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Time-sharing performance of choice-response tasks: factor structure and age differences

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The present study sought support for the notion of time sharing ability by analyzing whether time-sharing and single-task performance reveals different factor structures and exhibits differential relations to the subjects' age. A total of 80 truck drivers, ranging in age from 20 to 61 years, participated in the study. They performed four computerized reaction-time tasks both singly, one by one, and concurrently, in different two-task combinations. The analysis of the results proves that the performance under solitary and time-sharing conditions reveals different features: (a) in factor analysis they load on separate factors, and (b) in relation to the subjects' age they show a differential decline, the time-sharing performance declining faster. This indicates that time-sharing performance reveals some reliable individual differences which are not manifested in the same tasks when performed singly and, thus, supports the notion of time-sharing ability.

Ability assessment is traditionally based on a *serial* approach, in which discrete sub-tests of a battery are administered singly, one by one. Occasionally, some authors stress the need for a *parallel* approach in which two or more assessment tasks are administered simultaneously (e.g., Passey and McLaurin, 1966). There is a belief that such an approach might be more relevant, especially in predicting complex skills, such as flying or car driving, which are likely to involve simultaneous performance and overload. Inherent in this beliefis the assumption that individuals consistently differ in some kind of *time-sharing ability* which operates only under concurrent-task conditions and supposedly enables some individuals to work more easily and successfully than others under high work load conditions, when several tasks need to be performed more or less concurrently (Šverko, 1977). But, is there such an ability?

Studies attempting to answer this question typically employ the factor-analytic approach, in which subjects are asked to perform several tasks both singly and concurrently and their performance measured under both conditions is factor-analyzed to determine whether a time-sharing factor underlying concurrent-task performance can be identified. Its appearance would support the notion of time-sharing ability.

Studies using this approach have not confirmed the existence of a *general* time-sharing factor. However, *group* time-sharing factors, limited to some combinations of time-sharing tasks, have been found in several studies. For example, Jennings & Chiles (1977) identified a narrow time-sharing factor relating to visual scanning and sampling strategies in dual-task monitoring. Brookings (1990) found a similar factor specific to dual-task combinations including visual monitoring, and Šverko, Jerneić & Kulenović (1983) isolated a time-sharing factor underlying dual-task performance of different choice-response tasks. Instead of a general time-sharing ability, the notion of *process-specific time-sharing* abilities seems to be upheld by these studies. Nevertheless, this notion also implies that multiple-task performance reveals some additional individual differences which do not manifest themselves in singly performed tasks.

The purpose of the present study is twofold. First, to find out whether the time-sharing factor found in the previous study (Šverko et. al., 1983) could be replicated with a different sample of subjects. Instead of a homogeneous group of psychology students, this study used truck drivers of different ages. Our *second* purpose was to attempt another approach to supporting the notion of a time-sharing ability: by demonstrating that time sharing performance and single-task performance exhibit differential relations to some other variable(s). In this study we concentrate on age-related differences in single-task and dual-task performance. We hypothesize that both kinds of performance will decline with age in adulthood, but that the dual-task or time sharing performance will decline faster.

This is not a new hypothesis. In fact, a substantial body of experimental evidence supports the claim that older adults are at disadvantage when required to carry out multiple processes (see Kausler, 1991, and McDowd, Vercruyssen & Birren, 1991, for reviews). But, thus far the evidence has not been entirely conclusive. Somberg and Salthouse (1982) have called in question much of the existing evidence by pointing at some methodological shortcomings of earlier studies. They also

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presented their own data indicating that age-related changes in concurrently presented tasks could be well accounted for by changes in single-task performance.

