Lateralization of speech production using verbal/manual dual tasks: meta-analysis of sex differences and practice effects

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Abstract
The present paper reviews the findings of 30 years of verbal/manual dual task studies, the method most commonly used to assess lateralization of speech production in non-clinical samples. Meta-analysis of 64 results revealed that both the type of manual task used and the nature of practice that is given influence the size of the laterality effect. A meta-analysis of 36 results examining the effect size of sex differences in estimates of lateralization of speech production indicated that males appear to show slightly larger laterality effects than females. © 2002 Elsevier Science Ltd. All rights reserved.

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1. Introduction
The dominance of one cerebral hemisphere for language (language lateralization) is, “the most obvious and most often cited cognitive asymmetry” between the cerebral hemispheres ([6], p. 61). The purpose of this paper is to review the findings of studies on the lateralization of speech production using verbal/manual dual tasks.

Dual tasks were initially developed to study divided attention. When performing a dual task, the requirements of each task have to be held concurrently in working memory. The underlying assumptions are that the processing demands of the tasks are additive, and that attentional resources have to be distributed across both tasks, with sufficient resources being allocated to each task for it to be performed. The limited capacity of the central executive explains why the performance of concurrent tasks leads to increased cognitive demands [22]. Since coordination of the tasks requires additional resources, the amount of capacity/resources allocated to performance of each task decreases. The decline in the performance of the dual tasks compared to the single task levels is known as the dual task decrement. In right-handed individuals, the dual task decrement is typically more extreme for right-hand performance combined with simultaneous speech than for the left. This performance pattern is known as the lateralized dual task decrement and is interpreted as reflecting left-hemisphere lateralization of speech production.

Various theories have been proposed to explain this finding. One theory, the functional cerebral distance hypothesis, suggests that the lateralized dual task decrement seen in right-handers stems from the fact that in 95% of right-handers both right hand performance and speech production are controlled by the left-hemisphere [4,17,27]. In contrast, left hand performance is controlled by the right-hemisphere and speech by the left-hemisphere. Thus, when a concurrent manual task is being performed by the left hand, the two activities are under the control of separate hemispheres and may proceed in parallel. In contrast, during the concurrent right-hand performance, the left hemisphere is forced to serialize tasks. Alternatively, the theory of statistical bias suggests that the lateralized dual task decrement is due to an artifact caused by different levels of performance between the hands during the single task condition [33]. Since the lateralized dual task decrement is observed even when the left- and right-hand single task performance is equal [2], the statistical bias interpretation becomes untenable.

The finding that left-handers show a greater dual task decrement in the left hand lead to the development of the manual dominance theory [31]. This theory proposed that the dual task decrement is attributable to the differences in the amount of cortex allocated to the control of the dominant and non-dominant hand. However, one would expect that the cerebral laterality of left-handers would be attenuated,
because language functions are left-hemisphere lateralized in approximately 76% of left-handers, while 10% show right-hemisphere lateralization and the remaining 14% show bilateral representation of language functions [4,27]. Similarly, imaging studies have identified differences between right- and left-handers in cerebral dominance for control of motor functions. In right-handers, the left hemisphere contributes to the control of both hands, while the right hemisphere does not contribute to the control of the right hand [29,30]. However, this asymmetry has not been found in left-handers. Thus, the finding of a greater left-than right-hand dual task decrement would only contradict the predictions of the functional cerebral distance hypothesis if the size of this differential decrement in left-handers was equal to the size of lateralized dual task decrement shown by right-handers. This issue has not yet been examined.

Verbal/manual dual task methodology has been used to investigate sex differences in language lateralization. However, the investigation of sex differences is complicated because across the many different methods used to assess lateralization, “almost every conceivable pattern of results has been reported so that no clear pattern emerges” ([6], p. 235). Verbal/manual dual task studies investigating sex differences in lateralization typically find either no sex differences, or stronger lateralization of language function in males than in females. Attempts to account for the diversity of these results are complicated by the lack of methodological information provided in many studies. Many studies provide no information about the sex composition of their sample [8,14,23–25]. Nor have any studies attempted to match the male and female participants on variables such as the level of relative skill between the left- and right-hands or verbal intelligence. Although the methodology allows for analysis of performance of both tasks, most studies report analysis of the manual data only. Statistical analyses of the lateralized dual task decrement within the verbal/manual dual task literature are very similar. The lateralized dual task decrement is presented as a Hand (left, right) × Condition/Task (single, dual) analysis (in analyses of difference scores this interaction is presented as a main effect of Hand). In studies of right-handed samples, data analyses are consistent between studies. However, the amount of practice given, the type of tasks used, the trial duration, and the number of experimental trials have varied markedly. Although an early verbal/manual dual task study noted that the dual task decrement decreases with practice [16], the effects of practice across studies have not been systematically examined, and individual reports on the effects of practice have been on all male samples [7,26]. Such procedures have left unanswered the concomitant effects of task variables and sex differences in performance of verbal/manual dual tasks.

