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NOTE

THE EFFECT OF VISUAL GUIDANCE AND HEMISPACE ON LATERALIZED VOCAL-MANUAL INTERFERENCE

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Abstract—When right-handers speak while performing manually, their right-hand performance declines disproportionately to their left. The present study shows that this: (i) is true for a sequentially homogeneous activity—repetitive single finger tapping; (ii) does not depend on the hemispace location of the performing hand; (iii) is not abolished by viewing the performing hand; and (iv) is not an artifact of trade-off with rate of concurrent speech production. These findings contradict some suggested models for such effects.

INTRODUCTION

SINCE KINSBOURNE and COOK's [11] description of lateralized output interference effects, more than 30 studies have confirmed and extended knowledge about this form of output laterality testing (see [12] for review). However, some aspects of the behavioral mechanisms remain controversial. Whereas we regard verbal-manual interference as but one instance of a wide range of dual-task situations apt to generate lateralized interference [10], LOMAS and KIMURA [15] think that it specifically illustrates the nature of the left-hemisphere specialization for speech and for the programming of manual sequences by either hand. They hold that speech selectively interferes with right-hand activity only if the manual action involves rapid sequential repositioning (e.g. successively tapping four keys).

Further in accord with their theoretical formulations, LOMAS [14] claims that lateralized interference occurs only if the motor act is performed without visual feedback control. However, THORNTON and PETERS [20] obtained lateralized interference under visual and also under nonvisual guidance for a sequential motor task. They did not test the effect of visual guidance on repetitive finger tapping, which, according to LOMAS and KIMURA [15] and KIMURA and ARCHIBALD [9] should not be subject to lateralized interference at all.

In contrast, HEILMAN and VALENSTEIN [3] assume a special relationship between each hemisphere and its "hemispace" (the space on the other side of the body midline). They propose that each hemisphere mediates action in the contralateral hemispace (regardless of which extremity is used). Extended to vocal-manual interference, the model implies that the hemispace in which the hand is located should determine whether lateralized interference occurs. However, MCFARLAND [16] found comparable right-hand decrement in the crossed and uncrossed positions (left and right hemispace) when a sequential manual task was performed during speech. Nevertheless, left-hand tapping was somewhat more impaired in the right than in the left hemispace during speech, in accordance with the model. The reaction time studies that Heilman and Valenstein interpreted in terms of hemispace involved finger flexion only, which resembles repetitive more than sequential finger tapping. Possibly repetitive finger tapping is more susceptible to hemispace effects than sequential finger tapping.

Our choice of repetitive finger tapping addressed this possibility. Our subjects tapped with and without accompanying speech, with hands crossed and with hands uncrossed. Half the subjects tapped with vision (looking at the hand). The rest tapped with the hand occluded from view. The latter manipulation should clarify whether Thornton and Peters' demonstration of lateralized interference under visual guidance holds for repetitive single finger tapping as well as for sequential tapping.

METHODS

Subjects

Sixty-four undergraduates (46 women and 18 men) participated. Their expressed right-hand preference was confirmed by the Edinburgh Handedness Inventory. Nine men and 23 women were randomly assigned to the Visual Guidance (VG) group and the rest to the Nonvisual Guidance (NVG) group.

Procedure

Subjects first received four 10-sec practice trials, one for each hand in the crossed and uncrossed position. They tapped with the index finger as rapidly as possible on a telegraph key bolted to a wood board 30 × 32.5 cm. The key was connected to an electronic counter which recorded tapping. It was positioned 17.5 cm to the right of the body midline for right-hand tapping and 17.5 cm to the left for left-hand tapping. In the crossed hand position, the right and left hands were 17.5 cm to the left and right respectively of the body midline.

After practice, VG subjects were instructed to look at their hand while tapping. NVG subjects looked at their hand only when positioning it on the telegraph key. When they tapped, a screen occluded their view of the hand (and the tapping apparatus). However, they were asked to continue to look in the direction of the tapping hand.

Each subject received eight 20-sec experimental trials, four in the crossed and four in the uncrossed hand position. The four trials in each position were presented as a block that began with a control tapping trial (C), followed by tapping with each hand while vocalizing (V), and ending with a control tapping trial with the other hand. On vocal trials, subjects tapped while counting backwards by two's from different randomly assigned numbers that ranged from 198 to 160. A different number was assigned for each vocal trial.

