EFFORTFUL PROCESSING IN THE SPEED-ACCURACY TRADEOFF PHENOMENON

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Abstract

Forty students participated in a dual-task speed-accuracy trade-off experiment. The primary task required them to compare the relative sizes of two symbolic stimuli, and the secondary task required them to periodically identify a tone which sounded at the beginning of each trial. The primary task was performed under both speed-emphasized and accuracy-emphasized conditions. Measures of response time and proportion correct were taken for both tasks under both conditions. Results for the primary task suggested that participants adhered to the instructional emphases of speed and accuracy. Decremented performance in the secondary task was not evident with respect to proportion correct; however, secondary task response times in the speed-emphasized condition were slower than in the accuracy-emphasized condition. These data provide some evidence that speeded responding might indeed be an inherently effortful process and, hence, might not simply involve passive adjustments to response criteria.

The speed-accuracy trade-off is an important phenomenon in the study of both psychophysics as well as human information processing more generally. Whereas in the latter field this trade-off is often regarded as a potential nuisance factor with respect to interpreting both response time and accuracy data, in psychophysics the speed-accuracy trade-off is regarded as a phenomenon worthy of study in its own right. Indeed, asking participants to trade off speed for accuracy is viewed as a means through which the potential mechanisms of psychophysical decision making can be illuminated (Link, 1992; Petrusic, 1992; Vickers, 1979).

Two key theoretical frameworks within which to understand psychophysical decision making are the sequential-sampling-based random walk (Link, 1992; Ratcliff & Rouder, 1998) and accumulator (Vickers, 1979; Usher & McClelland, 2001) models. Each of these models assumes that the perceptual evidence for any decision is accrued over time (either in small packets or continuously) until a criterion amount of information has been obtained, at which point the response associated with that criterion is evoked. Random walk models regard this process as involving the diffusion of an evidence signal between two (positive and negative) absorbing response-threshold boundaries. Accumulator models regard this process as a buildup of evidence signals within two (or more) accumulators with set decision bounds.

A key assumption of both of these decision frameworks that allows them to account for the presence of speed-accuracy trade-offs surrounds the notion that participants are able to strategically lower their response boundaries under speeded conditions in order to provide faster decision times. Because the evidence signal in both of these decision frameworks is assumed to be noisy rather than deterministic, a lowering of the response boundaries will necessarily lead to more decisional errors (and, hence, lower accuracy). In other words, the lower an incorrect decision boundary is, the greater is the probability that it will be crossed in error. (Although for a completely alternative view of this phenomenon see the parallel sophisticated-guessing model of Meyer, Irwin, Osman, & Kounios, 1988.)

The issue of concern in the present study is the degree to which the lowering of the response boundaries in such models can be regarded as being either a fairly passive process or an active one which might actually require a great deal of effort. In order to measure the effort associated with performing decisions under either speed or accuracy sets, a dual-task methodology will be employed here. When participants are asked to perform two (primary and secondary) tasks simultaneously, any decrements in the performance of either or both tasks as compared to when they are being performed alone can be regarded as indicating that the amount of shared cognitive resources required to perform both tasks at the same time exceeds the available limits (Brown & Merchant, 2007; Kahneman, 1973; Wickens, 1984). Furthermore, decrements in secondary task performance across changes in the nature of the primary task can be regarded as indicating that the resource requirements of primary task have increased, hence, leaving less resources available to perform the secondary task. In the present study, the primary task will involve making size comparisons (under either speed or accuracy set), while the secondary task will involve identifying tones.

