Second Edition

# HUMAN PERFORMANCE, WORKLOAD, and SITUATIONAL AWARENESS MEASURES HANDBOOK

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ings showed wide individual differences well beyond those that could be attributed to experience and ability differences; (2) most of the measures were not comprehensive and assessed only a single dimension of workload; (3) many workload measures were intrusive in terms of requiring task responses or subjective ratings or the use of electrodes; (4) some measures were confusing to subjects under high stress, for example, the meanings of ratings would be forgotten in high-workload environments, so lower than actual values would be given by the pilot; and (5) subjects would misperceive the number of tasks to be performed and provide an erroneously low measure of workload. Gawron then returned to the purpose of workload measure: to identify potentially dangerous situations. Poor designs, inadequate procedures, poor training, or the proximity to catastrophic conditions could induce such situations. The most objective measure of danger in a situation is time until the aircraft is destroyed if control action is not taken. These times include time until impact, time until the aircraft is overstressed and breaks apart, and time until the fuel is depleted.

*Strengths and limitations.* The time-limit workload measure is quantitative, objective, directly related to performance, and can be tailored to any mission. For example, time until a surface-to-air missile destroys the aircraft is a good measure in air-to-ground penetration missions. In addition, the times can be easily computed from measures of aircraft performance. Finally, these times can be summed over intervals of any length to provide interval-by-interval workload comparisons.

*Data requirements.* This method is useful whenever aircraft performance data are available.

*Thresholds.* Minimum is 0 and maximum is infinity.

## SOURCE

Gawron, V.J., Schiflett, S.G., and Miller, R.C. Measures of in-flight workload. In Jensen, R.S. (Ed.) *Aviation psychology.* London: Gower, 1989.

## 3.2 SECONDARY TASK MEASURES OF WORKLOAD

One of the most widely used techniques to measure workload is the secondary task. This technique requires an operator to perform the primary task within that task's specified requirements and to use any spare attention or capacity to perform a secondary task. The decrease in performance of the secondary task is operationally defined as a *measure of workload.*

The secondary-task technique has several advantages. First, it may provide a sensitive measure of operator capacity and may distinguish between alternative equipment configurations that are indistinguishable by single-task performance (Slocum, Williges, and Roscoe, 1971). Second, it may provide a sensitive index of task impairment due to stress. Third, it may provide a common metric for comparisons of different tasks.

The secondary-task technique may have one major disadvantage: intrusion on the performance of the primary task (Williges and Wierwille, 1979) and as Rolfe (1971) stated: "The final word, however, must be that the secondary task is no substitute for competent and comprehensive measurement of primary task performance"

(p. 146). Vidulich (1989a), however, concluded from two experiments that secondary tasks that do not intrude on primary-task performance are insensitive to primary-task difficulty. Vidulich (1989b) argued that added task sensitivity is directly linked to intrusiveness.

Further, subjects may use different strategies when performing secondary tasks. For example, Schneider and Detweiler (1988) identified seven compensatory activities that are associated with dual-task performance: "(1) shedding and delaying tasks and preloading buffers, (2) letting go of high-workload strategies, (3) utilizing non-competing resources, (4) multiplexing over time, (5) shortening transmissions, (6) converting interference from concurrent transmissions, and (7) chunking of transmissions" (p. 539). In addition, Meshkati, Hancock, and Rahimi (1990) recommend not using secondary task and subjective measures in the same experiment, because operators may include secondary-task performance as part of their subjective workload rating.

Further, Ogdon, Levine, and Eisner (1979) concluded from a survey of the literature that there was not a single best secondary task for measuring workload. In another review study, Damos (1993) analyzed the results of 14 studies in which single- and dual-task performances were evaluated. She concluded that "the effect sizes associated with both single- and multiple-task measures were both statistically different from 0.0, with the effect size for the multiple-task increases statistically greater than that of the corresponding single task measures. However, the corresponding predictive validities were low" (p. 615).

Poulton (1965) pointed out that comparing the results of performance tests that vary in sensitivity may be difficult. To address this concern, Colle, Amell, Ewry, and Jenkins (1988) developed the method of double trade-off curves to equate performance levels on different secondary tasks. In this method, "two different secondary tasks are each paired with the same primary tasks. A trade-off curve is obtained for each secondary task paired with the primary task" (p. 646).

To help researchers select secondary-task measures of workload, Knowles (1963) developed a comprehensive set of criteria for selecting a secondary task: (1) noninterference with the primary task, (2) ease of learning, (3) self-pacing, (4) continuous scoring, (5) compatibility with the primary task, (6) sensitivity, and (7) representativeness. In a similar vein, Fisk, Derrick, and Schneider (1983) developed three criteria, which they then tested in an experiment. The criteria were the following: (1) the secondary task must use the same resources as the primary task, (2) single- and dual-task performance must be maintained, and (3) the secondary task must require "controlled or effortful processing" (p. 230). Brown (1978) recommended that "the dual task method should be used for the study of individual difference in processing resources available to handle work-load" (p. 224). Also, Liu and Wickens (1987) reported that tasks using the same resources had increased workload more than tasks that did not.

Finally, Wetherell (1981) investigated seven secondary tasks (addition, verbal reasoning, attention, short-term memory, random digit generation, memory search, and white noise) with a primary driving task and concluded that none were "outstanding as a measure of mental workload." However, there was a significant gender difference, with degradations in the primary task occurring for female drivers.

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### 3.2.1 Card-Sorting Secondary Task

*General description.* "The subject must sort playing cards by number, color, and/or suit." (Lysaght et al., 1989, p. 234).

*Strengths and limitations.* "Depending upon the requirements of the card sorting rule, the task can impose demands on perceptual and cognitive processes" (Lysaght et al., 1989, p. 234). Lysaght et al. (1989) state that dual-task pairing of a primary memory task with a secondary card-sorting task resulted in a decrease in performance in both tasks. Their statement is based on two experiments by Murdock (1965). Although used as a primary task, Courtney and Shou (1985) concluded that card sorting was a "rapid and simple means of estimating relative visual-lobe size" (p. 1319).

*Data requirements.* The experimenter must be able to record the number of cards sorted and the number of incorrect responses.

*Thresholds.* Not stated.

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Murdock, B.B. Effects of a subsidiary task on short-term memory. *British Journal of Psychology.* 56, 413–419, 1965.

### 3.2.2 Choice RT Secondary Task

*General description.* "The subject is presented with more than one stimulus and must generate a different response for each one" (Lysaght et al., 1989, p. 232).

*Strengths and limitations.* "Visual or auditory stimuli may be employed and the response mode is usually manual. It is theorized that choice RT imposes both central processing and response selection demands" (Lysaght et al., 1989, p. 232).

On the basis of 19 studies that included a choice RT secondary task, Lysaght et al. (1989) reported the following for dual-task pairings: performance of choice RT, problem solving, and flight simulation primary tasks remained stable; performance of tracking, choice RT, memory, monitoring, driving, and lexical decision primary tasks degraded; and tracking performance improved. Performance of the secondary task remained stable with tracking and driving primary tasks; and degraded with tracking, choice RT, memory, monitoring, problem-solving, flight simulation, driving, and lexical decision primary tasks (see table 4).

Hicks and Wierwille (1979) compared five measures of workload. They manipulated workload by increasing wind gust in a driving simulator. They reported that a secondary RT task was not as sensitive to wind gust as were steering reversals, yaw deviation, subjective opinion rating scales, and lateral deviations. Gawron (1982) reported longer RTs and lower percent correct scores when a four-choice RT task was performed simultaneously then sequentially.

Klapp, Kelly, and Netick (1987) asked subjects to perform a visual, zero-order, pursuit tracking task with the right hand while performing a two-choice, auditory reaction task with the left hand. In the dual-task condition, the tracking task was associated with hesitations lasting 333 ms or longer. Degradations in the tracking task were associated with enhancements of the RT task.

*Data requirements.* The experimenter must be able to record and calculate the following: mean RT for correct responses, mean (median) RT for incorrect responses, number of correct responses, and number of incorrect responses.

*Thresholds.* Not stated.