Two subsequent studies by Braune and Wickens corroborated these findings. In the first study (Braune & Wickens, 1985), 60 subjects ranging in age from 20 to 60 performed a number of tasks, including several versions of the Sternberg memory-search task, which were presented both singly and concurrently with a tracking task. The performance was generally inferior for older subjects, but the magnitude of performance decrement under dual task conditions was unaffected by age. In a replication study (Wickens, Braune & Stokes, 1987) a new group of 60 subjects ranging in age from 20 to 65 performed the same tasks. Again, the same results were observed: the processing speed decreased with age, but age trends for single and dual-task performance did not differ. The results were also subjected to factor analysis, which revealed that the scores on the factor identified as the time sharing factor did not differ with age, a finding „reinforcing the independence of time-sharing ability and age" (p. 74).

This conflicting conclusion was an additional impetus for the present study, in which a different type of tasks was used to assess time-sharing ability. We used serial reaction-time tasks in which stimulus events followed one another in a relatively rapid sequence, thus imposing time limits on the subject's responses and requiring rapid attention switching in dual-task situations. Such tasks typically create high task-interference conditions which are supposedly more difficult to deal with for older subjects.

METHOD

Subjects

A total of 80 male professional truck drivers, ranging in age from 20 to 61 years, participated in the study. They were tested while undergoing medical examinations required to obtain or renew their driving licenses. All subjects were healthy, without verified motor deficiencies, and had normal or corrected to-normal visual acuity.

Apparatus and Experimental Tasks

Computerized serial choice-reaction tasks were devised to study the problem. Stimulus presentation and response measurements were governed by an Apple II+ microcomputer with a real time clock. The tasks used visual stimuli generated on a 43-cm monochromatic monitor. It was located in front of the subject, at a distance of approximately 130 cm. The subject's responses were manual: four finger keys connected to the computer were provided for each of the hands. The apparatus was placed on a large desk at which, separated by a screen, sat the subject and the experimenter.

Four single tasks were used. The schemata in the upper row of Figure 1 present their display arrangement and response keys. The first task, named *Horizontal Lights*, was a computerized version of the four-lights task. Four circles, 1 cm in diameter and 0.3 cm apart, were horizontally displayed on the screen.

They lighted up (i.e., became bright) one after another, in a random sequence. The subjects had to respond as quickly as

