SENSORY-MOTOR INTEGRATION CAPACITY OF STUTTERERS AND NONSTUTTERERS

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ABSTRACT - We review a series of studies concerning the auditory-motor and visual-motor tracking performance of stutterers and nonstutterers. We find no evidence of lateralization differences between the groups and interpret the finding that stutterers perform auditory tracking tasks significantly less well than nonstutterers as evidence of a deficit in ability to form internal auditory-motor models which subserve speech control.

INTRODUCTION

Stuttering is a disorder of speech motor control. Among hypotheses concerning its nature, deficiency in sensory-motor integration processes has been a recurring theme. Some have proposed anomalous lateralization of such processes. Others, noting the similarity between stuttered speech and disfluency induced in nonstutterers by delayed auditory feedback, have argued that a deficit sensory-motor integration leads to control system breakdown. This presentation gives an overview of a series of studies in which we have addressed these issues. For further details see Neilson (1980), Neilson & Neilson (1980, 1987) and Neilson et al. (1985).

TRACKING PERFORMANCE OF STUTTERERS AND NONSTUTTERERS

The auditory-motor skills of 12 stutterers and 12 nonstutterers were tested by means of a dichotic pursuit pitch tracking task. Through one stereo earphone subjects heard a stimulus tone which varied continuously in pitch. Through the opposite earphone a response tone was heard with pitch controlled by the subject. The task was to keep the pitch of the tones matched. Each subject completed a five-minute test in each of four configurations designated RJ, LJ, RH, LH, the R or L indicating the ear receiving the response tone and the J or H indicating whether the tone was controlled by jaw or hand response. Subjects also completed two pursuit visual tracking tests, one using a jaw response (VJ), the other a hand response (VH). While the auditory tests required the pitch of the dichotically presented stimulus and response tones to be matched, the visual tests required the vertical position of stimulus and response display markers to be matched. Otherwise the tracking implementation remained identical for both auditory and visual tracking.

Speed and accuracy of each subject's performance was assessed using cross-correlational and power spectral analysis to compute phase and coherence characteristics for each test. Results were averaged within conditions and compared across groups using analysis of variance. Unlike Sussman and MacNeilage (1975) who used error score analysis, we found no evidence of lateralization differences between stutterers and nonstutterers. However, the systems measures showed the stutterers' auditory-motor tracking performance to be significantly inferior to that of the nonstutterers, whereas the visual-motor performance of the two groups was comparable. Figures 1 and 4 show the averaged characteristics for the auditory tracking performances of stutterers and nonstutterers. The greater phase lag for stutterers in Figure 1 reflects longer time delay between auditory stimulus and correlated motor response. The lower coherence for stutterers in Figure 4 indicates that a lower proportion of response variation was correlated with stimulus variation or, in other words, the stutterers tracked with a higher proportion of inappropriate response or "noise".

The differences observed in the characteristics which describe the auditory-motor tracking performances of stutterers and nonstutterers have parallels to the differences we have seen when comparing other types of tracking performances. Before attempting to interpret the above results we will examine these parallels. Two experiments will be reviewed, both of which examine the visual-motor tracking performance of normal, nonstuttering subjects.

THE EFFECT OF CONTROL-DISPLAY COMPATIBILITY ON TRACKING PERFORMANCE

The effect of differences in control-display (C-D) compatibility was examined in the visual pursuit tracking performance of 24 normal subjects. The task was to superimpose a response marker on a stimulus marker which moved continuously up and down the centre of a graphics display screen. Vertical position of the response marker was controlled either by a light pen (highly compatible C-D relationship) or by a lever (less compatible C-D relationship).

Speed and accuracy of each subject's performance in each condition were assessed by systems analysis measures, as above. Results were averaged within conditions and compared using analysis of variance. Figures 2 and 5 show the averaged characteristics and indicate that tracking performance with the less compatible lever was significantly inferior to that with the highly compatible light pen. The greater phase lag in Figure 2 reflects the longer delay between movement of the stimulus and movement of the response marker when the latter was controlled by the lever. Likewise, the lower coherence in Figure 5 reflects the higher proportion of noise in the response when generated by the lever rather than by the light pen.

THE EFFECT OF PRACTICE ON TRACKING PERFORMANCE

The second parallel with the finding on stutterers and nonstutterers involves extensive practice on a visual pursuit tracking task using a highly incompatible C-D relationship. A single subject's performance was assessed on a task where the response marker on a graphics display screen was required to be superimposed on a continuously vertically moving stimulus marker. Position of the response marker was controlled inversely by a remote light pen. This difficult C-D relationship was practised for a total of 1000 minutes spread over 100 days. Pre- and post-practice assessment used a stimulus signal different from that used in the practice period.

