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THE EFFECTS OF VOLUNTARY LATERAL ORIENTING
ON POSITIVE MANIFOLD FOR LATERALIZED
COGNITIVE TASKS

DISSERTATION

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As an extension of previous studies (Urbanczyk, Angel, & Kennelly, 1988) examining the effects of unimanual finger tapping on lateralized cognitive tasks, lateral body orienting was added to an established dual task paradigm to generate differential hemispheric activation and shifts of attention. One hundred twenty university students retained sequences of digits or spatial locations for 20 seconds either alone or during finger tapping. By turning both head and eyes left or right, the hemisphere congruent with the sequences (LH for digits, RH for locations) or incongruent (vice versa) was activated. Activation had little effect on retention means but greatly affected resource composition supporting task performance. Congruent orientation produced significantly higher positive correlations between digit and location tasks than incongruent orientation. Females showed higher sequence retention correlations than males across both orienting groups. For females, congruent activation enhanced tapping rates and retention-tapping correlations. For males, activation affected neither of these. Discussed in light

of neuroanatomical research, these results suggest that congruent attentional orienting may integrate regions of the less activated hemisphere into networks of the more activated hemisphere. This unification may occur more readily across the female corpus callosum, producing a greater dependence upon a general attentional resource than for males, who appear to depend more upon hemispheric resources.

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CHAPTER I

INTRODUCTION

In 1904, Charles Spearman conducted his first factor analytic studies from which he derived the concept of a general ability or "g" factor to describe the tendency for most cognitive tasks to be positively correlated. This "g" factor has become a robust fact in the study of human abilities (Humphreys, 1982) and is technically referred to as positive manifold. Since Spearman's time, it has commonly been used as a working definition of intelligence.

While there has been little controversy over the existence of a general ability factor at the level of correlational analysis, there is still no really satisfactorily accepted theory of its specific nature. Just what it is has been the subject of over eight decades of research and controversy. Spearman himself noted, "The trouble is not so much in proving the existence of the general factor as in revealing its precise nature (1912, p. 65). In 1927 however, he speculated that "g" might reflect attentional capacity based on the recognition that attention seems to be required for performance of all cognitive tasks. The intuitive appeal of this notion has carried it through some 60 years to the present time where

it remains a working hypothesis in more recent research into the nature of human cognitive abilities.

In 1980, Hunt reiterated Spearman's hypothesis that "g" might be equated with attention and accordingly suggested that positive manifold could be best examined under attention demanding situations. He specifically proposed the use of the split attention, or dual task experimental paradigm to test the theory. The dual task is a specific experimental competition procedure that requires subjects to perform two tasks at the same time and thus is known to be attention demanding. A number of researchers have taken Hunt's suggestion, making inferences about attentional processing abilities by comparing task performances and task intercorrelations under dual task and single task situations.

Stankov (1983a) for example, used auditory tasks in a dual task paradigm to measure attentional capacity. He discovered a consistent, substantial increase in positive manifold among task performances from the single to dual task condition. Again, the increase was thought to reflect a greater involvement of a general attentional resource, or "g" since performance in a dual task situation demands more attentional ability than performance in a single task situation. Fogarty and Stankov (1982) replicated the finding with multiple dual task pairs and suggested that

the dual task methodology may represent a more direct route to the measurement of "g" than single task methods.

Stankov's (1983a) conclusion that a link exists between attention and intelligence has intuitive appeal in that the ability to deal with increasing amounts of information seems basic to efficient cognitive functioning.

Urbanczyk, Angel, and Kennelly (1988) explored the degree to which hemispheric lateralization entered into obtaining data consistent with this hypothesis. It is well known that the left and right hemispheres are semi-independent in the control of certain mental and physical processes. The left hemisphere exercises control over verbal-auditory processing and right body movements (DeRenzi & Nichelli, 1975; Zangwill, 1960) while the right hemisphere controls visual-spatial processing and left body movements (DeRenzi, Faglioni, & Previdi, 1977; Kennelly & Wilcox, 1985; Milner, 1971).

By combining lateralized retention tasks (digit or visual-spatial memory spans) with a lateralized unimanual (left or right) finger tapping task, Urbanczyk et al. (1988) created two different dual task conditions. A same-hemisphere condition was created by combining two similarly lateralized tasks (a digit span and right finger tapping or a visual-spatial task and left finger tapping). A different-hemispheres condition was created when the two

tasks were lateralized to opposite hemispheres (a digit span and left finger tapping or a visual-spatial span and right finger tapping). The retention tasks were also performed alone with no tapping in a single task condition and in both forward and backward directions under all conditions.

Intercorrelations of retention task performances under the single and two dual task conditions were calculated and confirmed Stankov's hypothesis that positive manifold would increase under dual task conditions. Moreover, it was shown that the degree of positive manifold observed depended on the lateralized nature of the tasks. The highest intercorrelations were found among tasks in the same-hemisphere dual task condition. Positive manifold was somewhat lower when tasks were lateralized to different hemispheres and lower still under the single task condition. It was concluded that hemisphere-specific processing effects the finding of positive manifold such that the best measure of "g" appears to be a dual task situation in which the tasks are both lateralized to the same hemisphere.

Mean retention task performances under each of the three conditions were also calculated. As expected, recall of memory spans carried out alone in the single task condition was better than performance under dual task

conditions. However, task lateralization produced surprising variations in mean retention performances under the dual task conditions. Sequence retention was better in the same-hemisphere condition than in the different-hemispheres condition. In other words, recall improved when tasks were both lateralized to one hemisphere.

Kinsbourne's (1973) model of attention has been useful in explaining these mean findings and has also helped to elaborate the hypothesized relationship between attention and positive manifold. This model proposes that an individual is invested with a finite amount of attention that can be directed toward a single brain hemisphere or divided between hemispheres in accordance with the balance of neural activity between the two brain halves (Kinsbourne, 1975, p. 92). The orientation of attention is posited to be directed by attention control centers located in both left and right hemispheres. These are thought to be symmetrical and in a mutually inhibitory relationship. At any particular time, the direction of attention across sensory space is determined by the distribution of activation across these orienting centers and across the hemispheres in general. When the two hemispheres are equally activated, attention is centered in physical space. When a relative increase of activation is induced on one side of the brain via lateralized psychomotor and/or

cognitive activity, the gradient of attention swings toward the more activated hemisphere and the contralateral side of space (Kinsbourne, 1973). Further, when a relative increase of activation is induced on one side of the brain the cognitive processes which are localized within that hemisphere gain predominance and those of the opposite hemisphere are inhibited.

Kinsbourne's model can be applied to the dual task situation in the following way. Each individual task in the dual task paradigm would be a direct source of hemispheric activation and each would therefore affect the balance of attentional orientation. Since the lateralized nature of the tasks would dictate the ratio of left to right hemispheric activation, the lateralization of tasks would be an especially critical factor in determining the orientation of attention. Working from the premise that positive manifold reflects attention, lateralization of tasks would then also affect the finding of intercorrelations among the tasks. If a specific dual task interaction results in a consistent orientation of attention toward the same hemisphere, an increase in positive manifold would be expected relative to a dual task situation in which attention is split between different hemispheres. In the Urbanczyk et al. (1988) study then, it appears that hemisphere-specific processing, mediated by a

consistent orientation of attention, affected the finding of positive manifold. More specifically, it was concluded that the best evidence for "g" is obtained in a dual task situation in which both tasks activate the same hemisphere (Urbanczyk et al., 1988).

Kinsbourne and Hicks's (1978) Functional Cerebral Distance model also contributes to an explanation of this type of dual task interaction. This theory is derived from known characteristics of localization of function in the brain and states that "corresponding to, and underlying every pattern of behavior is a specific pattern of neuronal activity that is carried out in a certain locus of cerebral space" (Kinsbourne, 1981, p. 80). Since the brain is a highly linked neuronal network, the programming of a particular activity involves not only that one specific controlling area (locus), but also, by spread of activation, a larger proportion of functional cerebral space. In other words, neural activity in one control center overflows to other control mechanisms. According to this theory, this spread of influence is proportional to the interconnectedness of the area in question. Connectivity is more direct or extensive between some loci, those "close" in functional distance, than between others that are far apart in functional cerebral distance.

Applied to the dual task situation, the functional cerebral distance principle suggests that the extent to which a person can do two things at once depends, in part, on the distance between the involved cortical control centers. The more functionally close or neuronally interconnected two tasks are, the greater the degree of overlap between their processing mechanisms and the greater the spread of activation to surrounding brain areas. One determinant of cerebral distance is the hemispheric lateralization of the individual tasks. Two tasks lateralized to the same hemisphere would produce a greater spread of activation to certain homolateral control centers than to the contralateral control centers.

This activational overflow can be facilitating or interfering. For example, Kinsbourne and Hicks (1978) showed that a verbal memory task could increase activation of the left hemisphere producing a right visual field advantage on a perceptual task that followed. Hellige and Cox (1976), using a verbal memory load of varying difficulty, found limits to such facilitative effects of concurrent task however. When they increased a word load in size and difficulty beyond a certain point (six but not four words) facilitation of the concurrent shape recognition task was replaced by interference with this task. An inverted U-function characterized these findings; the ascending limb is

generated by initial activation and the descending limb by further activation that becomes interfering.

Kinsbourne and Byrd (1985) replicated these results. A light verbal memory load produced a left hemisphere/right visual field advantage and a heavier load produced interference for both the left hemisphere/right visual field and the right hemisphere/left visual field. It was suggested that the heavier word load necessitated greater rehearsal which in effect created a more attention demanding dual task situation.

Kinsbourne (1973) calls this interfering spread of activation "cross talk." Hiscock, Kinsbourne, Samuels, and Krause (1987) describe it as "neural noise" between two overlapping neural circuits. It is believed that cross talk can be precluded by establishing neural inhibitory barriers that isolate the involved cortical processing centers from each other (Kinsbourne, 1981). Segregation of tasks in this way allows for more efficient performance (LaTorre & LaTorre, 1981). The ability to establish effective inhibitory barriers is hypothesized to be an individual difference, more intelligent people being characterized by greater speed at establishing barriers to preclude cross talk.

