Performance of PWS on Self Select Reaction Time Paradigm Using Speech and Non Speech Tasks

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Abstract

The disorder of stuttering is viewed in terms of speech motor control perspective in the recent times. Most of the theories and models hint upon difficulty in initiating and controlling the speech movements as a common factor in persons with stuttering. Reaction time measures have been extended to study the common neuromotoric deficits across unrelated motor systems to generate an extensive data to verify that stuttering is a disorder extending beyond speech. Reaction time paradigms have been modified to tap the intended measure. In this study a modified reaction time paradigm called 'Self-Select Reaction Time Paradigm' is used to delineate the motor programming deficits if any seen in Person with stuttering (PWS) across non speech and speech tasks. Fifteen PWS who had undergone speech therapy, 10 PWS without any treatment and 25 normal controls in the age range of 16-30 years participated in the study. The Self Select Reaction Time Paradigm was used to measure the reaction time for two motor programming processes namely INT and SEQ across speech and non speech tasks within four (1short, 1long, 4long & 4short) conditions. The results revealed that both the groups differed in various conditions across speech and non speech tasks. A modality independent deficit in the INT process was evident which supported a generalized motor programming deficit in the organization of spatiotemporal sequences in PWS. The potential utility of the paradigm and the implications of the results to the current understanding of the disorder of stuttering are discussed.

Key words: stuttering, self select reaction time paradigm, motor programming

Van Riper (1982) defined stuttering as a disruption of the simultaneous and successive programming of muscular movements required to produce a speech sound or its link to the next sound in a word. This definition suggests a possible scope of understanding the disorder from the speech motor control perspective. The speech motor control perspective of stuttering is more than just one single theory or model and all these theories share the common hypothesis that PWS have difficulties in initiating and controlling speech movements in one way or other. They suggest that, in stuttering the speech mechanisms responsible for a precise adjustment of the respiratory, laryngeal and articulatory movements are operating less efficiently. At certain moments, this inefficiency causes a breakdown of speech fluency and results in dysfluencies. How exactly this takes place has not been understood in a strict sense.

The 'discoordination hypothesis' states that stuttering is presumably the result of constitutional inability to temporally co-ordinate respiratory, phonatory and articulatory subsystems in speaking (Perkins, Rudas, Johnson & Bell, 1976; Caruso, 1991). Few studies supported the discoordination hypothesis by using EMG measurements (Peters, Hulstijn & Starkweather, 1989). These studies reported a disruption of normal reciprocal action of abductor muscles in non fluent utterances which inturn suggested that stuttering might be due to the discoordinated activity between and within speech subsystems. Many other studies also supported the above hypothesis (Adams, 1974; Wingate, 1976; Zimmerman, 1980; Van Riper, 1982; Borden, 1983; Gracco, Caruso & Abbs, 1988; Harbison, Porter & Tobey, 1989). The hypothesis gradually lost its significance since few of the studies showed no differences in terms of discoordination between normals and PWS (Conture, Colton & Gleason, 1988). Also, it failed to account for the core behavioural features seen in PWS.

An alternative to the 'discoordination hypothesis' is the 'Speech planning hypothesis' (Postma & Kolk, 1993) where a central dysfunction is proposed which operates before the actual execution of speech occurs. The speech motor plan is an elaborate representation of all or most of the 'intended utterance' constructed prior to the actual execution of the utterance itself (Sternberg, Monsell, Knoll & Wright, 1978). Many models were also proposed which explained stuttering as a motor planning/programming deficit (Mackay, 1982; Schmidt, 1988; Postma & Kolk, 1993; Van Leishout,

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1995; Van Der Merwe, Mc Neil, Robin & Schmidt, 1997).