**TABLE 4**

**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Choice RT Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Choice RT | Becker (1976)<br>Ellis (1973) | Detweiler and Lundy (1995)*<br>Gawron (1982)*<br>Schvaneveldt (1969) | | Hicks and Wierwille (1979) | Becker (1976)<br>Detweiler and Lundy (1995)*<br>Ellis (1973)<br>Gawron (1982)*<br>Schvaneveldt (1969) | |
| Driving | Kantowitz (1995) | Allen, Jex, McRuer, and DiMarco (1976)<br>Brown, Tickner, and Simmonds (1969) | | Allen et al. (1976)<br>Drory (1985)* | Brown et al. (1969) | |
| Flight simulation | Bortolussi, Hart, and Shively (1987)<br>Bortolussi, Kantowitz, and Hart (1986)<br>Kantowitz, Hart and Bortolussi (1983)*<br>Kantowitz, Hart, Bortolussi, Shively, and Kantowitz (1984)*<br>Kantowitz, Bortolussi, and Hart (1987) | | | | Bortolussi et al. (1987)<br>Bortolussi et al. (1986) | |
| Lexical decision | | Becker (1976) | | | Becker (1976) | |
| Memory | | Logan (1970) | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Memory | | Logan (1970) | | | |
| Monitoring | | Smith (1969) | | Logan (1970) | |
| | | | | Krol (1971) | |
| Problem solving | Fisher ( 1975a) | | | Smith (1969) | |
| | Fisher (1975b) | | | Fisher (1975a) | |
| Tracking | | | | Fisher (1975b) | |
| | | Benson, Huddleston, and Rolfe (1965) | Loeb and Jones (1978) | Benson et al. (1965) | Klapp, Kelly, and Netick (1987)* |
| | | Loeb and Jones (1978) | | Damos (1978) | |
| | | Giroud, Laurencelle, and Proteau (1984) | | Giroud et al. (1984) | |
| | | Israel, Chesney, Wickens, and Donchin (1980) | | Israel et al. (1980) | |
| | | Israel, Wickens, Chesney, and Donchin (1980) | | Klapp et al. (1984) | |
| | | Klapp, Kelly, Battiste, and Dunbar (1984) | | | |
| | | Wempe and Baty (1968) | | | |
| | | Klapp, Kelly, and Netick (1987)* | | | |

* Not included in Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 246.

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### 3.2.3 Classification Secondary Task

*General description.* "The subject must judge whether symbol pairs are identical in form. For example, to match letters either on a physical level (AA) or on a name level (Aa)" (Lysaght et al., 1989, p. 233), or property (pepper is hot), or superset relation (an apple is a fruit). Cognitive processing requirements are discussed by Miller (1975).

*Strengths and limitations.* "Depending upon the requirements of the matching task, the task can impose demands on perceptual processes (physical match) and/or cognitive processes (name match or category match)" (Lysaght et al., 1989, p. 233).

Damos (1985) reported that percent correct scores for both single- and dual-task performance were affected only by trial and not by either behavior pattern or pacing condition. Correct RT scores, however, were significantly related to trial and pacing by behavior pattern in the single-task condition and trial, behavior pattern, trial by pacing, and trial by behavior pattern in the dual-task condition.

Mastroianni and Schopper (1986) reported that performance on a secondary auditory classification task (easiest version—tone low or high, middle version—previous tone low or high, hardest version—tone before the previous tone low or high) was degraded as the difficulty of the task increased or the amount of force needed

on the primary pursuit tracking task increased. Performance on the primary task degraded when the secondary task was present compared to when it was absent.

Carter, Krause, and Harbeson (1986) reported that RT increased as the number of memory steps to verify a sentence increased. Slope was not a reliable measure of performance.

Beer, Gallaway, and Previc (1996) reported that performance on an aircraft classification task in singular task mode did not predict performance in dual-task mode.

*Data requirements.* The following data are used to assess performance of this task: mean RT for physical match, mean RT for category match, number of errors for physical match, and number of errors for category match (Lysaght et al., 1989, p. 236).

*Thresholds.* Kobus, Russotti, Schlichting, Haskell, Carpenter, and Wojtowicz (1986) reported the following times to correctly classify one of five targets: visual = 224.6 s, auditory = 189.6 s, and multimodal (i.e., both visual and auditory) = 212.7 s. These conditions were not significantly different.

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Miller, K. Processing capacity requirements for stimulus encoding. *Acta Psychologica.* 39, 393–410, 1975.

### 3.2.4 Cross-Adaptive Loading Secondary Task

*General description.* Cross-adaptive loading tasks are secondary tasks that the subject must perform only while primary-task performance meets or exceeds a previously established performance criterion (Kelly and Wargo, 1967).

*Strengths and limitations.* Cross-adaptive loading tasks are less likely to degrade performance on the primary task but are intrusive and, as such, difficult to use in nonlaboratory settings.

*Data requirements.* A well-defined, quantifiable criterion for primary-task performance as well as a method of monitoring this performance and cueing the subject on when to perform the cross-adaptive loading task are all required.

*Thresholds.* Dependent on type of primary and cross-adaptive loading tasks being used.

## SOURCE

Kelly, C.R. and Wargo, M.J. Crossadaptive operator loading tasks. *Human Factors.* 9, 395–404, 1967.

### 3.2.5 Detection Secondary Task

*General description.* "The subject must detect a specific stimulus or event which may or may not be presented with alternative events. For example, to detect which of 4 lights is flickering. The subject is usually alerted by a warning signal (e.g., tone) before the occurrence of such events, therefore attention is required intermittently." (Lysaght et al., 1989, p. 233).

*Strengths and limitations.* "Such tasks are thought to impose demands on perceptual processes" (Lysaght et al., 1989, p. 233).

On the basis of a review of five studies in which detection was a secondary task, Lysaght et al. (1989) reported the following for dual-task pairings: performance of a primary classification task remained stable; and performance of tracking, memory, monitoring, and detection primary tasks degraded. In all cases, performance of the secondary detection task degraded (see table 5).

*Data requirements.* The following data are calculated for this task: mean RT for correct detections and number of correct detections.

*Thresholds.* Not stated.

**TABLE 5**

**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Detection Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| Type | Stable | Degraded | Enhanced | Stable | Degraded | Enhanced |
| Detection | | Wickens, Mountford, and Schreiner (1981) | | | Wickens et al. (1981) | |
| Driving | | | | | Verwey (2000)* | |
| Memory | | | | | Shulman and Greenberg (1971) | |
| Tracking | | Wickens et al. (1981) | | | Wickens et al. (1981) | |

* Not included in Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 246.

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Shulman, H.G. and Greenberg, S.N. Perceptual deficit due to division of attention between memory and perception. *Journal of Experimental Psychology*, 88, 171–176, 1971.

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Wickens, C.D., Mountford, S.J., and Schreiner, W. Multiple resources, task-hemispheric integrity, and individual differences in time sharing. *Human Factors*. 23, 211–229, 1981.

### 3.2.6 Distraction Secondary Task

*General description.* "The subject performs a task which is executed in a fairly automatic way such as counting aloud" (Lysaght et al., 1989, p. 233).

*Strengths and limitations.* "Such a task is intended to distract the subject to prevent the rehearsal of information that may be needed for the primary task" (Lysaght et al., 1989, p. 233).

Based on one study, Lysaght et al. (1989) reported degraded performance on a memory primary task when paired with a distraction secondary task. Drory (1985) reported significantly shorter brake RTs and fewer steering wheel reversals when a secondary distraction task (i.e., state the last two digits of the current odometer reading) was paired with a basic driving task in a simulator. The secondary distraction task had no effects on tracking error, number of brake responses, or control light response.

Zeitlin (1995) used two auditory secondary tasks (delayed digit recall and random digit generation) while driving on road. Performance on both tasks degraded as traffic density and average speed increased.

*Data requirements.* Not stated.

*Thresholds.* Not stated.

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### 3.2.7 Driving Secondary Task

*General description.* "The subject operates a driving simulator or actual motor vehicle" (Lysaght et al., 1989, p. 232).

*Strengths and limitations.* This "task involves complex psychomotor skills" (Lysaght et al., 1989, p. 232). Johnson and Haygood (1984) varied the difficulty of a

primary simulated driving task by varying the road width. The secondary task was a visual choice RT task. Tracking score was highest when the difficulty of the primary task was adapted as a function of primary task performance. It was lowest when the difficulty was fixed.

Brouwer, Waterink, van Wolffelaar, and Rothengatten (1991) reported that older adults (mean age 64.4) were significantly worse than younger adults (mean age 26.1) in dual-task performance of compensatory lane tracking with a timed, self-paced visual analysis task.

Korteling (1994) did not find a significant difference in steering performance between single task (steering) versus dual task (addition of car-following task) between young (21 to 34) and old (65- to 74-year-old) drivers. There was, however, 24% performance deterioration in car-following performance with the addition of a steering task.

*Data requirements.* "The experimenter should be able to record the following: total time to complete a trial, number of acceleration rate changes, number of gear changes, number of footbrake operations, number of steering reversals, number of obstacles hit, high pass-steering deviation, yaw deviation, and lateral deviation" (Lysaght et al., 1989, p. 235).

