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LATERAL DIFFERENCES IN SCHEMATIC FACE ENCODING DURING DUAL-TASK PERFORMANCE WITH INCREASING LEVELS OF DIFFICULTY[1]

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Summary.—20 normal, right-handed, familial dextral men performed (a) unimanual finger tapping, (b) encoding of schematic faces at three levels of difficulty (3, 5, and 7 faces), (c) verbal production, (d) concurrent tapping and verbal production, and (e) concurrent tapping and face encoding. Subsequent recognition of faces was disrupted more by concurrent left-hand tapping than by concurrent right-hand tapping, supporting both the hypothesis that the right hemisphere mediates face encoding in adults and Kinsbourne and Hicks' (1978) "functional cerebral distance principle." Left- and right-hand tapping rate and variability were not asymmetrically affected by either verbal production or face encoding. While there was an increase in generalized interference effects on face encoding, the degree of asymmetry of the interference remained constant. In addition, as the difficulty of the memory task increased, variability of tapping rate decreased. This was discussed in terms of attention and automatic motor programming.

Left-right differences in cerebral hemispheric functioning have been commonly attributed to the type of task subjects are asked to complete (i.e., verbal versus nonverbal/spatial). In general, research supports the premise that the left hemisphere is dominant for a majority of language tasks and the right hemisphere is dominant for many nonverbal/spatial tasks. Specifically, a speech-production task is usually controlled by the left hemisphere (Hicks, 1975; Hicks, Bradshaw, Kinsbourne, & Feigin, 1978; also see Kinsbourne & Hiscock, 1983a) while the right hemisphere appears to mediate performance on nonverbal/spatial tasks, such as the recognition of human faces (Berent, 1977; Klein, Moscovitch, & Vigna, 1976; Marcel & Rajan, 1975; Suberi & McKeever, 1977; Young & Ellis, 1976), cartoon drawings of faces (Ley & Bryden, 1979), and schematic drawings of faces (Bradshaw & Sherlock, 1982; Geffen, Bradshaw, & Wallace, 1971; Patterson & Bradshaw, 1975; Sergent, 1982).

Cerebral dominance can be inferred from a variety of behavioral measures. The dual-task paradigm is one method which is currently generating

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much attention (Hicks, 1975; Bowers, Heilman, Satz, & Altman, 1978; Hiscock, Kinsbourne, Samuels, & Krause, 1987). This paradigm measures asymmetry of interference between concurrent tasks. It is based on an attribute of brain organization that Kinsbourne and Hicks (1978) have termed the "functional cerebral distance principle." They hypothesize that performance on dual-tasks decreases to the extent that the cerebral programs that control the two tasks share the same functional space. For example, if an individual is right-handed, speech production and the control of right-hand motor programs are usually both mediated by the left hemisphere while control of left-hand motor programs are usually mediated by the right hemisphere. Consequently, speech production interferes more with right-hand tapping than left-hand tapping (Bowers, *et al.*, 1978; Dalby, 1980; Hellige & Longstreth, 1981; Hicks, *et al.*, 1978). In this case, the dual-task paradigm elicits competition between two output processes (e.g., finger tapping and speaking). Another type of dual-task paradigm commonly used in experimental research involves the competition between an output process and a cognitive process. For example, since face encoding and left-hand tapping are both mediated by the right hemisphere in adults, a memory task involving photographs of faces interferes more with left-hand tapping than right-hand tapping (McFarland & Ashton, 1978b). Interestingly, most dual-task studies have found that, when performance on both the manual and nonmanual tasks are measured, unimanual tapping rarely has a lateralized effect on either verbal production or cognitive processing (see Kinsbourne & Hiscock, 1983a). That is, tapping usually does not interfere with number of words spoken or performance on cognitive tasks. Tapping has been found to interfere asymmetrically with performance on a face-encoding memory task, but only for the most difficult trials, i.e., the highest memory load (McFarland & Ashton, 1978b).