Reaction Time (RT) Paradigm is the most commonly used technique to investigate motor programming in speech production and many investigators have used RT paradigms to address the issue of speech motor control in general and particularly in stuttering (Kahneman, 1973; Peters et al., 1989; Van Leishout, Hulstijn & Peters, 1996; Aravind & Savithri, 1997). The underlying assumption of this paradigm is that differences in the latency of reaction time (dependent variable) consequent to manipulation of the elicited stimuli (the independent variable) are a result of alteration in motor programming and helps in studying the response preparation in the temporal domain. The majority of these studies have recorded slower reaction times for stutterers than for non stutterers (Adams & Hayden, 1976; Cross & Luper, 1979; Cross, Shadden & Luper, 1979; Starkweather, Franklin & Smigo, 1983) along with few studies which contraindicated the presence of slower reaction times in speech as well as in non speech tasks (McFarlane & Prins, 1978; Till, Reich, Dickey & Seiber, 1983).

A two-stage model of motor programming for both speech and non speech movements was developed by Klapp (1995, 2003). Unlike the other models, this model distinguishes two separate processes in speech motor programming namely INT/SEQ and assumes that preparation of a sequential movement involves an organization of a series of motor programs. The first process (INT) refers to the internal spatiotemporal structure of an individual unit of movement and reads it into a motor buffer (Klapp, 2003). INT can be completed prior to initiation (preprogrammed) and is sensitive to unit complexity, with longer processing time for units that are more complex. The second process (SEQ) refers to the sequencing of units into their correct serial order after initiation. The SEQ process involves on-line retrieval of units from the motor buffer and therefore cannot be preprogrammed. SEQ is sensitive to the number of units in the buffer but not to the complexity of a unit.

Klapp (1995, 2003) validated the INT/SEQ model using RT paradigms. In a simple RT paradigm, the response to be produced on a given trial is cued before the imperative signal that prompts response production; this allows pre-programming and reflects SEQ process. In a choice RT paradigm, the imperative signal specifies the response to be produced, and thus preprogramming is not possible thereby reflecting the INT process. Klapp (1995) found an effect of button press duration (finger movements) on Choice Reaction Rime and an effect of sequence length on Simple Reaction Time.

Klapp's model (1995, 2003) was replicated using a Self-Selection RT Paradigm which measured the INT and SEQ processes on each trial (Immink & Wright, 2001; Wright, Black, Immink, Brueckner & Magnuson, 2004). In these studies the participants prepare the upcoming responses and indicated the same by pressing a button when they are ready. This preparation duration was referred to as the ST (ST) which inturn reflected on the INT process. A go-signal will prompt the individuals to execute the response. The latency between the go-signal and the response is measured and this was called as RT which inturn reflected on the SEQ process.

Many of the studies in the past have reported a programming deficit in Stuttering (Peters et al., 1989; Aravind & Savithri, 1997). All the studies viewed speech motor programming errors seen in stutterers as a unitary stage and a very few of these attempted to address the nature of speech and non speech motor programming deficit in stutterers. Studies based on Klapp's model (1995, 2003) have led to the observation that speech motor programming involves two distinct processes in a hierarchical sequence and it is not necessarily a unitary process (Immink & Wright, 2001; Wright et al., 2004). The two processes, INT and SEQ have been studied in subjects with Apraxia of speech (Immink & Wright, 2001; Wright et. al., 2004) using Self Select Reaction Time Paradigm. Such an attempt has not been made in persons with stuttering. This study is proposed to examine the performance of PWS on the Self Select Reaction Time paradigm for speech and non speech tasks.

The aim of the study was to compare the performance of PWS and normal controls on speech and non speech tasks using Self Select Reaction Time Paradigm. The study investigated the difference if any between normal controls, PWS with treatment and PWS without treatment with respect to: (a) Motor programming for non speech and speech tasks, and thus its relation to INT or SEQ processes of programming (b) the modality independent or modality dependent factors with respect to INT or SEQ processes and (c) the effect of treatment in PWS with respect to INT or SEQ processes.

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Method

Participants: There were two groups of participants; an experimental group and a control group. The experimental group was further divided into PWS without treatment and PWS with treatment. The experimental group included fifteen PWS who had undergone treatment and ten PWS without any treatment. The control group included 25 normal controls matched for age and educational level with the experimental groups and in the age range of 16-30 years.

