THE EFFECTS OF CONCURRENT VOCALIZATION ON FOOT AND HAND MOTOR PERFORMANCE: A TEST OF THE FUNCTIONAL DISTANCE HYPOTHESIS

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INTRODUCTION

The interference or dual-task paradigm (Kinsbourne and Hicks, 1978a), has become a frequently used method to study behavioral asymmetries associated with speech lateralization in normal individuals. The most common example of Kinsbourne's dual task method is to ask a subject to vocalize some material while simultaneously performing a motor task with either the left or right hand. The rationale of this paradigm as described by Kinsbourne is that if the two concurrent tasks are controlled by the same hemisphere they are closer in functional distance compared to tasks processed in different hemispheres. As a result of this competition for cortical processing and control, a decrement will be observed in one of the two tasks. The literature describing motor asymmetries in dual-task performance has recently been reviewed by Kinsbourne and Hiscock (1983). They conclude that generally, with some exceptions, verbal activity interferes more with right-than left-hand performance in normal, right-handed individuals.While the dual-task technique appears to be a useful behavioral method of obtaining information about cerebral lateralization of function, several problems and limitations of this procedure have been noted (Kinsbourne and Hicks, 1978a). These include a number of independent variable parameters that may confound the outcome of dual-task studies, resulting in either the failure to observe expected motor asymmetries or in complex, confusing findings (Johnson and Kozmo, 1977; Lomas, 1980; Summers and Sharp, 1979).

Kinsbourne has proposed a functional distance principle of cerebral organization to account for the interference effects of concurrent activities (Kinsbourne, 1978, 1981; Kinsbourne and Hicks, 1978a, 1978b). This hypothesis states that the functional distance between cerebral regions decreases as the interaction between them, in the performance of concurrent tasks, increases. Decreasing functional distance produces compe-

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tition for cerebral processing space, and inherent limitations of cerebral processing capacity subsequently result in a disruption of performance in one of the two tasks. Kinsbourne and his colleagues have suggested that functional distance is least between cerebral centers that control homologous limbs, intermediate for centers controlling ipsilateral limbs, and greatest for those centers controlling diagonally paired limbs (Kinsbourne and Hicks, 1978a). Despite criticisms of the functional distance hypothesis and its underlying assumptions (Bryden, 1982, Springer and Deutsch, 1985), the majority of studies support Kinsbourne's interpretation of interference effects. The major exception in these supporting data is the general, but theoretically inconsistent, finding of mutual asymmetry of interference between motor and verbal tasks (Kinsbourne and Hiscock, 1983).

We designed the two experiments reported here as a special test of the functional distance hypothesis. The notion of competition for functional space between intrahemispheric control centers suggests that the degree of "crosstalk" or "overflow" between those centers producing the interference effects must also be partly due to the distribution of motor centers in the cortex, and the degree of both functional and structural overlapping with the speech areas.

In the cortex of the precentral gyrus, the parts of the body are arranged topographically, approximating a caricature or homonculus. In the left hemisphere, the motor center for the larynx is close to the Sylvian fissure and probably extends into Broca's area. Proceeding upwards, we find the motor control projections for the face, a larger area for the fingers and hand, and smaller projections for the elbow, shoulder, trunk, and hip. The control centers for the foot are on the medial side where the motor area stops halfway between the dorsal margin and the corpus callosum. Note that in the left hemisphere, the control centers for the hand are much closer (functionally and anatomically) to both Broca's and Wernicke's areas than are the centers for the foot.

On the basis of this topographic arrangement of motor control centers, it seems reasonable to hypothesize that during concurrent vocalization, the left cerebral control centers for the right hand should compete relatively more for functional space or "units" than the centers for the right foot, since the latter projections are considerably more distant from the speech areas. Therefore, the control centers should more effectively time share on discordant tasks (Kinsbourne and Hicks, 1978a) and show less interference or disruption in a task such as foot tapping during concurrent vocalization compared to hand or finger-tapping. The presumed differences in within- and between-hemispheric functional distance lead us to expect not only asymmetrical motor performance in contralateral limbs during concurrent vocalization, but also differential disruption or inter-

ference in hand versus foot tapping. That is, both right hand- and foot-tapping should show interference effects in dual task performance, but foot tapping should show less interference effects than hand tapping since it is functionally more distant from the speech areas.