Some insight into the potential resource requirements of speeded responding can be found in a recent study by Van Veen, Krug, and Carter (2008) who investigated the neurological basis for speed-accuracy trade-offs through functional magnetic resonance imaging (for some related experimental work see Kleinsorge, 2001). Van Veen et al.'s methodology required participants to respond to a set of stimuli according to a conventional speed-accuracy procedure. Participants were instructed to emphasize either accuracy or speed at the beginning of each mini-block, which itself consisted of 4, 8, or 20 trials. Each trial consisted of a Simon task, wherein participants to respond to the colour of a stimulus appearing either to the left or the right of a fixation point. Imaging data revealed an increase in sustained metabolic baseline activity in the left dorsal premotor cortex, the left intraparietal lobe, basal ganglia/thalamus, and the dorsolateral prefrontal cortex during speed emphasis. Indeed, within all neurological areas measured, greater activation was consistently observed in conditions emphasizing speed. Accuracy-emphasized conditions on the other hand, were consistently accompanied by greater transient activation as indexed by further increases in brain activation (above the baseline level) that occurred in response to the presentation of the Simon stimuli.

The theoretical implications of these imaging results are extensive. Namely, it seems that speed-accuracy trade-offs might be directly influenced by activation of the dorsolateral prefrontal cortex. This area is thought to then increase baseline activation in subsequent decision-making, response-preparation, and motor execution areas. Hence, the results of Van Veen et al. (2008) could be regarded as providing some key insight into the workings of sequential-sampling-based decision models. Namely, that speed-emphasized responding is indeed characterized by a reduction in the distance between the baseline evidential starting points of these models and the response boundary thresholds. However, in accordance with Van Veen et al., this reduction is more likely to be due to active increases in the levels of non-specific baseline activation, as opposed to passive decrease in the levels of the response thresholds (see Bogacz, Wagenmakers, Forstmann, & Nieuwenhuis, 2010, for further discussion of this point).

Method

Participants. Forty Carleton University students (13 males and 27 females) participated in this study. All of them participated for experimental credit towards a first-year psychology course. Each participant performed the task individually, and each session took approximately 45 min.

Stimuli and Apparatus. The name stimuli for the primary comparison task consisted of two separate six-item lists of both animal and inanimate object names taken from the normative size rating results given in the study of Shoben, Čech, Schwanenflugel, and Sailor (1989). These norms were used to equate the rated sizes of the items at each of six ordinal positions across the two lists and also to equate (as best as possible) the interval-level, rated size differences between all pairs of ordinally adjacent items within each list. The mean size ratings for each ordinal list position were -4.80, -2.78, -1.05, 1.21, 3.13, and 4.90 (on a scale of -9 to 9). The two lists were (a) Peach, Book, Chicken, Rake, Bicycle, and Sofa, and (b) Comb, Dove, Pail, Banjo, Table, and Cannon. The stimuli for the secondary tone identification task were three tones with frequencies of 300, 900, and 1500 Hz, respectively. These tones were played through a speaker that was located in the tower of a 486 desktop computer sitting right beside the participants.

The whole experiment was programmed and ran using Micro Experimental Laboratory (MEL V.2.0) on a 486 computer. During each comparison trial, two of the six name stimuli were presented side by side in the center of the computer screen. The font size for the stimuli (as determined by MEL System48 font) was somewhat larger than a regular DOS font size. On all trials, the instruction for comparison task (i.e., "Larger?" or "Smaller?") was first presented at the top of the screen. Comparison task responses were made by pressing either the "z" or "/" keys on the left and right sides of the bottom row of the computer keyboard. Tone task responses were made by pressing one of the "v", "b" or "n" keys in the middle of the bottom row of the computer keyboard. All five keys were marked with colored stickers.

Procedure. Throughout the experiment, participants were seated in front of a computer screen in a dimly lit room. Each trial involved the following series of events. First, one of the three tones sounded for 250 ms. Next, the comparative instruction appeared for 1000 ms along with a temporary plus-sign fixation point (located in the middle of the screen). Then, a pair of name stimuli appeared and participants had to choose which one (i.e., the thing on the left or on the right) was either the smaller or the larger by pressing the appropriate response key with the index fingers of their left or right hand. Both the instruction and the stimulus pair remained on the screen until the response was made. On 25% of the comparison trials, a prompt then appeared asking the participant to report which tone had occurred on that trial (i.e., "the last tone" that they had heard). Participants reported that it was either the low, medium, or high tone by pressing either the left-most, middle, or right-most tone-task response keys, respectively. After 1000 ms, the next trial was initiated.