*Thresholds.* Not stated.

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### 3.2.8 Identification/Shadowing Secondary Task

*General description.* "The subject identifies changing symbols (digits and/or letters) that appear on a visual display by writing or verbalizing, or repeating a spoken passage as it occurs" (Lysaght et al., 1989, p. 233).

*Strengths and limitations.* "Such tasks are thought to impose demands on perceptual processes (i.e., attention)" (Lysaght et al., 1989, p. 233). Wierwille and Connor (1983), however, reported that a digit-shadowing task was not sensitive to variations in workload. Their task was control on moving-base aircraft simulator. Workload was varied by manipulating pitch-stability level, wind-gust disturbance level, and crosswind velocity and direction.

Savage, Wierwille, and Cordes (1978) evaluated the sensitivity of four dependent measures to workload manipulations (1, 2, 3, or 4 m) to a primary monitoring task. The number of random digits spoken on the secondary task was the most sensitive to work-

load. The longest consecutive string of spoken digits and the number of triplets spoken were also significantly affected by workload. The longest interval between spoken responses, however, was not sensitive to workload manipulations of the primary task.

Based on nine studies with an identification secondary task, Lysaght et al. (1989) reported that performance remained stable for an identification primary task and degraded for tracking, memory, detection, driving, and spatial transformation primary tasks. Performance of the identification secondary task remained stable for tracking and identification primary tasks and degraded for monitoring, detection, driving, and spatial transformation primary tasks (see table 6).

*Data requirements.* The following data are used for this task: number of words correct per minute, number of digits spoken, mean time interval between spoken digits, and number of errors of omission (Lysaght et al., 1989, p. 236).

*Thresholds.* Not stated.

**TABLE 6**

**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Identification Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Detection | | Price (1975) | | | Price (1975) | |
| Driving | | Hicks and Wierwille (1979) | | | Wierwille, Gutmann, Hicks, and Muto (1977) | |
| Identification | Allport, Antonis, and Reynolds (1972) | | | Allport et al. (1972) | | |
| Memory | | Mitsuda (1968) | | | | |
| Monitoring | | | | | Savage, Wierwille and Cordes (1978) | |
| Spatial transformation | | Fournier and Stager (1976) | | | Fournier and Stager (1976) | |
| Tracking | | Gabay and Merhav (1977) | | Gabay and Merhav (1977) | | |

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 246.

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### 3.2.9 Lexical Decision Secondary Task

*General description.* "Typically, the subject is briefly presented with a sequence of letters and must judge whether this letter sequence forms a word or a nonword" (Lysaght et al., 1989, p. 233).

*Strengths and limitations.* "This task is thought to impose heavy demands on semantic memory processes" (Lysaght et al., 1989, p. 233).

*Data requirements.* Mean RT for correct responses is used as data for this task.

*Thresholds.* Not stated.

## SOURCE

Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

### 3.2.10 Memory-Scanning Secondary Task

*General description.* These secondary tasks require a subject to memorize a list of letters, numbers, and/or shapes and then indicate whether a probe stimulus is a member of that set. Typically, there is a linear relation between the number of items

in the memorized list and RT to the probe stimulus. A variation of this task involves recalling one of the letters based on its position in the presented set.

*Strengths and limitations.* The slope of the linear function may reflect the memory-scanning rate. Fisk and Hodge (1992) reported no significant differences in RT in a single-task performance of a memory-scanning task after 32 d without practice. But Carter, Krause, and Harbeson (1986) warned that the slope may be less reliable than the RTs used to calculate the slope.

These tasks may not produce good estimates of memory load, because of the following: (1) addition of memory load does not affect the slope and (2) the slope is affected by stimulus-response compatibility effects. Further, Wierwille and Connor (1983), however, reported that a memory-scanning task was not sensitive to workload. Their primary task was to control a moving-base aircraft simulator. Workload was varied by manipulating pitch-stability level, wind-gust disturbance level, and crosswind direction and velocity. However, Park and Lee (1992) reported that memory tasks significantly predicted flight performance of pilot trainees.

Based on 25 studies using a memory secondary task, Lysaght et al. (1989) reported that performance remained stable on tracking, mental math, monitoring, problem solving, and driving primary tasks; degraded on tracking, choice RT, memory, monitoring, problem-solving, detection, identification, classification, and distraction primary tasks; and improved on a tracking primary task. Performance of the memory secondary task remained stable with a tracking primary task and degraded when paired with tracking, choice RT, memory, mental math, monitoring, detection, identification, classification, and driving primary tasks (see table 7).

*Data requirements.* RT to items from the memorized list must be at an asymptote to ensure that no additional learning will take place during the experiment. The presentation of the probe stimulus is intrusive and thus may be difficult to use in nonlaboratory settings.

*Thresholds.* 40 ms for RT.

**TABLE 7**

**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Memory Task**

| Type | Primary task | | | Secondary task | | |
|---|---|---|---|---|---|---|
| | Stable | Degraded | Enhanced | Stable | Degraded | Enhanced |
| Choice RT | | Broadbent and Gregory (1965)<br>Keele and Boies (1973) | | | Broadbent and Gregory (1965) | |
| Classification | | Wickens et al. (1981) | | | | |
| Detection | | Wickens et al. (1981) | | | Wickens et al. (1981) | |
| Distraction | | Broadbent and Heron (1962) | | | Wickens et al. (1981) | |
| Driving | Brown (1962, 1965, 1966)<br>Brown and Poulton (1961)<br>Kantowitz (1995)<br>Wetherell (1981) | Richard, Wright, Ee, Prime, Shimizu, and Vavrik (2002; task was to search visual driving scene) | | Brown (1965) | Brown (1962, 1965, 1966)<br>Brown and Poulton (1961)<br>Wetherell (1981) | |
| Identification | | Klein (1976) | | | | |
| Memory | | Broadbent and Heron (1962)<br>Chow and Murdock (1975) | | Shulman and Greenberg (1971) | Allpor, Antonis, and Reynolds (1972) | |
| Mental math | Mandler and Worden (1973) | | | Mandler and Worden (1973) | | |

Continued

**TABLE 7 (Continued)**
**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Memory Task**

| | Primary task | | | Secondary task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Monitoring | Chechile, Butler, Gutowski, and Palmer (1979)<br>Moskowitz and McGlothlin (1974) | Chiles and Alluisi (1979) | | Chechile et al. (1979)<br>Chiles and Alluisi (1979)<br>Mandler and Worden (1973)<br>Moskowitz and McGlothlin (1974) | | |
| Problem solving | Daniel, Florek, Kosinar, and Strizenec (1969) | Stager and Zufelt (1972) | | | | |
| Tracking | Finkelman and Glass (1970)<br>Zeitlin and Finkelman (1975) | Heimstra (1970)<br>Huddleston and Wilson (1971)<br>Noble, Trumbo, and Fowler (1967)<br>Trumbo and Milone (1971)<br>Wickens and Kessel (1980)<br>Wickens, Mountford, and Schreiner (1981) | Tsang and Wickens (1984) | Noble et al. (1967)<br>Trumbo and Milone (1971) | Finkelman and Glass (1970)<br>Heimstra (1970)<br>Huddleston and Wilson (1971)<br>Tsang and Wickens (1984)<br>Wickens and Kessel (1980)<br>Wickens et al. (1981) | |

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 246.

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### 3.2.11 Mental Mathematics Secondary Task

*General description.* Subjects are asked to perform arithmetic operations (i.e., addition, subtraction, multiplication, and division) on sets of visually or aurally presented digits.

*Strengths and limitations.* The major strength of this workload measure is its ability to discriminate between good and poor operators and high and low workload. For example, Ramacci and Rota (1975) required pilot applicants to perform progressive subtraction during their initial flight training. They reported that the number of subtractions performed increased although the percentage of errors decreased with flight experience. Further, successful applicants performed more subtractions and had a lower percentage of errors than those applicants who were not accepted.

Green and Flux (1977) required pilots to add the digit three to aurally presented digits during a simulated flight. They reported increased performance time of the secondary task as the workload associated with the primary task increased. Huddleston and Wilson (1971) asked pilots to determine if digits were odd or even, their sum was odd or even, two consecutive digits were the same or different, or every other digit was the same or different. Again, secondary task performance discriminated between high and low workload on the primary task. The major disadvantage of secondary tasks is their intrusion into the primary task. Harms (1986) reported

similar results for a driving task. However, Andre, Heers, and Cashion (1995) reported greater rmse in roll, pitch, and yaw in a primary simulated flight task when paired with a mental mathematics secondary task (i.e., fuel range).