We know of no other studies in the literature that have investigated the comparative asymmetry of the hand and foot tapping in the dual task paradigm. The only studies in foot performance that have been reported deal with footedness and the laterality of dominance (i.e., Borod, Caron and Koff, 1981;Peters and Durding, 1979).

MATERIALS AND METHOD

Experiment 1

Subjects

In Experiment 1, the sample consisted of 30 college undergraduates, 11 males and 19 females, ranging in age from 18 to 35. All subjects were right-handed as assessed by the Edinburgh Inventory (Oldfield, 1971).

Apparatus

The apparatus for finger tapping was a telegraph key mounted on a wooden base with a contact area of 2.7 centimeters in diameter. A Sony foot switch (Model FS-6) with a contact area of 10 centimeters was used for foot tapping. Number of taps was recorded on a BSR Foeringer counter panel (Model CP-901) which was activated by a Tenor timer (Model TI-902). The timer was set for 15 seconds for all trials. Sentry Mark IV headphones were worn by each subject to prevent auditory feedback from the apparatus.

Procedure

Subjects were instructed to tap on the telegraph key using the index finger while keeping the wrist and forearm in contact with the table. After a brief practice session, 15-second baseline measures of right- and left-hand finger tapping were established by asking subjects to tap as quickly as possible until instructed to stop. Similar baseline measures for right- and left-foot tapping were obtained by asking subjects to tap as quickly as possible on the foot switch while keeping the heel on the floor and the knee at approximately a 90 degree angle. Baseline vocalization rates were obtained by asking each subject to repeat the appropriate phrase as rapidly as possible until instructed to stop. Each subject was then instructed to repeat each of the four baseline tapping trials while simultaneously repeating the phrase "To be or not to be, that is the question" as rapidly as possible. All vocalizations for each subject were recorded on tape for later analysis of word frequency to determine trade-off effects.

Experiment 2

In Experiment 2, an additional 36 undergraduate students, 15 males and 21 females, were used in experimental procedures identical to Experiment 1, except that the vocalization task was to utter the words "cat, dog, horse" as rapidly as possible. The vocalization task was changed because it seems to be a more difficult verbal task, and is often used in dual task studies. We considered that increasing vocalization difficulty might produce clearer interference effects.

RESULTS

Experiment 1

A mixed-model repeated measures analysis of variance was used to analyse the tapping-rate data, with sex as the between-subjects variable and condition (baseline vs. dual task), part (hand vs. foot), and side (right vs. left) as the within-subjects variables. Mean performance under these conditions is presented in Table I. There was a significant main effect for sex ($F = 4.86$; d.f. $= 1, 28$; $p < .004$), with males tapping at a higher rate than females across all conditions. The results also revealed a main effect for side ($F = 60.20$; d.f. $= 1, 28$; $p < .001$), with subjects tapping more rapidly with the right hand and foot. There were no significant interactions.

A separate mixed-model ANOVA was used to determine if vocalization trade-off effects accounted for the absence of interference effects.

TABLE I

Mean Tapping Rates in Baseline and Dual Task Conditions (Experiment 1)

	Baseline Condition	
	Side	
	Left	Right
Hand Mean	68.97	76.94
S.D.	13.71	12.91
Part		
Foot Mean	46.10	54.23
S.D.	10.40	15.02
	Dual-task Condition	
	Side	
	Left	Right
Hand Mean	66.66	74.82
S.D.	13.69	16.03
Part		
Foot Mean	48.10	57.31
S.D.	12.70	13.78

The results of this analysis showed a main effect for condition ($F = 8.31$; d.f. $= 1, 28$; $p < .02$), indicating that the number of vocalizations increased across all dual task conditions (mean word counts for baseline and dual task = 89.17 and 91.66, respectively). That is, the vocalization trade-off effect was bilateral, with all hand and foot tapping remaining the same.

Experiment 2

A mixed-model repeated measures ANOVA was used to analyze the tapping data with sex as the between-subjects variable and condition, part, and side as the within-subjects variables. Mean tapping performance is presented in Table II. Results indicated a main effect for sex ($F = 4.71$; d.f. $= 34$; $p < .03$), with males tapping faster than females. There was also a significant main effect for condition ($F = 7.56$; d.f. $= 1, 34$; $p < .009$), showing that baseline tapping rates were faster than those in the dual-task condition. A significant main effect for side was also found ($F = 64.43$; d.f. $= 1, 34$; $p < .001$), with right-side tapping rates faster than left side. No significant interactions were found.