In each half of the experiment, participants first performed a practice block of 20 trials that was followed by two test blocks of 60 trials. In each respective half, participants were asked either to try to be as accurate as possible for the comparison task or to try to respond as quickly as possible for the comparison task. The order of usage of these two speed-accuracy emphases was completely counterbalanced across all participants. They were also told to always try to remember the tones as best as they could, regardless of the speed or accuracy emphasis placed on the comparison task. When accuracy was emphasized, feedback was provided throughout about the correctness of each comparison task response. When speed was emphasized, a response time deadline of 550 ms was invoked such that participants were given a "Too Slow" message whenever they did not respond before that much time had elapsed after the presentation of the comparison stimuli

Only pairs of stimuli that were adjacent in the ordering were used in the practice block, whereas in the test blocks, all possible pairs of stimuli were used. The order of presentation of both the comparison pairs (in each possible left-right positional ordering) and the smaller or larger instructions was completely randomized within each block of trials. The stimulus set was switched for each half of the experiment. The order of usage of each of the two stimulus sets was counterbalanced across all participants and also completely crossed with the speed-accuracy emphasis conditions. Two random orderings of tone stimuli across trials were derived and used for every participant in each of the two test blocks within each of the accuracy- and speed-emphasized halves of the experimental session (with a part of one of these ordering used for the practice trials). At set places within each of these two orderings (i.e., Trials 5, 10, 12, 16, 19, 25, 28, 29 32, 37, 42, 45, 50, 52, and 57 for the first test block, and Trials 7, 9, 13, 16, 19, 20, 22, 28, 33, 37, 39, 46, 49, 55, and 58 for the second test block) participants were cued to recall the tones. Each ordering contained an equal number of presentations of each of the three tones and, hence, recall for each of the three tones was tested equally.

Results

Only the data obtained from the test blocks were used in the following analyses. Separate analyses were performed for each of the following four dependent variables computed separately for each participant (a) median response times for the primary comparison task across the 120 trials in each of the speed- and accuracy-emphasized conditions, (b) the proportion of correct responses made to the primary comparison task across the 120 trials in each of the speed- and accuracy-emphasized conditions, (c) median response times to the secondary tone task across the 30 tone-recall trials in each of the speed- and accuracy-emphasized conditions, and (d) the proportion of correct responses made to the secondary tone task across the 30 tone-recall trials in each of the speed- and accuracy-emphasized conditions. For each dependent variable, a paired samples *t*-test was performed that contrasted performance under speed and accuracy emphasis (of course, much more extensive analyses of these data could have been performed but such analyses were not deemed necessary for the present purposes). Response time medians were used in order to minimize the effects of any really long response times (although note that it is the means of these medians across the 40 participants that are reported descriptively) and analyses of the proportion correct measures were conducted using arcsine-transformed proportions (even though it is the means for the untransformed accuracy measures that are reported descriptively).

With respect to response times, the *t*-tests revealed that there was a significant difference in response times for the accuracy-emphasized and speed-emphasized conditions of the primary symbolic comparison task; $t(39) = 9.409$, $p < .001$. There was also a significant difference in the response times for the secondary tone identification task across the accuracy-emphasized and speed-emphasized primary task conditions; $t(39) = -2.052$, $p < .05$. The corresponding mean response time results are summarized in Table 1.

Table 1. Mean response times for the speed- and accuracy-emphasized conditions.

