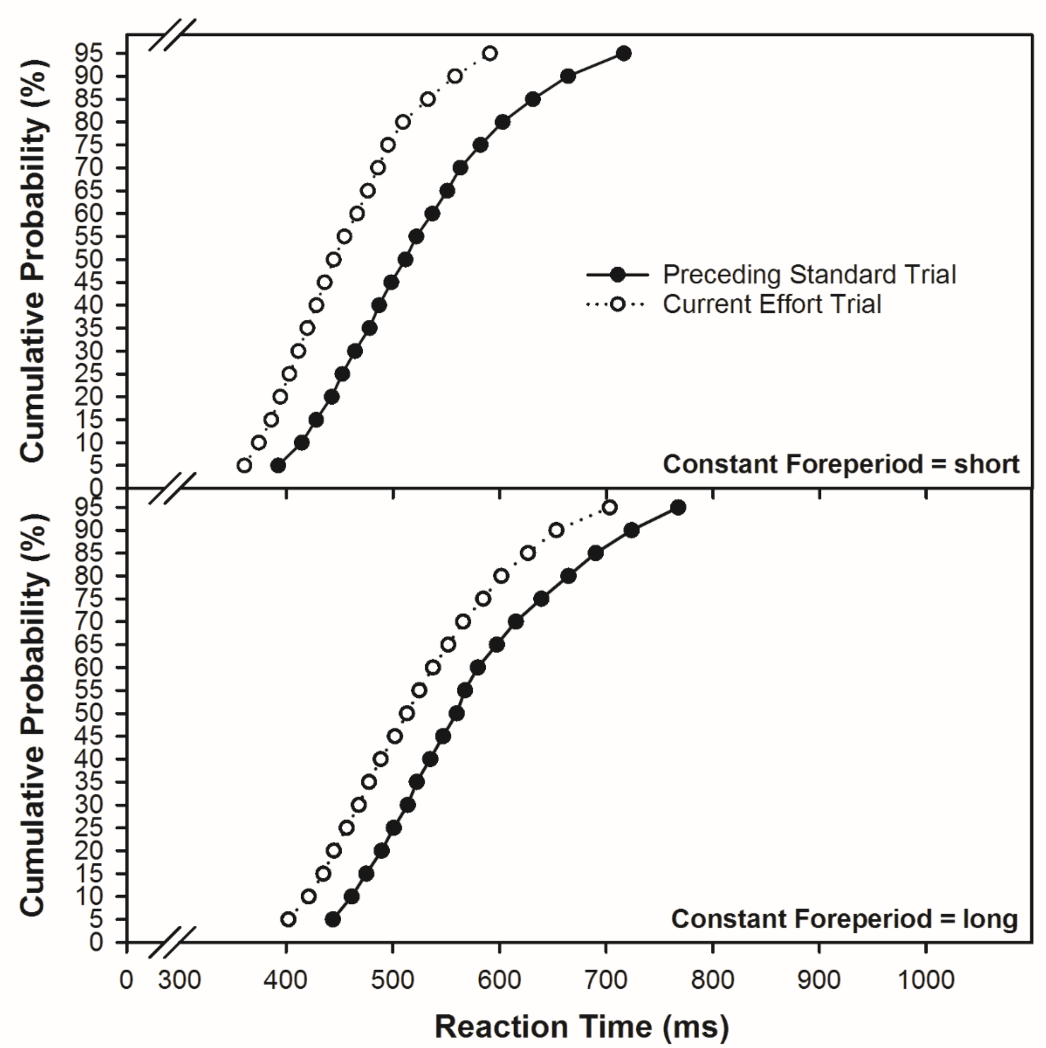
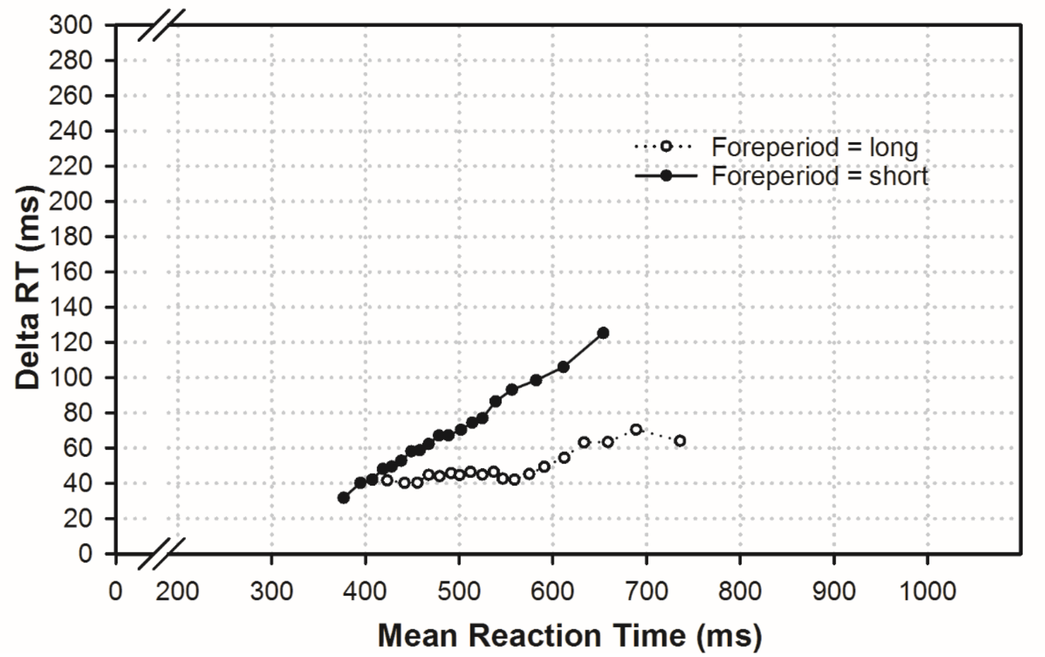

Cumulative Probability (%)
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Preceding Standard Trial
Current Effort Trial
Constant Foreperiod = short
Cumulative Probability (%)
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Constant Foreperiod = long
0
300
400
500
600
700
800
900
1000
Reaction Time (ms)

Figure 6



Delta RT (ms)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
Foreperiod = long
Foreperiod = short
0
200
300
400
500
600
700
800
900
1000
Mean Reaction Time (ms)