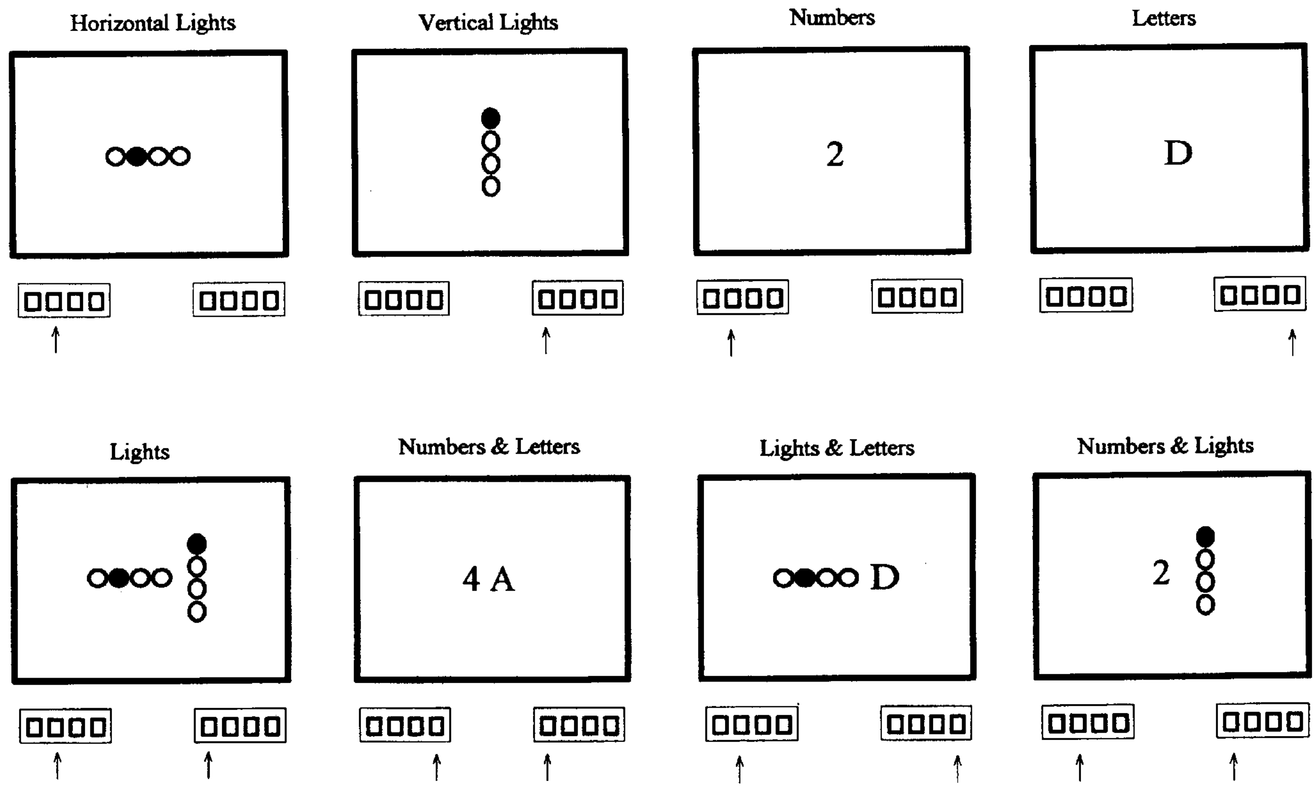

Figure 1. Schematic representation of stimulus displays and corresponding response keys (indicated by arrows) for single-task (upper row) and dual-task (bottom row) conditions.

possible by pressing the appropriate left hand key. The stimulus response mapping was compatible: that is, the correct response to the lighting of the leftmost circle was to press the leftmost key, and so on.

The second task, *Vertical Lights*, was similar except that the circles were now arranged vertically, and the subjects had to use their right-hand keys. The lighting of the uppermost circle required the pressing of the leftmost key, and so on.

In the third task, called *Numbers*, the computer displayed the numerals 1, 2, 3, and 4, one at a time, in a random sequence. As soon as a numeral appeared, the subject had to press the proper left-hand key: the leftmost key corresponded to number 1, and so on.

In the fourth task, called *Letters*, the letters A, B, C, and D were generated, one at a time, in a random sequence. The subjects responded with their right-hand keys, with the leftmost key corresponding to the letter A, and so on.

The time-sharing performance was measured by the same tasks presented in different two-task combinations. As shown in the schemata (lower row of Figure 1), four dual-task combinations were used: *Concurrent Lights, Numbers & Letters, Lights & Letters*, and *Numbers & Lights.* The presentation of successive stimuli in concurrent tasks was synchronized, but each task stimuli followed their own random sequence. The subjects were required to respond to both tasks simultaneously, or in close succession within the limits of the interstimulus interval. The instructions emphasized equal task priorities.

The interstimulus interval in the single and dual-task conditions was 1.5 s and 2 s, respectively. Since the test trials lasted for one minute, the number of stimuli was 40 and 30, respectively.

Procedure

After a short briefing about the study, the subjects performed the tasks in the following sequence: 1. *Horizontal Lights*, 2. *Vertical Lights*, 3. *Concurrent Lights*, 4. *Numbers*, 5. *Letters*, 6. *Numbers & Letters*, 7. *Lights & Letters*, 8. *Numbers & Lights*.

Each of the tasks began with instructions and a 10-second practice trial, followed by the one-minute test trial. After all tasks were completed, the subject was allowed a short rest, and then the eight one-minute test trials were repeated. Thus, two one-minute test trials were measured for each of the tasks. The whole session lasted about 45 minutes with each subject.

Several performance measures were recorded. The computer registered and calculated the number of correct responses, wrong responses, and omissions, as well as the average latency of the responses. In dual tasks, the *combined* performance was recorded: correct responses were scored only when the subject completed the reactions required by both concurrent tasks.