Sixteen subjects in each group began the first control trial with the right hand (R_1 order), the rest, with the left (L_1 order). The R_1 group tapped while counting, first with the left hand then right. This was followed by a control tapping trial with the left hand. R_1 subjects followed the sequence $R_C \rightarrow L_V \rightarrow R_V \rightarrow L_C$; L_1 subjects, $L_C \rightarrow R_V \rightarrow L_V \rightarrow R_C$.

Eight R_1 and eight L_1 subjects in each group began tapping in the uncrossed hand position (UC_1 order). The rest began in the crossed position (C_1 order). After completing the sequence, UC_1 subjects changed to the crossed position and C_1 subjects changed to the uncrossed position. The procedure was repeated for the changed hand position in the same sequence.

RESULTS

Mean right- and left-hand tapping rates in the uncrossed and crossed positions are shown in Table 1 for the VG and NVG groups, separately for C_1 and UC_1 order. Although these data were analyzed mainly for the purpose of establishing any differences in baseline tapping, we included tapping rate in the vocal condition as a factor. Thus, the analysis of variance had two between-subjects factors, Visual Guidance and Position Order. The three within-subjects factors were (1) Hand, (2) Position, and (3) Conditions (Control vs Vocal). Tests for simple main effects were used to analyze statistically significant interactions.

Uncrossed (UC) hand tapping was faster than crossed (C) tapping [F (1, 60) = 8.50, $P < 0.01$], but this finding was qualified by an interaction with conditions [F (1, 60) = 7.84, $P < 0.01$], based on faster tapping in the UC position for control tapping, [F (1, 60) = 13.02, $P < 0.01$], and not during speech [F (1, 60) < 1]. Hand position also interacted with position order [F (1, 60) = 21.56, $P < 0.01$]. This interaction reflects faster uncrossed tapping by C_1 order subjects [F (1, 60) = 28.82, $P < 0.01$], but not by UC_1 order subjects [F (1, 60) = 1.54, $P > 0.05$]. This finding probably represents a practice effect on the second block of trials. There was also an interaction between position, position order, and hand [F (1, 60) = 12.08, $P < 0.01$]. Inspection of Table 1 reveals that the right hand tapped faster on the second block of trials, regardless of position, suggesting that the interaction was due to a larger practice effect for the right hand.

The overall difference in tapping rate between the VG and NVG groups was not reliable [F (1, 60) = 2.11, $P > 0.05$]. However, since visual guidance entered into a five-way interaction [F (1, 60) = 4.01, $P < 0.05$], the data were reanalyzed separately for C_1 and UC_1 order, using a 2 (Visual Guidance) × 2(Hand) × 2(Position) × 2 (Conditions) mixed-design analysis of variance in each instance. The analysis for C_1 order subjects revealed that VG subjects tapped faster than NVG subjects [F (1, 30) = 4.50, $P < 0.05$], and that all interactions with visual guidance were unreliable [$P > 0.05$]. In contrast, the main effect of visual guidance was not reliable for UC_1 order [F (1, 30) < 1]. Although visual guidance interacted with conditions [F (1, 30) = 5.15, $P < 0.05$], analysis of this interaction showed comparable tapping rate by the VG and NVG groups in the control [F (1, 30) = 2.80, $P > 0.05$] and also in the vocal condition[F (1, 30) = 2.31, $P > 0.05$]. The interaction therefore is based on a larger difference between control and vocal tapping rate in VG than in NVG subjects.

The effect of concurrent speech on tapping rate was determined by converting each subject's data into a decrement ratio, $(T_c - T_v)/T_c \times 100$; where T_c = control tapping rate and T_v = tapping rate when speaking. Mean percentage decrement for each hand in the C and UC positions is shown in Table 2 for the VG and NVG groups, according to position order. Hand order (R_1 vs L_1) is included because it seemed to affect the degree of decrement. The analysis of

Table 1. Mean right- and left-hand tapping in the uncrossed (UC) and crossed (C) position in the control and speech conditions by the visual and nonvisual guidance groups

