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Effects of Speaking upon the Rate and Variability of Concurrent Finger Tapping in Children

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Tapping rate and variability were measured as 73 normal, right-handed children in Grades 1–4 engaged in speeded unimanual finger tapping with and without concurrent recitation. Speaking reduced the rate of tapping and increased its variability to a greater extent in younger children than in older children. Developmental changes in variability but not rate were attributable to a greater number of lengthy (>500 ms) pauses in the tapping of younger children. Speaking slowed the right hand more than the left, and the degree of this asymmetry was constant across grade levels. The right-hand effect for tapping rate was not attributable to lengthy pauses. In contrast, asymmetric increases in tapping variability occurred only among children in Grade 1 and only when lengthy pauses were included in the data. The results implicate three mechanisms of intertask interference: one involving capacity limitations, a second involving cross-talk

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between motor control mechanisms for speech and finger movement, respectively, and a third factor involving occasional diversion of attention from tapping to speaking. These mechanisms are discussed in relation to developmental changes in mental capacity. © 1985 Academic Press, Inc.

The pattern of interference between selected tasks performed concurrently can reveal aspects of the functional organization of the brain (Kinsbourne & Hicks, 1978). For example, among right-handers, speaking typically disrupts the concurrent performance of the right hand more than that of the left (e.g., Briggs, 1975; Hicks, 1975; Kinsbourne & Cook, 1971; Lomas & Kimura, 1976). This asymmetric interference has been attributed to the left lateralization of speech control in the cerebral cortex, i.e., to cross-talk within the left hemisphere between neural programs that control speech output and those that control right-hand movement (Kinsbourne & Cook, 1971). There is less, or sometimes no, interference between speaking and left-hand performance, presumably because control of the respective activities is divided between the two cerebral hemispheres rather than shared within one hemisphere. Among left-handers, with their more diverse patterns of speech representation, speaking is most often found to interfere about equally with left- and right-hand performance (Hicks, 1975; Lomas & Kimura, 1976; Sussman, 1982).

Children show asymmetric interference similar to that found with adults. In particular, speaking interferes to a greater degree with right-hand finger tapping than with left-hand finger tapping (Hiscock, 1982; Hiscock & Kinsbourne, 1978, 1980; Kinsbourne & McMurray, 1975; McFarland & Ashton, 1975; Obrzut, Hynd, Obrzut, & Leitgeb, 1980; Piazza, 1977; White & Kinsbourne, 1980). Significant asymmetries are found in children as young as three years, and the average magnitude of the asymmetry does not increase with increasing age. Consequently, the concurrent-task data support the view that speech control is lateralized at an early stage of development (Kinsbourne & Hiscock, 1977).

The degree of generalized (i.e., bilateral) interference decreases with increasing age in children (Hiscock & Kinsbourne, 1978, 1980). When interference is defined as the percentage of decrement in tapping rate, relative to the rate in the single-task condition, interference declines linearly between the ages of 3 and 12 years. This suggests a linear developmental increase in time-sharing ability and perhaps in mental capacity of a more general nature (Pascual-Leone, 1970).

Previous studies of interference with tapping have been limited by an almost exclusive focus on tapping rate, which represents only one aspect of tapping performance. In the present study, we measured tapping variability as well as rate. In addition, by reanalyzing rate and variability data after relatively lengthy (>500 ms) intertap intervals have been excluded, we determined which effects are attributable to lengthy pauses in tapping (coarse-grained time-sharing) and which are attributable to a more continuous division of capacity (fine-grained time-sharing). These analyses provide a more complete account of children's time-sharing than has been available.

Our objectives are (1) to confirm previously reported developmental patterns of generalized and lateralized interference between speaking and rate of speeded finger tapping, (2) to measure the effect of speaking upon the variability of concurrent finger tapping, (3) to attribute age-related differences and hand differences to either fine- or coarse-grained time-sharing, and (4) to measure any reciprocal interference effects of left- and right-hand tapping upon speaking.