	Speed-Emphasis (ms)	Accuracy-Emphasis (ms)	Probability
Symbolic Comparison	$M = 735$, $SD = 278$	$M = 1670$, $SD = 625$	$P < .001$
Tone Identification	$M = 1696$, $SD = 357$	$M = 1581$, $SD = 488$	$P < .05$

With respect to accuracy, the *t*-tests revealed that there was a significant difference in the proportion of correct responses in the accuracy-emphasized and speed-emphasized conditions of the primary symbolic comparison task; $t(39) = 12.658$, $p < .001$. On the other hand, there was no significant difference in the proportion of correct responses for the secondary tone identification task across the accuracy-emphasized and speed-emphasized primary task conditions; $t(39) =.594$, $p < .556$. The corresponding mean proportion correct results are summarized in Table 2.

Table 2. Proportion of correct responses for speed- and accuracy-emphasized conditions.

	Speed-Emphasis	Accuracy-Emphasis	Probability
SymbolicComparison	$M = .714$, $SD = .197$	$M = .933$, $SD = .186$	$P < .001$
Tone Identification	$M = .747$, $SD = .362$	$M = .761$, $SD = .350$	$P < .556$

Discussion

The present experiment utilized a dual-task methodology to determine the cognitive effort affiliated with making speeded responses compared to accurate ones. Methodologically, participants were required to compare the sizes of pairs of symbolic stimuli while intermittently responding to a tonal presentation (i.e., the primary and secondary tasks, respectively). The present results showed that correct responding in the primary task was significantly lower under speed emphasis than under accuracy emphasis indicating that participants adhered to the primary task requirements. However, accuracy for the secondary task was not differentially affected (to any great extent) by the speed-accuracy emphasis placed on the primary task. Moreover, participant response times for the primary task in the speeded condition were significantly faster than in the accuracy condition, also indicating that participants adhered to the primary task requirements. However, for the secondary task, participants were significantly slower when speed was emphasized in the primary task in comparison to when accuracy was emphasized.

It had initially been expected that any increased demands on centrally-located cognitive processing resources that were associated with enhancing baseline levels of neural activation, in order to provide speeded responses to the primary comparison task, should indeed have served to significantly affect the accuracy of responding to the secondary tone identification task. Namely, accurate responding to this secondary task could be regarded as depending on the degree to which the participants could faithfully maintain the identity of the presented tone in memory while responding to the comparison task. Hence, if more resources were required to respond to the comparison task under speed emphasis, less would have been available to allocate to the maintenance of the tone, making it less likely that participants would then have been able to keep track of it. However, it is possible that the nature of the cognitive resources used to invoke speeded comparison responses and those used to maintain the memory of the tones do not actually overlap (i.e., they come from separate pools of resources, Wickens, 1984; such as those associated with the central executive and the phonological stores in Baddeley's, 1986, working memory model). If so, then one way to extend the present research would be to consider the use of a secondary task involving cognitive resource demands that are more likely to overlap with those used to make comparison responses under speed (where perhaps even an "n-back" tone identification task might serve this purpose). Note, as well, that the fact that secondary task accuracy was around 75% suggests that it was not simply the case that the secondary task was too easy (although the fact that accuracy was at this level for this task might also suggest that participants did not actually try to maintain the tones but simply attempted to recollect them whenever prompted to do so; at which point the resource requirements of the primary task would have had no effect because the comparison response had already been made).

On the other hand, in the present study, a performance decrement in secondary task response time was associated with speeded responding to the primary task. Such a result is indeed somewhat promising because it suggests that some sort of enhanced refractory period might have been occurring after responding under speed to the primary task, which then affected participant's ability to perform the secondary task efficiently (perhaps, by increasing the difficulty of switching to the tone task; Monsell, 2003). Unfortunately, this result is also open to a number of other interpretations which makes it hard to determine the exact locus of this effect. For example, if speeded responding in the primary task was simply associated with enhanced muscle tension, a subsequent slowing of the motor component of response time in the secondary task could certainly then be expected. As well, it is possible that because more errors were occurring in the speeded condition of the primary task, larger response times in a subsequent secondary task might simply represent a form of the well-known post-error slowing effect.

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