Using the dual-task paradigm, other studies have assessed the effect of task difficulty on asymmetrical cerebral functioning. These studies were designed to determine the lateralized effect (i.e., right vs left) of a unimanual motor task (i.e., finger tapping) on a concurrent task while increasing the difficulty level of the concurrent tasks. Both motor tasks (e.g., verbal production) and cognitive tasks (e.g., block design and face encoding) with increasing difficulty levels have been presented concurrently with the unilateral finger-tapping task. In most cases, increasing the difficulty level of the concurrent cognitive task has little effect on asymmetry of tapping interference. Increasing the memory load of faces (from 1 to 3 items) and numbers (from 1 to 4 items) does not appear to increase asymmetry of tapping interference in children (Hiscock, *et al.*, 1987). Similarly, increasing the difficulty level of a block design from "moderately difficult" to "difficult" does not increase asymmetry of interference (Hellige & Longstreth, 1981).

In fact, one study (McFarland & Ashton, 1978a) reported that increasing the running memory span of words (average span of 10 to 20) and shapes (average span of 5 to 10) led to a decrease in asymmetry of tapping variability in adults. In the former two cases performance on the cognitive task was not affected in a lateralized fashion, while in the latter case performance on the cognitive task was significantly disrupted on the most difficult task.

It is surprising that dual-task studies do not show that increasing the difficulty of a concurrent cognitive task increases the asymmetrical functioning (and therefore asymmetrical interference) considering that other behavioral methods have shown that it does. For example, dichotic listening studies have found that increasing the difficulty (i.e., memory load) of both verbal (i.e., digits) and nonverbal (i.e., environmental sounds) stimuli increases the right and left ear advantage, respectively (Geffen, 1978; Geffen & Wale, 1979; Kraft, 1982). One would think that as the limits of short-term memory store are approached, the system which usually mediates the type of information being processed would experience greater processing demands and therefore demonstrate greater interference effects. It has been suggested, however, that at some point a more difficult task elicits a change in processing strategy and/or diffuse activation of the hemispheres (McFarland & Ashton, 1978a).

The purpose of this study was to further investigate the asymmetrical interference effects of increasing task difficulty of a schematic face-encoding task which is thought to elicit greater right than left hemispheric mediation. It is hypothesized that as memory load is systematically varied within the normal range of short-term memory store (7 ± 2 items), the asymmetry of interference will increase with increasing task difficulty.

METHOD

Subjects

Twenty normal, right-handed, right-eyed, familial dextral, adult males, who were 19 to 21 yr. of age and belonged to a university-affiliated fraternity, served as subjects. Since research indicates that brain organization may be different for those who are left-handed or have a familial history of left-handedness (Kee, Bathurst, & Hellige, 1984; Kraft, 1983; Tinkcom, Obrzut, & Poston, 1983), or who have experienced brain trauma (Kinsbourne & Hiscock, 1983b), or who have mixed eye-hand dominance (Porac & Coren, 1981), subjects were screened for these variables.

Hand preference was assessed using a behavioral version of the Edinburgh Handedness Inventory (Oldfield, 1971). The subjects were considered right-handed if they used their right hands to write and draw and performed at least six of the other eight activities with their right hands. A questionnaire developed by Kraft (Kraft, 1983; Kamptner, Kraft, & Harper, 1984) was used to screen for family history of handedness. Subjects who reported to have any left-handed first-degree relatives, or more than one second-degree relative, or any combination of left-handed relatives whose genetic relatedness equalled more than 30% were eliminated. Right-eye dominance was determined by performance on a behavioral test. The subjects were asked to focus on an object at distances of 3, 6, 9, and 12 ft. while looking through a cone extended at arm's length and then slowly to bring the cone up to the face. Individuals were considered right-eye dominant if they sighted with the right eye on at least three of the four trials.

Apparatus

Subjects sat at a table and repetitively tapped on a standard computer key that had been mounted in a 4½- × 6¾- × 1½-in. plastic box. The key stood ⅜-in. above the surface of the box. A force of 55.5 gm. closed the contact. The tapping button was connected to a Macintosh computer located in an adjacent room. A computer program was developed to record the speed and variability of the taps, using intertap intervals, during the first 10 sec. of each tapping condition. The first tap of each tapping condition signaled the beginning of a 10-sec. recording. A portable Panasonic tape recorder was used to record the number of words spoken during the verbal conditions.