METHOD

Subjects

Subjects were 73 normal, right-handed children, all of whom were students in Grades 1–4 at a university-affiliated school. There were 10 girls and 10 boys from Grade 1, 10 girls and 8 boys from Grade 2, 8 girls and 11 boys from Grade 3, and 6 girls and 10 boys from Grade 4. Mean ages for each grade level were 6.7, 7.9, 8.8, and 10.0 years, respectively. The respective age ranges were 6.3–7.3, 7.3–8.3, 8.0–9.3, and 9.4–10.4 years.

All 73 children were right-handed according to both preference and performance criteria. Hand preference was assessed using a behavioral version of the Edinburgh Handedness Inventory (Oldfield, 1971), i.e., the children wrote their names, cut with scissors, drew a circle, used a spoon, used a knife, demonstrated how they brush their teeth, threw a ball, swept with a broom, and opened a box. Data from 5 children were excluded from analysis because the children failed to meet the criteria of right-handed writing and at least four other instances of right-hand preference. None of the remaining 73 children failed to meet the performance criterion, which was right-hand superiority for finger-tapping rate in the control conditions.

Apparatus

Children sat at a table and tapped a telegraph key with a knob 2.7 cm in diameter. The gap between key contacts was adjusted to 0.1 mm and the spring tension was set so that a force of 20 g was needed to close the contacts. The key controlled an audio oscillator whose output was fed into one channel of a two-channel tape recorder. The oscillator output was not audible while the tapping was being performed. Children spoke into a microphone that was connected to the opposite tape recorder channel.

Tapping data were analyzed using a Digital Equipment Corporation PDP-11 minicomputer with real-time clock. The tape-recorded audio signals were passed through a passive filter to smooth the waveforms and then fed into a Schmitt trigger. Each pulse (representing a key closure) fired the Schmitt trigger, which in turn started the clock. The next pulse caused the clock to be read and the interval since previous Schmitt trigger firing to be stored, provided that the interval fell within the range of 133–2000 ms.

Procedure

Each child was tested individually in a quiet room by one of two experimenters, one male, the other female. The experiment was explained as an attempt to determine how rapidly children can tap and how well they can tap and talk at the same time. The experimenter demonstrated key tapping and gave the child 5 s of practice with each hand. The experimenter ensured that only the index finger contacted the knob, that the forearm was resting on the table, and that an appropriate amount of force was being applied.

The speaking task to be performed concurrently with finger tapping was continuous recitation of a nursery rhyme (Jack and Jill went up the hill, etc.). Prior to the first trial requiring recitation of the rhyme, the child was given instruction and practice until he or she could recite the material fluently and without error.

The experiment comprised five conditions: (1) right-hand tapping with no concurrent task; (2) left-hand tapping with no concurrent task; (3) right-hand tapping with recitation of the nursery rhyme; (4) left-hand tapping with recitation of the rhyme; and (5) recitation of the nursery rhyme without concurrent tapping. Approximately half of the children at each grade level performed the tasks in the order 1, 4, 5, 3, 2, and the other half performed the tasks in the reverse order.

Children were instructed to tap as rapidly as possible during specified 15-s intervals. When speaking was required, children were instructed to repeat the verbal material as many times as possible. They were told that speaking and tapping were equally important.

Scoring

The PDP-11 computer accumulated intertap intervals for the first 10 s of each trial or for a lesser period when a full 10 s of scorable data was not available. After conversion of intertap intervals to equivalent rates, in taps per second, the rate scores from each trial were used to calculate mean rate and variability for that trial. The coefficient of variation (standard deviation divided by the mean) was used as the measure of variability, because it provides a relative rather than an absolute estimate of dispersion. It was found that the coefficient of variation (V) was relatively independent of rate (median correlation of $-.04$ across various combinations of experimental conditions and dependent measures, compared with a median correlation of $+.38$ between rate and standard deviation).

Means and coefficients of variation were recomputed after excluding intertap intervals exceeding 500 ms. Preliminary scoring, with the aid of on-line histograms displayed on a cathode ray tube, revealed that the 500-ms criterion was optimal for eliminating intervals that fell far from the central cluster of scores. This criterion usually had the same effect as a criterion of three standard deviations above the mean, but the 500-ms criterion was more stringent when more than one extreme score was present.