RESULTS

Unlike our experience with university students, who were able to complete almost all of their reactions within the given interstimulus intervals (Jerneić & Šverko, 1994), the adult drivers in the present study made a sizable number of omissions. Since this makes use of the latency of correct responses meaningless, we decided to utilize the *number of correct responses* as the main performance measure. However, in order to preserve the information in latency measurements, we also used the *calculated response intervals* (RI) in *ms*:

$$RI = (CR \times RTcr + WR \times RTwr + O \times int) / (CR + WR),$$

where CR is the number of correct responses and *RTcr* their mean latencies; WR is the number of wrong responses and *RTwr* their mean latencies; *O* is number of omissions, and *int* is the inter signal interval. The calculated value is a subject's mean interval between his reactions. However, since extremely low values of *RTwr* were observed, indicating that the majority of wrong responses were probably overdue correct responses, our RIs approximate the mean *correct response intervals*.

Table 1.
Means, standard deviations, and reliabilities of performance measures

Task	Number of correct responses			Response interval in ms		
	Mean	SD	rtt	Mean	SD	rtt
Single						
Horizontal Lights	36.5	4.04	.67	601.5	118.64	.72
Vertical Lights	37.1	4.70	.54	634.1	107.72	.69
Numbers	37.3	2.60	.75	696.2	91.64	.81
Letters	33.5	7.23	.88	786.0	140.22	.84
Dual						
Concurrent Lights	13.4	8.26	.84	2594.0	1958.61	.77
Numbers & Letters	10.8	8.49	.87	1925.4	612.75	.77
Lights & Letters	16.6	8.30	.92	2286.1	1421.88	.72
Numbers & Lights	15.3	9.05	.91	2506.0	2018.70	.46

Table 1 shows the means and standard deviations of the two performance measures for each task, averaged beforehand across the two test trials. Also, given are the reliabilities estimated by applying the Spearman-Brown formula to correlations between two successive trials. Most of the reliability estimates are reasonably high. A comparison of the single and dual-task means reveals pronounced time-sharing decrements: the number of correct responses in dual tasks is severely reduced and the RIs are greatly augmented. This indicates the presence of a high task interference and overload, a condition regarded asessential for eliciting time-sharing ability.

Factor structure

Two separate principal components analyses, one for correct responses and the other for response intervals (*RIs*), were performed to meet the first objective of this study. The intercorrelations of the eight tasks, computed separately for the correct responses and *RIs*, âre presented in Table 2.

Table 2.
Correlations among the variables

Variables	Correct responses 1	2	3	4	5	6	7	8
1. Horizontal Lights	-	.578	.756	.610	.485	.536	.589	.468
2. Vertical Lights	.660	-	.630	.773	.441	.482	.561	.413
3. Numbers	.720	.690	-	.686	.438	.483	.549	.434
4. Letters	.609	.673	.657	-	.516	.605	.712	.473
5. Concurrent Lights	.462	.506	.440	.406	-	.786	.837	.822
6. Numbers & Letters	.509	.451	.620	.619	.443	-	.886	.844
7. Lights & Letters	.420	.351	.522	.459	.392	.503	-	.826
8. Numbers & Lights	428.	423	.511	.480	.375	.488	.518	-

Note: In the upper right triangle of the correlation matrix are shown correlations between correct responses and in the lower left triangle are shown correlations between calculated response intervals

Both intercorrelation matrices were submitted to the principal components analysis with varimax rotation. The eigenvalue-one criterion indicated two significant principal components for correct responses and one for RIs. However, two components were rotated in both analyses, accounting for 82 % and 68.2 % of the total variance, respectively. The rotated factor loadings obtained in both analyses are presented in Table 3.