The current paper addressed notable gaps in the published studies of verbal/manual dual tasks. Firstly, the statistical significance and effect size of the lateralized dual task decrement has not been subjected to meta-analysis and similarly, there is no meta-analytic review of sex differences in the lateralized dual task decrement. The present study addressed both of these issues.

Recent reviews of functional lateralities have examined the effect sizes and significance of laterality and sex effects across a range of dual task laterality studies [13], and in the visual hemifield [12,32], auditory (dichotic) [11,32], and tactile (dichaptic) modalities [10,32]. The main findings were medium–large laterality effects and small sex effects across modalities [11,12,32]. However, the laterality and sex effects shown on verbal/manual dual tasks have not been examined using quantitative meta-analytic methods.

As stated above, statistical analyses of the lateralized dual task decrement observed in most reports on the verbal/manual dual task have been very similar. However, studies differ on the type of tasks used and the amount of practice given. Across modalities (visual, auditory and tactile) Voyer [32] found that different types of tasks produced different sized laterality effects. In the verbal/manual dual task literature, the majority of studies used finger tapping as a manual task. However, some early studies used dowel-balancing tasks [7,15,16,20,21] and a variety of other motor tasks [3,19,20,21]. Since these manual activities are very different, corresponding differences in the sizes of the effects they produce may be expected.

The amount of practice given before data are recorded potentially confounds the size of the lateralized dual task decrement. Details of practice sessions, the number of experimental trials and the duration of trials differ markedly between studies and some studies do not report the details of participant’s practice [1,5,14,18]. There are two ways in which practice may affect performance. If practice leads to more automatic responses, with an implied reduced competition for resources, then the size of the lateralized dual task decrement may decrease with practice. However, an opposite effect of practice may be to decrease error variance, which may increase the size of the lateralized dual task decrement. Studies differ in the type of practice they report with some reporting only single task performance while others report both single and dual task performance. Since the laterality analyses examines dual task performance, relative to single task performance, it is possible that including practice in the dual task condition may have a different effect on the lateralized dual task decrement than only single task practice.

Sex differences in the size of laterality effects observed in the auditory, visual and tactile modalities are small, but significant, suggesting that consistent sex differences exist across modalities, with males showing greater lateralization of function than females [32]. Of the verbal/manual dual task studies reviewed in the present paper that examine sex differences in language lateralization, at least one-fifth report greater lateralization of language functions in males than females. Thus, across verbal/manual studies that examine sex differences in the lateralized dual task decrement, a significant sex effect with males showing greater lateralization of
language functions than females would be expected. Four hypotheses were developed:

1. Since most (75%) published Verbal/Manual Dual Task results report a significant lateralized dual task decrement, it was hypothesized that across studies, the lateralized dual task decrement would be significant.

2. Mean effect size of studies that used finger tapping as a manual task would differ from those that used dowel balancing or other types or tasks (whole arm tapping, wheel turning, etc.).

3. The type of practice trials (single and dual task practice versus single task only practice) would affect the size and significance of the lateralized dual task decrement.

4. Across the Verbal/Manual Dual Task studies that examine sex differences in lateralization, a significant sex effect would be found. Males were expected to show a greater lateralized dual task decrement on manual task performance than females.

2. Method

2.1. Selection criteria for inclusion in the meta-analysis

Studies listed in the PsychINFO database were elicited using the keywords language, speech, dual task, concurrent task, time sharing, verbal, manual or lateralization and were reviewed. Only those studies that used the verbal/manual dual task methodology to assess lateralization of spoken language in a sample of neurologically ‘normal’ right-handed individuals were included. This procedure resulted in sampling the results of 65 laterality analyses, and 36 analyses of sex differences in lateralization that were drawn from 44 studies (34–77).

Limiting the sample to published research helps to ensure that scientific rigor of methods and results has been applied to these studies selected for inclusion in a meta-analysis. However, this procedure may lead to an overestimation of effect sizes [28]. This is known as the ‘file drawer’ problem and refers to the tendency to file rather than publish results that produced no significant differences in the effects of interest. This issue was addressed by conducting a ‘fail safe analysis’ to determine whether the significance of a meta-analytic result was due to the sampling of published research rather than a true significant effect. The fail safe analysis compares the ‘fail safe number’ (the number of studies averaging null results that would be needed to offset the significance of results) with a criterion of five times the number of sampled studies plus 10 (5k + 10, where k equals the number of studies sampled) [32].