Group	Right hand Control	Right hand Speech	Right hand Mean	Left hand Control	Left hand Speech	Left hand Mean	Mean
Visual guidance							
UC_1 order							
Uncrossed	128.4	107.7	118.1	117.1	103.5	110.3	114.2
Crossed	128.1	112.9	120.5	116.1	106.1	111.1	115.8
C_1 order							
Uncrossed	131.2	116.8	124.0	120.3	110.3	115.3	119.7
Crossed	127.1	112.3	119.7	116.1	110.5	113.3	116.5
Mean							
Uncrossed	129.8	112.2	121.0	118.7	106.9	112.8	116.9
Crossed	127.6	112.6	120.1	116.1	108.3	112.2	116.2
Nonvisual guidance							
UC_1 order							
Uncrossed	124.9	112.8	118.9	115.8	105.4	110.6	114.8
Crossed	126.4	115.5	121.0	113.7	104.6	109.2	115.1
C_1 order							
Uncrossed	126.6	111.9	119.3	110.5	103.8	107.2	113.3
Crossed	118.0	107.1	112.6	107.4	98.8	103.1	107.8
Mean							
Uncrossed	125.7	112.3	119.0	113.1	104.6	108.9	114.0
Crossed	122.2	111.3	116.8	110.5	101.7	106.1	111.5

Table 2. Mean percentage right (R) and left (L) hand decrement in the crossed (C) and uncrossed (UC) positions for the visual and nonvisual guidance groups as a function of position order and hand order

Group	Uncrossed Right (%)	Uncrossed Left (%)	Uncrossed Mean (%)	Crossed Right (%)	Crossed Left (%)	Crossed Mean (%)
Visual guidance						
UC_1–R_1	17.2	13.5	15.4	11.5	9.7	10.6
UC_1–L_1	15.1	10.6	12.9	12.4	7.5	10.0
C_1–R_1	7.7	4.3	6.0	6.7	1.4	4.1
C_1–L_1	15.2	9.4	12.3	16.2	8.4	12.3
Nonvisual guidance						
UC_1–R_1	11.2	9.1	10.2	10.2	8.7	9.5
UC_1–L_1	7.7	8.2	8.0	7.7	8.2	8.0
C_1–R_1	16.0	8.5	12.3	10.2	6.1	8.2
C_1–L_1	7.7	6.4	7.5	8.4	8.4	8.4

variance had two repeated measures (Hand, Position), and three between-subjects factors (Visual Guidance, Position Order, Hand Order). Each factor had two levels. The outcomes are discussed for (a) Hand, (b) Visual Regard, and (c) Position.

Speech resulted in more right- than left-hand decrement [F (1, 56) = 18,25, $P<0.01$], to a comparable degree in the crossed and uncrossed positions [F (1, 56) < 1]. The right–left asymmetry was also impervious to the effects of Position Order [F (1, 56) = 2.70, $P>0.05$] and Hand Order [F (1, 56) < 1]. Although the right–left asymmetry was larger for VG than for NVG subjects, the interaction between Hand and Visual Guidance was not reliable [F (1, 56) = 3.04, $P>0.05$]. All higher-order interactions which included Hand as a factor were likewise unreliable [$P>0.05$].

The main effect of Visual Guidance was not statistically significant [F (1, 56) = 1.98, $P>0.05$]. However, Visual Regard interacted with Hand Order [F (1, 56) = 5.55, $P<0.05$], and also entered into a three-way interaction with

Hand Order and Position Order [F (1, 56) = 5.02, P < 0.05]. Analysis of the latter interaction revealed more decrement for VG than for NVG subjects in UC_1 order [F (1, 56) = 4.65, P < 0.05], and for VG-C_1L_1 than for NVG-C_1L_1 subjects [F (1, 56) = 5.08, P < 0.05]. The interaction reflects less decrement by VG R_1C_1 subjects than by the corresponding NVG group [F (1, 56) = 5.55, P < 0.05].

Crossed hand tapping resulted in more mean decrement than uncrossed, [F (1, 56) = 6.04, P < 0.05], regardless of Position Order [F (1, 56) < 1]. Since tapping during speech was comparable in the C and UC positions, the finding derives from faster control tapping for the UC relative to the C position. While the differential decrement due to position was greater for R_1 than for L_1 order, the interaction between Position and Hand Order was not reliable [F (1, 56) = 3.41, P > 0.05]. All higher-order interactions which included Hand Position were likewise unreliable [P > 0.05].