The results of Experiment 1 in the Urbanczyk et al. (1988) study demonstrate how the specific lateralized

nature of a finger tapping task influenced the spread of activation predicted by Kinsbourne's (1978) Functional Cerebral Distance model. This study also highlighted the consequences of this spread of activation on the orientation of attention and on cognitive task performance. Relatedly, Kinsbourne and Hicks (1978) have posited that the control centers for right finger tapping and the rightward orienting of attention form a functionally close cluster within the left hemisphere in most right handers. Thus, in the same-hemisphere condition of the Urbanczyk et al. (1988) study, neural activity generated in the left hemisphere's motor area by right finger tapping can be assumed to have spread to the left hemisphere's attentional orienting mechanism. This in turn would direct attention to the left hemisphere thereby facilitating its specialized processing abilities. Since the left hemisphere is specialized for verbal-auditory processing, higher means and increased intercorrelations on the digit retention tasks were found.

By the same reasoning, in the different-hemispheres condition where the two tasks were lateralized to opposite hemispheres and were therefore more functionally distant, less spread of activation would likely have taken place. Rather, right finger tapping activated the left hemisphere's motor area concentrating attention in that

hemisphere and directing it away from the right hemisphere which was retaining the visual-spatial sequence. Consequently, lesser asymmetrical activation occurred and attention was less definitively directed to any one hemisphere. As a result, lower intertask correlations were found in the different-hemispheres condition than in the same-hemisphere condition. Splitting attention between hemispheres in this way (finger tapping to the left and visual-spatial memory span to the right) also resulted in inhibited visual-spatial performance as evidenced in lower mean performances in the different-hemispheres condition than in the same-hemisphere condition. Despite this division of activation, attentional demand in the different-hemispheres condition was still greater than that in the single task condition, so the overall pattern of intercorrelations was: same-hemisphere > different-hemispheres > single task.

In sum then, the results of Experiment 1 of the Urbanczyk et al. (1988) study confirm Stankov's notion regarding an increase in positive manifold in the dual task and extend it to suggest that this finding depends on the hemispheric lateralization of the tasks involved. Kinsbourne's (1973) attentional activation hypothesis suggests that the mechanisms underlying this effect are hemispheric activation and the orientation of attention

since variations in the dual task which affect these processes, such as lateralization of task, affected the pattern of intercorrelations between retention task performances across conditions.

Kinsbourne (1973) suggests that submotor shifts in attention reflected in cognitive performance asymmetries like those described in Urbanczyk et al.'s (1988) Experiment 1, represent only one end of a continuum of attentional orientation effects. More overt lateral orienting behaviors such as spontaneous lateral eye movements and head and body turning are thought to reflect shifts in the gradient of attention as well. Kinsbourne (1973) suggests that these occur not necessarily in order to look at external stimuli in a particular direction, but rather as reflexive, secondary products of unilateral hemispheric activation.

Posner and his associates (Posner, 1980, 1982; Posner, Nissen, & Ogden, 1978) have closely analyzed the process of attentional orienting. Their research explores three general areas, the first of which is an investigation of covert attention. By measuring changes in reaction time, evoked potentials, threshold detection, and firing rates of single cells in the absence of head and eye movements, they have shown that purely covert changes in orienting are possible (Posner et al., 1978). Directing attention covertly or independently of any ocular orienting response

has been shown to reduce the threshold for processing events and to improve the efficiency of detecting stimuli that occur in the attended visual field (Posner, 1980).

Eye and head movements are obviously closely related to shifts in attention though and Posner's second area of investigation centered on the functional relationship between covert attention and lateral eye movements. Lateral eye movements commonly serve as indices of relative cerebral activation because the direction of their movement corresponds to the differences in functional specialization between the hemispheres (Kinsbourne, 1972; Schwartz, Davidson & Maer, 1975). Rightward gazes predictably reflect left hemisphere activation and processing and leftward gazes similarly indicate right hemisphere activation and processing.

For example, Kinsbourne (1972) demonstrated a relationship between the mode of cognitive processing and orienting behavior by asking right-handed subjects three sets of questions--verbal, spatial, and numerical in nature. The direction of subjects' head and eye movements (right, left, up or down) was recorded as they responded to the questions. The attentional model predicted that the direction of orienting would be related to question type. For example, when a subject was confronted with verbal questions the left hemisphere would be activated and the

subject would spontaneously and visibly orient to the right. Similarly, questions requiring visualization of spatial relationships were hypothesized to stimulate the right hemisphere causing a leftward shift of head and eyes. No predictions were made regarding numerical processing. Results of the study confirmed the hypothesized link between the lateralized nature of concurrent mental activity and the direction of visual orientation. Eye movements were generally to the right in response to verbal questions and to the left for spatial questions. No consistent shifts were found in response to numerical questions.

Investigations of similar hypotheses have yielded findings consistent with the proposal that lateral eye movements indicate asymmetrical activation and hence can be manipulated by tasks that call for hemispherically lateralized cognitive processing (Galin & Ornstein, 1974; Griffiths & Woodman, 1985; Gur, Gur, & Harris, 1975; Kocel, Galin, Ornstein, & Merrin, 1972; Tucker & Suib, 1978; Weiten & Etaugh, 1975).

The relationship between task demands and orienting behavior is by no means perfect however, and a number of studies have failed to find significant associations. Erlichman, Weiner, and Baker's (1974) study of the effects of verbal and spatial questions on initial gaze shifts

showed that vertical gaze shifts were the ones affected, verbal questions eliciting more downward movements. The horizontal movements recorded were at odds with those reported by Kinsbourne. Berg and Harris (1980) and Saring and von Cramon (1980) noted that lateral eye movements seem very sensitive to known and unknown task, subject, and environmental variables that cast doubt on the reliability of using them as measures of hemispheric activation. In a recent review of such experiments, Hiscock (1986) acknowledged a variety of these active, uncontrolled systematic biases and yet concluded that the interaction between direction of eye gaze and the lateralized nature of the concurrent task has been "sufficiently confirmed to be credible" (p. 271).

In a related vein, Gopher (1973) found that not only the lateralized nature, but the specific difficulty or attentional demand of dual tasks influenced the resultant pattern of eye movements. His subjects consistently made large gaze deviations in the direction of relevant input in an auditory dual task situation, but these eye movements disappeared when messages were presented singly in situations of no competition. He concluded that lateral gaze shifts are part of a general orienting system which serves to emphasize the selected direction of attention. This is thought to improve the efficiency of processing in

a general way rather than exclusively as visual orientation to the source of important input. Gopher suggests that a complementary part of this same general orienting system appears to be an inhibitory mechanism that dampens interference from unimportant physiological activity or stimuli during periods of focused attention. In support, he points to a significant decline in subjects' spontaneous eye motility following the initial large gaze shift. Subjects consistently maintained their initial shift over time. Moreover, some of these subjects reported that listening became more difficult when they attempted to resist the natural lateral eye movement tendency and orient in an incompatible direction.

Fisher and Breitmeyer (1987) offer similar evidence. They found a saccadic reflex to be largely inhibited with directed or "engaged" visual attention, and that "disengaging" focused attention permitted the saccade. They concluded that lateral eye movements are a natural spontaneous response that allows the organism to concentrate attention and that their suppression must be an active inhibition of this process.

Given the significant and replicable links made between lateral eye movements and shifts of attention, Urbanczyk et al. (1988) examined subjects' spontaneous eye movements in a second study utilizing lateralized dual

task procedures similar to those described in Experiment 1. It was hypothesized that if lateral eye movements emphasize shifts in the gradient of attention, their direction should be predictably related to the variations in attentional activation created by lateralized finger tapping in Experiment 1.

Shifts of eye gaze were found to accompany hemispheric activation in a predictable fashion. In the single task condition, rightward lateral eye movements accompanied digit retention tasks while more central gazing was related to visual-spatial retention tasks. This latter central "stare" reaction is a frequent finding in the eye movement literature (Berg & Harris, 1980; Galin & Ornstein, 1974; Kinsbourne, 1972; Lempert & Kinsbourne, 1982; Walker, Wade, & Waldman, 1982). It is hypothesized to result from a more diffuse distribution of activation across the hemispheres (MacDonald & Hiscock, 1985).

In the dual task conditions of Experiment 2, lateral eye movement direction closely and strongly followed finger tapping on a trial by trial basis regardless of the nature (digit or visual-spatial) or direction (forward or backward) of the retention task. Left finger tapping produced significantly more leftward looking and less rightward looking; right finger tapping produced more rightward looking and less leftward looking. These results

are not surprising in light of Mather and Fisk's (1985) claim that the muscle effectors for ocular and manual movements are highly integrated. More importantly, though, the strong link between finger tapping and spontaneous homolateral eye movements in this experiment confirms the powerful effect of psychomotor activity in shifting the orientation of attention.

Unfortunately, ceiling effects in several conditions of Experiment 2 curtailed a valid analysis of retention task intercorrelations. Mean memory performances were calculated however, and were again lowest in the different-hemispheres condition. As in Experiment 1, this was interpreted as being the result of the finger tapping task activating one hemisphere and simultaneously directing attention away from the hemisphere involved in memory retention. Results from both Experiments 1 and 2 show that the withdrawal of attentional support in this way clearly inhibits performance.

The significant drop-off in mean retention performance from the single task condition to the same-hemisphere dual task condition found in Experiment 1 was not evidenced in Experiment 2. Instead, there was no significant difference between these conditions. This may have been the result of a procedural modification made in the tapping task in the second experiment. The tapping hand was screened from the

subject's view. Thus, visually guided tapping was not possible in Experiment 2 as it had been in Experiment 1. Lempert and Kinsbourne (1985) found a greater decrement in performance under visually guided tapping than under nonvisually guided conditions.

The Functional Cerebral Distance model (Kinsbourne & Hicks, 1978) suggests that without visual guidance tapping is more automatic and less demanding of attention. Kinsbourne (1981) notes that in contrast to more difficult tasks which involve more cortical mass and therefore more spread of activation, "very simple biologically preprogrammed or highly automatized actions generate minimal spread" (p. 80). Thus, tapping without visual guidance is thought to consume less functional cerebral space and to generate less spread of activation. Therefore, the retention and tapping tasks are carried out with less cross talk interference.

