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Attention and Task Difficulty: When Is Performance Facilitated?

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Under certain conditions, when initiating a trial is made difficult, task performance improves as the task becomes harder to do. This counterintuitive finding has led to a distinction between the motor difficulty and the cognitive difficulty of a task. The present report summarizes three replications of an experiment in which the two aspects of difficulty were manipulated orthogonally in a recognition task. Participants (total $N = 67$) responded significantly more accurately and rapidly under conditions in which a cursor had to be moved very precisely (versus imprecisely) into a circle fixed in the center of a computer screen. However, accuracy and response time were compromised with increases in the cognitive difficulty variable (stimulus exposure duration). Visual gaze and pupil dilation data supported the interpretation that attention is elicited by increases in motor difficulty and that performance can benefit from this allocation of attention or mental effort.

Since the relationship between task difficulty and attention was first addressed by Kahneman (1973) and Norman and Bobrow (1975), it has been examined empirically in a multitude of studies (see reviews by Pashler, 1993, 1998). In the typical paradigm, individuals are required to perform two tasks concurrently while the difficulty of the primary task is manipulated. The major focus of this research has been on disruption of secondary-task performance as a function of the difficulty of the primary task. The common (albeit not exclusive) explanation is that increasing task difficulty elicits an allocation of attention in order to maintain the quality of performance; consequently, there are fewer attentional resources available for the performance of other simultaneous tasks.

Whereas numerous studies have been designed to examine this comple-

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mentarity between primary-task difficulty and secondary-task performance, few have addressed a second prediction derived from the theory: Increasing the difficulty of the primary task results in shifts of attention that may facilitate primary task performance. Of course, the facilitative effect is generally obscured by the fact that the task itself has become more difficult. Consequently, an asymptotic level of performance on the primary task is typically maintained even with increases in the difficulty of that task. Nonetheless, the relation between difficulty and attention suggests that one could see improvements in primary task performance as a result of increased difficulty if one could uncouple the variable that reflects the difficulty manipulation from the other variables that reflect task performance.

This prediction has been the focus of our previous research, where the results from a series of experiments indicated that learning and recognition performance on computerized tasks were improved by making stimuli move on the screen rather than remain stationary (Washburn, 1993; Washburn & Putney, 1998). This effect was found to be attentional in nature and not to be an artifact of exposure duration, figure–ground distinction, or the perceptual bias to attend to change and motion. Neither was the effect an instance of ‘‘attention capture’’ (Yantis, 1993) or the perceptual propensity to orient to movement in the environment. Rather, more accurate and faster responding appeared to result from the increase in difficulty caused by requiring participants to catch moving rather than stationary stimuli—an increase in difficulty that was independently (i.e., noncircularly) corroborated by the fact that it required significantly longer time for participants to capture the moving versus the stationary stimuli. That is, it appears that making trials more difficult using stimulus movement resulted in increased attention to, and consequently improved performance on, the task.

This interpretation of the stimulus movement effect suggests two additional tests that should be conducted. First, it must be determined whether other manipulations of motor difficulty—manipulations of task difficulty that do not involve stimulus movement, but that do not increase the cognitive difficulty of the task—will affect performance in this way or whether the effect is unique to stimulus movement. Second, an independent measure of attention or mental effort other than performance should be shown to respond to motor demands in order to provide additional evidence that an increase in attention results in improved performance. In the present experiment, trial-initiation difficulty and exposure duration were manipulated orthogonally in a stimulus-recognition task designed to provide these two tests. It was hypothesized that increasing the difficulty of initiating a trial, a motor-difficulty variable reflected in the time required to begin a trial, would result in improved recognition performance. In contrast, increasing the mental difficulty of the task by reducing the exposure duration of stimuli in the recognition task was expected to compromise performance. Finally, pupillary dilation was recorded as an additional measure of mental effort or attention

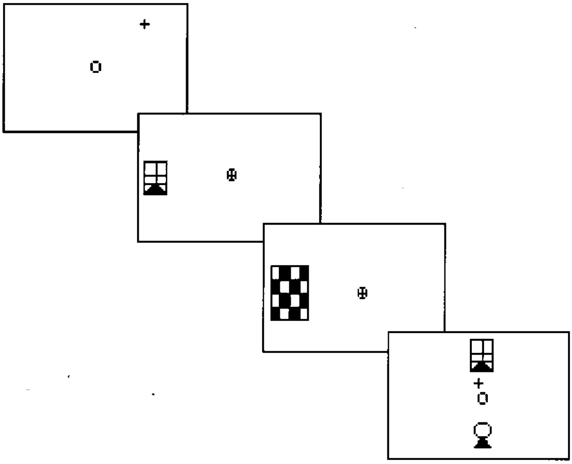

FIG. 1. A depiction of the sequence of a trial in this study. The figure also illustrates the type of target stimuli used in this task.

demand during task performance. Although pupil size can be influenced by other variables, Beatty (1982) argued that pupil dilation provides a straightforward measure of mental effort, and the variable continues to be used in cognitive research for this purpose (Granholm, Asarnow, Sarkin, & Dykes, 1996; Hyona, Tommola, & Alaja, 1995; Just & Carpenter, 1993). It provides a sensitive, independent measure of the mechanisms of interest.