Was tapping rate in the C and UC positions comparable during speech due to a differential trade-off between words per unit time and tapping rate? If so, subjects should have emitted fewer digits when tapping in the more difficult crossed position. The number of digits spoken by 26 subjects while tapping in each position had been recorded. During right-hand tapping, the mean number of digits was 20.3 in each position. During left-hand tapping, the mean for the uncrossed (20.6) and crossed position (19.4) did not differ reliably ($t_{1,25}$ = 1.26, P > 0.05). Nor was the mean difference between digits emitted during right- and left-hand tapping reliable [P > 0.05].

Fourteen subjects were in the VG group and 12 in NVG. Mean digits for the VG subjects during right- and left-hand tapping were 19.8 and 19.5 respectively for UC tapping and 19.8 and 19.9 respectively for C tapping. The means for the NVG subjects during right- and left-hand tapping were 20.6 and 21.6 respectively in the UC position and 20.7 and 19.5 respectively in the C position. Although the mean for NVG subjects is higher than that for VG subjects, the difference is not reliable ($t_{1,24}$ = 0.43, P > 0.05). Since these VG and NVG subjects were drawn proportionately from the cells formed by the Hand and Position Order factors, their comparable speech output implies that the greater decrement in tapping for VG than for NVG subjects (excepting those in C_1R_1 order) cannot be explained in terms of a trade-off with speech output.

DISCUSSION

Lateralized interference was found to the same degree under visual and nonvisual conditions. This finding contradicts LOMAS [14] but confirms THORNTON and PETERS' [20] finding with sequential finger tapping. Thus, the mechanism underlying lateralized interference is independent of visual conditions. The notion that verbal–manual interference occurs only when the manual act, like the verbal, consists of rapidly changing sequential movement, must also be rejected. Further evidence against the LOMAS and KIMURA [15] model derives from the repeated finding that interference of a qualitatively similar nature can be generated when the lateralized behavior is not overtly verbal, but involves covert lateralized cognitive operations [2, 4, 6, 17–19].

The finding of more decrement under visual than under nonvisual conditions suggests that while visual guidance may facilitate under nonspeech conditions, it may interfere with the motor task during concurrent speech. THORNTON and PETERS' [20] subjects also showed more decrement in the VG than in the NVG condition (10.2% and 7.2% respectively in experiment 1 and 10.1% and 8.0% respectively in experiment 2, there being a significant interaction between the visual (VG vs NVG) and tapping conditions (control vs speech).

Finger tapping was slower in the crossed hand condition, but lateralized interference was comparable in the crossed and uncrossed hand conditions. This confirms MCFARLAND'S [16] findings for sequential finger tapping. The side of lateralized interference is determined by the hemisphere in control of the performing limb, and not by the limb's location in hemispace. The hemispace model was not supported.

It is unlikely that the physical awkwardness of the crossed hand position explains the reduction in tapping rate. The effect may instead be due to the unaccustomed source of kinesthetic feedback that accrues from the crossed hand position. The fact that the right hand actually tapped somewhat faster in the crossed hand position for UC_1 order subjects could indicate faster adaptation to its position (WALLACE [21] had a similar finding in a reaction time paradigm). With extended performance, the hand position effect might dissipate even for the left hand.

THORNTON and PETERS [20] explain vocal–manual interference as a resolution of the conflict in basic rhythms. Claiming that "the brain can only produce one basic chain of timed motor commands at a time" [20, p. 68], they hold that subjects accommodate their tapping rate to the temporal sequence specified by speech. But, since verbal output was comparable concurrent with left- and right-hand tapping, why did lateralized interference occur? Others [5, 8, 22] have also reported that lateralized interference does not occur as part of a verbal–manual trade-off. In addition, the Thornton and Peters model does not clarify why visual regard should result in more decrement than not looking at the hand, given the finding of no difference in speech output.

An alternative explanation is that verbal–manual interference is a special case of conflict between two activities relatively close in "functional cerebral space", a concept which has been shown to hold in a number of test cases [13]. Speech interferes more with right- than left-hand tapping because the speech area is closer in functional cerebral space to that which programs the right hand. Further, if tapping is more automatized (less subject to voluntary control) when subjects tap without visual guidance, and therefore consumes relatively less functional cerebral space, this could be why speech was less disruptive to tapping without than with visual regard.

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