The experimental situation in this study in which such reduced cross talk would have the greatest impact would be the same-hemisphere dual task condition, because in this condition tasks must share the limited functional cerebral space of a single hemisphere. Apparently, minimizing cross talk in this way removed the primary interference in this condition. Consequently, performances under the same-hemisphere dual task condition more closely approximated performances under the single task condition.

In sum, the Urbanczyk et al. (1988) studies demonstrate a link among activating psychomotor movements, the orientation of attention, and shifts in lateral eye movements even when visual guidance of the hand movements were impossible. Further, memory retention was influenced by the shift of attention. When tapping directed attention toward the hemisphere specialized for performing the retention task (same-hemisphere condition) it facilitated memory retention and increased the positive manifold among tasks. When tapping directed attention away from the appropriately specialized hemisphere (different-hemispheres condition), it inhibited memory retention and decreased the intercorrelations among tasks.

In a recent review, Hiscock (1986) notes that a recurrent problem in lateral eye movement studies has been that experimental procedures frequently restrict the subject's range of physical orienting. For example, Saring and von Cramon (1980), Bowers and Heilman (1980), Casey (1981), LaTorre and LaTorre (1981) anchored subjects' heads in chin rests which allowed for gaze deviations, but not head deviations. It is believed that eye movements are only one component of a natural series of orienting behaviors, head and eye movements comprising a specific orienting synergism (Penfield & Rasmussen, 1957). Experimentally restricting the natural range of overt

orienting with procedures that are physically immobilizing may limit the degree of eye movement, reduce the magnitude of hemispheric activation and be responsible for some of the negative findings in laterality research (MacDonald & Hiscock, 1985).

The procedures established in the Urbanczyk et al. (1988) experiments rectify this problem. The simple psychomotor task and natural gaze shifts employed are features of our natural orienting behaviors. We do drum fingers, tap pencils and feet, and gaze off in one direction while thinking. Thus, finger tapping and eye movements are an ecologically valid way of studying hemispheric activation and the orientation of attention.

While eye movements in Experiment 1 of the Urbanczyk et al. (1988) study were interpreted as spontaneous by-products of lateralized motor processing (finger tapping) and shifts in the orientation of attention, voluntarily directed lateral gazing itself has been shown to dictate the orientation of attention and affect concurrent task performance. Preconcerted lateral eye and head movements that are directionally congruent with respect to hemispherically lateralized concurrent cognitive activity have been shown to facilitate performance on the latter tasks.

For example, Kinsbourne (1975) examined the effects of deliberate preconcerted shifts in head and gaze direction on hemispheric activity by having subjects perform a verbal word association recall task with head and eyes turned 90 degrees right or left. Latency of response was recorded and compared across direction of orientation. The attentional model predicted a right side advantage since voluntarily orienting to the right would supposedly activate the left hemisphere which, in turn, would deploy attention to, and increase the efficiency of its specialized language processor. This prediction was confirmed by a finding of briefer response latencies to verbal questions.

By including right lateral eye movements, Gross, Franko, and Lewins (1978), Hines and Martindale (1974), and Walker, Wade, and Waldman (1982) all demonstrated better performance on a variety of verbal tasks. The same authors similarly found that voluntarily induced leftward fixation increased performance on a number of spatial tasks. Lempert and Kinsbourne (1982) directed subjects' eyes and head left or right prior to a noun recall task. Subjects were also instructed to use a verbal (rehearsal) or a nonverbal (imagery) mental set to remember sentences. Results showed better noun recall during right than left turning for subjects employing the verbal rehearsal mental

set. Compatibility between direction of orienting and activity in the contralateral hemisphere via induced mental set was believed to be responsible for an increase in activation and the resulting enhanced performance.

Such results have been explained by positing that orienting behaviors generate an imbalance in hemispheric activation that favors the "appropriate" hemisphere (Gur, Gur, & Harris, 1975). Similarly, performance inhibition can be generated by "incongruent" eye shifts that bias activation and attention in a misaligned direction with respect to the specialized processing hemisphere. Drake and Bingham (1985) noted that

despite the lack of specific knowledge regarding the necessary and sufficient conditions needed to produce biases in attention [with lateral orienting behaviors] and to predict the latency and duration of such effects, the relative ease with which activation can be manipulated and the potency of its effect make [voluntary orienting] a useful means of testing hypotheses about differential functioning of the hemispheres of intact, normal brains. (p. 161)

The present study makes use of the hemispherically activating properties of voluntary, overt lateral orienting to further investigate the relationship between attention and positive manifold. In this study, eye and head

movements as physical orienting actions were introduced into the simple, effective dual task procedure established in the previous Urbanczyk et al. (1988) experiments.

Right-handed subjects performed lateralized unimanual finger tapping and digit and visual-spatial retention tasks together, with head and eyes systematically oriented left or right. Since tapping, orienting and cognitive activity can be lateralized and are capable of producing hemispheric activation, the effect of hemispherically similar (all left or all right) and hemispherically dissimilar (split between left and right) combinations of these activating behaviors on task intercorrelations as well as mean task performances were examined.

More specifically, two groups were established, a congruent orienting and an incongruent orienting group. In the congruent group, head and gaze orientation always activated the hemisphere congruent with the memory sequence being retained. In this group, subjects turned their heads and directed their gaze to the right while retaining digit spans and to the left while retaining visual-spatial spans. In the incongruent orienting group, the reverse pairings always occurred such that lateral orientation activated the hemisphere incongruent with the sequence being retained. Here subjects turned their heads and directed their gaze to the right while retaining visual-spatial spans and to the

left while retaining digit spans. Consequently, both hemispheres were always activated, one by orienting and the other by performance of the memory task.

Finger tapping was included in the dual task trials to create same-hemisphere and different-hemispheres conditions with respect to the lateralized nature of the concurrent cognitive task. As a result, the following combinations were investigated: (a) one in which tapping and orienting were directionally similar to the retention task such that they all taxed the same hemisphere--a congruent orienting/same-hemisphere tapping condition; (b) one in which both tapping and orienting were directionally dissimilar to the retention task such that they tax a different hemisphere than the retention task--an incongruent orienting/different-hemispheres tapping condition; and (c and d) two mixed conditions in which one of these tasks was directionally similar to and one was directionally dissimilar to the retention task. For example, right hand tapping (a left hemisphere task) combined with leftward orienting and visual-spatial retention (right hemisphere tasks) comprised a congruent orienting/different-hemispheres condition. Leftward orienting (a right hemisphere task) combined with a digit retention and right hand tapping (both left hemisphere tasks) comprised an incongruent orienting/same-hemisphere tapping condition.

Given the interconnectivity between finger tapping and orienting lateral eye movements already demonstrated, we predicted the pattern of effects of the first two situations described above based on the findings of our previous research (Urbanczyk et al. 1988). These conditions are similar to the same-hemisphere (a) and different-hemispheres (b) dual task conditions examined previously. In both cases tapping and orienting are directionally similar to each other, directing attention toward the hemisphere retaining the span in the first situation, the congruent orienting/same-hemisphere tapping condition, or away from it in the second, the incongruent orienting/different-hemispheres tapping condition.

The two mixed conditions described above (c and d) involved situations of potential conflict between the direction of tapping and orienting. According to Kinsbourne's (1973) attentional model, if both tapping and orienting are activating, subjects would be unable to reliably and consistently attend to either hemisphere in such a conflict situation.

In the context of a reaction time task, Tassinari, Aglioti, Chelazzi, Marzi, and Berlucchi (1987) compared situations of conflict and compatibility between the ocular-motor control center that maintains fixation and the manual-motor control center responsible for executing hand

responses. It was concluded that if the general instructional set for these two responses contained directionally conflictual orders with regard to eye and hand direction, the conflict would be reflected in manual performance deterioration. On the other hand, optimal performance was predicted when the eyes and hands receive directionally congruent commands. Posner, Walker, Friedrich, and Rafal (1987) likewise, discussed the unstable conditions and conflicting results produced when one's eyes are directionally misaligned with other orienting actions. The general conclusion is that performance is inhibited in the presence of such conflict.

It was difficult to make specific predictions about the effect of this type of conflict on retention task performance in the proposed study. The exact individual contributions of tapping and orienting to hemispheric activation are unknown so the interactions between them and the retention tasks are also unknown. If head turn and gaze direction are both activating in this situation, one reasonable expectation is that performances in conflict situations will fall somewhere between the extremes produced under the congruent orienting/same-hemispheres tapping and incongruent orienting/different-hemisphere tapping dual task conditions. The hypotheses proposed are based on the untested assumption that there would be

positive effects of congruent orienting and same-hemisphere tapping and that these effects would be additive.

By analyzing retention task intercorrelations across conditions, the study also served as a further test of the hypothesis that positive manifold is greatest in dual task situations in which attention is concentrated in one hemisphere rather than when it is divided between the hemispheres. Recently, Stankov (personal communication, March 26, 1986) speculated that higher task intercorrelations under dual task conditions may be due to something other than attention. An alternate explanation that also meshes well with the Urbanczyk et al. (1988) findings is to assume that positive manifold represents the ability to establish effective inhibitory barriers to control cross talk. Since cross talk was likely present to a significant degree in the same-hemisphere condition, which led to the highest intertask correlations in the Urbanczyk et al. (1988) Experiment 1, this ability rather than the orientation of attention may be "g." It is possible then that this study may shed light on the nature of "g" as well.

Hypotheses

If attention is supporting the positive manifold found in the first Urbanczyk et al. (1988) experiment, the pattern of intercorrelations among the cognitive tasks was

expected to be as follows: retention tasks were expected to be most highly correlated in the congruent orienting/same-hemisphere tapping dual task condition, next best in the single task congruent orienting condition, and in the mixed conditions, less intercorrelated in the incongruent orienting/different-hemispheres tapping condition, and least correlated in the single task incongruent orienting condition.