METHOD

Participants

A series of three successive replications of the basic experiment were conducted, involving a total of 67 participant volunteers (age range 18 to 32 years; 37 females). Due to similarities in procedures and findings, the replications are discussed together with differences in procedures identified as a grouping variable. Group 1 consisted of volunteers from Georgia State University ($N = 25$). Groups 2 and 3 were volunteers from the Atlanta University Center ($N = 20$ and 22, respectively). All 67 of these undergraduate students performed the same recognition task in exchange for course credit.

Apparatus and Task

A 386-based computer and 13-inch (diagonal) SVGA monitor were used to administer a task that required recognition of visual forms that were briefly and parafoveally presented (a divided-visual-field task; see Fig. 1; Beaumont, 1982). The participants responded to the computer-generated stimuli by manipulating a standard analog joystick, which in turn controlled the movements of a 1.25×1.25 cm (i.e., subtending a 1° visual angle) white cursor

(‘‘+’’) on the black screen. Each trial began with the cursor presented in random position on the screen (but not within 2.5 cm, or 2° of visual angle, of midscreen) and a 1.25-cm-diameter fixation circle (subtending 1° of visual angle) presented midscreen. The student initiated a trial by bringing the cursor into the stationary fixation circle, whereupon a sample stimulus was flashed to the left or to the right of the circle for 50 to 150 ms (see below). Each computer-generated visual form measured 5.0 × 7.5 cm, subtended 4° of visual angle, and was comprised of randomly selected geometric elements overlaid to form novel patterns (Fig. 1; see Washburn, 1990 for a complete description of stimulus generation). The inside edge of the sample stimulus was 5 cm from the fixation circle, or 4° visual angle when viewed from the distance of 72 cm. Following this brief presentation to a randomly selected side of the screen, the sample was then masked by a checkerboard pattern for 50 ms. When the checkerboard mask was removed, two choice stimuli were immediately presented on the screen, one 2.5 cm above and one 2.5 cm (or 2°) below the cursor. One of the choice stimuli identically matched the briefly presented sample stimulus, whereas the other was a randomly selected foil. The position of the matching stimulus (top or bottom) was randomly determined each trial. The participant was instructed to move the cursor as quickly and as accurately as possible into contact with the choice stimulus that matched the sample. Differential auditory feedback was provided for correct (a tone) and incorrect (a buzzing noise) recognition of the target stimulus.

In order to obtain independent assessment of effort using pupillometric measurement (e.g., Granholm *et al.*, 1996), additional apparatus was used for Group 3. Each participant was seated in front of a computer monitor and used a chinrest to keep her/his head stationary at a distance of 72 cm from the computer screen throughout the experiment. An ISCAN (Burlington, MA) RK-426PC eye-tracker/pupillometer was used to record the position and diameter of each student’s right pupil throughout testing. This unit uses corneal reflection of an infrared light source to calculate gaze and dilation. These data were recorded at the moment that each trial was initiated, that is, when the student had precisely positioned the cursor in the fixation circle, immediately prior to the brief presentation of the sample stimulus.

Procedure

Each participant in Groups 1 and 2 performed 100 trials on this task, during which two variables were manipulated. Initiating a trial was either easy (the cursor had to be within 0.5° of the center of the circle) or difficult (the center pixel of the cursor had to be exactly atop the center pixel of the fixation circle). Additionally, the exposure duration for the flashed stimulus was varied. For participants in Group 1, stimuli were flashed on the screen for either 50 or 100 ms. Group 2 was tested with exposure durations of 100 or 150 ms in order to extend the results of Group 1 with slower presentations. Exposure duration was selected randomly between these values across trials, whereas the trial-initiation condition was administered by blocks of 50 trials (100 trials total) and with order counterbalanced across participants.