2.2. Procedure

Since few studies report any analysis of the verbal task data, the current meta-analysis was conducted on the results of the manual task. The laterality analyses sampled were Hand × Condition (raw data) or Hand (derived data) analyses. The sex differences in laterality analyses sampled were Sex × Hand × Condition (raw data) or Sex × Hand (derived data) analyses. Rosenthal’s [28] procedures for the combination of significance levels were followed to determine the significance of effects across studies and heterogeneity. A value of zero was substituted if a study did not report the significance of a result, however, if a result was reported as significant but the exact significance of a result was not reported a significance level of p = .05 was substituted. Differences between the significance levels were assessed using Rosenthal’s formulae for linear comparison of Z-values [28].

The laterality analysis followed Voyer’s [32] hierarchical approach by first calculating the main effect of laterality and then partitioning the sampled studies into groups based on predetermined variables until statistical homogeneity of the significance levels was detected. Studies were partitioned by the type of manual task that was used and then by the type of practice that was given. The process that was used to partition studies is illustrated in Fig. 1. The hierarchical approach was not needed in the sex differences analysis as the results sampled were found to be statistically homogeneous.

<table>
<thead>
<tr>
<th>Studies using the verbal/manual dual task paradigm to assess lateralisation of spoken language in neurologically normal individuals</th>
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<tbody>
<tr>
<td>What manual task was used?</td>
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<tr>
<td>Balancing a length of dowel</td>
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<tr>
<td>Was practice given?</td>
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<tr>
<td>Single and dual task conditions were practiced</td>
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Fig. 1. Procedure that was used to partition the studies included in the analysis of laterality effects.
3. Results

3.1. Meta-analysis of the dual task decrement

The results of the analysis of laterality effects are presented in Table 1. As hypothesized, there was a large laterality effect across both the unpartitioned and the partitioned results. In the unpartitioned result, the laterality effect was significant. The fail safe analysis indicated that 6770 studies averaging null results would be required to offset the significance of this effect. However, there was significant heterogeneity within the sampled studies.

Partitioning according to the type of manual task used revealed that balancing tasks formed a homogeneous group, which showed large significant laterality effects that were unlikely to be due to the file drawer problem. A significant laterality effect was also found within the finger tapping studies and was unlikely to be due to the file drawer problem, but there was significant heterogeneity within this group of studies. Studies using other tasks were both heterogeneous and likely to be due the file drawer problem as only eight studies would be required to offset the significance of this effect. As hypothesized, different manual tasks produced different effect sizes. Finger tapping studies had a greater effect size than studies that did not use finger tapping ($z = 10.48$, $p < .001$). However, due to the small number of published studies that used other manual tasks, there was no difference in effect size among the studies using tasks other than finger tapping (balancing tasks compared to other miscellaneous tasks $z = 1.53$, n.s.).

Partitioning the finger tapping studies according to the type of practice revealed significant laterality effects. In studies that gave only single task practice and studies in which practice was not specified, the significant laterality effect was unlikely to be due to the exclusive sampling of published studies. However, the significant laterality effect for the group of studies in which both single and dual task practice was given, may be due to the exclusive sampling of published results. As hypothesized, studies in which only single task practice was given, showed larger effect sizes than those in which both single and dual task practice was given ($z = 5.67, p < .001$).

3.2. Meta-analysis of sex differences in the dual task decrement

As previously stated, the heterogeneity statistic revealed that the 36 results sampled belonged to a homogeneous group. A small but significant effect of sex differences in laterality was found, with males showing greater lateralization than females. However, the fail safe analysis revealed that this significant result may to be due to the exclusive sampling of published results. The significant effect of sex differences in laterality on verbal/manual dual tasks would be negated if 50 studies averaging null results existed.

4. Discussion

The aim of the current study was to ascertain the significance and size of the laterality effect obtained from verbal/manual dual tasks and to examine the effects of task variables and sex on this lateralized decrement. As hypothesized, a large significant laterality (dual task decrement) effect was found. Task type, and the type of practice that participants were given (in finger tapping studies) were both found to affect the size of the laterality effect.

Differences in effect sizes were evident between studies that used finger tapping as the manual task and studies that used other types of tasks. One possible explanation of this result lies with the difficulty of the tasks, and the allocation of attention between the verbal and manual tasks. Instructing the participant to concentrate on either the manual or the verbal task has been found to affect the lateralized dual task decrement.
decement [9]. In the absence of such instructions, the participant may be expected to allocate more attention to the task that presents greater difficulty. In a dowel-balancing dual task the manual task may be perceived as more difficult than the concurrent speech task. In contrast, in a finger-tapping dual task, the verbal task may appear more difficult. Based on previous research [9], the effect of allocating attention in this way would lead to smaller lateralized dual task effects in dowel-balancing studies than in finger-tapping studies. If this hypothesis is correct, one might expect to find a larger lateralized dual task decrement in the verbal task with concurrent balancing compared to a verbal task with concurrent finger tapping.