There were two rate and two variability measures for each trial of tapping: the unrestricted measures, based on all intervals between 2000 and 133 ms, which is a range equivalent to 0.5–7.5 taps per second; and the restricted measures, based on intervals between 500 and 133 ms, equivalent to 2.0–7.5 taps per second. Effects obtained with the unrestricted data but not with the restricted data reflect the influence of relatively long (0.5–2.0 s) pauses in tapping.

Three judges listened to the tape-recorded speech and counted the number of words produced during each epoch that involved speaking. Each judge scored about one-third of the tapes, divided across children of various ages. The scorers were blind to the order in which the different conditions had been administered.

RESULTS

Control Condition Tapping

Data from the tapping-only conditions were analyzed using 4 × 2 × 2 × 2 analyses of variance with grade level, sex, order, and hand as the respective factors. The first three factors were between-subject variables; hand was a within-subject variable. Table 1 shows left- and right-hand means for each of the four dependent variables at each grade level.

Rate. Analysis of rate data yielded significant main effects for grade level, $F(3, 57) = 10.80$, $p < .0001$, and hand, $F(1, 57) = 244.02$, $p < .0001$. The grade level effect was totally attributable to the linear trend component, $F(1, 57) = 31.95$, $p < .0001$, indicating that tapping rate increased linearly with increasing grade level. The hand effect reflected right-hand superiority ($M = 5.08$ taps/s with the right hand versus 4.33 with the left). The Grade Level × Hand interaction was nonsignificant, $F < 1$, implying a constant right-hand superiority across Grades 1–4. Neither the main effect for sex nor the Sex × Hand interaction was significant, $F < 1$. An identical analysis performed on the restricted rate data yielded very similar results.

Variability. Analysis of the variability data yielded neither a significant main effect for grade level nor a significant linear trend component, $F < 1$. Thus, in contrast to rate, variability of finger tapping remained constant across grade levels. The only significant sources in the analysis of variance table were hand, $F(1, 57) = 4.11$, $p < .05$, and sex, F(1,

TABLE 1
RATE AND VARIABILITY OF TAPPING IN LEFT- AND RIGHT-HAND CONTROL CONDITIONS AS A FUNCTION OF GRADE LEVEL

	Rate		Rate (restricted)		Variability		Variability (restricted)	
Grade	Left hand	Right hand	Left hand	Right hand	Left hand	Right hand	Left hand	Right hand
1								
M	3.91	4.65	3.96	4.67	.155	.109	.131	.098
SD	0.322	0.462	0.297	0.431	.063	.055	.063	.037
2								
M	4.29	5.00	4.33	5.02	.156	.138	.142	.131
SD	0.667	0.695	0.671	0.700	.040	.057	.029	.053
3								
M	4.37	5.21	4.41	5.23	.138	.121	.124	.112
SD	0.613	0.559	0.560	0.550	.104	.046	.066	.043
4								
M	4.84	5.56	4.86	5.59	.141	.132	.133	.124
SD	0.564	0.570	0.558	0.587	.043	.060	.044	.042
All grades								
M	4.33	5.08	4.36	5.10	.148	.124	.132	.115
SD	0.632	0.653	0.611	0.651	.068	.055	.053	.045

Note. Rate is expressed as taps per second. Variability is expressed as the coefficient of variation, which is a unit-free ratio.

57) = 5.06, $p < .05$. Left-hand variability (M = 0.148) was significantly greater than right-hand variability (M = 0.124), and males were significantly more variable (M = 0.147) than were females (M = 0.123). Results from the analysis of variability scores were not altered appreciably when intertap intervals greater than 500 ms were excluded.

Dual-Task Tapping

The mean rate and variability of tapping in the concurrent-task conditions are shown in Table 2. In accordance with the convention for dual-task laterality studies (see Kinsbourne & Hiscock, 1977), the interfering effect of speaking upon tapping was assessed using proportional change scores, i.e., the difference between performance in the control condition and performance in the dual-task condition involving the same hand, divided by performance in the control condition. For convenience in exposition, these ratios have been multiplied by 100 and are cited and graphed as percentages. The proportional change scores were subjected to analysis of variance with the same factors as described above, viz., grade level, sex, order, and hand.