Pre-post performance was compared in terms of speed and accuracy using systems analysis measures, as above. After extensive practice using the incompatible C-D relationship, tracking performance improved significantly as shown in Figures 3 and 6. The decrease in phase lag after practice (Figure 3) reflects a reduction in the average delay between movement of the stimulus and movement of the response marker. Likewise in Figure 6, the higher coherence after practice indicates that the subject reduced the amount of inappropriate movement in his response. These improvements were distinct from stimulus prediction effects.

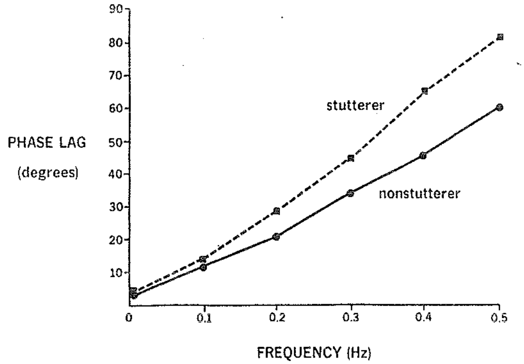

Figure 1.
Mean phase characteristics for auditory tracking in stutterers and nonstutterers.

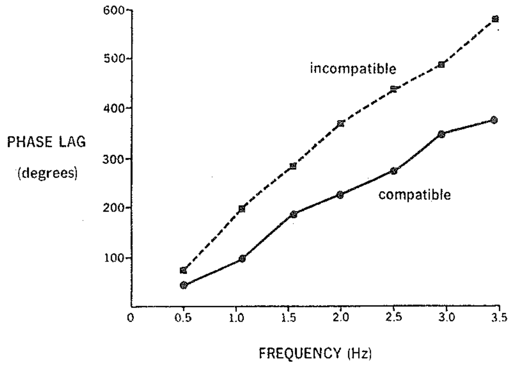

Figure 2.
Mean phase characteristics for visual tracking with high and low control-display compatibility.

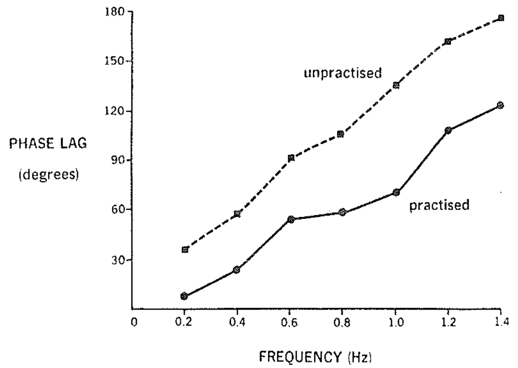

Figure 3.
Phase characteristics for practised and unpractised visual tracking.

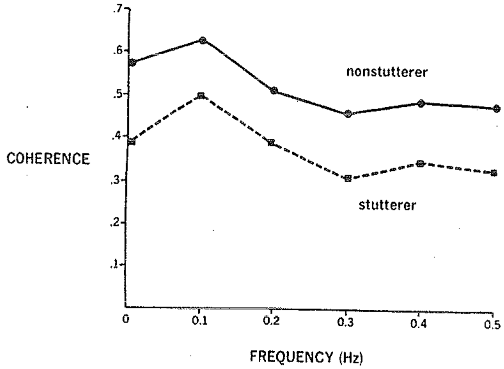

Figure 4.
Mean coherence characteristics for auditory tracking in stutterers and nonstutterers.

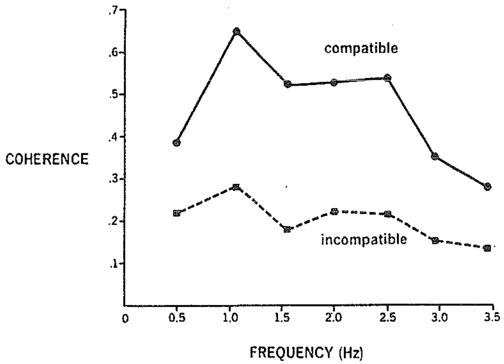

Figure 5.
Mean coherence characteristics for visual tracking with high and low control-display compatibility.

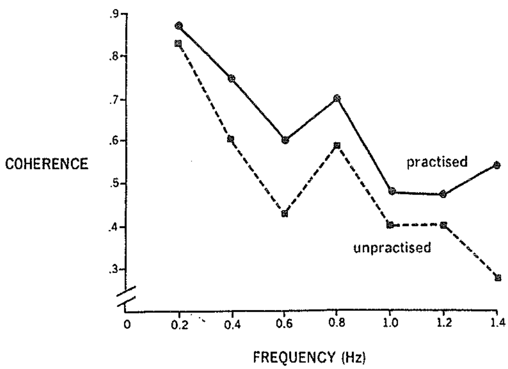

Figure 6.
Coherence characteristics for practised and unpractised visual tracking.

DISCUSSION

There are obvious similarities between the various tracking characteristics presented in the three experiments above. We contend that the following interpretation of the two sets of visual tracking data sheds light on the processes which mediate the differences in auditory tracking performance between stutterers and nonstutterers. This, in turn, has implications concerning the aetiology of stuttering.