If the ability to erect inhibitory barriers in order to dampen down cross talk is responsible for positive manifold rather than attention, then the procedure used in this study of tapping without visual guidance would be expected to produce a different pattern of results across the various conditions. Since tapping without visual guidance is thought to reduce cross talk and the need to erect inhibitory barriers, the condition which would be affected the most would be the congruent orienting/same-hemisphere dual task condition. In addition to a replication of the mean results of Experiment 2 of the Urbanczyk et al. (1988) study, the same-hemisphere dual task condition would not be expected to produce significantly greater intercorrelations than the single task condition, if the ability to erect inhibitory barriers underlies positive manifold.

Significantly different mean performances on the retention tasks in the various conditions were expected. The incongruent orienting/different-hemispheres tapping dual task condition in which tapping and orienting were both lateralized to the hemisphere opposite the one specialized for the cognitive task being carried out was expected to show the poorest mean performance. The congruent orienting/same-hemisphere condition and the single task congruent orienting conditions were expected to yield better retention task mean performance. Means in the two mixed conditions and in the single task/incongruent orienting condition was expected to fall in between.

CHAPTER II

METHOD

Subjects and Design

One hundred twenty right-handed undergraduates (60 females, 60 males) voluntarily served as subjects in exchange for extra course credit. A 2 X 2 X 3 factorial design with repeated measures was used. Sex of subject and orienting congruence were between group factors. Tapping condition was a within group repeated measures factor with three levels, single task, same-hemisphere dual task and different-hemispheres dual task.

Apparatus

A Durant finger tapping counter (model 4-X-2) was used for the key tapping task. A 35 X 50 cm (14" X 20") wooden board with nine 3.81 cm (1.5") unmarked wooden blocks fixed to it in an irregular pattern was used for the visual-spatial tasks (Corsi, cited in Milner, 1971).

Instruments

Forward and backward digit and visual-spatial location sequences were presented under both single and dual task conditions, serving as the secondary tasks under dual task conditions. The digit tasks are known to make demands primarily on the left hemisphere's resource because of

their verbal auditory nature while the visual-spatial spans reflect primarily right hemisphere functioning. For the former, a digit string was presented to the subject orally, one digit per second. For the forward digit trials, the subject was asked to repeat an eight digit string back as presented for the first two trials and then a nine digit string for the second two trials. For the backward digit task, repetition of a seven digit string in reverse order of presentation was required on the initial two trials and eight on the latter.

The visual-spatial task trials involved the examiner pointing to a string of blocks in a sequential manner, one block per second. For the forward visual-spatial trials, the subject was asked to repeat back the sequence by pointing to the seven blocks in the same sequence as the experimenter on the initial two trials and eight blocks on the second two trials. For the backward visual-spatial task, repetition of six blocks in the reverse order in which they were pointed to by the experimenter was required first and then seven blocks on the last two trials.

The length of the retention spans were of moderate difficulty initially and were increased by one on the last two trials to prevent the problem of incurring ceiling effects which eliminated a valid analysis of intercorrelation in Urbanczyk et al., (1988) Experiment 2.

Based on the number of digits or blocks in correct position, a partial or full credit score was assigned for each digit or block trial based on an interval scoring system designed by Paulman and Kennelly (1984) (see Appendix A).

The retention tasks were performed under three conditions, alone in a single task condition and concurrently with a finger tapping task in dual task conditions. Finger tapping involved the subject repetitively tapping a mechanical key mounted on a wooden board with his or her index finger. The key and the subject's tapping hand were screened from view during tapping by a box-like cover and drape. Tapping was maintained at a fast pace for 20 second intervals and the number of taps per interval was recorded.

For half of the dual task trials, tapping was lateralized to the same hemisphere as the memory sequence, thus comprising the same-hemisphere condition. For the other half of the dual task trials, the pairings were reversed so that tapping was lateralized to a different hemisphere than the sequence being retained, making up the different-hemispheres condition. For digit task trials then, same-hemisphere tapping was right finger tapping, while for visual-spatial task trials, it was left finger tapping. The different-hemispheres tapping conditions were

left-handed for digit trials and right-handed for visual-spatial trials. The Edinburgh Handedness Inventory (Oldfield, 1971) was used to screen subjects' preferred hand as only right-handed subjects were used.

Procedure

Subjects were randomly divided into two groups (30 males and 30 females in each), a congruent orienting and an incongruent orienting group. In the congruent group, head and gaze orientation always activated the hemisphere congruent with the memory sequence being retained. In this group, subjects turned their heads and directed their gaze to the right while retaining digit spans and to the left while retaining visual-spatial spans.

In the incongruent orienting group, the reverse pairings always occurred such that lateral orientation activated the hemisphere incongruent with the sequence being retained. Here, subjects turned their heads and directed their gaze to the right while retaining visual-spatial spans and to the left while retaining digit spans. Consequently, both hemispheres were always activated, one by orienting and the other by performance of the memory task.

A dual task trial consisted of the following sequence of events: (a) presentation of instructions regarding the hand to be used for tapping, the direction in which

orienting was to be maintained (left or right) and the direction in which the memory span was to be reported (forward or backward), (b) presentation of the digit or visual-spatial string, (c) orientation of head to the left or right and of the eyes still further in the same direction, (d) a 20-second interval during which subjects tapped the key as fast as possible, simultaneously maintaining the directed head and gaze orientation, (e) a prompt to repeat back the required sequence, and (f) recording of the subject's recall of the memory span. The single task condition included left or right orienting, but omitted the 20-second tapping interval of event (d) above and substituted 20 seconds of "empty" time during which span retention and head and gaze orienting were the only requirements.

After completing the Handedness Inventory, subjects were seated at a small table directly across from the experimenter. In front of the subject was the block board for the visual-spatial task and two draped boxes, one each to the right and left of the block board. The tapping key was moved from the left box to the right box depending on the hand to be used for tapping on a particular trial. Instructions for task procedures were given, followed by four practice trials with the subject alternating hands and direction of orienting on each trial.

In each orienting group, every retention task was performed four times under each of three tapping conditions for a total of 48 trials per subject. The trials were ordered randomly with the following restrictions: one trial under each condition was required before any condition was repeated; a retention task in each direction (forward/backward) was run before either direction was repeated; and a dual task trial with each hand (left/right) was required before tapping with either hand was repeated. The order of presentation was the same for all subjects and is presented in Appendix B. Completion of the experimental trials took approximately 55 minutes after which subjects were issued their extra credit points and dismissed.

CHAPTER III

RESULTS

Correlational Data

Estimates of internal consistency reliability (trials 1 + 2 vs. trials 3 + 4) calculated on the retention task performances proved to be comparable to those in our previous work. These are presented in Appendix D. Correlations were calculated between digit and visual-spatial task performances within each tapping condition (single, same-hemisphere and different-hemispheres) for each sex in each orienting group. The average correlations are presented in Table 1. Here, five of six of the correlations between digit and visual-spatial tasks are higher in the congruent orienting group than in the incongruent group, a significant portion by sign test ($p < .05$). Also, five of six of the correlations between digit and visual-spatial tasks are higher for females than for males, again a significant proportion by sign test ($p < .05$). Thus, both orienting group and sex of subject significantly affected the size of the correlations between retention task performance. Table 1 also shows that variation in the size of the intercorrelations across the tapping conditions found in our previous work, same

Table 1

Average Correlations Between Digit and Visual-Spatial Task
Performances by Tapping Condition

Group/Sex	Single	Condition	
		Different- Hemispheres $\bar{r}$	Same Hemisphere $\bar{r}$
Congruent- Females	.320	.362*	.450*
Congruent- Males	.178	.378*	.230
Incongruent- Females	.186	.426*	.322
Incongruent- Males	.092	.062	.196

Note. $\bar{r} p < .05$, .361; $\bar{r} p < .01$, .463.

*significant correlation

hemisphere > different hemispheres > single, was not obtained. In general, the dual tasks produced higher correlations than the single tasks, but more significant correlations were obtained under the different-hemispheres than the same-hemisphere conditions. For males, the strongest intercorrelations were found in the different-hemispheres condition of the congruent orienting group. Females obtained significant correlations in the different-hemispheres condition in both orienting groups, but their strongest correlations were found in the same-hemisphere condition of the congruent orienting group.

All possible intercorrelations between the digit and visual-spatial task performances both within and across tapping conditions were calculated. Figure 1 presents the proportion of these correlations that are both significant and positive for each sex in each orienting group. Figure 1 shows that for both males and females, orienting in a direction that is hemispherically congruent with the concurrent memory task significantly enhanced the proportion of significant positive correlations between the digit and visual-spatial task performances relative to incongruent orienting (overall $Z = 3.28$, $p < .001$, two-tailed test). The effect of orienting direction was significant for both sexes, but was somewhat stronger for males than females (males $Z = 3.08$, $p < .001$, two-tailed; females $Z = 1.73$, $p < .05$, one-tailed). Figure 1 also shows a sex effect on these intercorrelations independent of the direction of orienting. Females show a higher proportion of significant positive correlations among digit and visual-spatial memory tasks than males in both orienting groups ($Z = 3.93$, $p < .001$, two-tailed).

Correlations were also calculated for all possible pairs of memory task performances and finger tapping frequencies. Figure 2 shows the proportion of these correlations that were significant and positive for each sex in each orienting group. For females, congruent

Figure 1. The Proportions of Significant Positive Correlations Between Digit and Spatial Tasks as a Function of Orientation and Sex

Figure 2. The Proportion of Significant Positive Correlations Between Tapping Frequencies and Retention Tasks as a Function of Orientation and Sex

orienting produced a significantly greater proportion of significant positive correlations overall than did the incongruent orienting group ($Z = 8.18$, $p < .001$, two-tailed). Females had 51 of 96 significant positive correlations in the congruent orienting group and zero significant positive correlations in the incongruent orienting group. Moreover, four significant negative correlations were obtained between females' memory and tapping task performances in the incongruent orienting group. The males showed fewer significant positive correlations overall, but these were distributed more evenly across the orienting groups with 16 of 96 significant positive correlations in the congruent orienting group and 17 of 96 in the incongruent orienting group ($Z = .002$, $p > .05$). Additionally, all of the males' significant positive correlations between memory and tapping tasks in both orienting groups involved strictly digit retention tasks. So overall, females obtained a greater proportion of significant positive correlations between the memory and tapping tasks than males in the congruent group ($Z = 5.68$, $p < .001$) with the reverse sex pattern in the incongruent group ($Z = 4.12$, $p < .001$).