Mental mathematics tasks have also been used in the laboratory. For example, Kramer, Wickens, and Donchin (1984) reported a significant increase in tracking error on the primary task when the secondary task was counting flashes. In addition, Damos (1985) required subjects to calculate the absolute difference between the digit currently presented visually and the digit that had preceded it. In the single-task condition, percent correct scores were significantly related to trial. Correct RT scores were related to trial and trial by pacing condition. In the dual-task condition, percent correct scores were not significantly related to trial, behavior pattern, or pacing condition. Correct RT in the dual-task condition, however, was related to trial, trial by pacing, and trial by behavior pattern.

On the basis of 15 studies that used a mental math secondary task, Lysaght et al. (1989) reported that performance remained the same for tracking, driving, and tapping primary tasks and degraded for tracking, choice RT, memory, monitoring, simple RT, and detection primary tasks. Performance of the mental math secondary task remained stable with a tracking primary task; degraded with tracking, choice RT, monitoring, detection, driving, and tapping primary tasks; and improved with tracking primary task (see table 8).

*Data requirements.* The following data are calculated: number of correct responses, mean RT for correct responses, and number of incorrect responses (Lysaght et al., 1989, p. 235). The researcher should compare primary task performance with and without a secondary task to ensure that subjects are not sacrificing primary task performance to enhance secondary task performance.

*Thresholds.* Not stated.

**TABLE 8**

**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Mental Math Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Choice RT | | Chiles and Jennings (1970)<br>Fisher (1975)<br>Keele (1967) | | | Fisher (1975)<br>Keele (1967)<br>Schouten, Kalsbeek, and Leopold (1962) | |
| Detection | | Jaschinski (1982) | | | Jaschinski (1982) | |
| Driving | Brown and Poulton (1961)<br>Wetherell (1981) | | | Verwey (2000)* | Brown and Poulton (1961)<br>Wetherell (1981) | |
| Memory | | Roediger, Knight, and Kantowitz (1977)<br>Silverstein and Glanzer (1971) | | | | |
| Monitoring | | Chiles and Jennings (1970)<br>Kahneman, Beatty, and Pollack (1967) | | | Chiles and Jennings (1970)<br>Kahneman et al. (1967) | |
| Simple RT | | Chiles and Jennings (1970)<br>Green and Flux (1977)*<br>Wierwille and Connor (1983)* | | | Green and Flux (1977)* | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Simulated flight task | Green and Flux (1977)*<br>Wierwille and Connor (1983)* | Andre, Heers, and Cashion (1995)* | | | Green and Flux (1977)* | |
| Tapping | Kantowitz and Knight (1974) | | | | Kantowitz and Knight (1974, 1976) | |
| Tracking | Huddleston and Wilson (1971) | Bahrick, Noble, and Fitts (1954)<br>Chiles and Jennings (1970)<br>Heimstra (1970)<br>McLeod (1973)<br>Wickens, Mountford, and Schreiner (1981) | Kramer, Wickens, and Donchin (1984) | Bahrick et al. (1954)<br>Heimstra (1970) | Huddleston and Wilson (1971)<br>McLeod (1973)<br>Wickens et al. (1981) | Chiles and Jennings (1970) |

* Not included in Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 247.

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### 3.2.12 Michon Interval Production Secondary Task

*General description.* "The Michon paradigm of interval production requires the subject to generate a series of regular time intervals by executing a motor response (i.e., a single finger tap [every] 2 sec.). No sensory input is required." (Lysaght et al., 1989, p. 233). On the basis of a review of six studies in which the Michon Interval Production task was the secondary task, Lysaght et al. (1989) stated that, in dual-task pairings, performance of flight simulation and driving primary tasks remained stable; performance of monitoring, problem-solving, detection, psychomotor, Sternberg, tracking, choice RT, memory, and mental math primary tasks degraded; and performance of simple RT primary task improved. In these same pairings, performance of the Michon Interval Production task remained stable with monitoring, Sternberg, flight simulation, and memory primary tasks; and degraded with problem-solving, simple RT, detection, psychomotor, flight simulation, driving, tracking, choice RT, and mental math primary tasks (see table 9).

*Strengths and limitations.* "This task is thought to impose heavy demand on motor output/response resources. It has been demonstrated with high demand primary tasks that subjects exhibit irregular or variable tapping rates." (Lysaght et al., 1989, p. 233). Crabtree, Bateman, and Acton (1984) reported that scores on this secondary task discriminated the workload of three switch-setting tasks. Johannsen, Pfendler, and Stein (1976) reported similar results for autopilot evaluation in a fixed-based flight simulator. Wierwille, Rahimi, and Casali (1985), however, reported that tapping regularity was not affected by variations in the difficulty of a mathematical problem to be solved during simulated flight. Further, Drury (1972) recommended a correlation to provide a nondimensional measure.

*Data requirements.* Michon (1966) stated that a functional description of behavior is needed for the technique. The following data are calculated: mean interval per trial, standard deviation of interval per trial, and sum of differences between successive intervals per minute of total time (Lysaght et al., 1989, p. 235).

*Thresholds.* Not stated.

## TABLE 9

## References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Michon Interval Production Task

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Choice RT | | Michon (1964) | | | Michon (1964) | |
| Detection | | Michon (1964) | | | Michon (1964) | |
| Driving | Brown (1967) | Brown, Simmonds, and Tickner (1967)* | | | Brown (1967); Brown et al. (1967)* | |
| Flight simulation | Wierwille, Casali, Connor, and Rahimi (1985) | | | Wierwille, Casali, Connor, and Rahimi (1985) | Wierwille et al. (1985) | |
| Memory | | Roediger, Knight, and Kantowitz (1977) | | Roediger, Knight, and Kantowitz (1977) | | |
| Mental math | | Michon (1964) | | | Michon (1964) | |
| Monitoring | | Shingledecker, Acton, and Crabtree (1983) | | Shingledecker et al. (1983) | | |
| Problem solving | | Michon (1964) | | | Michon (1964) | |
| Psychomotor | | Michon (1964) | | | Michon (1964) | |
| Simple RT | | | Vroon (1973) | | Vroon (1973) | |
| Sternberg | | Shingledecker et al. (1983) | | Shingledecker et al. (1983) | | |
| Tracking | | Shingledecker et al. (1983) | | | Shingledecker et al. (1983) | |

* Not included in Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 245.

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### 3.2.13 Monitoring Secondary Task

*General description.* Subjects are asked to respond either manually or verbally to the onset of visual or auditory stimuli. Both the time to respond and the accuracy of the response have been used as workload measures.

*Strengths and limitations.* The major advantage of the monitoring-task technique is its relevance to system safety. It is also able to discriminate between levels of automation and workload. For example, Anderson and Toivanen (1970) used a force-paced digit-naming task as a secondary task to investigate the effects of varying levels of automation in a helicopter simulator. Bortolussi, Kantowitz, and Hart (1986) reported significant differences in two- and four-choice visual RT in easy and difficult flight scenarios. Bortolussi, Hart, and Shively (1987) reported significantly longer RTs in a four-choice RT task during a high-difficulty scenario than during a low-difficulty one. Brown (1969) studied it in relation to flicker.

On the basis of the results of 36 studies that included a secondary monitoring task, Lysaght et al. (1989) reported that performance remained stable on tracking, choice RT, memory, mental math, problem-solving, identification, and driving primary tasks; degraded on tracking, choice RT, memory, monitoring, detection, and driving primary tasks; and improved on a monitoring primary task. Performance of the monitoring secondary task remained stable when paired with tracking, memory, monitoring, flight simulation, and driving primary tasks; degraded when paired with tracking, choice RT, mental math, monitoring, problem-solving, detection, identification and driving primary tasks; and improved when paired with tracking and driving primary tasks (see table 10).

*Data requirements.* The experimenter should calculate the following: number of correct detections, number of incorrect detections, number of errors of omission, mean RT for correct detections, and mean RT for incorrect detections (Lysaght et al., 1989, p. 235).

The Knowles (1963) guidelines are appropriate in selecting a vigilance task. In addition, the modality of the task must not interfere with performance of the primary task, for example, requiring a verbal response while a pilot is communicating with Air Traffic Control (ATC) or other crew members.

*Thresholds.* Not stated.