The participants were screened for any visual, auditory, psychological, neurological and gross language deficits. Auditory deficits were ruled out through an auditory screening evaluation. Psychological and neurological deficits were ruled out through clinical examination. All the participants had a basic educational qualification of 10th grade in English Medium. The severity of stuttering in the experimental group was rated using Stuttering Severity Instrument (Riley, 1986) by an experienced Speech - Language Pathologist. Individuals with mild to moderate degree of stuttering only were included in the experimental group. Those individuals with a history of seizures, open head injuries and motoric deficits were excluded. Informed consent was obtained from the participants before conducting the study.

Instrumentation: The study was conducted in an individual set up with no distractions. The Self Select Reaction Time Paradigm was developed using DMDX (Kenneth & Jonathan, 2003) software. DMDX is a freeware which was basically developed for behavioral psychology experiments for measuring reaction times. In this study, two separate programs, the first a non speech program and the other a speech program were individually programmed by the investigator and these two programs were loaded on to a Personal Computer while carrying out the experiments. The computer was connected to a compatible microphone for recording the Speech Reaction Time in the speech experiment. In the speech task the waveform recorded was analyzed with the help of PRAAT (Boersma & Weenink, 2010) software.

Task and procedure: Self Select Reaction Time Paradigm (Immink & Wright, 2001, Wright et. al., 2004) was used to measure ST and RT in both speech and non speech tasks. A pilot study was conducted to test the sensitivity and applicability of the Reaction Time Paradigm. The pictorial representation of self select paradigm is given in the Figure 1.

As is evident from Figure 1, initially a visual symbol 'star' will appear on the screen and this symbol will alert the participants to pay attention to the upcoming stimuli. After the appearance of the star, a visual word is displayed which can be either 1 short (1S) / 1 long (1L) / 4 short (4S) /4 long (4L). At this stage, the participants get ready to execute the response that they are going to produce after they see the visual stimuli.

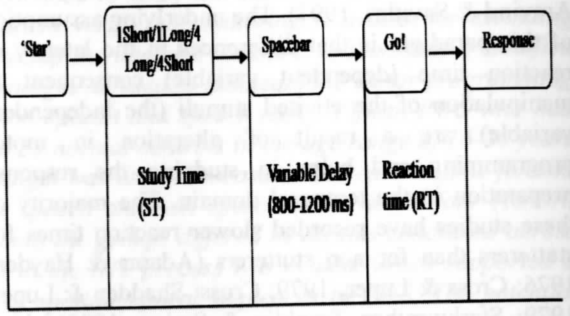

Figure 1. *Self Select Reaction Time Paradigm (Immink & Wright, 2001; Wright et al., 2004).*

When they are ready with respect to the key press (what key they are going to press for a particular duration) as required in the non speech task or what syllable should be produced for a particular duration as in the speech task, they are asked to press the 'spacebar'. The time taken by the subjects to press the spacebar from the appearance of the visual cue is recorded as the ST (ST) which reflects the INT process (internal spatiotemporal structure of an individual unit of movement) of motor programming of Klapp's model (1995, 2003). After a variable delay, a visual stimuli 'Go!' is presented and the subjects are asked to produce the responses as fast as possible. The latency between the appearance of the go signal and the initiation of the response indicates SEQ process of motor programming proposed by Klapp (1995, 2003). SEQ sequences the programmed units of movement and stores it in a short term buffer.

Material: The experimenter synthesized two different pure tones of 1000 KHz for a duration of "150ms" and "450ms" with the help of 'Cool Edit Pro software (Syntrillium Software). A visual alerting symbol "star" and the key press priming visual symbol "Go!" were directly downloaded from the internet. These two symbols were used in both speech and non speech Self Select Reaction Time paradigm of this study. Also, for the speech programming task the experimenter recorded the phoneme /pa/ and the vowel portion of the same was edited to synthesize a shorter /pa/ of 150 ms duration and a longer /pa/ of 450ms.