In sum then, as hypothesized, orienting direction influenced the size and significance of positive correlations between the digit and visual-spatial tasks.

Orienting congruently with the retention tasks enhanced the intercorrelations relative to orienting incongruently with the same tasks. For females, orienting congruently markedly enhanced the size and significance of the positive correlations between the retention and tapping tasks relative to incongruent orienting. For males, the few significant positive correlations between memory and tapping tasks obtained involved only digit tasks and the direction of orienting did not influence their frequency.

Mean Tapping Data

A 2 X 2 X 2 X 4 (sex X group X hand X task) ANOVA with repeated measures on hand and task was used to compare the mean frequencies of tapping per 20-second interval. The means and standard deviations are presented by sex and group for each hand in Table 2.

The main effects of hand, sex and task were all significant for tapping associated with all of the retention tasks. As expected, all subjects tapped faster with their right hands than with their left hands, $F(1, 116) = 23.68$, $p = .000$, and males consistently tapped faster than females, $F(1, 116) = 24.95$, $p = .000$. Tapping rate varied as a function of the memory sequence retained, $F(3, 348) = 14.19$, $p = .000$ such that significantly slower tapping was associated with the backward digit task relative to the three other tasks which did not differ

Table 2

Means and Standard Deviations for Tapping Task Frequencies
by Orienting Group and Sex Under Single and Dual Task
Conditions

Task		Orienting Group			
		Congruent		Incongruent	
		Females	Males	Females	Males
<u>Right Hand</u>					
Forward Digits	<u>M</u>	96.63	101.42	86.18	103.13
	<u>SD</u>	13.51	13.81	13.62	16.17
Backward Digits	<u>M</u>	96.66	101.31	84.43	103.78
	<u>SD</u>	13.08	12.92	12.54	14.93
Forward Visual	<u>M</u>	93.88	100.50	85.68	104.45
	<u>SD</u>	13.32	13.99	12.46	15.64
Backward Visual	<u>M</u>	94.78	100.48	86.54	105.40
	<u>SD</u>	13.40	14.17	13.47	14.89
<u>Left Hand</u>					
Forward Digits	<u>M</u>	86.62	94.48	80.10	97.28
	<u>SD</u>	14.90	13.57	13.79	15.10
Backward Digits	<u>M</u>	85.76	90.95	77.46	94.72
	<u>SD</u>	13.87	12.56	13.86	15.11
Forward Visual	<u>M</u>	88.20	94.85	81.74	98.59
	<u>SD</u>	14.25	11.93	12.89	15.69
Backward Visual	<u>M</u>	87.62	94.39	81.23	99.98
	<u>SD</u>	14.07	12.09	12.44	14.94

Note. N = 120; Visual = visual-spatial retention span.

significantly from one another (for forward digits, $\bar{M}$ = 93.23, for backward digits, $\bar{M}$ = 91.88, for forward visual-spatial, $\bar{M}$ = 93.49, for backward visual-spatial, $\bar{M}$ = 93.80).

Also, there was a significant interaction of task X group on the tapping data, $F(3, 348) = 6.96, p = .0001$. Tapping associated with all four memory tasks was faster in the congruent orienting group than the incongruent group overall, though not at significant levels. There were no significant differences among tapping rates associated with the four memory tasks in the congruent orienting group, $F(3, 177) = 1.77, p = .17$. However, there were in the incongruent orienting group, $F(3, 177) = 23.28, p = .000$. Newman-Kuels tests show tapping associated with forward digits, forward visual-spatial, and backward visual-spatial to be significantly faster than that with backward digits. Tapping with forward digits was also slower than that with backward visual-spatial. (Overall means in the incongruent orienting group were: for forward digits, $\bar{M}$ = 91.67; for backward digits, $\bar{M}$ = 90.10; for forward visual-spatial, $\bar{M}$ = 92.62; for backward visual-spatial, $\bar{M}$ = 93.29).

Of particular interest was the significant effect of the interaction of group and sex, $F(1, 116) = 6.19, p = .01$, shown in Figure 3. Newman-Kuels showed that

tapping rates for females dropped significantly from the congruent to the incongruent orienting group (congruent orienting group $M = 91.26$; incongruent orienting group $M = 82.92$). In contrast, males showed no significant differences in their tapping rates across the orienting groups (congruent orienting group $M = 97.30$, incongruent orienting groups $M = 100.91$).

A significant memory task by hand interaction, $F(3, 348) = 13.78$, $p = .0000$, indicates that the nature of the memory sequence retained differentially influenced tapping rates for the left and right hands. Figure 4 presents the significant results of two $2 \times 2 \times 4$ (group $\times$ sex $\times$ task) ANOVAs that were run on tapping frequencies, one for each hand.

For the left hand, a significant main effect of memory sequence retained, $F(3, 348) = 22.70$, $p = .000$, indicates that tapping frequencies were significantly higher during visual-spatial sequence retention than during digit sequence retention. Also, left hand tapping associated with forward digits was also faster than that with backward digits.

For the right hand, a significant task $\times$ group interaction, $F(3, 348) = 7.40$, $p = .0001$, was obtained. Simple effects analyses indicate significant effects of memory task within each group, congruent, $F(3, 177) = 4.84$, $p = .003$, and incongruent, $F(3, 177) = 3.69$, $p = .013$.

Figure 3. The Significant Orientation by Sex Interaction for Tapping Frequency

Note. x — x = Right hand, congruent orienting group
 o — o = Left hand, incongruent orienting group
 - - - - = Left hand

Figure 4. Mean Finger Tapping Frequency per 20 Second Interval: The Retention Task by Orienting Group Interaction (Right Hand), the Retention Task Main Effect (Left Hand).

Newman-Kuels tests show right hand tapping associated with digit tasks to be faster than with the visual-spatial tasks in the congruent orienting group. Within the incongruent orienting group, right hand tapping associated with visual-spatial sequence retention was significantly faster than with the digit memory tasks. For both orienting groups, faster right hand tapping occurred when subjects oriented to the right.

In sum, for all subjects the highest mean tapping frequencies were obtained with the right hand. Males out-tapped females in every case. Further, a group X sex interaction on tapping rates was found such that females' tapping rate slowed significantly from the congruent to the incongruent orienting group while males' tapping rates did not. Right hand tapping was faster when subjects oriented to the right relative to the left regardless of whether orienting was congruent or incongruent with respect to the retention task. In contrast, left hand tapping was faster while subjects retained visual-spatial tasks relative to retaining digit tasks regardless of the direction of orienting.

Retention Task Means

A 2 X 2 X 4 X 3 (group X sex X task X condition) MANOVA with repeated measures on task and condition was used to analyze retention performance on the four memory tasks.

The means and standard deviations for each task are presented by sex and group in Table 3.

There were no significant main effects of orienting group or sex on the memory task means, $F(1, 116) = .43$, $p = .51$; $F(1, 116) = .13$, $p = .72$, respectively. The multivariate effect of tapping condition was highly

Table 3

Means and Standard Deviations for Retention Task Scores by Orienting Group Under Single and Dual Task Conditions

Task		Condition					
		Single		Different Hemispheres		Same Hemisphere	
		Con	Incon	Con	Incon	Con	Incon
Forward Digits	<u>M</u>	6.07	6.08	5.94	6.19	6.09	5.95
	<u>SD</u>	1.03	1.17	1.03	1.23	1.07	1.50
Backward Digits	<u>M</u>	5.61	5.64	5.18	4.89	5.30	5.76
	<u>SD</u>	1.23	1.15	1.07	1.19	1.32	1.08
Forward Visual-Spatial	<u>M</u>	4.78	5.03	4.91	5.18	4.93	5.01
	<u>SD</u>	1.24	1.00	1.30	1.00	1.14	1.16
Backward Visual-Spatial	<u>M</u>	3.78	3.89	3.34	3.41	3.81	3.70
	<u>SD</u>	1.14	0.86	1.20	1.22	1.11	0.98

Note. $N = 120$. Con = congruent orienting group; Incon = incongruent orienting group; Visual = visual-spatial retention task.

significant however, $F(2, 117) = 12.51, p = .000$.

Univariate analyses showed this effect only for the backward memory measures, backward digits, $F(2, 232) = 20.41, p < .01$; and backward visual-spatial, $F(2, 232) = 16.23, p < .01$. Newman Kuels tests showed that both of the backward memory tasks were performed better under the single task and same-hemisphere conditions than under the different-hemispheres condition ($p < .01$). Memory retention under the single and same-hemisphere conditions did not differ significantly (total means: for backward digits, single $M = 5.62$; different-hemispheres $M = 5.04$; same-hemisphere $M = 5.53$; for backward visual-spatial, single $M = 3.83$; different-hemispheres $M = 3.37$; same-hemisphere $M = 3.76$).

The MANOVA indicates a significant task X group X condition interaction, $F(6, 696) = 3.58, p = .002$, on the retention performances as well. The corresponding ANOVAs indicate that this interaction was significant for the backward digit task, $F(2, 236) = 7.12, p < .001$. Simple effect analyses indicate significant differences on the backward digit task among the three conditions within each orienting group, congruent, $F(2, 117) = 5.06, p = .008$, and incongruent, $F(2, 117) = 27.14, p = .000$. Newman-Kuels tests show that performances on the backward digits task in the congruent group were significantly better under the single task condition than under both of the dual task conditions

($p < .05$), different-hemispheres and same-hemisphere, which did not differ significantly. In the incongruent orienting group, backward digit retention under the single task and same-hemisphere conditions was significantly better than under the different-hemispheres condition. Performances under the single task and same-hemisphere conditions did not differ significantly, however.