**TABLE 10**

**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Monitoring Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Choice RT | Boggs and Simon (1968) | Hilgendorf (1967) | | | Hilgendorf (1967) | |
| Detection | | Dewar, Ells, and Mundy (1976)<br>Tyler and Halcomb (1974) | | | Tyler and Halcomb (1974) | |
| Driving | Brown (1962, 1967)<br>Hoffman and Jorbert (1966)<br>Wetherell (1981) | Brown (1965) | | Hoffman and Jorbert (1966) | Brown (1962, 1965) | Brown (1967) |
| Flight simulation | | | | Soliday and Schohan (1965) | | |
| Identification | Dornic (1980) | | | | Dornic (1980)<br>Chiles, Jennings, and Alluisi (1979) | |
| Memory | Tyler and Halcomb (1974) | Chow and Murdock (1975)<br>Lindsay and Norman (1969)<br>Mitsuda (1968) | | Lindsay and Norman (1968) | | |
| Mental math | Dornic (1980) | | | | Chiles, Jennings, and Alluisi (1979)<br>Dornic (1980) | |
| Monitoring | | Chechile, Butler, Gutowski, and Palmer (1979)<br>Fleishman (1965) | McGrath (1965) | Stager and Muter (1971) | Chechile et al. (1979)<br>Hohmuth (1970)<br>Long (1976) | |

Continued

**TABLE 10 (Continued)**
**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Monitoring Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| | | Goldstein and Dorfman (1978)<br>Hohmuth (1970)<br>Long (1976)<br>Stager and Muter (1971) | | | | |
| Problem solving | Wright, Holloway, and Aldrich (1974) | | | | Chiles et al. (1979)<br>Wright et al. (1974) | |
| Tracking | Bell (1978)<br>Figarola and Billings (1966)<br>Gabriel and Burrows (1968)<br>Huddleston and Wilson (1971)<br>Kelley and Wargo (1967)<br>Kyriakides and Leventhal (1967)<br>Schori and Jones (1975) | Bergeron (1968)<br>Heimstra (1970)<br>Herman (1965)<br>Kramer, Wickens, and Donchin (1984)<br>Malmstrom, Reed, and Randle (1983)<br>Monty and Ruby (1965)<br>Putz and Rothe (1974) | | Figarola and Billings (1966)<br>Kramer et al. (1984)<br>Malmstrom et al. (1983) | Bell (1978)<br>Bergeron (1968)<br>Gabriel and Burrows (1968)<br>Herman (1965)<br>Huddleston and Wilson (1971)<br>Kelley and Wargo (1967)<br>Kyriakides and Leventhal (1967)<br>Monty and Ruby (1965)<br>Putz and Rothe (1974)<br>Schori and Jones (1975) | Heimstra (1970) |

* Not included in Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

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### 3.2.14 Multiple Task Performance Battery of Secondary Tasks

*General description.* The Multiple Task Performance Battery (MTPB) requires subjects to time-share three or more of the following tasks: (1) light and dial monitoring, (2) mental math, (3) pattern discrimination, (4) target identification, (5) group problem solving, and (6) two-dimensional compensatory tracking. The monitoring

tasks are used as secondary tasks and performance associated with these tasks as measures of workload.

*Strengths and limitations.* Increasing the number of tasks being time-shared does increase the detection time associated with the monitoring task. The MTPB may be difficult to implement in nonlaboratory settings. Lysaght et al. (1989) reported the results of one study (Alluisi, 1971) in which the MTPB was paired with itself. In dual-task performance, performance of both the primary and the secondary MTPB tasks degraded.

*Data requirements.* The MTPB requires individual programming and analysis of six tasks as well as coordination among them during the experiment.

*Thresholds.* Not stated.

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### 3.2.15 Occlusion Secondary Task

*General description.* "The subject's view of a visual display is obstructed (usually by a visor). These obstructions are either initiated by the subject or imposed by the experimenter in order to determine the viewing time needed to perform a task adequately" (Lysaght et al., 1989, p. 234).

*Strengths and limitations.* This task can be extremely disruptive of primary-task performance.

On the basis of the results of four studies in which a secondary occlusion task was used, Lysaght et al. (1989) reported that performance remained stable on monitoring and driving primary tasks and degraded on driving primary tasks. Performance of the secondary occlusion task degraded when paired with primary driving tasks (see table 11).

*Data requirements.* The following data are used to assess performance of this task: mean voluntary occlusion time and percent looking time/total time (Lysaght et al., 1989, p. 236).

*Thresholds.* Not stated.

**TABLE 11**
**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Occlusion Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Driving | Farber and Gallagher (1972) | Hicks and Wierwille (1979)<br>Senders, Kristofferson, Levison, Dietrich, and Ward (1967) | | | Farber and Gallagher (1972)<br>Senders et al. (1967) | |
| Monitoring | Gould and Schaffer (1967) | | | | | |

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 250.

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### 3.2.16 Problem-Solving Secondary Task

*General description.* "The subject engages in a task which requires verbal or spatial reasoning. For example, the subject might attempt to solve anagram or logic problems" (Lysaght et al., 1989, p. 233).

*Strengths and limitations.* "This class of tasks is thought to impose heavy demands on central processing resources" (Lysaght et al., 1989, p. 233). On the basis of eight studies in which a problem-solving secondary task was used, Lysaght et al. (1989) reported that performance remained stable on a primary monitoring

**TABLE 12**
**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Problem-Solving Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Choice RT | | | | | Schouten, Kalsbeek, and Leopold (1962) | |
| Driving | | Wetherell (1981) | | | Wetherell (1981) | |
| Memory | | Trumbo, Noble, and Swink (1967) | | | Trumbo et al. (1967) | |
| Monitoring | Gould and Schaffer (1967)<br>Smith, Lucaccini, Groth, and Lyman (1966) | | | | | Smith et al. (1966) |
| Problem solving | | | | | Chiles and Alluisi (1979) | |
| Tracking | | Trumbo et al. (1967) | | | Trumbo et al. (1967) | |

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 250.

task and degraded on driving, tracking, and memory primary tasks. Performance of the secondary problem-solving task remained stable when paired with a primary tracking task; degraded when paired with problem-solving, driving, choice RT, and memory primary tasks; and improved when paired with a primary monitoring task (see table 12).

*Data requirements.* The following data are used for these tasks: number of correct responses, number of incorrect responses, and mean RT for correct responses (Lysaght et al., 1989, p. 233).

*Thresholds.* Not stated.

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### 3.2.17 Production/Handwriting Secondary Task

*General description.* "The subject is required to produce spontaneous handwritten passages of prose" (Lysaght et al., 1989, p. 234).

*Strengths and limitation.* "With primary tasks that impose a high workload, subject's handwriting is thought to deteriorate (i.e., semantic and grammatical errors) under such conditions" (Lysaght et al., 1989, p. 234). Lysaght et al. (1989) cite a study reported by Schouten, Kalsbeek, and Leopold (1962) in which a spontaneous writing secondary task was paired with a choice RT primary task. Performance on the secondary task degraded.

*Data requirements.* The number of semantic and grammatical errors is used as data for this task (Lysaght et al., 1989, p. 236).

*Thresholds.* Not stated.

## SOURCES

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Schouten, J.F., Kalsbeek, J.W.H., and Leopold, F.F. On the evaluation of perceptual and mental load. *Ergonomics.* 15, 251–260, 1962.

### 3.2.18 Psychomotor Secondary Task

*General description.* "The subject must perform a psychomotor task such as sorting different types of metal screws by size" (Lysaght et al., 1989, p. 233).

*Strengths and limitations.* "Tasks of this nature are thought to reflect psychomotor skills" (Lysaght et al., 1989, p. 233). On the basis of three studies in which a psychomotor secondary task was used, Lysaght et al. (1989) reported that performance of a tracking primary task degraded. Performance of the secondary psychomotor task degraded when paired with either a tracking or choice RT primary task (see table 13).

*Data requirements.* The number of completed items is used to assess performance of this task.

*Thresholds.* Not stated.

**TABLE 13**
**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Psychomotor Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| Type | Stable | Degraded | Enhanced | Stable | Degraded | Enhanced |
| Choice RT | | | | | Schouten, Kalsbeek, and Leopold (1962) | |
| Tracking | | Bergeron (1968)<br>Wickens (1976) | | | Bergeron (1968) | |

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 251.

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Wickens, C.D. The effects of divided attention on information processing in manual tracking. *Journal of Experimental Psychology: Human Perception and Performance.* 2, 1–12, 1976.

### 3.2.19 Randomization Secondary Task

*General description.* "The subject must generate a random sequence of numbers, for example. It is postulated that with increased workload levels subjects will generate repetitive responses (i.e., lack randomness in responses)" (Lysaght et al., 1989, p. 232).

*Strengths and limitations.* The task is extremely intrusive, and calculating "randomness" difficult and time consuming. On the basis of five studies that used a randomization secondary task, Lysaght et al. (1989) reported that performance remained stable on tracking, card-sorting, and driving primary tasks; and degraded on tracking and memory primary tasks. Performance of the secondary randomization task remained stable when paired with a tracking primary task and degraded when paired with tracking and card-sorting primary tasks (see table 14).

