VERBO-MOTOR PRIMING IN PHONETIC ENCODING: SOME EVIDENCE FROM HIGH AND LOW FREQUENCY WORDS

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ABSTRACT

We report an investigation of the production of high and low frequency words across four subject groups: 1) young non-brain damaged controls (NBDC1, N=7: mean age 25 years); 2) older non-brain damaged controls (NBDC2, N=6: mean age 53 years); 3) brain damaged controls (BDC, N=3: mean age 64 years), and 4) speakers with apraxia of speech (AOS, N=5: mean age 63 years). The BDC and AOS groups were differentiated by the presence of apraxia. The stimuli used in the study consisted of three repetitions of ten pairs of high-low frequency nouns e.g. bile-mile (high frequency>100 occurrences per million, low frequency <10 occurrences per million). The results from all three repetitions of the acoustic measures (response latency, utterance duration and word duration) of all four groups are presented and discussed with reference to observed patterns of verbo-motor priming, together with implications for phonetic encoding and the motor execution of speech.

1. INTRODUCTION

Acquired apraxia of speech (AOS) is a motor speech disorder that *typically* results from damage in the area of the pre-motor cortex in the language-dominant hemisphere. The characteristics of this motor speech disorder include: a slow rate of speaking [5]; prosodic abnormalities [4]; inconsistent and variable articulatory movements [2], and disruptions in all speech production systems involved in the phonetic encoding of the linguistic message. These disruptions result in multiple phonetic and perceived phonemic errors in speech output that therefore can result in lowered speech intelligibility [9].

The traditional conceptualisation of AOS is influenced by psycholinguistic models that suggest that the speech segment plays a critical role in the encoding of speech [1, 7]. In these models, speech encoding is viewed as a process of segment-by-segment access and the subsequent assembly of the syllable/word. Much of the empirical evidence for such theories rests on speech error data from normal speakers (e.g. segmental switches which convert 'car park' to 'par cark'), and AOS is viewed as a failure of these segmental access and syllable assembly processes.

Contemporary psycholinguistic models have, however, begun to challenge the role of the segment in speech production [6]. It has been suggested that there are two possible routes in speech encoding: a direct[1] route that operates via stored syllabic schemas, and an indirect[2] assembly route that utilises sub-syllabic units. Direct route encoding is more likely to be used for higher frequency syllables and the indirect route for lower frequency or novel syllables. Direct route encoding permits an efficient and relatively error free output as the multiple degrees of freedom of the speech motor system are constrained into schemas or gestural gestalts [3].

Whiteside and Varley [11] suggest that AOS can usefully be reconceptualised within the direct/indirect or dual-route route hypothesis. They argue that in AOS, either the access to and/or the storage of high frequency verbo-motor patterns are disrupted, and that much of the abnormal speech behaviours of speakers with AOS represents an attempt to compensate for this fundamental processing impairment by a reliance on indirect mechanisms. They also suggest that indices of encoding route include parameters such as response latency, utterance and word durations and the degree of coarticulation, with increasing latencies and durations and decreasing coarticulation with indirect route encoding. There is some evidence, which suggests that there may be dual routes operating in the encoding of speech of both speakers with AOS [10] and young and older normal speakers [12]. These results were based upon the data of the first repetition set of three repetitions of high and low frequency words.

We report here, an investigation of the production of the high and low frequency words across four subject groups: 1) young non-brain damaged controls; 2) older non-brain damaged controls; 3) brain damaged controls; and 4) speakers with AOS. The data used in the study are based upon *all three* repetitions of ten pairs of high-low frequency nouns e.g. bile-mile (high frequency>100 occurrences per million, low frequency <10 occurrences per million), that have been previously reported [10, 12].

The results from all three repetitions of the acoustic measures (response latency, utterance duration and word duration) from the four groups of subjects are presented and discussed with reference to observed patterns of verbo-motor priming learning effects, together with implications for phonetic encoding and the motor execution of speech.

2. METHODOLOGY

2.1. Subjects

Four groups participated in the study:

1. young non-brain damaged controls (NBDC1, N=7, mean age 25 years);
2. older non-brain damaged controls (NBDC2, N=6, mean age=53 years);
3. brain damaged controls (BDC, N=3, mean age=64 years); and
4. speakers with acquired apraxia of speech (AOS, N=5, mean age=63 years).

All participants in the study were female. All speakers from groups 2, 3 and 4 were from South Yorkshire except for one brain-damaged control, and although speakers from Group 1 were living in South Yorkshire at the time of the study, they did not originate from this region.