Rate. The first dependent variable was percentage of change in tapping rate (unrestricted), relative to the control condition. The left panel of

TABLE 2
RATE AND VARIABILITY OF TAPPING IN LEFT- AND RIGHT-HAND CONCURRENT-TASK CONDITIONS AS A FUNCTION OF GRADE LEVEL

	Rate		Rate (restricted)		Variability		Variability (restricted)	
Grade	Left hand	Right hand	Left hand	Right hand	Left hand	Right hand	Left hand	Right hand
1								
M	3.22	3.20	3.33	3.37	.196	.214	.142	.147
SD	0.695	0.895	0.660	0.879	.078	.104	.045	.065
2								
M	3.69	4.03	3.82	4.15	.219	.177	.169	.133
SD	0.920	0.972	0.878	0.950	.099	.088	.071	.051
3								
M	3.91	4.28	3.97	4.30	.163	.147	.131	.134
SD	0.603	0.793	0.580	0.771	.059	.034	.046	.024
4								
M	4.48	4.76	4.51	4.80	.150	.144	.135	.127
SD	0.587	0.672	0.605	0.672	.037	.045	.031	.035
All grades								
M	3.79	4.03	3.88	4.12	.183	.172	.144	.136
SD	0.833	1.01	0.795	0.963	.076	.079	.051	.046

Note. Rate is expressed as taps per second. Variability is expressed as the coefficient of variation, which is a unit-free ratio.

Fig. 1 shows the mean decrement in left- and right-hand rate at each grade level. Analysis of variance yielded significant main effects for grade level, $F(3, 57) = 4.75$, $p = .005$, and for hand, $F(1, 57) = 20.35$, $p < .0001$. The grade level effect was attributable to the linear trend, $F(1, 57) = 13.19$, $p < .001$, which shows that the overall degree of interference decreased with increasing grade level in a linear fashion. The significant hand effect confirms that speaking interfered to a greater degree with right-hand tapping than with left-hand tapping (M = 21.06% decrement with the right hand versus 12.52% with the left). Neither the Grade Level × Hand interaction nor the Grade Level Linear Trend × Hand interaction was significant, $p > .10$. The only other significant source in the analysis of variance was the Order × Hand interaction, $F(1, 57) = 8.19$, $p < .01$, which can be interpreted as a fatigue effect or as a changing trade-off with speaking rate (see below). The mean magnitude of interference, for either hand, was about 5 percentage points greater if that hand were used second than if that hand were used first. There were no significant sex differences.

When intertap intervals greater than 500 ms were excluded, the two significant main effects and one significant interaction described above were again the only significant sources in the analysis. All three effects

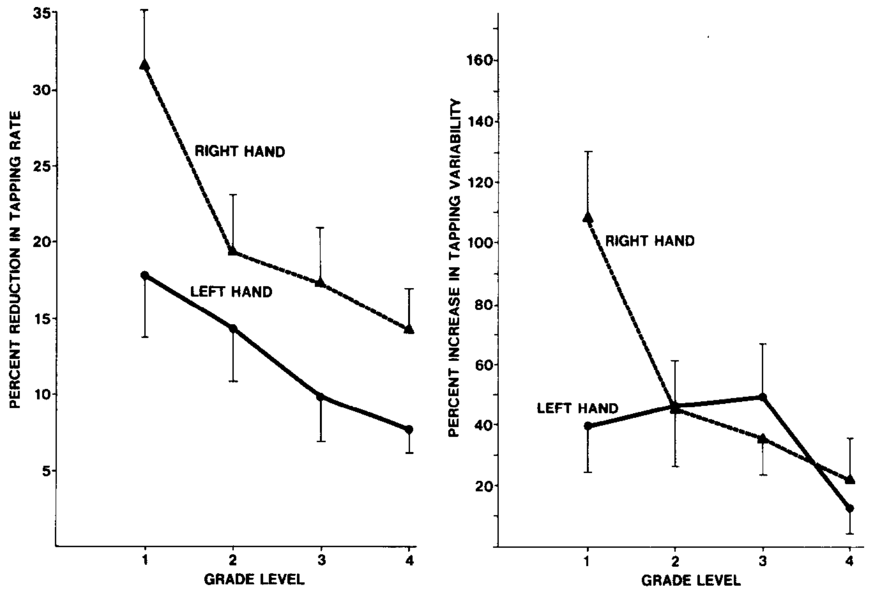

FIG. 1. Mean decrement in left- and right-hand tapping rate (left panel) and mean increment in left- and right-hand tapping variability (right panel), relative to control conditions, as children concurrently recited a nursery rhyme. Vertical bars represent the standard error of the mean.

were similar in magnitude to the corresponding effects in the previous analysis. Consequently, none of the effects depend on relatively lengthy interruptions of tapping.