Materials

Face recognition.—Stimuli were simple schematic drawings with three composite features—eyes, eyebrows, and mouth. Target faces, 2½ in. in diameter, were drawn in black on white cards (see Fig. 1). Placement of target and nontarget faces on the response cards was randomly determined, and faces varied on all three composite features in each set. There were approximately 46 different types of eyes and mouths and 52 different types of eyebrows used as composite features. Ten sets of cards were prepared: 4 sets consisting of 3 target faces to be identified from an array of 6 (3A, 3B, 3C, 3D), 3 sets consisting of 5 target faces to be identified from an array of 10 faces (5A, 5B, 5C), and 3 sets consisting of 7 target faces to be identified from an array of 14 (7A, 7B, 7C). In all, there were three levels of task difficulty. Target faces in Sets 3A, 3B, 3C, and 3D were placed all in one row; response cards were arranged with two rows of three faces each. Target faces in Sets 5A, 5B, and 5C were arranged in two rows, with one row of two faces and one row of three faces; response cards were arranged with alternating rows of two and three faces each. Target faces in Sets 7A, 7B, and 7C were arranged in two rows, one row of three faces and one row of four faces; response cards were arranged with alternating rows of three and four faces each.

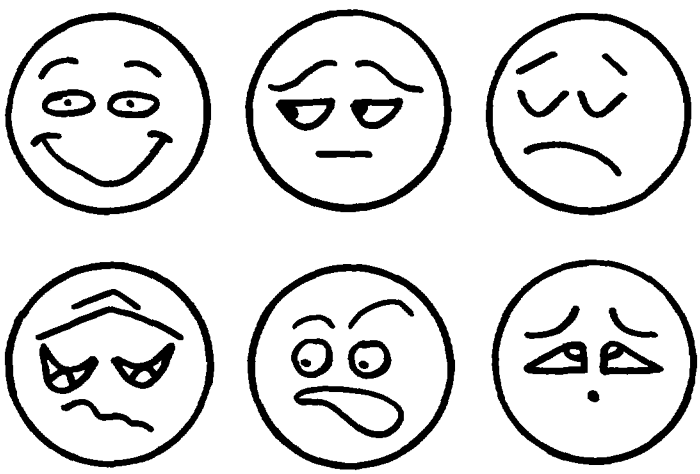

FIG. 1. Sample of schematic faces illustrating that all three composite features (eyes, mouth, eyebrows) were varied in each set.

All 10 sets were presented in the same order to all adults even though two different task sequences, as will be described later, were employed. Thus, Sets 3A, 5A, and 7A were associated with left-hand tapping for half the subjects and with right-hand tapping for the other half. Sets 3B, 5B, and 7B were presented to all subjects during control conditions for face recognition. Sets 3C, 5C, and 7C were associated with right-hand tapping for half the subjects and left-hand tapping for the other half. Set 3D was used for demonstration purposes.

Verbal production task.—Recitation of a nursery rhyme was selected as the verbal production task. To ensure that any interference effects that might occur as a result of concurrent tapping and speaking were due to interference with verbal production and not to memory of a recently learned rhyme, a nursery rhyme well known to this cohort group was chosen. Pilot studies indicated that the most familiar rhyme was "Mary Had a Little Lamb," so it was chosen as the verbal task.

Memory span.—Each subject's short-term memory span was individually assessed by the Backward Digit Span subtest from the Wechsler Adult Intelligence Scale (WAIS). This subtest was administered and scored according to the WAIS manual (Wechsler, 1955). It is a measure of the ability to hold information in short-term store and retrieve it in a different order than that presented (Matarazzo, 1972, pp. 204-206). The average number of items which an adult can hold in short-term store is 7 ± 2, with a range of 5 to 9 items (Klatzky, 1980). The Backward Digit Span mean for the adult subjects in this study was 5 ($SD = 1.3$), with a range of 3 to 7 items. Since we were planning to require subjects in this study to hold a number of schematic faces in short-term memory while concurrently performing another task (unimanual tapping) and then retrieve them in a different order from the original presentation (recognize them from a randomly ordered display which also included a number of items which they had not seen), we decided to use the spans of 3, 5, and 7 for our three levels of difficulty.