Analysis for trade-off effects was again conducted using the same analysis as in Experiment 1. The results indicated a significant main effect for part ($F = 11.81$; d.f. $= 1, 34$; $p < .01$). Vocalization rates were higher during finger tapping across all conditions. There was also a significant

TABLE II

Mean Tapping Rates in Baseline and Dual Task Condition (Experiment 2)

	Baseline Condition	
	Side	
	Left	Right
Hand Mean	70.14	79.44
S.D.	9.53	12.76
Part		
Foot Mean	47.58	54.78
S.D.	12.05	12.73
	Dual-task Condition	
	Side	
	Left	Right
Hand Mean	66.61	73.22
S.D.	9.05	11.92
Part		
Foot Mean	46.64	55.19
S.D.	13.40	12.20

part by condition interaction ($F = 85.58$; d.f. $= 1, 34$; $p < .001$). Post-hoc analysis revealed a significant increase in vocalization from baseline to dual-task when finger tapping with either hand. No such differences were observed for foot tapping (mean baseline vocalizations = 52.86, dual-task with hand = 54.83, dual-task with foot = 52.65).

DISCUSSION

In the context of the functional distance hypothesis, we had predicted that the dual-task paradigm would produce asymmetrical and differential laterality effects. Specifically,that concurrent vocalization would produce the greatest motoric interference effects on right-hand tapping, followed by ordered, decreasing interference effects on the left hand, right foot, and left foot. It was expected that right-side tapping, with its control centers closer to the speech centers, would show greater disruption in the dual-task condition than left-side tapping.

We found no evidence to support our hypothesis. In Experiment 1, no motor interference effects were observed under the verbalization condition of "To be or not to be...". Neither hand nor foot tapping declined in the dual task. Although there was a slight decrement in both right-hand and left-hand tapping during vocalization, the decline was not significantly different from baseline rates. Foot tapping increased in the dual task, but not significantly. Significant vocalization trade-off effects were found across all dual-task conditions, suggesting that mean vocalization rates increased under both hand and foot tapping. The observed attention shift from motor to cognitive task was not great enough to produce a decrement in motor performance, however. There was no evidence of differential interference effects between hand and foot tapping. Foot tapping did not change significantly despite increases in vocalization rate in the dual-task condition.

In Experiment 2, verbalization of "cat, dog, horse" produced bilateral declines in hand tapping. Under this somewhat more difficult task, the interference effects were symmetrical, but vocalization trade-off was found to account for these interference effects. There was no evidence of disruption of foot tapping during vocalization, and no trade-off effects were found in this condition. Increases in vocalization occurred only under the finger-tapping condition. We again found no evidence of differential interference effects between hand and foot tapping in Experiment 2.

If one examines the studies reporting laterality effects in the dual-task paradigm over the past 10 years, only a very few are found to include an

analysis for trade-off effects (i.e., Bowers, Heilman, Satz and Altman, 1978).

The majority do not consider trade-off effects as an explanation of observed interference effects (i.e., Johnson and Kozmo, 1977; Lomas and Kimura, 1976; Thorton and Peters, 1982; Wolff and Cohen, 1980). Without such analysis, it is impossible to establish interference asymmetries in the dual-task paradigm. It is quite possible that systematic shifts in attention between right- and left-manual tasks and the non-motor or cognitive tasks account for reported interference effects, and subsequent support of the functional distance hypothesis. In the absence of statistical control for asymmetric trade-off between tasks, dual-task experiments cannot be unambiguously interpreted as support for lateralization phenomena and the principle of functional distance.

ABSTRACT

The effects of concurrent vocalization on hand and foot motor performance were examined in two dual-task experiments as a test of the functional distance hypothesis. No interference effects were found with either hand or foot tapping under two difficulty levels of verbal activity. There was no evidence of differential or asymmetrical interference patterns despite the differential functional and anatomical distances of these motor centers from the sppech centers. Consequently, the data provided no support for the functional distance hypothesis.

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