Variability. In the dual-task conditions, variability increased substantially. The right panel of Fig. 1 shows the mean percentage of change in left- and right-hand variability (unrestricted) at each grade level. The only similarity between those data and the rate data was a significant main effect for grade level, $F(3, 57) = 3.35$, $p = .025$, which reflects decreasing interference, irrespective of hand, with increasing grade level. The effect can be attributed to the linear component, $F(1, 57) = 9.57$, $p < .01$. The interference was not lateralized, i.e., the main effect for hand was not significant, $p > .15$. However, there was a significant Grade Level × Hand interaction, $F(3, 57) = 3.19$, $p < .05$. Analysis of simple main effects (Winer, 1971) showed that right-hand interference was significantly greater than left-hand interference at Grade 1, $F(1, 57) = 9.73$, $p < .01$, but not at any subsequent grade level, $F < 1$. The only other significant source was the Sex × Hand interaction, $F(1, 57) = 4.44$, $p < .05$. Analysis of simple effects showed that interference was lateralized for males, $F(1, 57) = 6.08$, $p < .05$, but not for females, $F < 1$.

When the variability analysis was recomputed with intervals greater than 500 ms excluded, there were no significant effects ($p > .10$ in all cases). Thus, the variability findings described above depend upon relatively lengthy pauses in tapping.

Independence of Single- and Dual-Task Performance Measures

Despite the use of proportional change scores to assess the effects of speaking upon tapping, it is possible that the various dependent measures were not independent of single-task (i.e., control condition) performance. The question of independence between change scores and control condition tapping was addressed by performing a series of multiple regression analyses in which each dependent measure was expressed as a function of single-task performance with that hand, after grade level, sex, and order were forced into the equation (i.e., partialed out).

As there were four dependent measures and two hands, eight separate regression analyses were performed. In the case of rate measures, none of the four regression coefficients for control condition performance were significant, $p > .10$. The average percentage of variance accounted for by control condition performance was 0.65%. Each of the variability change scores, however, was related significantly to control condition variability, $p < .01$, and the average percentage of variance accounted for was 25.00%. The polarity of the regression coefficients indicates an inverse relationship between control condition variability and the degree to which variability increased in the dual-task conditions. This relationship cannot be attributed to any specific characteristic of the coefficient of variation because similar results were obtained when standard deviations were substituted for coefficients of variation in the regression equations. It is therefore construed as a range effect, but one that is comparable for the left and right hands.

Verbal Production

Table 3 shows the mean rate of speech production at each grade level for each of the three experimental conditions that entailed speaking. These verbal production data were analyzed in a $4 \times 2 \times 2 \times 3$ analysis of variance whose factors were grade level, sex, order, and condition. The analysis yielded a significant main effect for grade level, $F(3, 57) = 26.03$, $p < .0001$, which can be ascribed entirely to the linear trend, $F(1, 57) = 75.74$, $p < .0001$. Production rate increased from Grade 1 to Grade 4 in a linear manner. There was also a significant effect for sex, $F(1, 57) = 4.76$, $p < .05$, and significant Grade Level × Sex interaction, $F(3, 57) = 5.67$, $p < .005$. Girls ($M = 4.47$) spoke faster than boys ($M = 4.13$), but the difference was not consistent across grade levels, there being a substantial sex difference only among Grade 2 children.