Table 3
Rotated factor loadings

Task	Analysis for correct responses Factor 1	Factor 2	Analysis for response intervals Factor 1	Factor 2
Single				
Horizontal Lights	.31	.78	.82	.25
Vertical Lights	.24	.83	.88	.15
Numbers	.23	.86	.76	.43
Letters	.37	.81	.73	.39
Dual				
Concurrent Lights	.88	.26	.54	.36
Numbers & Letters	.87	.34	.49	.62
Lights & Letters	.84	.45	.20	.84
Numbers & Lights	.91	.22	.27	.77
% of total variance accounted for	66.6	15.4	57.8	10.5

The factor structure obtained with correct responses is very clear: all of the single tasks load heavily on one factor (Factor 2), and all of the dual tasks on the other (Factor 1). A congruent factor structure is obtained also with *RIs*, except that Factor 1 is now defined by single tasks, and Factor 2 by dual tasks. The only incongruous data are for *Concurrent Lights*: in the second analysis, this dual-task variable loads higher on the single-task factor. But, this exception does not change the general observation that singly and concurrently performed tasks define their own, distinctive factors.

Age differences

In the analysis of age differences in single- and dual-task performance, the subjects were divided in four age groups (20-29, 30-39, 40-49, and 50-61), with 20 subjects each. Since factor analysis revealed that the tasks within each presentation condition (single/dual) were factorially similar, the performance measures were averaged across all single tasks, as well as across all dual-task measurements. Thus, a 4 (age) x 2 (single/dual) analysis of variance, with repeated measures on the second factor, was carried out for each performance measure.

Figure 2A portrays the results for correct responses. The age groups are on the abscissa and their mean scores are plotted for single and dual-task performance. As can be seen, both kinds of performance decline with age, but the time-sharing performance seems to decline faster. The analysis of variance revealed that both the main effect of age, F (3, 76)= 15.23, $p < .001$, and the Age x Single/Dual interaction, F (3, 76) = 5.05, $p < .01$, were statistically significant

The main effect for the presentation condition (single/dual) was also significant, F (1, 76) = 1057.81, $p < .001$, indicating a pronounced reduction of correct responses under dual-task conditions. But these data are spurious, because owing to different interstimulus intervals the number of stimuli in one-minute trials was different for single and dual-tasks condition (40 and 30, respectively). Therefore, additional analysis with omissions was attempted. Although omissions are nearly complementary to correct detection, they are not equally hampered by different number of stimuli. As Figure 2B shows, the results partly mirror those for correct responses. Omissions were significantly more numerous underdual-task conditions, F (1, 76) = 182.57, $p < .001$, and they increased in number with age, F (3, 76) = 10.12, $p < .001$. The increase was much steeper for the dual-task performance, as confirmed by significant Age x Single/Dual interaction: F (3, 76) = 5.05, $p < .01$.

Figure 2C presents the results for the response intervals, which reveal congruous findings. Again, RIs were much longer for the dual-task performance, F (1, 76) = 202.06, $p < .001$, and they increased with age, F (3, 76) = 7.06, $p < .001$, slightly for single-task performance and very steeply for dual-task performance. The Age x Single/Dual interaction was again significant: F (3, 76) = 4.03, $p < .01$.

DISCUSSION

Our first analysis explored factor structure of serial choice-reaction tasks presented under solitary and concurrent conditions. Two separate factor analyses, one for correct responses and the other for response intervals, congruently revealed that singly and concurrently presented tasks define