A pilot study was conducted on five participants to ensure the utility of the program developed using the DMDX software for the experimental tasks. Totally there were 10 blocks containing 40 trials in both speech and non speech tasks. Each block consisted of four trials which included 1 Short, 1 Long, 4 Short or 4 Long. Followed by the instructions a single block consisting of 4 trials was shown to the participants' in order to understand the task better. Also, it was noticed that the subjects committed more mistakes in the first block and the responses were slowed down at the last block. Hence, it was decided to exclude the first and last block in the experimental trials.

Experiment of the study: The RT paradigm developed by the investigator which was tested and modified based on the outcome of the pilot study was included in the experiment of this study. The present study included two experiments: (a) Experiment 1: RT paradigm for non speech tasks and (b) Experiment 2: RT paradigm for speech tasks.

Experiment 1: RT paradigm for non speech tasks
Finger movement task as used in earlier studies (Klapp, 1995; Wright et al., 2004) and that was tested in the pilot study was included in this experiment. Appropriate instructions were given to each participant regarding different key presses and their sequences which are used in the experiment. The instruction was prepared using Power Point slides by the experimenter and this was presented to each subject before they participated in the experimental trials.

Initially, subjects were familiarized with the different key press responses which included a "Short press" ('S' Key for 150 ms) and a "Long press" ('L' Key for 450 ms). Each subject was provided with an auditory model regarding "short" and "long" press responses which consisted of two separate tones which included a short duration tone of '150 ms' and a long duration tone of "500 ms". Later they were familiarized with the number of responses which they have to produce which included either a "single key press" or a "multiple key presses". Accordingly, four different key press responses would elicit four targets namely; 1S (Single short press: 150 ms), 1L (Single long press: 450 ms), 4S (SLLS sequence: 150-450-450-150 ms), 4L (LSSL sequence: 450-150-150-450 ms).

Each experimental trial followed a particular sequence in which each trial was initiated by presenting a visual symbol of "star" which was followed by presenting the visual cue which could be either 1 Short, 1 Long, 4 Short or 4 Long. The subjects were asked to think about the required response which they have to produce mentally and press the space bar when they are ready to respond. This preparation interval is termed as "ST" and this would reflect the demands associated with the INT process. Followed by a variable delay, 'go' signal of 300 ms was presented which prompted the individual to execute the required response. The time between the 'go' signal and the response is called "Reaction Time" and this would reflect on demands associated with SEQ process.

Experiment 2: RT paradigm for speech tasks
Speech movements used in earlier studies (Klapp, 1995; Wright et al., 2004) and that was tested in the pilot study was included in this experiment. Appropriate instructions were given regarding different speech movements and their sequences which were used in the experiment. The instruction was prepared using PowerPoint slides by the experimenter and this was presented to each subject before they participated in the experiment.

Initially an auditory model of non sense syllable /pa/ which varied in duration and length was recorded by a male native speaker. The participants were familiarized with the nonsense syllable /pa/ which varied in terms of syllable duration and sequence length. This included a "Short syllable" (/pa/ of 150 ms duration) and a "Long syllable" (/pa/ of 450 ms duration). When the participants were familiarized with the different types of responses, they were asked to produce a "Short /pa/" for a duration equivalent to "150 ms" and a "Long /pa/" for a duration equivalent to "450 ms". Later they were familiarized with the number of responses which they had to produce which included either a "single syllable" or a "multiple syllable sequence" responses. Accordingly, four different syllabic productions would elicit four targets namely; 1S (Single short syllable: 150 ms), 1L (Single long syllable: 450 ms), 4S (SLLS sequence: 150-450-450-150 ms), 4L (LSSL sequence: 450-150-150-450 ms).