Within the studies that used finger tapping, differences in the size of the lateralized effect were seen between those that gave both single and dual task practice, and those that gave only single task practice. Studies that gave both types of practice yielded smaller effect sizes than those that gave only single task practice. These findings suggest that the type of practice given has an important effect on the size of the lateralized effect, but does not address the issue of differing amounts of practice. Further research is needed to examine whether the amount of practice given affects the size of the lateralized dual task decrement obtained.

The majority of recent verbal/manual dual tasks use finger tapping as the manual task. However, selecting a manual task when designing dual task experiments has been largely based on convenience. The popularity of the finger-tapping methodology may be due to its practicality when compared to other manual tasks. Finger-tapping tasks can be run using computer programs and they are efficient in terms of experimenter and participant time. Furthermore, the finger-tapping task has a number of specific advantages over the dowel-balancing task. In the finger-tapping task there is less chance of potential injury (to both experimenter and participant), there is less chance of human error in measurement (dowel-balancing experiments have used stop watches to time duration of balancing) and the dowel-balancing methodology typically results in a large number of participants being excluded for failing to meet a minimum balancing time.

Although there are numerous reasons for the popularity of the finger tapping methodology, the choice of which manual task to use has not been based on experimental evidence that objectively assesses the size of the lateralities effects obtained by different tasks. The findings of the present meta-analysis address this problem. It showed that at a group level verbal/manual dual tasks that use finger tapping as the manual task yield similar effect sizes to those using dowel-balancing. However, when the type of practice given is considered, dual tasks using finger tapping that give only single task practice show a larger effect size than dual tasks using other manual tasks. These results suggest that verbal/manual dual tasks that use finger tapping, and give only single task practice may be most suitable for assessing language lateralization, on the basis of yielding larger effect sizes.

Previous reviews of sex differences in laterality in the visual, auditory and tactile modalities have reported small but significant sex differences, finding greater lateralization of function in males than females [10–12,32]. Similarly, a recent qualitative review of sex differences in dual task studies (including some verbal/manual dual task studies) reported this pattern of results but did not provide quantitative information about the size of the sex effect [13]. The results of the present study support these findings showing that across studies using verbal/manual dual tasks, there is a small but significant sex effect, with males showing greater lateralized dual task decrements than females. While the sex effect was significant across studies the null results showed by the majority of studies may be due to insufficient sample size, sampling or characteristics of tasks which were used (e.g. using a pen tapping task [1]). As Voyer [32] suggests, based on the available meta-analytic evidence, “it is legitimate to state that sex differences in laterality are significant but small in the context of meta-analysis, but that null results are prevalent at the level of individual studies” (p. 69). While sex differences in laterality may reflect differences in the organization [13] or physiology [32] of male and female brains, there are other possible explanations. Firstly, it is possible that males and females may approach and perform tasks differently. However, given the range of tasks and modalities across which significant sex differences have now been found; it seems unlikely that there is a consistent difference in strategy between male and female participants which would result in a finding of greater lateralization of function in males, both during a verbal/manual dual task and a dichotic stimulation task.

A second suggestion is that the findings of sex differences in laterality are due to the exclusive sampling of published research and that the significant finding would be reversed if all unpublished papers were available. Given that the quantitative meta-analytic reviews which have examined the topic of sex differences in laterality (Voyer [32] and the current study) have found that the fail safe number for the sex effect was smaller than the $5k + 10$ criteria suggested by Rosenthal [28], it is possible that these findings may be due to the file drawer problem. It has previously been suggested that the failure to find sex differences will not preclude publication as the question of sex differences is not central to the majority of studies [13]. However, it is possible that the anecdotal nature of this experimental effect may have lead to the non-reporting of non-significant sex differences in many published verbal/manual dual task studies.

In conclusion, the present meta-analytic review investigated the significance and size of the lateralized dual task decrement and the effect of task variables and sex on this decrement. Both task type and the nature of practice given were found to affect the size of the laterality effect with the largest lateralized dual task decrement found in studies that used a finger-tapping manual task and gave only single task practice. A small but significant sex difference was found with males showing greater lateralization of function.
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References

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[64] Lomas J. Competition within the left hemisphere between speaking and unimanual tasks performed without visual guidance. Neuropsychologia 1980;18:141–9.