The brain-damaged subjects all:

- had left-hemisphere lesions;
- were pre-morbidly right-handed;
- were neurologically stable (a minimum of 1 year post onset);
- had varying degrees of aphasic impairment; and
- had no significant dysarthria.

The brain-damaged controls had no apraxic difficulties. Two were fluent conduction aphasics, and one was an agrammatic aphasic.

The criteria used in the diagnosis of AOS included:

- the agreement of two independent clinicians;
- prosodic abnormality which was characterised by marked syllable segregation and effort, accompanied by sudden bursts of energy with rapid decay; and
- intact gross oral movement.

2.2. Speech data

The speech material used in the study consisted of three repetitions of a set of phonetically matched 10 high frequency words (occurrence of more than 100 per million) and 10 low frequency words (occurrence of less than 10 per million). These words were selected from Thorndike and Lorge [8].

The high frequency words were: 'mile', 'base', 'pound', 'bag', 'school', 'cold', 'foot', 'group', 'cup' and 'car'. The low frequency words were: 'bile', 'mace', 'mound', 'bog', 'stool', 'colt', 'soot', 'croup', 'cub', and 'tar'. This gave a total of thirty tokens for each of the high and low frequency word groups, which were then randomised into a single list. Subjects were instructed to repeat each word after the experimenter. Each word was preceded either by 'a' or 'the'. All sessions were recorded in a quiet room using a DAT recorder. A repetition paradigm was used to limit the level of linguistic encoding in the phonetic encoding of the speech data.

2.3. Acoustic analysis

All speech data were digitized (SR 10kHz) and analysed using a KAY Computerized Lab (CSL) Model 4300. Speech pressure waveforms and wideband FFT spectrograms were used in the acoustic analysis. Only stimuli that were perceived as being 'on target' were analysed.

The measures that were taken using acoustic data included:

- response (or repetition) latencies (in milliseconds) - these were measured from the end of the acoustic activity associated with the experimenter's utterance to the start of the acoustic activity associated with the participant's utterance;
- utterance durations (in milliseconds) - these were measured from the acoustic activity marking the beginning of the utterance to the end of the acoustic activity of entire utterance (i.e. 'The Mile');
- word durations (in milliseconds) - these were measured from the start of the acoustic activity of the target high/low frequency word to the end of the acoustic activity associated with the target high/low frequency word;

5. RESULTS

5.1. Response Latencies

Mean and standard deviation values for the response latencies (in milliseconds) are given in Table 1 for all four groups by repetition and frequency. A three way repeated measures ANOVA (frequency x repetition x group) indicated that there were significant frequency ($F(1, 161)=5.9$, $p<.05$) and repetition ($F(2, 160)=14.1$, $p<.0001$) effects, with the high frequency words showing shorter response latencies than the low frequency words, and decreasing response latencies with increasing repetition. There were also significant interaction effects of repetition by group ($F(6, 322)=2.9$, $p<.01$), frequency by repetition ($F(2, 160)=4.2$, $p<.05$) and frequency by repetition by group ($F(6, 322)=4.4$, $p<.0001$). There was however, no significant interaction effect of frequency by group.

In addition, there were significant differences between groups ($F(3, 161)=83.1$, $p<.0001$). Post-hoc Bonferroni tests indicated that there were significant differences ($p<.05$) for the following inter-group comparisons for the response latencies of the high frequency words: First repetition - NBDC1, NBDC2, BDC groups vs. the AOS group, with the AOS group showing longer response latencies for all inter-group comparisons; Second repetition - NBDC1, NBDC2 and BDC groups vs. the AOS group, with the AOS group showing longer response latencies for all inter-group comparisons; NBDC1 and NBDC2 groups vs. the BDC group, with the BDC group showing longer response latencies for both inter-group comparisons; and Third repetition - NBDC1 and NBDC2 vs. the AOS and BDC groups, with the NBDC1 and NBDC2 groups having shorter response latencies than both the AOS and BDC groups;

Group	High Frequency			Low Frequency		
	Repetition 1	Repetition 2	Repetition 3	Repetition 1	Repetition 2	Repetition 3
NBDC1 (N=7)	138.2 (95.6)	112.0 (88.2)	87.1 (68.6)	175.6 (115.5)	134.5 (78.0)	90.2 (70.4)
NBDC2 (N=6)	176.0 (79.3)	141.3 (98.4)	109.8 (68.8)	232.4 (115.1)	161.8 (81.2)	131.5 (75.6)
AOS (N=5)	912.0 (821.9)	562.8 (220.9)	561.1 (256.9)	747.3 (474.6)	947.5 (1264.1)	557.9 (289.5)
BDC (N=3)	366.1 (260.7)	358.3 (247.3)	457.0 (530.2)	535.6 (407.4)	477.1 (358.4)	405.4 (256.1)

Table 1. Mean and standard deviation values (given in milliseconds) for response latencies for all four groups by frequency and repetition.