Because they were required to keep their heads stationary during testing, participants in Group 3 were only required to complete 4 blocks of 10 trials. The eye-tracker was recalibrated prior to each block by requiring participants to fixate on a series of nine dots displayed on the monitor. This allowed the experimenters to translate changes in position of the eye into X-Y coordinates of gaze at the computer screen. As with Group 2, exposure duration was selected randomly on each trial between 100 and 150 ms. Trial-initiation difficulty was counterbalanced across blocks of trials.

RESULTS

The precision-of-centering variable resulted in a substantial difference in trial-initiation difficulty. Across groups, the students initiated trials in the easy-initiation condition in an average of 983 ms. An average of 2753 ms was required to find the exact center of the fixation circle in the difficult-initiation condition.

Separate analyses of the response-accuracy and response-time measures were performed for each group using exposure duration and trial initiation condition as independent variables. Because the main results of these six separate analyses were comparable, a combined analysis (across groups) is reported here for each dependent measure. Stimulus recognition was more accurate and rapid when trials were difficult to initiate than when trials were relatively easy to initiate. On the contrary, recognition was significantly more accurate and significantly faster with longer (easier) versus shorter (harder) exposure durations. These reverse effects of the two difficulty variables were replicated in each of the three groups and are presented as averages in Table 1.

Both for accuracy and response-time measures, reliable differences were found between exposure duration conditions: $F(1, 64) = 99.14$ and 22.52, respectively; $P < .01$. Similarly, the trial-initiation manipulation produced reliable differences in accuracy and response time: $F(1, 64) = 58.8$ and 64.92, respectively; $P < .01$. Again, it is noteworthy that these main effects were comparable in degree but opposite in direction.

In the combined analysis of the accuracy data, a significant three-way interaction was observed, $F(2, 64) = 5.45$, $P < .01$. This interaction only reflects asymmetries across the groups in the amount of difference between the Exposure X Initiation conditions. The overall pattern of results was the same for all three groups: Accuracy was highest on the long-exposure, hard-initiation trials and worst on the short-exposure, easy-initiation trials. The same pattern was true of the response time data, despite reliable two- and three-way interactions found between exposure duration, initiation difficulty,

TABLE 1
Mean Accuracy and Response Time by Group and Condition

Group 1 (N =25)	Exposure duration (50 ms)	Exposure duration (100 ms)	Means
Hard trial initiation	61% accuracy 1518-ms RT	66% 1500 ms	63.5% 1509 ms
Easy trial initiation	51% 1630 ms	60% 1524 ms	55.5% 1577 ms
Means	56% 1574 ms	63% 1513 ms	
Group 2 (N = 20)	**Exposure duration (100 ms)**	**Exposure duration (150 ms)**	**Means**
Hard trial initiation	70% accuracy 1183-ms RT	80% 1185 ms	75% 1184 ms
Easy trial initiation	62% 1526 ms	75% 1330 ms	68.5% 1428 ms
Mean	66% 1355 ms	77.5% 1258 ms	
Group 3 (N = 22)	**Exposure duration (100 ms)**	**Exposure duration (150 ms)**	**Means**
Hard trial initiation	76% accuracy 1355-ms RT	86% 1205 ms	81% 1280 ms
Easy trial initiation	70% 1666 ms	73% 1510 ms	71.5% 1588 ms
Means	66% 1511 ms	77.5% 1358 ms	

and group. Responses were fastest on long-exposure, hard-initiation trials and slowest on short-exposure, easy-initiation trials.

For Group 3, pupil position and dilation measures were also analyzed as a function of initiation difficulty and exposure duration. The pupils were significantly more dilated in the difficult-initiation than the easy-initiation condition—a difference of about 8% [$F(1, 21) = 18.22$, $P < .05$]. Participants also gazed significantly closer to the center of the fixation circle in the difficult-initiation than in the easy-initiation conditions [$F(1, 21) = 3.98$, $P < .05$], although visual gaze was on average within 1° of midscreen in both conditions. However, these deviations from midscreen were as likely to be in the direction of the sample stimulus as away from it (or, indeed, above or below the fixation point and still 4° from the sample). Thus, the accuracy of fixation associated with the difficult initiation condition did not bias and cannot explain the differences described above in recognition accuracy and response time. Indeed, the average accuracy of fixation for a session was not significantly correlated with the accuracy of recognition in that session ($r = -.15$, $P > .05$). However, pupil dilation was found to correlate significantly, albeit modestly, with recognition accuracy ($r = .43$, $P < .05$) and recognition latency ($r = -.54$, $P < .05$). No other reliable differences were found in the analysis of pupillometric data.