*Data requirements.* The experimenter must calculate a percent redundancy score in bits of information.

*Thresholds.* Not stated.

**TABLE 14**
**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Randomization Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Card sorting | Baddeley (1966) | | | | Baddeley (1966) | |
| Driving | Wetherell (1981) | | | | | |
| Memory | | Trumbo and Noble (1970) | | | | |
| Tracking | Zeitlin and Finkelman (1975) | Truijens, Trumbo, and Wagenaar (1976) | | Zeitlin and Finkelman (1975) | Truijens et al. (1976) | |

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 250.

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Wetherell, A. The efficacy of some auditory-vocal subsidiary tasks as measures of the mental load on male and female drivers. *Ergonomics.* 24, 197–214, 1981.

Zeitlin, L.R. and Finkelman, J.M. Research note: Subsidiary task techniques of digit generation and digit recall indirect measures of operator loading. *Human Factors.* 17, 218–220, 1975.

### 3.2.20 Reading Secondary Task

*General description.* Subjects are asked to read digits or words aloud from a visual display. Measures can include number of digits or words read, longest interval between spoken responses, longest string of consecutive digits or words, and the number of times three consecutive digits or words occur (Savage, Wierwille, and Cordes, 1978).

*Strengths and limitations.* This task has been sensitive to the difficulty of a monitoring task. There were significant differences in the number of random digits spoken, the longest consecutive string of spoken digits, and the number of times three

consecutive digits were spoken (Savage, Wierwille, and Cordes, 1978). The longest interval between spoken responses was not significantly different between various levels of primary task difficulty (i.e., monitoring of 2, 3, or 4 m).

Wierwille, Gutmann, Hicks, and Muto (1977) asked subjects to read random digits aloud while driving in a simulator while steering ratio and wind disturbance level were manipulated. They reported that this secondary task was significantly affected by both independent variables. They concluded that this secondary task was simple to implement but may not be able to detect small changes in disturbance. In a follow-on study in 1978, Wierwille and Gutmann reported that this secondary task degraded primary-task performance, but only at low levels of workload.

*Data requirements.* Spoken responses must be recorded, timed, and tabulated.

*Thresholds.* Not stated.

## SOURCES

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### 3.2.21 Simple Reaction-Time Secondary Task

*General description.* "The subject is presented with one discrete stimulus (either visual or auditory) and generates one response to this stimulus" (Lysaght et al., 1989, p. 232).

*Strengths and limitations.* This task minimizes central processing and response selection demands on the subject (Lysaght et al., 1989, p. 232).

On the basis of 10 studies in which a simple RT secondary task was used, Lysaght et al. (1989) reported that performance remained stable on choice RT and classification primary tasks; degraded on tracking, classification, and lexical decision tasks; and improved on detection and driving primary tasks. Performance of the secondary simple RT task degraded when paired with tracking, choice RT, memory, detection, classification, driving, and lexical decision primary tasks; and improved when paired with a tracking primary task (see table 15).

Lisper, Laurell, and van Loon (1986) reported that subjects who had longer RTs on driving with simple auditory RT task on a closed course were more likely to fall asleep during an on-road drive.

Andre, Heers, and Cashion (1995) reported significant increase in pitch, roll, and yaw error of a simulated flight task while performing a secondary simple RT task.

*Data requirements.* The experimenter must be able to calculate mean RT for correct responses and the number of correct responses.

*Thresholds.* Not stated.

**TABLE 15**
**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Simple RT Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Choice RT | Becker (1976) | | | | Becker (1976) | |
| Classification | Comstock (1973) | Miller (1975) | | | Comstock (1973)<br>Miller (1975) | |
| Detection | | | Laurell and Lisper (1978) | | Laurell and Lisper (1978) | |
| Driving | | | Laurell and Lisper (1978) | | Laurell and Lisper (1978)<br>Lisper, Laurell, and Stening (1973) | |
| Lexical decision | | Becker (1976) | | | Becker (1976) | |
| Memory | | Dodds, Clark-Carter, and Howarth (1986)* | | | Martin and Kelly (1974) | |

| | | | | | |
|---|---|---|---|---|---|
| Simulated flight task | | Andre, Heers, and Cashion (1995)* | | | |
| Tracking | Martin, Long, and Broome (1984) for verbal response on secondary task | Heimstra (1970)<br>Kelly and Klapp (1985)<br>Klapp, Kelly, Battiste, and Dunbar (1984)<br>Martin, Long, and Broome (1984) for pointing response on secondary task<br>Wickens and Gopher (1977) | Martin, Long, and Broome (1984) | Wickens and Gopher (1977) | Heimstra (1970) |

* Not included in Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 251.

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### 3.2.22 Simulated Flight Secondary Task

*General description.* "Depending on the purpose of the particular study, the subject is required to perform various maneuvers (e.g., landing approaches) under different types of conditions such as instrument flight rules or simulated crosswind conditions" (Lysaght et al., 1989, p. 234).

*Strengths and limitations.* This task requires extensive subject training.

*Data requirements.* The experimenter should record the following data: mean error from required altitude, root-mean-square localizer error, root-mean-square glide-slope error, and number of control movements, and attitude high-pass mean square (Lysaght et al., 1989, p. 236).

*Thresholds.* Not stated.

## SOURCE

Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

### 3.2.23 Spatial-Transformation Secondary Task

*General description.* "The subject must judge whether information (data)—provided by an instrument panel or radar screen—matches information which is spatially depicted by pictures or drawings of aircraft" (Lysaght et al., 1989, p. 233). Lysaght et al. (1989) cite work by Vidulich and Tsang (1985) in which performance of a spatial transformation secondary task was degraded when paired with a primary tracking task.

Kramer, Wickens, and Donchin (1984) reported a significant decrease in tracking error on a primary task when subjects performed translational changes of the cursor as a secondary task.

*Strengths and limitations.* "This task involves perceptual and cognitive processes" (Lysaght et al., 1989, p. 233). Damos (1986) paired a visual matrix rotation task with a subtraction task. She reported no significant differences between speech responses or manual responses on the first experiment. There was a significant decrease in RTs for correct speech responses to the subtraction task when the responses were adjusted for the delay in the speech recognition system being used.

*Data requirements.* The following data are used to assess performance of this task: mean RT for correct responses, number of correct responses, and number of incorrect responses (Lysaght et al., 1989, p. 236).

*Thresholds.* Not stated.

## SOURCES

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Vidulich, M.A. and Tsang, P.S. Evaluation of two cognitive abilities tests in a dual-task environment. *Proceedings of the 21st Annual Conference on Manual Control.* 12.1–12.10, 1985.

### 3.2.24 Speed-Maintenance Secondary Task

*General description.* "The subject must operate a control knob to maintain a designated constant speed. This task is a psychomotor type task" (Lysaght et al., 1989, p. 234).

*Strengths and limitations.* This task provides a constant estimate of reserve response capacity but may be extremely intrusive on primary-task performance.

*Data requirements.* Response is used as data for this task.

*Thresholds.* Not stated.

## SOURCE

Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

### 3.2.25 Sternberg Memory Secondary Task

*General description.* The Sternberg (1966) recognition task presents a subject with a series of single letters. After each letter, the subject indicates whether that letter was or was not part of a previously memorized set of letters. RT is typically measured at two memory set sizes, two and four, and is plotted against set size (see figure 6). Differences in the slope (*b* in figure 6) across various design configurations indicate differences in central information processing demands. Changes in the intercept (*a*1 and *a*2 in figure 6) suggest differences in either sensory or response demands. Additional data for this task include number of correct responses and RTs for correct responses.

*Strengths and limitations.* The Sternberg task is sensitive to workload imposed by wind conditions, handling qualities, and display configurations. For example, Wolf (1978) reported that the longest RTs to the Sternberg task occurred in the high gust, largest memory set (4), and poorest handling qualities condition. Schiflett (1980) reported both increased Sternberg RT and errors with degraded handling qualities during approach and landing tasks. Similarly, Schiflett, Linton, and Spicuzza (1982) reported increases in four Sternberg measures (RT for correct responses, intercept, slope, and percent errors) as handling qualities were degraded. Poston and Dunn (1986) used the Sternberg task to assess a kinesthetic tactile display. They recorded response speed and accuracy.

A second advantage of the task is that it is minimally intrusive on performance of a primary flight task (Schiflett, Linton, and Spicuzza, 1980; Dellinger and Taylor, 1985). Used alone, the Sternberg provided reliable measure of mercury exposure (Smith and Langolf, 1981).