Group	High Frequency			Low Frequency		
	Repetition 1	Repetition 2	Repetition 3	Repetition 1	Repetition 2	Repetition 3
NBDC1 (N=7)	630.8 (73.7)	619.9 (67.7)	605.8 (52.6)	628.5 (69.5)	619.7 (61.1)	608.9 (59.9)
NBDC2 (N=6)	651.9 (96.7)	658.5 (98.4)	666.0 (104.1)	668.4 (113.3)	660.8 (113.4)	669.0 (113.4)
AOS (N=5)	1154.7 (336.8)	1104.6 (276.8)	1018.3 (264.7)	1180.1 (383.5)	1238.0 (421.2)	1106.9 (266.8)
BDC (N=3)	757.5 (115.5)	724.1 (176.4)	728.8 (125.3)	845.9 (236.2)	814.1 (208.2)	787.1 (195.0)

Table 2. Mean and standard deviation values (given in milliseconds) for utterance durations for all four groups by frequency and repetition.

Group	High Frequency			Low Frequency		
	Repetition 1	Repetition 2	Repetition 3	Repetition 1	Repetition 2	Repetition 3
NBDC1 (N=7)	513.3 (82.6)	502.0 (74.7)	495.4 (63.8)	513.2 (86.0)	509.9 (77.8)	494.1 (84.0)
NBDC2 (N=6)	536.8 (106.2)	537.9 (105.9)	546.8 (107.8)	553.1 (133.8)	549.9 (127.2)	550.3 (122.2)
AOS (N=5)	659.8 (177.0)	656.3 (155.2)	622.4 (129.7)	632.0 (163.0)	621.1 (189.3)	615.1 (155.2)
BDC (N=3)	582.8 (111.8)	614.7 (153.4)	582.1 (102.4)	666.7 (236.0)	668.1 (228.5)	636.6 (186.2)

Table 3. Mean and standard deviation values (given in milliseconds) for word durations for all four groups by frequency and repetition.

In addition, the following significant group comparisons were found for the response latencies of the low frequency words: First repetition - NBDC1, NBDC2 and BDC groups vs. the AOS group, with the AOS group showing longer response latencies for all inter-group comparisons; NBDC1 and NBDC2 groups vs the BDC group with the BDC group having longer response latencies; Second repetition - NBDC1, NBDC2 and BDC groups vs. the AOS group, with the AOS group showing longer response latencies for all inter-group comparisons; Third repetition - NBDC1, NBDC2 and BDC groups vs. the AOS group, with the AOS group showing longer response latencies for all inter-group comparisons; NBDC1 and NBDC2 groups vs the BDC group with the BDC group having longer response latencies.

5.2. Utterance durations

Mean and standard deviation values for utterance durations (in milliseconds) are given in Table 2 for all four groups by repetition and frequency. A three way repeated measures ANOVA (frequency x repetition x group) indicated that there were significant effects of frequency ($F(1, 140)=32.1$, $p<.0001$) and repetition ($F(2, 139)=16.1$, $p<.0001$), with longer utterance durations for the low frequency words compared to the high frequency words, and shorter utterance durations with increasing repetition. There were also significant interaction effects for frequency by group ($F(3, 140)=10.1$, $p<.0001$) and repetition by group ($F(6, 280)=5.9$, $p<.0001$). There were however, no significant interaction effects for frequency by repetition, or for frequency by repetition by group.

There were also significant differences between groups ($F(3, 140)=55.2$, $p<.0001$). Post-hoc Bonferroni tests indicated that there were significant differences ($p<.05$) for the following inter-group comparisons for the utterance durations of the high frequency words: First repetition - NBDC1, NBDC2, BDC groups vs. the AOS group, with the AOS group showing longer utterance durations for all inter-group comparisons; NBDC1 and NBDC2 groups vs. BDC group with the BDC group showing longer utterance durations; Second repetition - NBDC1, NBDC2 and BDC groups vs. the AOS group, with the AOS group showing longer utterance durations for all inter-group comparisons; NBDC1 group vs. the BDC group, with the BDC group showing longer utterance durations; Third repetition - NBDC1, NBDC2 and BDC groups vs. the AOS group, with the AOS group showing longer utterance durations for all inter-group comparisons; NBDC1 group vs. the BDC group, with the BDC group showing longer utterance durations; NBDC1 vs NBDC2 groups with the NBDC2 group showing longer utterance duration values;