There was a significant main effect for condition, $F(2, 114) = 5.76$, $p < .005$, and a significant Order × Condition interaction, $F(2, 114) =$

TABLE 3
RATE OF VERBAL PRODUCTION AS A FUNCTION OF GRADE LEVEL

Grade	Condition		
	Left-hand tapping	Right-hand tapping	Speaking only
1			
M	3.68	3.48	3.55
SD	0.67	0.87	0.64
2			
M	3.78	3.64	3.99
SD	1.12	0.95	1.05
3			
M	4.51	4.55	4.91
SD	0.99	0.70	0.68
4			
M	5.21	5.06	5.42
SD	0.99	1.13	0.91
All grades			
M	4.26	4.15	4.42
SD	1.11	1.10	1.09

Note. Rate is expressed in words per second.

47.20, $p < .0001$. The main effect for condition was accounted for by the control vs pooled left-hand, right-hand component, $F(1, 57) = 11.70$, $p = .001$. In other words, tapping significantly reduced speech rate, but there was no significant rate difference for left- vs right-hand tapping, $p > .25$. Orthogonal decomposition of the Order × Condition interaction revealed only a significant Order × Left-Hand vs Right-Hand component, $F(1, 57) = 81.90$, $p < .0001$. This can be characterized as a practice effect, insofar as word production was faster in the condition encountered second than in the condition encountered first; or as a trade-off between speaking and tapping, as tapping rate was found to be greater in the condition encountered first.

DISCUSSION

In aspects of the study that duplicate prior work—particularly the analysis of gross (unrestricted) tapping rate in single-task and concurrent-speech conditions—the results confirm earlier findings (e.g., Hiscock & Kinsbourne, 1978, 1980). The degree to which speaking slows finger tapping diminishes in a linear fashion from Grades 1 to 4; the right hand is affected more than the left at each grade level; and the degree of asymmetry does not change with grade level. None of these outcomes are altered by removal of lengthy pauses in tapping. Thus, age differences and hand differences in interference, as indexed by tapping rate, mutually derive from a relatively continuous division of capacity between tapping and speaking rather than from periodic intermittency of tapping. Moreover, the equivalence of verbal production during left- and right-hand tapping shows that the lateralized effect of speaking upon tapping is not due to a differential trade-off, i.e., to differential allocation of capacity between speaking and tapping, depending on which hand is tapping. The present findings lend support to the developmental invariance hypothesis of lateralization (Kinsbourne & Hiscock, 1977). Down to the youngest age tested, speech control appears to be lateralized, and to the extent that degree of asymmetry signifies degree of lateralization, as lateralized at the youngest age as at the oldest age.

Analysis of change in tapping variability from single-task to concurrent-speech conditions yielded a similar pattern of results insofar as the magnitude of change decreased with increasing grade level. However, the degree of asymmetry also decreased with increasing grade level, and neither the main effect for grade level nor the Grade Level × Hand interaction was significant after intervals greater than 500 ms had been excluded. Thus, the variability caused by secondary task interference is sensitive to developmental change only because young children show a relatively great number of pauses exceeding 500 ms. In the control conditions the younger children exhibited no such excess of lengthy pauses. Consequently, the increased incidence of these pauses in the dual-task conditions clearly is associated with concurrent speaking. Without implying that young children are similar to split-brain adults in other respects (cf. Galin, 1977), we would compare their pauses in dual-task tapping to those of a commissurotomized (split-brain) adult tested by Kreuter, Kinsbourne, and Trevarthen (1972). When this patient performed a concurrent verbal or calculation task of moderate difficulty, her finger tapping with the right (but not the left) hand became intermittent. But when she paused in her speech after making an error, she momentarily ceased to tap with either hand. None of the tasks had a noticeable effect on the tapping of normal adults.

The overall pattern of results suggests that capacity for dual-task performance does increase with increasing age (Pascual-Leone, 1970). Case (1978) has claimed that apparent increases in attentional capacity with increasing age are due not to increased structural capacity but to increased "operational automaticity" in performing basic operations: if one holds tasks constant across age levels, one effectively gives the older children easier tasks. It follows from this view that the older children's greater ease in time-sharing between tasks is secondary to the decreased capacity required to execute each task. This argument would be compelling if the tasks were fixed at some constant performance level, but, in fact, performance of both the speaking and tapping tasks was limited only by the child's ability to perform. Children were instructed to perform at the limits of their ability in both tasks and those limits (as measured by tapping rate and verbal production in the control conditions) varied with age as expected. If the children actually were working at their limits, the older children could in addition time-share more effectively than younger children (i.e., the proportional slowing of tapping was less in older children).