However, there are several problems associated with the use of the task. Based on data collected in a flight simulator (Taylor, Dellinger, Richardson, Weller, Porges, Wickens, LeGrand, and Davis, 1985), RTs increase with workload but more so for negative than for positive responses. Further, work by Micalizzi (1981) suggests that performance of the Sternberg task is poorest when it is time-shared with a failure detection task. Gawron, Schiflett, Miller, Ball, Slater, Parker, Lloyd, Travale, and

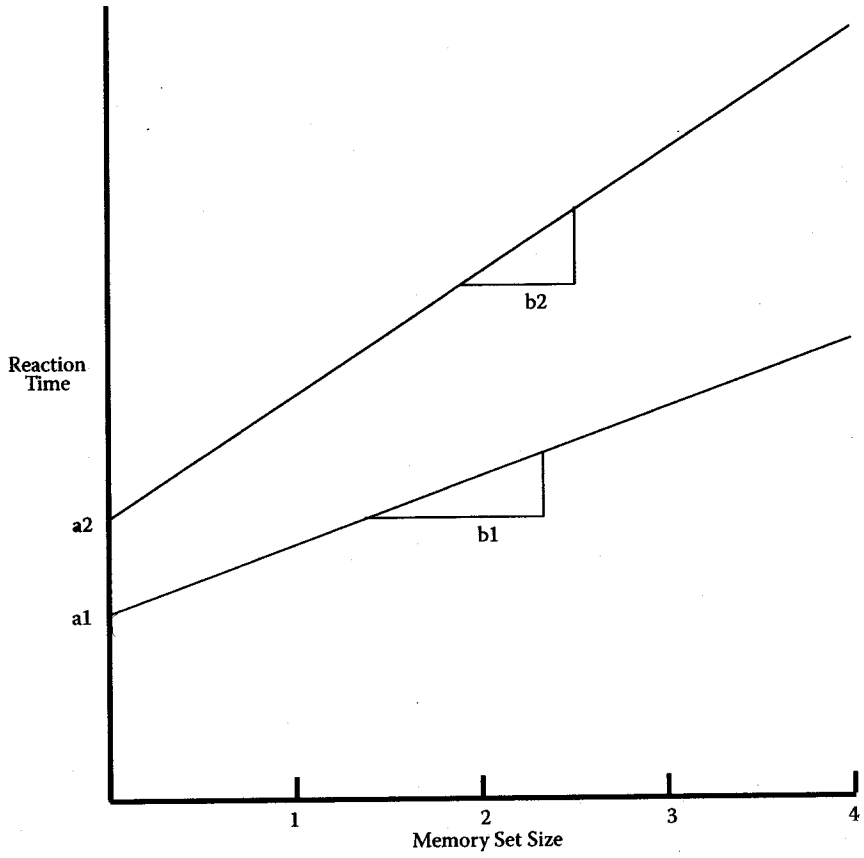


**FIGURE 6** Sternberg Memory Task Data.

Spicuzza (1988) used the Sternberg memory search task to access the in-flight effects of pyridostigmine bromide. There were no significant effects of drug or crew position (pilot or copilot). This finding may be due to a true lack of a drug or crew position effect or to insensitivity of the measure. In an earlier study, Knotts and Gawron (1983) reported that the presence of the Peripheral Vision Display (PVD) reduced Sternberg RTs for one subject but not for another. They also reported that performance of the Sternberg task improved throughout the flight program and suggested extensive training before using the task in flight.

Micalizzi and Wickens (1980) compared Sternberg RT under single- and dual-task conditions. There were three manipulations of the Sternberg task: no mask, single mask, or double mask. They reported a significant increase in Sternberg RT under dual-task condition for the two masked conditions as compared to the no-mask condition.

On the basis of the results of four studies in which a secondary Sternberg task was used, Lysaght et al. (1989) reported performance degraded on tracking, choice RT, and driving primary tasks; and improved on a tracking primary task. Performance of the secondary Sternberg task degraded when paired with a primary tracking task (see table 16) or a simulated flight task.

**TABLE 16**

**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Sternberg Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Choice RT | | Hart, Shively, Vidulich, and Miller (1985) | | | | |
| Driving | | Wetherell (1981) | | | | |
| Mental math | | Payne, Peters, Birkmire, Bonto, Anatasi, and Wenger (1994)* | | | | |
| Simple RT | | Payne, Peters, Birkmire, Bonto, Anatasi, and Wenger (1994)* | | | | |
| Simulated flight | Crawford, Pearson, and Hoffman (1978)*<br>Wierwille and Connor (1983) | O'Donnell (1976)* | | | Schiflett, Linton, and Spicuzza (1982)*<br>Hyman, Collins, Taylor, Domino, and Nagel (1988) | |
| Tracking | Tsang, Velaquez, and Vidulich (1996) | Wickens and Yeh (1985)<br>Vidulich and Wickens (1986) | Briggs, Peters, and Fisher (1972) | | Briggs et al. (1972)<br>Wickens and Yeh (1985) | |

* Not included in Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 252.

Vidulich and Wickens (1986) reported that the "addition of the tracking task tends to overwhelm distinctions among the Sternberg task configurations" (p. 293). Further, Manzey, Lorenz, Schiewe, Finell, and Thiele (1995) reported significant differences in dual-task performance of the Sternberg, and tracking prior and during space flight. However, there was no difference in single-task performance of the Sternberg.

The Sternberg has also been used as a primary task to evaluate the effects of altitude on short-term memory. Kennedy, Dunlap, Banderet, Smith, and Houston (1989) reported significant increases in time per response and decreases in number correct. Rolnick and Bles (1989) also used the Sternberg but evaluated the effect of tilting and closed cabin conditions simulating shipboard conditions. RT increased in the closed cabin condition compared to the no-motion condition but showed no significant difference with the artificial horizon or windows conditions.

Van de Linde (1988) used a Sternberg-like test to assess the effect of wearing a respirator on the ability to recall numbers and letters from memory, and to concentrate. Memory sets were 1, 2, 3, or 4 with 24 targets mixed with 120 nontargets. Letter targets took longer to find than number targets. There was no significant difference between trials 1 and 3. However, there was a 12% decrease in time while wearing the respirator.

Tsang and Velazquez (1996) used the Sternberg combined with tracking to evaluate a workload profile measure consisting of ratings of perceptual/central, response, spatial, verbal, visual, and manual. They concluded that the variance accounted for by the memory set size variations of the Sternberg was comparable to the subjective workload ratings.

*Data requirements.* The slopes and intercepts of the RT are used as data for this task. Wickens, Hyman, Dellinger, Taylor, and Meador (1986) have recommended that the Sternberg letters in the memorized set be changed after 50 trials. Schiflett (1983) recommended the use of an adaptive interstimulus interval (ISI). Adaptation would be based on response accuracy. Knotts and Gawron (1983) recommended an extensive training on the Sternberg task before data collection.

*Thresholds.* Not stated.

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### 3.2.26 Three-Phase Code Transformation Secondary Task

*General description.* "The subject operates the 3P-Cotran which is a workstation consisting of three indicator lights, a response board for subject responses and a memory unit that the subject uses to save his/her responses. The subject must engage in a 3-phase problem solving task by utilizing information provided by the indicator lights and recording solutions onto the memory unit" (Lysaght et al., 1989, p. 234).

*Strengths and limitations.* "It is a synthetic work battery used to study work behavior and sustained attention" (Lysaght et al., 1989, p. 234).

*Data requirements.* The following data are used to evaluate performance of this task: mean RT for different phases of response required and number of errors (resets) for different phases of response required (Lysaght et al., 1989, p. 236).

*Thresholds.* Not stated.

## SOURCE

Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

### 3.2.27 Time-Estimation Secondary Task

*General description.* Subjects are asked to produce a given time interval, usually 10 s, from the start of a stimulus, usually a tone. Measures for this task include the number of incomplete estimates and/or the length of the estimates.

*Strengths and limitations.* The technique is sensitive to workload (Hart, 1978; Wierwille, Casali, Connor, and Rahimi, 1985). For example, Bortolussi, Kantowitz, and Hart (1986) found a significant increase in 10 s time production intervals between easy and difficult flight scenarios. Bortolussi, Hart, and Shively (1987) reported similar results for a 5 s time production task.

In addition, the length of the time interval produced decreased from the beginning to the end of each flight. Gunning (1978) asked pilots to indicate when 10 s had passed after an auditory tone. He reported that both the number of incomplete estimates and the length of the estimates increased as workload increased. Similarly, Madero, Sexton, Gunning, and Moss (1979) reported that the number of incomplete time estimates increased over time in an aerial delivery mission. These researchers also calculated a time estimation ratio (the length of the time estimate in flight divided by the baseline estimate). This measure was also sensitive to workload, with significant increases occurring between cruise and Initial Point (IP), and cruise and Computed Air Release Point (CARP).