The following significant group comparisons were also found for the utterance durations of the low frequency words: First and second repetition for the low frequency words - NBDC1, NBDC2 and BDC groups vs. the AOS group, with the AOS group showing longer utterance durations for all inter-group comparisons; NBDC1 and NBDC2 groups vs the BDC group, with the BDC group having longer utterance durations for both inter-group comparisons; Third repetition for the low frequency words - NBDC1, NBDC2 and BDC groups vs. the AOS group, with the AOS group showing longer utterance durations for all inter-group comparisons; NBDC1 and NBDC2 groups vs the BDC group, with the BDC group having longer utterance durations for both inter-group comparisons; NBDC1 vs NBDC2 groups with the NBDC2 group showing longer utterance duration values;

5.3. Word durations

Mean and standard deviation values for word durations (in milliseconds) are given in Table 3 for all four groups by repetition and frequency. A three way repeated measures ANOVA (frequency x repetition x group) indicated that there were significant differences by repetition ($F(2, 153)=4.8$, $p<.01$) with word durations decreasing with repetition. There were however, no significant frequency effects. There was also a significant frequency by group interaction ($F(3, 154)=4.1$, $p<.01$). No significant interaction effects of repetition by group, frequency by repetition, or frequency by repetition by group were found.

In addition, there were significant differences between groups (F(3, 154)=11.3, p<.0001). Post-hoc Bonferroni tests indicated that there were significant differences (p<.05) for the following group comparisons for the word durations of the high frequency words: First repetition - NBDC1, NBDC2, BDC groups vs. the AOS group, with the AOS group showing longer word durations for all inter-group comparisons; Second repetition - NBDC1 and NBDC2 groups vs. the AOS group, with the AOS group showing longer word durations; NBDC1 group vs. the BDC group, with the BDC group showing longer word durations; Third repetition - NBDC1 and NBDC2 groups vs. the AOS group, with the AOS group showing longer word durations for both inter-group comparisons; NBDC1 group vs. the BDC group, with the BDC group showing longer word durations; NBDC1 vs NBDC2 groups with the NBDC2 group showing longer word duration values;

In addition, the following significant group comparisons were found for the word durations of the low frequency words: First repetition - NBDC1 group vs. the BDC and AOS groups, with the NBDC1 group showing shorter word durations for both comparisons; NBDC2 groups vs the BDC group, with the BDC group having longer word durations; Second repetition - NBDC1 group vs the AOS group, with the AOS group having longer word durations; NBDC1 and NBDC2 groups vs. the BDC group, with the BDC group showing longer word durations for both inter-group comparisons; Third repetition-NBDC1 group vs. the AOS and BDC groups, with the AOS and BDC groups both showing longer word durations than the NBDC1 group.

6. DISCUSSION

The group differences in the patterns of the response latencies, utterance durations and word durations by frequency, all have implications for speech encoding. For example, the subjects with AOS generally displayed significantly longer response latencies and longer utterance durations than those of the other three groups, for all three repetitions of both the low and high frequency words. In addition, this pattern was observed for the word durations of the high frequency words. These data characterise the nature of AOS where access to and/or the storage of verbo-motor patterns are disrupted and therefore result in delayed verbo-motor access and motor speech execution and longer utterance and word durations. There was also evidence of the BDC group displaying longer response latencies, utterance durations and word durations than both of the non-brain damaged control groups. Although the BDC group displayed no evidence of apraxia, it is suggested that LH damage may have affected the efficiency with which the speech motor plans were retrieved and executed for the low and high frequency words. The BDC subjects generally displayed strong frequency effects with longer response latencies, longer utterance durations and longer word durations for the low frequency words when compared to the high frequency words. However, the low frequency data showed stronger facilitation effects than the high frequency words, across the three repetitions.

Despite the group differences that were observed in the data, there were significant patterns in the *combined* data of the four groups. These combined data showed that the response latencies showed significant frequency effects with high frequency words generally showing shorter response latencies. In addition, significant repetition effects were found with decreasing response latencies with repetition. Utterance durations also showed significant frequency and repetition effects, with similar patterns to those for the response latencies. The word duration data showed significant repetition effects with decreasing word durations with increasing repetition. These data present some evidence for verbo-motor priming in the phonetic encoding of both high and low frequency words through the repeated elicitation of speech within a repetition paradigm.

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NOTES

1. This is termed the 'indirect' route in Levelt and Wheeldon [6].
2. This is termed the 'direct' route in Levelt and Wheeldon [6].

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