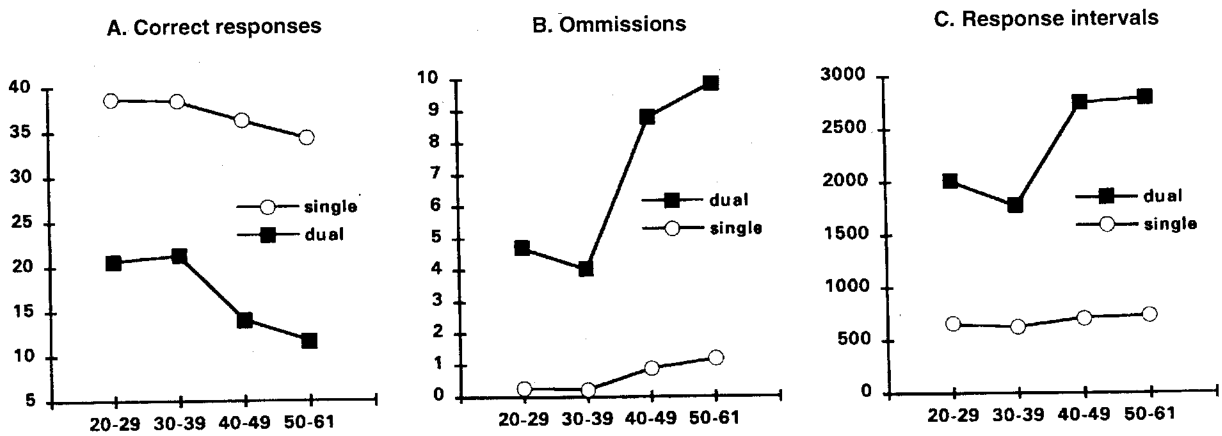

Figure 2. Mean number of correct responses, mean number of omissions, and mean duration of response intervals as a function of the subjects' age and task conditions.

their own distinctive factors. Out of two isolated factors in both analyses, one was defined exclusively by singly presented tasks, and the other by the same tasks when performed concurrently. The later factor is clearly related to the time-sharing factor in complex choice-reaction tasks identified by Šverko *et al.* (1983) and by Jerneić and Šverko (1994). Since the present study used a sample from a different population (i.e., professional drivers of different ages, instead of university students used in previous analyses), the replication of the time-sharing factor stresses the generality of the finding.

Our *second* analysis sought an additional support for the notion of time-sharing ability, demonstrating that dual-task performance exhibits a different relation to other variables than single-task performance. In this study we explored age differences in single and dual-task performance, under the hypothesis that both kinds of performance will decline with age in adulthood, but that dual-task performance will decline faster. The results support the hypothesis. For each performance measure, the interaction between age and single/dual performance was statistically significant, showing that older subjects were less capable under dual-task conditions than young subjects.

Our results are at variance with the three aforementioned studies which failed to evidence age-related decrements in time-sharing performance. For Somberg and Salthouse's (1982) study, this failure can be attributed to their use of simple tasks (i.e., visual target detection, simple RT, and repetitive keying of a constant digit sequence). McDowd and Craik (1988) suggested that such tasks require relatively shallow or automatic processing, and presented their own data supporting the view that age differences are expanded as tasks are made more complex. But, what about the studies of Braune and Wickens (1985;Wickens *et al.*, 1987), which used relatively complex memory and tracking tasks and yet failed to reveal age-related differences in time sharing decrements? In an attempt to explain this result, McDowd et al. (1991) point out that the mean age of the oldest group of subjects in these two studies was relatively low (under 60 yrs), and that the results of Ponds, Brouwer and Wolffellar (1988) indicate that impairment in time-sharing performance begins in older age (after 60 yrs). But the results of the present study clearly contradict this explanation: they indicate that a steeper decline in time-sharing performance begins much earlier, in the 40s.

The explanation of different findings must then take into account possible differences in processes involved in the tasks. According to Wickens et al. (1987), one important component that their tasks failed to incorporate was „that involved in time sharing of two discrete RT tasks. This particular combination is one that would be likely to place a premium on rapid attention switching ... and manifest a loss in time-sharing ability with age" (p. 77). A similar view is expressed by Ponds *et al.* (1988), who suggested that the locus of the age deficit might be in central processes of rapid decision-making and attention switching between tasks. And these are the processes which our fast paced choice-reaction tasks certainly included.

To conclude, both findings of the present study, i.e., that single-task and dual-task performance reveals differing factor structures and exhibits differential relations to age, jointly indicate that time-sharing performance reveals some reliable individual differences which are not manifested in the same tasks when performed singly. This conclusion supports the notion of time-sharing ability.

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