Connor and Wierwille (1983) recorded time estimation mean, standard deviation, absolute error, and rmse of completed estimates during three levels of gust and aircraft stability (load). There was only one significant load effect: the standard deviation of time estimates decreased from the low to the medium load then increased from the medium to high load. This same measure was sensitive to communication load, danger, and navigation load. Specifically, Casali and Wierwille (1983) reported significant increases in time estimation standard deviation as communication load increased. Casali and Wierwille (1984) found significant increases between low- and high-danger conditions. Wierwille, Rahimi, and Casali (1985) reported the same results for navigation load, and Hartzell (1979) for difficulty of precision hover maneuvers in a helicopter simulator.

Hauser, Childress, and Hart (1983) reported less variability in time estimates made using a counting technique than those made without a counting technique. Bobko, Bobko, and Davis (1986) reported, however, that verbal time estimates of a fixed time interval decrease as screen size (0.13, 0.28, and 0.58 diagonal meters) increased. In addition, men gave significantly shorter time estimates than women.

On the basis of the results of four studies in which a time estimation secondary task was used, Lysaght et al. (1989) reported that performance on a primary flight simulation task remained stable but degraded on a primary monitoring task. Performance of the secondary time estimation task degraded when paired with either a monitoring or a flight simulation primary task (see table 17).

*Data requirements.* Although some researchers have reported significant differences in several time estimation measures, the consistency of the findings using time estimation standard deviation suggests that this may be the best time estimation measure.

*Thresholds.* Not stated.

**TABLE 17**

**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Time Estimation Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Flight simulation | Bortolussi, Hart, and Shively (1987)<br>Bortolussi, Kantowitz, and Hart (1986)<br>Casali and Wierwille (1983)*<br>Kantowitz, Bortolussi, and Hart (1987)*<br>Connor and Wierwille (1983)*<br>Wierwille, Rahimi, and Casali (1985) | | | | Bortolussi et al. (1987, 1986)<br>Gunning (1978)*<br>Wierwille et al. (1985) | |
| Monitoring | | Liu and Wickens (1987) | | | Liu and Wickens (1987) | |

* Not included in Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 252.

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### 3.2.28 Tracking Secondary Task

*General description.* "The subject must follow or track a visual stimulus (target) which is either stationary or moving by means of positioning an error cursor on the stimulus using a continuous manual response device" (Lysaght et al., 1989, p. 232). Tracking tasks require nullifying an error between a desired and an actual location. The Critical Tracking Task (CTT) has been widely used.

*Strengths and limitations.* Tracking tasks provide a continuous measure of workload. This is especially important in subjects with large variations in workload. Several investigators (Corkindale, Cumming, and Hammerton-Fraser, 1969; Spicuzza, Pinkus, and O'Donnell, 1974) have used a secondary tracking task to successfully evaluate workload in an aircraft simulator. Spicuzza et al. (1974) concluded that a secondary tracking task was a sensitive measure of workload. Clement (1976) used a cross-coupled tracking task in a STOL (Short Take-Off and Landing) simulator to evaluate horizontal situation displays. Park and Lee (1992) reported that tracking task performance distinguished between passing and failing groups of flight students. Manzey, Lorenz, Schiewe, Finell, and Thiele (1995) reported significant decreases in performance of tracking and tracking with the Sternberg tasks between pre- and post-space flight.

The technique may be useful in ground-based simulators but inappropriate for use in flight. For example, Ramacci and Rota (1975) required flight students to perform a secondary tracking task during their initial flights. The researchers were unable to quantitatively evaluate the scores on this task because of artifacts of air turbulence and subject fatigue. Further, Williges and Wierwille (1979) state that hardware constraints make in-flight use of a secondary tracking task unfeasible and potentially unsafe.

In addition, Damos, Bittner, Kennedy, and Harbeson (1981) reported that dual performance of a critical tracking task improved over 15 testing sessions, suggesting a long training time to asymptote. Robinson and Eberts (1987) reported degraded performance on tracking when paired with a speech warning rather than a pictorial warning.

Andre, Heers, and Cashion (1995) reported increased pitch, roll, and yaw rmse in a primary simulated flight task when time-shared with a secondary target acquisition task.

Korteling (1991, 1993) reported age differences in dual-task performance of two one-dimensional compensatory tracking tasks.

On the basis of the results of 12 studies in which a secondary tracking task was used, Lysaght et al. (1989) reported that performance remained stable on tracking, monitoring, and problem-solving primary tasks; degraded on tracking, choice RT, memory, simple RT, detection, and classification primary tasks; and improved on a tracking primary task. Performance of the secondary tracking task degraded when paired with tracking, choice RT, memory, monitoring, problem-solving, simple RT, detection, and classification primary tasks and improved when paired with a tracking primary task (see table 18).

*Data requirements.* The experimenter should calculate the following: integrated errors in mils (rmse), total time on target, total time of target, number of times of target, and number of target hits (Lysaght et al., 1989, p. 235). A secondary tracking task is most appropriate in systems when a continuous measure of workload

**TABLE 18**
**References Listed by the Effect on Performance of Primary Tasks Paired with a Secondary Tracking Task**

| | Primary Task | | | Secondary Task | | |
|---|---|---|---|---|---|---|
| **Type** | **Stable** | **Degraded** | **Enhanced** | **Stable** | **Degraded** | **Enhanced** |
| Choice RT | | Looper (1976)<br>Whitaker (1979) | | | Hansen (1982)<br>Whitaker (1979) | |
| Classification | | Wickens, Mountford, and Schreiner (1981) | | | Wickens et al. (1981) | |
| Detection | | Wickens et al. (1981) | | | Wickens et al. (1981)<br>Robinson and Eberts (1987)* | |
| Memory | | Johnston, Greenberg, Fisher, and Martin (1970) | | | Johnston et al. (1970) | |
| Monitoring | Griffiths and Boyce (1971) | | | | Griffiths and Boyce (1971) | |
| Problem solving | Wright, Holloway, and Aldrich (1974) | | | | Wright et al. (1974) | |

| | | | | | |
|---|---|---|---|---|---|
| Problem solving | Wright, Holloway, and Aldrich (1974) | | | Wright et al. (1974) | |
| Simple RT | | Schmidt, Kleinbeck, and Brockman (1984) | | Schmidt et al. (1984) | |
| Simulated flight task | | Andre, Heers, and Cashion (1995)* | | | |
| Tracking | Mirchandani (1972) | Gawron (1982)*<br>Hess and Teichgraber (1974)<br>Wickens and Kessel (1980)<br>Wickens, Mountford, and Schreiner (1981) | Tsang and Wickens (1984) | Gawron (1982)*<br>Tsang and Wickens (1984)<br>Wickens et al. (1981) | Mirchandani (1972) |

* Not included in Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989.

*Source:* From Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., and Wherry, R.J. *Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report 851).* Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences; June 1989, p. 251.

is required. It is recommended that known forcing functions be used rather than unknown, quasi-random disturbances.

*Thresholds.* Not stated.

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### 3.2.29 Workload Scale Secondary Task

*General description.* A workload scale was developed by tallying the number of persons who performed better in each task combination of the Multiple Task Performance Battery (MTPB) and converting these proportions to $z$ scores (Chiles and Alluisi, 1979). The resulting $z$ scores are multiplied by $-1$, so that the most negative score is associated with the lowest workload.

*Strengths and limitations.* Workload scales are easy to calculate but must satisfy the following conditions: (1) linear additivity and (2) no interaction between tasks. Some task combinations may violate these assumptions. Further, the intrusiveness of secondary tasks may preclude their use in nonlaboratory settings.

*Data requirements.* Performance of multiple combinations of tasks is required.

*Thresholds.* Dependent on task and task combinations being used.

## SOURCE

Chiles, W.D. and Alluisi, E.A. On the specification of operator or occupational workload with performance-measurement methods. *Human Factors.* 21 (5), 515–528, 1979.

## 3.3 SUBJECTIVE MEASURES OF WORKLOAD

There are five types of subjective measures of workload. The first is comparison measures, in which the subject is asked which of two tasks has the higher workload. This type of measure is described in section 3.3.1. The second type is a decision tree, in which the subject is stepped through a series of discrete questions to reach a single workload rating (see section 3.3.2). The third type of subjective workload measure is a set of subscales, each of which is designed to measure different aspects of workload (see section 3.3.3). The fourth type is a single number, which as the