DISCUSSION

Increasing task difficulty with a relatively demanding trial-initiation procedure resulted in trials that took longer to begin, but resulted in faster and more accurate recognition performance. Additionally, the increase in trial-initiation difficulty resulted in significant dilation of the pupils and more accurate fixation (Group 3). Thus we have extended our earlier findings based on stimulus movement to a second kind of trial-initiation difficulty involving the degree of precision required to center a cursor in a circle fixed at midscreen and have also provided an independent assessment of the associated attention demands using the pupillometric measures. These results were in marked contrast to the effects of increasing cognitive difficulty with relatively brief stimulus presentations, which disrupted recognition and slowed responding as has typically been found in previous studies (see reviews by Beaumont, 1982; Roitblat, 1987).

Thus, the main effects for the two difficulty manipulations on recognition performance were similar in magnitude but opposite in direction. Furthermore, recognition was best when trials were cognitively easy but motorically difficult and generally worst with easy trial initiation and brief stimulus exposures. These findings were replicated across three independent groups of participants from different subject pools and with different sets of exposure durations and other procedural differences (e.g., variations in numbers of trials and recording of pupillometric measures).

It is counterintuitive—even contradictory—to suggest that increasing task difficulty can result in improved performance. However, even the most basic tasks in psychological research are themselves composed of component tasks or operations (Posner & Raichle, 1994). Some of these component operations are more cognitive (e.g., recognize and remember) in nature than others (e.g., motoric components like move the joystick, click a button, and speak a word). The ease or difficulty of any one component task may influence performance on other subtasks or operations, even in unexpected ways. We have argued (Washburn, 1983; Washburn & Putney, 1998) that an increase in the motor demands of a task (e.g., by requiring participants to capture moving rather than stationary stimuli) elicits a shift in the allocation of attention that benefits performance on the cognitive components or operations of the task. The present findings are consistent with, and were directly predicted by, this interpretation of stimulus movement effects—even though stimulus movement was not used in this experiment. As such, it would seem fruitful to posit some conclusions based on both the present and prior phenomena.

First, increasing task difficulty can improve cognitive performance (a) if one increases the difficulty of motor components of the task without simultaneously increasing cognitive difficulty, (b) if the motor demands do not compete in time with the cognitive operations to be measured, and (c) if cognitive performance is not already asymptotic. This latter point reflects the finding that stimulus movement improves learning much more reliably than it does asymptotic performance (Washburn, Hopkins, & Rumbaugh, 1989).

Second, it must be acknowledged that ''the difficulty of a task'' is an elusive thing to define, in part because the concept is inextricably linked to the probability of error or the time or effort required to avoid error. Additionally, it is tricky to specify the difficulty of a task because each task itself is composed of subtasks and operations that have individual levels of difficulty. If nothing else, the present findings attest to the importance and interrelatedness of the subtasks that constitute even simple cognitive skills. Consequently, it is important to note that difficulty was operationally defined for the present study in noncircular ways. The difficulty of initiating a trial was assessed in the time required to start each trial. The difficult-initiation condition, in which the cursor had to be precisely centered in the circle and which resulted in reliably longer initiation times, produced faster and more accurate recognition performance. It would be contradictory to conclude that trials were easier because they were more difficult to initiate and circular to claim that trials were easier because participants performed better. Thus, we conclude that participants performed better when trials were more difficult to initiate. Also, because performance was facilitated rather than disrupted by the increase in difficulty, Navon's (1984) important ''soupstone'' criticism of resource theories of attention do not apply to the present findings.

Third, improvements in performance as motor difficulty is increased have been found not to result from artifactual considerations (Washburn, 1993) such as figure–ground distinctiveness, exposure duration, motion detection, the prepotency of motion in perception, or (from the present study) visual fixation. That is, motor difficulty did improve fixation, but the accuracy of fixation, which was generally good in all conditions, was not reliably related to the accuracy of recognition. Further, the difficulty of initiating a trial did not provide for a capture or shift in attention of the type studied by Yantis (1993) and others. All trials were participant-paced, and the students made an orienting response to the fixation circle in both the easy and the difficult initiation conditions. Notwithstanding, performance was relatively improved in the difficult-initiating condition.