Procedure

Each subject was tested in a quiet room by a female experimenter. The testing session lasted approximately one-half hour. The subjects were told that they would be asked to tap as rapidly as possible, talk as rapidly as possible, and remember pictures of faces, or perform two of these tasks simultaneously. The experimenter demonstrated key tapping and had each subject practice for 10 sec. with each hand. They were instructed to begin tapping when the experimenter said "Go" and cease tapping when the experimenter said "Stop." The experimenter ensured that only the index finger contacted the key, that the elbow was resting on the table, and that they key was pushed all the way down and released with each tap. Next, the subjects were presented the instructions and given practice trials for the verbal production and face-encoding conditions. Both the practice trials for speaking and face recognition were performed without simultaneous tapping. They were first asked to recite the nursery rhyme as many times as possible from the time the experimenter said "Go" until she said "Stop." This was practiced to ensure fluent and continuous recitation for a full 10-sec. interval. The average number of words produced during the baseline condition was 58.3.

The face-recognition task was introduced with the demonstration set of face cards. Each subject was shown the target faces for 10 sec. with prior instructions to look at the faces carefully because they would be asked to remember them. They were then shown the response card and asked to point to the three faces that they had just seen.

After all the tasks had been practiced, the subjects were told that they would be asked to complete each of the activities separately, and to tap and talk, or tap and remember faces at the same time. Each subject completed 14 conditions: (1) right-hand tapping without a concurrent task, (2) left-hand tapping without a concurrent task, (3) right-hand tapping with verbal production, (4) left-hand tapping with verbal production, (5) right-hand tapping with encoding of three target faces, (6) left-hand tapping with encoding of three target faces, (7) encoding of three target faces without concurrent tapping, (8) verbal production without concurrent tapping, (9) right-hand tapping with encoding of five target faces, (10) left-hand tapping with encoding of five target faces, (11) encoding of five target faces without concurrent tapping, (12) right-hand tapping with encoding of seven target faces, (13) left-hand tapping with encoding of seven target faces, (14) encoding of seven target faces without concurrent tapping. Half the adults performed the tasks in the order 3, 6, 7, 5, 2, 8, 9, 11, 10, 1, 13, 14, 12, 4, and the other half in the order 4, 5, 7, 6, 1, 10, 11, 9, 8, 2, 12, 14, 13, 3. There were no significant order effects for any of the measures (Wilcox, 1988). During concurrent tapping and face encoding conditions the subjects were instructed to tap and look at the faces from the time the experimenter said "Go" until she said "Stop." After the 10-sec. interval they were tested for subsequent recognition. Throughout the experiment the subjects were reminded that both tasks in a concurrent condition were equally important.

The experiment described here is a part of a larger study that included additional subjects and tasks. Consequently, there are differences in the order that some of the subjects completed these tasks in relation to additional tasks. Half of the subjects completed another set of tasks, including the Digit Span subtest, before completing these tasks, while for the other half the reverse was true.

Scoring

A computer program was developed to record interarrival times between taps for the first 10 sec. of each trial. Tapping rate was determined by the mean number of cycles, or ticks, that the computer completed between each tap. Two measures of variability were also computed: the standard deviation from the mean number of ticks between taps and the coefficient of variation (the standard deviation divided by the mean). To facilitate communication of results, tapping rate was converted to mean number of taps per second and a corresponding measure of variability computed. The measure of variability used in subsequent statistical analyses was the coefficient of variation as it has been found to be the most independent of tapping rate (Hiscock, Kinsbourne, & Krause, 1985; Wilcox, 1988).

Responses from each of the face recognition trials were recorded on paper by the experimenter at the time of recognition testing. To allow for comparison across varying levels of task difficulty, scores were converted to a proportion of the possible number correct on each trial. The average percent of faces identified correctly from three target faces was 98.0%, from five target faces 92.0%, from seven target faces 87.1%.

Results

Baseline Tapping Performance

Although there were no significant differences between left- and right-hand baseline tapping variance, there was a significant difference between the two for baseline tapping rate ($t_{19} = -2.71$, $p < .05$). On the average, right-hand tapping was faster than left-hand tapping (6.42 vs 6.00 taps per sec.). To compare changes in these baselines due to concurrent performance of another task and control for these baseline differences, we converted these baseline scores into proportional change scores which are thought to be one of the most reliable methods for assessing the effects of "treatment" on baseline performance (Hiscock, 1982; Hiscock, *et al.*, 1985). The formula for the proportional change score is: [(baseline tapping performance minus dual-task tapping performance) divided by baseline tapping performance]. We computed four proportional change scores for the right hand and four for the left hand. For each hand there was the proportional change in tapping rate while speaking and while encoding faces and proportional change in tapping variability while speaking and while encoding faces.