It remains to be determined whether this developmental increase in time-sharing performance is a general phenomenon, reflecting developmental growth in overall mental capacity, or whether it is specific to instances in which two speeded motor tasks are conjoined. If developmental increases in ability to time-share prove to be limited to motor tasks performed at maximal rates, then some temporal mechanism would be implicated. More specifically, if the respective tasks share a common timing mechanism (Klapp, 1979; Peters, 1977), there might be a tendency to synchronize tapping and speaking, in which case an increase in the rate of one activity would be correlated with an increase in the rate of the other (see Hiscock, 1982; Hughes & Sussman, 1983). The time-sharing advantage of older children then could be attributed to the synchronization of tasks, which would tend to offset the interference between them. It should be noted, however, that there were contrasting order effects for tapping rate and for speaking rate; this should not occur if the tasks were synchronized.

The finding that boys' tapping was more variable than that of girls in the control condition is reminiscent of Wolff and Hurwitz's (1976) report that girls are more accurate than boys in tapping to the beat of a metronome and in maintaining the same rate when the metronome is turned off. Wolff and Hurwitz attributed sex differences in their study to earlier development of left-hemisphere functions in girls than in boys (Buffery & Gray, 1972), but in the present study it was boys and not girls in whom recitation of the nursery rhyme produced lateralized disruption of tapping regularity, i.e., asymmetric increase in variability. As there were no other sex differences in laterality within the present study, there is little justification for invoking sex differences in speech lateralization. Girls spoke at a significantly faster rate than boys when reciting the nursery rhyme. Even though this finding is attributable largely to a sex difference at one grade level (Grade 2), it is congruent with the general tendency for girls to excel on tests of articulation and verbal fluency (Maccoby & Jacklin, 1974).

Tapping rate and variability clearly did not provide redundant information. (As noted previously, the coefficient of variation was found to be independent of rate.) The respective indices reflect different aspects of tapping performance. The fact that tapping variability (with lengthy pauses removed) did not decrease with increasing age suggests that, unlike rate, it is not limited by general mental capacity, but reflects the structural organization of motor control of the finger movements involved. Tapping variability increased with the addition of the concurrent-speech task, but age (and sex) differences were based on the intermittent occurrence of large pauses. In contrast, variability differences between hand and sex in the control conditions were due to a finer grain of variability. We thus distinguish among (a) rate, which is affected by concurrent performance to an extent determined by propinquity of the relevant control centers in "functional cerebral space" (Kinsbourne & Hicks, 1978); (b) fine variability, which is inherent in the motor control mechanism; and (c) coarse variability, which may represent momentary shifts of attention away from tapping (and toward speaking) in the absence of ability to automatize tapping.

If this analysis is correct, it follows that potential interference is dealt with by a mechanism that restricts rate of information transmission (e.g., as manifested in finger-tapping rate), rather than permit perturbation of the performance by cross-talk. One way of conceptualizing such a mechanism is in terms of an inhibitory barrier that protects the performance from cross-talk at the cost of restricting the area of its processing base (Kinsbourne, 1981). With increasing brain maturation and the accompanying increase in overall mental capacity, there is increasing ability to perform at a high rate in spite of the limitations imposed by the inhibitory barrier. Whatever amount of cross-talk occurs (e.g., as manifested in increased variability after elimination of lengthy pauses) is relatively invariant across age groups. It remains to be seen, however, whether the above considerations apply only to the particular tapping task used, i.e., speeded repetitive tapping, or also apply when subjects attempt to maintain a steady tapping rhythm (e.g., McFarland & Ashton, 1978; Michon, 1964, 1966).

Because the speaking task was performed without, as well as with, concurrent tapping, it was possible to ascertain that tapping also disrupted speaking. However, the disruption did not vary as a function of the hand performing the tapping. Thus, as in nearly all previous dual-task laterality studies with children (see Kinsbourne & Hiscock, 1983), lateralized interference was observed only in one direction, i.e., from the nonmanual to the manual task. There is as yet no satisfactory explanation for this intransitivity of lateralized interference (Hiscock, 1982).

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