The multivariate interaction of task X sex X condition was also significant, $F(6, 696) = 32.96$, $p = .007$. However, the only significant univariate F is for forward digits, $F(2, 232) = 3.38$, $p = .04$. Simple effects analyses showed no significant performance differences on this task between the sexes under any of the three conditions. However, the simple effect of condition on each sex yields a nonsignificant F for males, $F(2, 117) = .88$, $p = .42$, and a significant F for females, $F(2, 117) = 3.38$, $p = .04$. Newman-Kuels test showed that females performed better on forward digits under both the single task and different-hemispheres conditions than they did in the same-hemisphere condition ($p < .05$). Performances on forward digits under the single task and different-hemispheres conditions were not significantly different from each other (total means for females: single $M = 6.1$, different hemispheres $M = 6.2$, same-hemisphere $M = 5.87$). None of the other possible multivariate interactions reached significant levels.

Neither orienting nor sex had overall effects on the memory task means. Tapping condition had a substantial effect only on the retention of backward spans. Both backward digit and backward visual-spatial tasks were performed better under the single and same-hemisphere conditions than under the different-hemisphere condition with one exception. In the congruent orienting group, better backward digit performance was obtained in the single task condition than in either of the dual task conditions, same-hemisphere or different hemispheres. There was also a significant sex X condition interaction on the forward digit tasks. Females retained the forward digit sequences better under both the single and different-hemispheres conditions than in the same-hemisphere condition.

In sum, several major findings emerged in the analyses. Firstly, congruent orienting enhanced the size and significance of the correlations between the digit and visual-spatial tasks for both sexes. The correlations between the memory and tapping tasks for females were affected by gaze directions. Congruent orienting enhanced their significance relative to incongruent orienting. Males showed only a low level of relatedness between the memory and tapping task performances in both orienting groups. Parallel sex results were manifest in the mean finger tapping performances. Females' tapping frequencies

dropped significantly with the shift from congruent to incongruent orienting. Males' tapping frequencies were unaffected by the direction of orienting. Right hand tapping was faster when subjects oriented to the right regardless of the associated memory task. Left hand tapping was unaffected by orienting, but was faster when accompanied by visual-spatial memory tasks relative to digit tasks.

In general, mean retention performances were significantly affected by tapping condition and not the direction of orienting. The backward retention measures were consistently performed better under the single and same-hemisphere conditions than under the different-hemispheres conditions with one exception. In the congruent orienting group, retention of backward digit sequences was significantly better under the single task condition than under either of the dual task conditions, same-hemisphere and different-hemispheres which did not significantly differ. The only significant finding on the forward memory sequences was for females who retained forward digit sequences better under single and different-hemispheres task conditions than under the same-hemisphere condition.

CHAPTER IV

DISCUSSION

The major hypothesis of this study was that hemispherically congruent orienting maintained during lateralized dual task performance would produce an increase in positive manifold between the tasks. Findings of higher intercorrelations and a greater proportion of significant positive correlations between digit and visual-spatial memory tasks under situations of congruent orienting relative to incongruent orienting confirm this hypothesis. This rise in the size and significance of the correlations suggests that, under conditions of congruent orienting, performances of the digit and spatial memory tasks share a common resource despite the fact that they are known to be lateralized to opposite hemispheres. Lower correlations and a lesser proportion of significant positive correlations among the digit and spatial tasks were found under conditions of incongruent orienting suggesting a reduction in the degree to which performance on the two memory tasks share a common resource in this orienting situation.

Since variations in the orientation of attention differentially affected the finding of positive manifold

between the retention tasks, the common resource appears to be an attentional one. With congruent orienting, this attentional resource played a significant role in retention task performance. With incongruent orienting, performances on the different tasks shared a great deal less of this common attentional resource and instead were performed with a mix of a number of different resources, possibly hemisphere-specific ones.

Viewing these correlational findings from an individual difference perspective, it would seem that those individuals with greater attentional resources would perform better under conditions of congruent orienting than those with lesser attentional resources, regardless of the nature of the task. However, a greater reliance on attention would become a relative disadvantage for some of these individuals under conditions of incongruent orienting. Here, hemispheric rather than attentional resources are better able to support task performance.

The data show several sex differences in the way the tasks were performed under the two orienting conditions. Retention task intercorrelations of greater overall size and significance were found for females relative to males regardless of whether attentional orientation was congruent or incongruent. This evidence suggests that females consistently relied on a general attentional resource to

support retention task performance despite gaze direction. While females performed the retention tasks equally well in both orienting groups, a relative disadvantage of their greater dependence on attention became evident upon examination of the way in which dual task performances were maintained.

Two findings suggest that in the incongruent orienting group, females made a trade-off between the use of attention for finger tapping and that for sequence retention. Firstly, females' finger tapping rate slowed significantly from the congruent to the incongruent orienting situation. Secondly, in the congruent orienting situation, females demonstrated a very high proportion of significant positive correlations between the retention and tapping task performances. This effect was independent of tapping hand or retention task and indicates that with congruent orienting, these tasks shared a common resource. In the incongruent orienting group however, there were zero significant positive correlations between the retention and tapping tasks. This dramatic drop-off in the proportion of significant positive correlations indicates that the females' retention and tapping tasks were not supported by the shared attentional resource in the incongruent orienting group as they were in the congruent orienting group.

Together, these findings suggest that attentional support was withdrawn from tapping when attention was

directed incongruently. This seems to have allowed females to maintain the use of attention to support sequence retention though, as indicated by the fairly high proportion of significant positive correlations between the digit and visual-spatial retention tasks found in this group. Apparently, when faced with an incongruent orienting situation, females could no longer invest attention in both the tapping and retention tasks and so withdrew it from tapping to protect memory task performance. Although clearly at the expense of tapping, the trade-off worked; females performed the retention tasks equally well in both orienting groups.

Males also performed the retention tasks equally well in both orienting groups. However, the correlational data indicates they did so with a different mix of resources, one less dependent on a general attentional resource than females. Retention task correlations for males in the congruent orienting group indicate some use of the common attentional resource to support the retention tasks, though clearly not as much as the females. A significant drop-off in the size and significance of these positive intercorrelations in the incongruent orienting group indicates that males made less use of an attentional resource in this orienting situation. However, males showed no evidence of an attentional trade-off between the

retention and tapping tasks. Shifts in the direction of orienting did not affect their actual memory task performance, tapping rates, or their proportion of significant positive correlations between memory and tapping task performances.

In sum then, sex differences in the correlational data suggest that while males and females performed the same tasks equally well in both orienting groups, they did so with a different mix of resources. A finding of overall greater positive manifold for females show them to be more dependent on a general attentional resource than males who are better able to make use of hemispheric resources. Further, the differences in tapping task performance for the females under the two orienting conditions indicate they are more readily affected by congruency of attentional orientation than males.

In support of these interpretations are two regional cerebral blood flow studies (Deutsch, Bourbon, Papanicolaou, & Eisenberg, 1988; Gur, Gur, Obrist, Hungerbuhler, Younkis, Rosen, Skolnick, & Reivich, 1982) which indicate that females are, in general, characterized by a greater degree of bihemispheric brain activation than males. Regional cerebral blood flow research is based on the premise that brain activity is accompanied by increased cerebral blood flow in the relevant activated cortical

fields (Roland & Friberg, 1985). In the blood flow studies mentioned, it was repeatedly shown that females performing lateralized verbal and spatial tasks registered consistently higher overall blood flow across all brain regions of both hemispheres than males performing the same tasks. These sex differences in activation can be interpreted as being attentional in nature.

Mesulum (1985) views the overall process of attentional activation as being comprised of two physiologic operations. The first is a tonic or state operation which regulates a general underlying level of activation and is associated with the reticular activation system. The second operation is a vector function which controls the direction of attention and is associated with more neocortical neural mechanisms. In the regional cerebral blood flow studies discussed above, the greater overall brain activation manifest by females suggests they are perhaps characterized by a greater degree of the state function of attention than are males. Likewise, in the present study, the greater degree of intercorrelation between digit and visual-spatial tasks for females regardless of the direction of orienting may reflect a greater reliance on the state or general attentional activation relative to males.

Mesalum (1985) notes that despite the physiologic state and vector distinctions in the attentional process, most attentional behaviors actually represent an interaction of the two operations. In the present study, the rise in correlations between the digit and visual-spatial tasks under the congruent orienting situation for all subjects may represent such an interaction. The data indicate that with attention directed (vectored) toward the congruent hemisphere, performances on tasks typically controlled by the resources of different hemispheres were strongly positively correlated, again suggesting they shared a common resource for their performance. In Mesalum's terminology, it may be that the congruent orienting of attention directed the general, nonlateralized state activation in support of hemispherically lateralized tasks. Findings of positive manifold under these conditions then, appear to be indicative of bihemispheric brain functioning which further suggests that the orientation of attention plays a critical role in unifying the functioning of the hemispheres.

Relatedly, Holtzman and Gazzaniga's (1982) work with split brain patients has shown that even disconnected hemispheres depend upon a common attentional resource. For example, one commissurotomy patient showed a decrement in performance on a task presented to one visual field when

the difficulty of a similar task, presented simultaneously to the opposite hemisphere, was increased. In light of the patient's disconnected hemispheres, Holtzman and Gazziniga conclude that the attentional resource in question must be a nonlateralized one that resides in subcortical structures or one capable of being directed to different areas in the cortex along subcortical circuits. This notion is consistent with Mesalun's model of attentional processing in which subcortical reticular activation is directed upward to the cortex where it may have hemispherically unifying as well as activating effects in intact brains.

In a review dealing with joint functioning of the hemispheres, Levy (1985) identified the corpus callosum as a key mechanism in this process in normal brains. By coordinating the specialized and lateralized operations of each hemisphere, balancing the hemispheres' activation levels and distributing attention between them the corpus callosum allows for hemispheric collaboration even on asymmetrically demanding tasks. Again, this type of integrated functioning of the hemispheres appears to be reflected in the finding of positive manifold.