Interference Effects of Dual-task Performance

Interference on tapping from verbal production and face encoding.—We expected to find a decrease in tapping rate and an increase in tapping variability (1) of the right hand but not the left hand while concurrently tapping and speaking and (2) of the left hand but not the right hand while concurrently tapping and encoding faces. Although there was a general increase in tapping variability during concurrent face encoding compared to that found during concurrent speaking ($F_{1,19} = 13.91$, $p < .01$), this effect was found for both hands. Furthermore, left- and right-hand tapping rates were not significantly affected by either concurrent speaking or face encoding. Thus the expected asymmetric interference effect of verbal production and face encoding while concurrently tapping was not found.

Interference on face encoding and verbal production performance from left- and right-hand tapping.—We expected to find a decrease in face-encoding performance while concurrently tapping with the left but not right hand and a decrease in verbal production while concurrently tapping with the right but not the left hand. We found that condition significantly ($F_{2,38} = 19.35$,

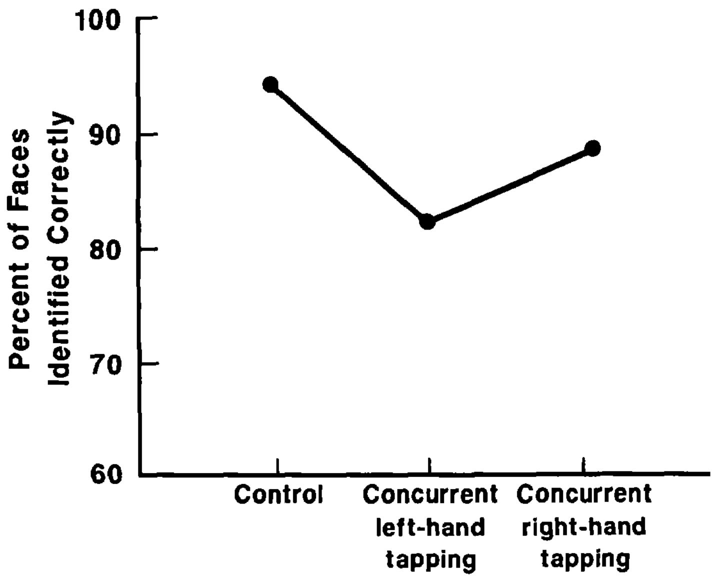

FIG. 2. Mean percentage of faces identified correctly averaged across levels of difficulty

$p < .001$) affected the ability to recognize faces (see Fig. 2) but not verbal production.

Averaging across difficulty level of the faces, subjects recognized a smaller percentage of faces when they were tapping with the left hand ($M = 81.1\%$, $SD = 8.3$) compared to their recognition of faces when they were tapping with the right hand ($M = 86.9\%$, $SD = 8.3$) and when they were not performing a concurrent tapping task ($M = 92.5\%$, $SD = 8.0$).

Interference effects on face encoding when increasing task difficulty.—Since we had found interference effects of left-hand tapping of face recognition, we expected to find that increasing task difficulty would increase this effect. Although face recognition did decrease as task difficulty increased ($F_{2,38} = 17.93$, $p < .001$), there were no significant differences in face recognition across the three levels of task difficulty in relation to tapping hand. There was also an increase in tapping variability ($F_{2,38} = 3.81$, $p < .05$) across hands as the task became more difficult.

DISCUSSION

The results of this study show that the dual-task condition of unimanual finger tapping while concurrently encoding schematic faces results in asymmetrical interference effects. Face encoding (as measured by subsequent recognition) was disrupted more by concurrent left-hand tapping than right-hand tapping. In terms of brain organization as a determinant of interference effects, this finding supports the hypothesis that face encoding is mediated by the right hemisphere in adults. It also supports an attribute of brain organization that Kinsbourne and Hicks (1978) have termed the "functional cerebral distance principle"—that performance on dual-tasks decreases to the extent that the cerebral programs which control the two tasks share the same functional space. Although this effect has been previously reported for face encoding and tapping (McFarland & Ashton, 1978b), it is unusual to find that performance on the cognitive task, rather than the manual task, is asymmetrically affected (Kinsbourne & Hiscock, 1983a). It is not unusual for lateralized interference to be observed in only one direction (i.e., from the nonmanual to the manual task). Why lateralized interference is usually observed in only one direction is as yet unknown. In this case perhaps repetitive finger tapping was automatized, rendering it much less susceptible to interference.