Fourth, the present effects are consistent with theories in which attention (or mental effort, resources, or some comparable term) is allocated in response to increases in task difficulty. What is unique about the phenomena discussed here is that this allocation mechanism is tricked, as it were, into investing more attention than is necessary (or longer than is necessary, as in the present case), so that subsequent cognitive performance (in this case, recognition) benefits from the fact that participants must ‘‘try harder’’ to meet the trial-initiation demands. It remains unclear whether this shift in the allocation of attention is automatic or volitional (Shallice, 1988), although the present experiment does provide anecdotal evidence relevant to this issue. The students in the present study frequently reported in postexperiment debriefing that it was difficult to initiate a trial in the hard-initiation condition, but not one suggested that their performance was improved on these trials. Many, in fact, believed that initiation demands detracted from their performance. Thus, they recognized the need to try harder to initiate some trials, but did not report a corresponding shift in effort or concentration on the recognition component of those trials. However, the pupillometric data from Group 3 indicates, quite independently from the percentage correct and response-time measures, that increased mental effort was associated with those difficult-to-initiate trials (Beatty, 1982). This increase in pupil dilation, which could not have been caused by illuminance or other low-level perceptual explanations, suggests that the increased demand may recruit attention automatically.

From a theoretical standpoint, there are several ways in which this recruitment might occur. Precisely centering a cursor (or capturing the moving stimuli in previous studies) may have resulted in a substantial increase in alerting or phasic (transient) arousal (compared to the stationary or coarse centering conditions). This would suggest that conditions of difficult trial initiation or of stimulus movement result in relatively increased arousal, which in turn may yield corresponding increases in the capacity of available attention (see Kahneman, 1973). The present evidence of pupil dilation may be interpreted as support for the mediating role of arousal in these effects (but see Beatty, 1982 for an opposing view). However, all trials in both trial-initiation conditions were participant-paced and began with what amounted to a warning stimulus. Thus, participants should have been alerted in all conditions. Indeed, the temporal relation between initiating a trial and presentation of the target stimulus was more predictable in the easy-initiation condition, suggesting that it was the easy-initiation condition that should have served as the better alerting stimulus. Additionally, Washburn and Putney (1998) reported evidence of movement-induced secondary-task complementarity that contradicts an arousal hypothesis.

At issue here is ‘‘What aspect of attention is being elicited or allocated?’’ In other studies, the focusing of visual attention is specific to the spatial region around a cued location or target stimulus (e.g., see review by Kinchla, 1992). The ‘‘focus’’ of attention in this case refers to the size of the attentional spotlight. In the present experiment, difficult trial initiation should have restricted attention to the region of the fixation circle and away from the loci of stimulus presentation—conditions that should have compromised performance. However, this selective aspect of attention is but one component of what is certainly a multidimensional construct (e.g., Mirsky, 1991; Putney & Washburn, 1997; Stankov, 1988). We interpret the present results as increasing the intensive aspects of attention (i.e., concentration or focusing in the sense of the intensity of the spotlight) rather than the selective nature. Researchers since Kahneman (1973) have suggested a relationship between arousal and the intensity of attention or mental effort. Thus, whether the present results reflect an increase in mental effort, arousal, or some combination of the two would seem to be less important than the fact that the results stem directly from an increase in particular types of task difficulty and that participants are induced by the difficulty to concentrate or try harder on the matching task rather than to limit visual selection to a specific spatial location. Note, however, that this effect is not necessarily—or even probably—conscious, but rather appears to reflect the natural and automatic adaptation of the attention system.

An intriguing alternative possibility is that the difficult conditions (stimulus movement and exact centering, which both required additional attentional focusing to complete initiation) also recruited a more rapid shifting of visual attention to the correct target. The implication is that these two primary attention related operations, focusing and shifting, are thus linked. Unfortunately, the present data do not distinguish between the potential explanatory mechanisms (focusing, scanning, and arousal/alerting). In fact, these tentative explanatory mechanisms should not be considered mutually exclusive because alerting might provide the means of recruitment, for example.

The finding that increasing the motor difficulty of a task can elicit attention and result in improved cognitive performance would seem to have obvious implications beyond the laboratory. Educational or training activities—particularly those in the form of computer-based instruction or drills—are frequently designed with the goal of making procedures as easy as possible and introducing material slowly. The present findings suggest that this may be a counterproductive strategy, as students are unlikely to sustain concentration if the task becomes too easy. Rather, each type or dimension of task difficulty must be carefully considered in the design and analysis of instructional and research tasks. Skillful alteration of motor demands may provide useful methods for eliciting and sustaining attention, accelerating learning and improving performance (Washburn, Putney, & Henderson, 1995).

We have specified as clearly as current understanding allows the types of manipulations of motor difficulty that will enhance performance and the conditions that must be met for the effect to be manifest. We hope that these conclusions will allow researchers to predict in advance which aspects of difficulty will improve and which aspects will disrupt performance, as we were able to predict the trial-initiation effects from the stimulus movement studies. In the final analysis, we believe that for optimum learning and subsequent performance, conditions must be sufficiently difficult that research participants, trainees, or students cannot reach the important, cognitive portion of a task unless they are already paying attention.

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