The sex differences in intercorrelations noted in the present study then may reflect sex differences in the process of bihemispheric activation or in the level of integration. DeLacoste-Utamsing and Holloway (1982) and

Wittelson (1987) provide evidence that there are actual structural differences in proportions of the hemispheric-connecting callosum of males and females, females' being proportionately larger in certain posterior sections. This may enhance the interconnectivity of females' hemispheres, making bihemispheric activation more likely or more efficient for them than for males. Such a notion could account for the sex differences in positive manifold found in the present study.

The view that attention serves an integrative role in unifying the halves of the brain and the interpretation of the correlational data in the present study in line with this view, brings us full circle to the original interpretations of the nature of "g." Spearman (1927) espoused a view of "g" as being a single, unitary fund of "mental energy" that supports mental operations by activating specific systems of cortical neurons, referred to as "s" factors. Thus, "g" as a general resource, perhaps attentional in nature, is capable of being transferred from one area of the brain to another. In 1949, Thomson presented an opposing conceptualization of "g." He argued that the mind consists of an immense number of neural bonds that form a complex and integrated whole and that "g," rather than a single activating factor,

represented the total number of neural bonds one has integrated and can bring to bear on a problem.

The correlational data in the present study suggests that these two views of "g" may be seen as co-extensive. "G" as a general attentional resource, may determine the actual network of neural circuits or bonds activated and under some circumstances, facilitate their integration. Those with a lot of "g" under certain conditions, can produce a bigger, more integrated network. The results of the present study clearly show that the orientation of attention in particular, plays a significant role in this process.

In our previous research (Urbanczyk et al., 1988), the correlations among the retention tasks were affected by the finger tapping conditions under which they were performed. It was believed that lateralized tapping produced asymmetric hemispheric arousal which shifted the gradient of attention either in support of task performance as in the same-hemisphere condition, or away from the hemisphere performing the cognitive task in the different hemispheres condition. Consequently, the observed pattern of correlations across the tapping conditions was, same-hemisphere > different hemispheres > single task. Such shifts in the orientation of attention were less likely in the present study however, because attention was already

voluntarily oriented to the left or right by instruction prior to each tapping/retention interval. So, although still asymmetrically activating, finger tapping could not redirect the orientation of attention and the retention task intercorrelations were not as systematically affected as in our previous work.

The asymmetric activating effects of finger tapping did however, produce a pattern of mean retention performances across the three conditions that closely replicates that found in the second experiment of the Urbanczyk et al. (1988) study. The single and same-hemisphere conditions yielded significantly better backward span retention than did the different-hemispheres condition. Whereas Kinsbourne's (1973) model of attention was previously used to explain these findings, suggestions by Boles (1987) and Hellige, Johnson, and Michimata (1988) concerning the conditions under which inhibition occurs across hemispheres, provide an alternative explanation.

In the context of visual hemifield reaction time experiments, Hellige et al. (1988) found consistent increases in both reaction times and error rates under conditions of bilateral stimulation, but not under unilateral stimulation conditions. By way of explanation, neurophysiologic evidence was cited that showed there to be both facilitatory and inhibitory neurochemical effects of

hemispheric activation. Leviel, Chesselet, Glowinski, and Cheramy (1981) found that facilitatory arousal in one hemisphere is typically accompanied by an inhibition of arousal in the opposite hemisphere. In situations of unilateral stimulation, the facilitative effects of activation would be primary because the inhibitory effects would be focused in the hemisphere not directly involved with task performance. In each hemisphere in the bilateral stimulation situation, facilitatory arousal produced by one lateralized stimulus would be partially offset by the inhibition produced by the other lateralized stimulus. As a result, neither hemisphere would be as aroused as when presented with unilateral stimulation. Such a drop in activation would account for the consistent decrements in task performance and increase in reaction times in Hellige et al.'s (1988) study.

The three tapping conditions in the present study can be conceptualized similarly. Both the single and same-hemisphere conditions are situations of unilateral stimulation since, in each, only one hemisphere is activated. So, in the absence of inhibitory effects, higher mean scores were obtained in these unilateral stimulation situations relative to the different-hemispheres situation, regardless of the specific nature of the memory task or the direction of orientation involved.

The different-hemispheres condition though is a bilateral stimulation situation since both hemispheres are activated, one by the tapping task and the other by the encoding and retaining of the memory span. Inhibition in the form of an overall significant decrement in task performance on both of the backward sequences was found in this condition independent of orienting direction. The fact that there was no specific decrement in tapping frequency under the different-hemispheres condition suggests that the hemisphere controlling tapping, when activated, produced contralateral inhibitory effects on the retention of the backward sequences. The fact that the backward but not the forward measures were affected suggests this inhibition was not directed to the contralateral hemisphere in a global way, but rather, to specific areas within the hemisphere. The parietal regions in particular seem to be especially affected since they are responsible for mental transformations required for successful performance on the backward retention tasks.

In neuroanatomic terms, it appears that in the different-hemispheres condition, lateralized finger tapping had its facilitatory effects in the contralateral frontal lobe where it supported tapping. Its inhibitory effects apparently occurred in the parietal lobe of the ipsilateral hemisphere. For example, left finger tapping activates the

right frontal lobe. The facilitatory effects of this right hemisphere activation apparently supported left finger tapping. Activation in the right frontal lobe also spreads to the left parietal lobe where it has inhibitory effects on the retention of backward digit sequences. Again, this effect was manifest on both digit and visual-spatial tasks independent of orienting direction.

Schwartz and Goldman-Rakic (1982) report specialized neurons of the cingulate cortex that project simultaneously to both the frontal lobe of one hemisphere and the parietal lobe of the other hemisphere. The decrement noted above in backward retention performance in the different-hemisphere condition may reflect an interhemispheric relay through this type of neuron. Specifically, lateralized activation of the frontal axon collateral of such a neuron by finger tapping, may have spread through the cingulate cortex to the contralateral parietal lobe where it had inhibitory effects on the concurrent mental transformation of the memory sequences. Thus, the backward retention means in this study may provide a behavioral example of the interplay between facilitation and inhibition in the two hemispheres involving the posterior parietal, frontal, and cingulate cortices (Mesulam, 1985).

In contrast, two other findings in the mean retention data are consistent with Kinsbourne's (1973) notion of

cross talk interference. These two findings provide some evidence of interference of tapping on retention performance in the same-hemisphere condition. The first involves backward digit retention in the congruent orienting situation. Here, mean retention in the single task condition was significantly greater than that in both of the dual task conditions, same-hemisphere and different-hemispheres which did not differ significantly. The second finding was found on forward digit retention for females. Their performance on this task was significantly worse in the same-hemisphere condition than in both the single and different-hemispheres conditions. More specifically, in this case the combination of forward digit tasks and right finger tapping produced a decrement in performance. A number of studies have also shown greater interference of right hand and left hand tapping upon vocal and subvocal verbal tasks (Friedman, Polson, & Dafoe, 1988; Hellige & Longstreth, 1981; Hicks, Provenzano, & Rybstein, 1975).

Interference of this type, between tasks lateralized to the same hemisphere, is consistent with Kinsbourne's (1973) notion of cross talk. In the same-hemisphere dual task condition of the present study, the tapping and retention tasks were lateralized to one hemisphere putting them in closer functional cerebral space than when they were lateralized to opposite hemispheres as in the

different-hemispheres condition. The decrements in performance in the same-hemisphere condition relative to the different-hemispheres or single task conditions then appears to reflect the interfering effects of greater cross talk. Such effects are limited in the present study though, and must be considered marginal relative to the highly significant and more robust effect of inhibition from bilateral stimulation on the backward retention tasks in the different-hemispheres condition.

In our previous work (Urbanczyk et al., 1988), finger tapping was generally viewed as an activating task which directed lateral eye movements and the orientation of attention. Analysis of finger tapping in the current study though, shows quite clearly that in addition to being an activating factor, tapping itself was affected by the orientation of attention in the case of right tapping and by concurrent cognitive activity in the case of left finger tapping. Although right and left tapping performances were affected somewhat differently, the results appear to demonstrate facilitatory effects of what appears to be hemispheric compatibility between various combinations of tapping hand, orienting direction and memory task retained.

Fitts and Seeger (1953) introduced the concept of stimulus-response compatibility, noting that in reaction time tasks the particular combination of stimulus and

response influenced the speed of performance on the tasks. They found some combinations to be faster, and therefore more compatible than others. Theoretical explanations for compatibility effects have called upon a variety of concepts, one of which relates to attentional processing (Verfaellie, Bowers, & Heilman, 1988). Research suggests that a stimulus presented on one side of space generates hemispheric activation in the contralateral hemisphere which directs attention to the corresponding hemisphere. This creates an attentional bias that favors responses on the same side as the stimulus. Cotton, Tzeng, and Hardyck (1980) concur that activating the hemisphere which mediates the response, either implicitly or explicitly, appears to be critical for compatibility effects to occur.

In the present study, both left and right tapping performances demonstrate facilitatory effects of what appears to be hemispheric compatibility. Two effects were found for the right hand. Right tapping in both the congruent and incongruent orienting situations was faster when subjects were looking right, regardless of the nature of the concurrent retention task. The alignment between the rightward orienting of attention and right hand tapping appears to have created a hemispherically compatible situation in the left hemisphere which in turn facilitated tapping. Bowers, Heilman, and Van den Abell (1981)

demonstrated a similar result when they had subjects respond to lateralized lights while deviating their eyes to a left, central, or right fixation point. When stimulus presentation was aligned compatibly with the direction of fixation, responses were faster than when they were aligned incompatibly.

For the left hand, the critical factor affecting tapping rate was the lateralized nature of the concurrent retention task. Faster tapping occurred when subjects held visual-spatial sequences in memory, regardless of the direction of orienting. Activation of the right hemisphere by the visual-spatial memory task appeared to create a response bias favoring the right hemisphere-controlled left hand. It is not clear why the compatibility effects are different for the two hands. The data does however, provide support for the Verfaillie et al., (1988) notion that compatibility effects vary as a function of manipulations in the underlying pattern of hemispheric activation and/or attentional orientation.