The present findings also suggest that during dual-task conditions a difficult activity will be disrupted by a concurrent task more than an easy activity, but that the degree of asymmetry of interference will not be significantly affected. The percentage of faces recognized after concurrent tapping, averaged across hands, at each level of difficulty were 93.3%, 86.5%, and 73.2%, indicating that interference of tapping on subsequent recognition increased with increasing difficulty of the memory encoding task. Although performance in the control condition also decreased with increasing task difficulty (percentage of faces identified correctly were 98.3%, 92.0%, and 87.1%, indicating that each task was progressively more difficult), the effects were not as great as those found in the concurrent tapping conditions. The fact that generalized interference increased with increasing task difficulty, but that degree of lateralized interference did not increase, suggests that a change in processing strategy and/or diffuse activation of the hemispheres may have occurred with the increase in task difficulty (McFarland & Ashton, 1978a).

Surprisingly, as difficulty of the encoding task increased, variability of tapping rate decreased. One explanation may be that as the cognitive task began to make more demands on mental abilities, the subjects became more attentive to both tasks. Assuming that an equal amount of attention was then given to both tasks, performance on the face-encoding task suffered because it was the more difficult of the two tasks, while tapping rate became less variable and more even with the added resources (in this case, attention). On the other hand, a decrease in variability could be indicative of an increase in control of tapping by automatic motor programming. Often simple motor tasks are considered automatized, meaning that they are tasks which are well practiced, requiring less cortical territory and attention for execution (Kinsbourne & Hiscock, 1983a). At the first level of face-encoding, it may have been relatively easy to attend to both the manual and the nonmanual task. As the face encoding task began to make more demands on available resources, rendering dual-task performance more difficult, tapping may have been gradually "switched" over to automatic programming. In addition, the subjects were probably more concerned with tapping speed than variability, as they were instructed to tap as rapidly as possible rather than as evenly as possible. Initial attempts to tap very rapidly may have resulted in the tensing of forearm and hand muscles, causing uneven spurts of tapping. With increasing difficulty of the cognitive task, tapping might have become automatized and consequently tapping rate became more even.

Some support for the hypothesis that automaticity of manual tasks facilitates a steady control of movement can be found in the attention and performance literature. Kahneman and Treisman (1984) suggest that there are three different levels of automatic processing for perceptual information. One of these levels, partial automatic processing, is described as being "normally completed even when attention is diverted from the stimuli, but can be speeded or facilitated by attention" (p. 42). It may be that automaticity of efferent motor programming can be viewed in much the same way except that motor automaticity may actually facilitate a more even, in addition to a decreased, rate of tapping. With less attention given to the motor task, tapping performance may become more relaxed and easily regulated.

Contrary to what was expected, and what has been consistently reported in the literature (Kinsbourne & Hiscock, 1983a), verbal production did not disrupt right-hand tapping rate and variability more than left-hand tapping rate and variability. This may be due to the fact that both tasks were relatively easy to perform concurrently, resulting in minimal overall interference effects. Past research has shown that the asymmetry of interference increases as the phonetic difficulty of the verbal material increases (e.g., a tongue twister instead of recitation of a nursery rhyme) (Hicks, 1975), or the difficulty of the manual task increases (e.g., a sequenced pattern of key tapping rather than repetitive tapping of one key) (Hicks, *et al.*, 1978).

In sum, these findings support the hypothesis that encoding of simple schematic faces is mediated by the right hemisphere but that increasing the memory load of the task, within the limits of short-term store, does not increase asymmetry of interference. Studies using other behavioral methods for assessing laterality, such as dichotic listening, show that increasing the memory load of a right-hemisphere-mediated task does result in an increase in lateralized performance. This fact suggests differences in cerebral functioning related to the nature of the task and/or to the hemispheric processing demands made by differing behavioral measures (e.g., competition between stimuli of the same input modality vs competition between an output process and an input cognitive process). Further investigation of the effect that task difficulty of both manual and nonmanual tasks has on dual task performance would be beneficial in not only answering questions about brain organization as a determinant of interference effects (i.e., functional organization of processing centers) but also in helping to clarify the role that automatic programming plays in dual-task performance.

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