When a subject tracks with an incompatible C-D configuration, there is a greater amount of inappropriate response movement and a longer response time lag than when tracking the same stimulus with a compatible C-D configuration. The idea presented here is that C-D compatibility is not so much a property of the C-D hardware itself but rather, a reflection of the subject's familiarity with the sensory-motor relationship involved in moving the control and experiencing the consequent effect on the display. Thus a direct light pen control is compatible because subjects routinely move pens under visual guidance. As shown in the practice experiment, an incompatible C-D configuration can cease to be so if sufficient experience with the underlying sensory-motor relationship is obtained. Many authors support the idea that skilled movement is generated with reference to an internal store of information established by integration of sensory feedback with the motor activity which produced it. Such internal models of the relationship between efferent and reafferent signals are regularly verified and where necessary updated (Neilson & Neilson, 1987), thereby facilitating both adaptive behaviour and learning. We have consequently interpreted the first experiment as indicating that stutterers have inferior ability to form and/or utilize internal models of auditory-motor relationships.

REPLICATION

More recently we carried out a further investigation of tracking performance in stutterers and nonstutterers. The experimental method replicated that of the first study with only one important and intentional exception. Because the first study was principally designed to address lateralization issues we had imposed a minimum performance criterion for subjects to enter the study. Our concern then was to use each subject as his own control in establishing laterality bias, or the lack of it, and we therefore chose to use well-practised subjects to minimize variance due to unfamiliarity with the task. Subjects practised for one hour and did not proceed to the main tests if they failed to reach a moderate performance criterion. When our focus turned to the performance difference found, despite this selection, between stutterers and nonstutterers, we checked our log of rejected subjects and found that a significant majority were stutterers! We therefore hypothesized that had we used less practised subjects without selection, our stutterer-nonstutterer differences might have been even greater. Our subsequent experiment therefore used subjects who completed the same auditory and visual tests after undergoing only basic task familiarization.

Contrary to expectation, results were not enhanced. Phase characteristics for the groups are given in Figure 7 and show a reduced effect. While still reaching significance the test could only be conducted in terms of the difference in slope between regression lines fitted to phase estimates where squared coherence had reached .05 or better. Extremely poor coherence, and consequent unreliability of the corresponding phase measures, was not a problem in the previous study because of the

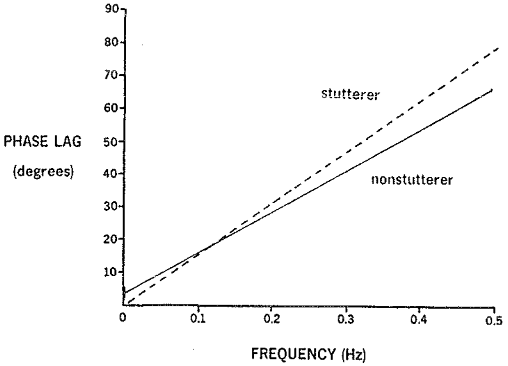

Figure 7. Regression lines for stutterers and nonstutterers fitted to phase characteristics for auditory tracking with coherence square >= .05

performance criterion. The diminished result could be attributable to sampling, but we submit that lack of practice, operating contrary to our original expectations, is a more likely source. We reason as follows. If we fit an equivalent time lag to the phase characteristics in our first experiment we obtain a delay between stimulus and response of 429 ms and 316 ms for stutterers and nonstutterers respectively. In the replication experiment we get 445 ms and 363 ms respectively. Thus it seems, despite practice, the stutterers learned minimally whereas the nonstutterers improved. This supports the idea that stutterers are deficient in their ability to form internal models of auditory-motor relationships, a view that fits well with most established facts about the disorder (see Andrews et al., 1983).

REFERENCES

Andrews, G., Craig, A., Feyer, A-M., Hoddinott, S., Howie, P., Neilson, M. (1983) "Stuttering: A Review of Research Findings and Theories Circa 1982", J. Speech Hear. Disord. 48, 226-246.

Neilson, M.D. (1980) "Stuttering and the Control of Speech: A Systems Analysis Approach", Ph.D. Dissertation, University of N.S.W.

Neilson, M.D., Neilson, P.D. (1987) "Speech Motor Control and Stuttering", Speech Communication 6, 325-333.

Neilson, P.D., Neilson, M.D. (1980) "Influence of Control-Display Compatibility on Tracking Behaviour", Quart. J. Exp. Psychol. 32, 125-136.

Neilson, P.D., O'Dwyer, N.J., Neilson, M.D. (1985) "Acquisition of Motor Skill in Tracking Tasks: Learning Internal Models", in "Motor Memory and Control", ed. Russell, D.G., Abernethy, B. (Human Performance Associates: Dunedin).

Sussman, H.M., MacNeilage, P.F. (1975) "Hemispheric specialization for speech production and perception in stutterers", Neuropsychologia 13, 19-26.