Conclusions

The results of this study show that the orientation of attention clearly affected the intercorrelations among the tasks. The higher correlations between left and right hemisphere tasks in situations of congruent orienting relative to incongruent orienting show that it is possible

to manipulate the utilization of the general attentional resource by manipulating attentional orienting. Relatedly, the results also provide evidence which suggests that the orientation of attention plays a role in integrating the functioning of the hemispheres since, in the case of congruent orienting, task performances that are usually lateralized to different hemispheres were unified by a shared attentional processing resource. In the case of incongruent orienting, the tasks were carried out more independently with less of the shared resource.

The correlational results of this study clearly support the notion that attention underlies positive manifold or "g," a general intellectual ability. Multiple metaphors have been used to describe attentional processing resource(s) and general intellectual abilities; both single and multiple resource theories have been forwarded. The data from the current study suggest that there is some validity to both conceptualizations. With proper orientation of attention, a single attentional resource or general intellectual ability appears to support the functioning of multiple, hemisphere-specific attentional resources or intellectual abilities. With an improper orientation of attention, the hemisphere-specific resources or abilities function more independently. Further, the data show sex differences in the utilization of the single and

multiple resources such that females appear more dependent on the single attentional resource or "g" than males.

The results of this study strongly support the use of correlational analyses in addition to mean analyses of task performances since the correlations clearly provide insight into the processes by which performance outcomes are obtained. One type of research that would be particularly helpful in further evaluating the validity of these interpretations would involve adding regional cerebral blood flow monitoring into the existing procedures to examine the effects of head and eye gaze orientation on actual brain activation. Including left handers and experimenting with a variety of other tasks would also extend the potential generalizability of the results.

APPENDIX A

Scoring for Retention Tasks

Scoring for Retention Tasks

General Rule

The span score on any single trial equals the total possible number of digits or blocks correct minus the minimum number of moves (as defined below) required to restore the subject's response to the correct sequence.

Definition of a Move

Each of the following situations constitutes one move to be subtracted from the maximum span score.

- (1) Addition of an omitted number or block to the series.

Example: 201385 correct response

20 385 subject's response

Score $6 - 1 = 5$

- (2) Removal of a confabulated or extraneous number or block from the series.

Example: 201385 correct response

2013857 subject's response

Score $6 - 1 = 5$

- (3) Relocation of an incorrectly placed number or block to another position.

Example: 201385 correct response

201358 subject's response

Score $6 - 1 = 5$

Example: 201358 correct response

501382 subject's response

Score $6 - 2 = 4$

APPENDIX B

Congruent and Incongruent Orienting Tasks

Congruent and Incongruent Orienting Tasks

Direction of Span	Nature of Task	Tapping Hand	Span	Direction of Orienting
<u>Congruent Orienting</u>				
Forward	Spatial		6354281	Left
Backward	Digits	Left	8742193	Right
Backward	Spatial	Right	457398	Left
Backward	Digits		9571823	Right
Backward	Spatial	Right	493251	Left
Forward	Digits	Left	26784531	Right
Forward	Digits		85396451	Right
Backward	Spatial	Left	541872	Left
Backward	Digits	Right	1396452	Right
Forward	Spatial	Left	1568437	Left
Backward	Spatial		965142	Left
Forward	Digits	Right	69478123	Right
Backward	Digits	Right	4593782	Right
Forward	Spatial	Left	6579214	Left
Forward	Digits		14786539	Right
Backward	Spatial	Right	658139	Left
Forward	Digits	Left	79834162	Right
Backward	Spatial		162375	Left
Forward	Digits	Right	52798341	Right
Backward	Spatial	Left	645137	Left

Direction of Span	Nature of Task	Tapping Hand	Span	Direction of Orienting
Backward	Digits		6382541	Right
Forward	Spatial	Right	1283475	Left
Backward	Digits	Left	7239148	Right
Forward	Spatial		2715386	Left
Forward	Digits	Left	691283745	Right
Backward	Spatial		7183952	Left
Forward	Spatial	Right	98172643	Left
Backward	Digits		45698372	Right
Forward	Spatial	Left	84369752	Left
Backward	Digits	Right	26743158	Right
Backward	Digits	Left	41295763	Right
Forward	Spatial		81245367	Left
Backward	Spatial	Right	5392471	Left
Forward	Digits		128937546	Right
Backward	Spatial	Left	6328174	Left
Forward	Digits	Right	267539148	Right
Backward	Spatial		3548761	Left
Forward	Digits	Left	154693582	Right
Backward	Spatial	Right	9327816	Left
Forward	Digits		295468317	Right
Forward	Spatial	Right	14839725	Left
Backward	Digits	Left	97348651	Right
Forward	Spatial		73241569	Left

Direction of Span	Nature of Task	Tapping Hand	Span	Direction of Orienting
Backward	Digits	Right	32187495	Right
Forward	Spatial	Left	62873951	Left
Backward	Digits		41529768	Right
Forward	Digits	Right	435268719	Right
Backward	Spatial	Left	7293184	Left
<u>Incongruent Orienting</u>				
Forward	Spatial		6354281	Right
Backward	Digits	Left	8742193	Left
Backward	Spatial	Right	457398	Right
Backward	Digits		9571823	Left
Backward	Spatial	Right	493251	Right
Forward	Digits	Left	26784531	Left
Forward	Digits		85396451	Left
Backward	Spatial	Left	541872	Right
Backward	Digits	Right	1396452	Left
Forward	Spatial	Left	1568437	Right
Backward	Spatial		965142	Right
Forward	Digits	Right	69478123	Left
Backward	Digits	Right	4593782	Left
Forward	Spatial	Left	6579214	Right
Forward	Digits		14786539	Left
Backward	Spatial	Right	658139	Right
Forward	Digits	Left	79834162	Left

Direction of Span	Nature of Task	Tapping Hand	Span	Direction of Orienting
Backward	Spatial		162375	Right
Forward	Digits	Right	52798341	Left
Backward	Spatial	Left	645137	Right
Backward	Digits		6382541	Left
Forward	Spatial	Right	1283475	Right
Backward	Digits	Left	7239148	Left
Forward	Spatial		2715386	Right
Forward	Digits	Left	691283745	Left
Backward	Spatial		7183952	Right
Forward	Spatial	Right	98172643	Right
Backward	Digits		45698372	Left
Forward	Spatial	Left	84369752	Right
Backward	Digits	Right	26743158	Left
Backward	Digits	Left	41295763	Left
Forward	Spatial		81245367	Right
Backward	Spatial	Right	5392471	Right
Forward	Digits		128937546	Left
Backward	Spatial	Left	6328174	Right
Forward	Digits	Right	267539148	Left
Backward	Spatial		3548761	Right
Forward	Digits	Left	154693582	Left
Backward	Spatial	Right	9327816	Right
Forward	Digits		295468317	Left

Direction of Span	Nature of Task	Tapping Hand	Span	Direction of Orienting
Forward	Spatial	Right	14839725	Right
Backward	Digits	Left	97348651	Left
Forward	Spatial		73241569	Right
Backward	Digits	Right	32187495	Left
Forward	Spatial	Left	62873951	Right
Backward	Digits		41529768	Left
Forward	Digits	Right	435268719	Left
Backward	Spatial	Left	7293184	Right

APPENDIX C
Task Instructions

Task Instructions

The subject was introduced to the experiment and the primary task in the following way.

I'm interested in finding out how well people can do two things at the same time so I'm going to be giving you some different things to do. The first one is tapping this key. For this task you need to place your hand here, keep your wrist on the board and tap the key as fast as possible with your index finger. Sometimes, I'll ask you to tap with your right finger and sometimes with your left. I'll tell you which hand to use and when to start. Keep tapping as fast as you possibly can until I say "stop." Practice now for a few minutes starting with your right finger.

Before you do the tapping I'm going to be giving you one of four different tasks to do. In one task, I'll read you a string of numbers which I'll want you to repeat back to me in the same order I say them. For example, if I say 3-7-4-8 what would you say? That's right, you repeat them in the same order I say them. In another task, I'll give you a string of numbers and I'll ask you to repeat them in the reverse order of the way I say them. For example, if I say 9-3-2-6 what would you say? Good. For the other two tasks, we'll use these blocks. I'll point to them in a sequence like this. (Experimenter points to series of blocks.) Then, when I'm finished, I'll want you to repeat

back the series by pointing to the blocks in the same order I do. Try this one. (Experimenter points to a five block string.) Good. Sometimes, I'll ask you to point to them in reverse order. For example, if I do this (experimenter points out a five block string) what would you do? Good.

So the four tasks are: repeating numbers the way I say them, repeating them backwards, pointing to the blocks the way I point to them and pointing to them backwards. It is important that you do your very best on each of them. Listen carefully to this next part. After I read you the numbers or point to the blocks, I'm going to time out a 20 second interval on this stop watch. During this 20 seconds you will turn your head to your left or right and look off in that direction. At the same time, you'll either be tapping the key as fast as possible, or you'll do nothing but maintaining that gaze direction. I'll tell you ahead of time what you'll be doing. When the 20 seconds is up, I'll say "stop." That will be your cue to repeat the sequence back to me. Do you have any questions?

Before we start, let's practice a few of these combined tasks so you get the hang of them. Ready? Remember this one, tap with your right hand, look to the right, then repeat this in the same order I say it. (Experimenter reads digit string, prompts the subject to orient and begin tapping, says "stop" after 20 seconds, and

records subject's response to FD. Subject is given two more dual task trials.) Do you have any questions about what I want you to do? Okay, let's start.

APPENDIX D

Test-Retest Table

Table 4

Test-Retest Estimates (Trials 1 + 2 versus 3 + 4) of
Reliability for the Retention Tasks

Task	Condition					
	Single r_c		Different Hemispheres r_c		Same Hemisphere r_c	
	Con	Incon	Con	Incon	Con	Incon
Forward Digits	.371	.618	.407	.703	.438	.444
Backward Digits	.709	.592	.536	.607	.598	.559
Forward Visual	.670	.432	.655	.500	.503	.495
Backward Visual	.598	.230	.634	.681	.478	.413

Note. r_c = corrected reliability estimates; Con = congruent orienting group; Incon = incongruent orienting group.

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