The experiment began with the presentation of the "READY" signal which was followed by a visual cue of 1S, 1L, 4S or 4L. The presentation of the visual cue prompted the required response from the subjects. The subjects were instructed to press the space bar when they were ready; this measures the ST and in turn reflects on the INT process. Pressing the 'Space bar' produced a variable time delay followed by a 'go' signal prompted for the execution of the response. The time delay between 'go' signal and the response is called "Reaction Time (RT)" and reflected on the SEQ process.

Totally, both speech and non speech tasks consisted of 10 blocks in which each block consisted of 4 different types of responses i.e. 1S, 1L, 4S and 4L. The order of presentation of these was randomized across 10 blocks which totally constituted 40 trials.

Analysis: In both experiments 1 & 2, raw scores were obtained for each condition (1S, 1L, 4S & 4L) in non speech tasks across ST and RT. Later mean scores were calculated for each condition across ST and RT. Mean scores of ST and RT for speech and non speech tasks of the participants were calculated and compared within the group and across the groups and also across four different conditions. While analyzing the speech motor programming the RT was measured from the burst of the syllable /pa/. The raw data was treated with suitable statistical procedures to make the inter and intra group comparisons.

Results and Discussion

A. Between group comparisons of ST & RT

a] Non speech Task: MANOVA was used to compare the differences across subjects in non speech task. Results in Table 1 point to a significant difference at less than 0.05 level between the three subject groups across Non Speech Study Time (NSST). The overall reaction time for the NSST was shortest for normal controls followed by PWS with treatment and then the PWS without treatment.

The longer ST reflecting INT process (Klapp, 1995, 2003) in the two experimental groups indicated that PWS took longer time in organizing the spatial temporal characteristics of an individual unit of utterance. The results obtained in the present study are in congruence with other studies which have used a different experimental paradigm (Webster, 1986; Rastatter & Dell, 1987; Webster & Ryan, 1991) which showed longer reaction times across various manual reaction time measures. Duncan's post hoc analysis revealed a significant difference between normals and PWS with no treatment and significant difference between PWS with treatment and without treatment. The PWS group with treatment performed similar to the normal controls, and this could be attributed to the treatment variable.

b] Speech Task: MANOVA was used to check the differences across groups statistically for the speech ST and RT tasks. As it is evident from Table 2, there was a significant difference at 0.05 level across the subject groups for Speech Study Time task (SST).

From the mean values, we can infer that the overall ST for the SST was shortest for normal controls followed by PWS with treatment and finally by PWS without treatment. The results suggests that PWS with or without treatment takes longer time than normal controls while preparing the responses in advance before they execute the speech movements.

Table 1. *Mean (in msec) and Standard Deviation (SD) for ST and RT across subjects in non speech tasks*

Experimental condition	Group	N	Mean	SD	F value
NSST	Normal	25	1049.79	331.66	5.138*
	PWS No Tx	10	1472.71	324.71	
	PWS with Tx	15	1155.52	402.23	
NSRT	Normal	25	815.90	277.86	3.872*
	PWS No Tx	10	1121.61	360.06	
	PWS with Tx	15	941.91	283.70	

*p< 0.05

NSST = Non Speech Study Time, NSRT = Non Speech Reaction Time, Tx = Treatment

Duncan's post hoc test revealed that there were no significant differences between normal controls and PWS who have undergone therapy. But, significant differences were found between normal controls and PWS with no treatment; PWS with treatment and PWS without treatment only for speech ST (SST) and not for Speech RT (SRT). It can probably be reasoned out that many of the fluency remediation therapies would provide sufficient time to plan the upcoming utterances by reducing the overall speech rate and this inturn gets reflected in the preparation of responses in advance. A similar notion has been supported by the study done by Savithri and Pooja (2000) wherein a reduced reaction time was observed after therapy in PWSA modality independent motor programming deficit in INT process irrespective of variables like treatment and severity of the condition is evident from the above findings.

B] Within group comparison across non speech and speech task

a] Within group comparison of normals for non speech and speech tasks: Table 3 shows that the mean of the non speech ST (NSST) is longer than the non speech reaction time (NSRT) in normals. Paired t test revealed significant difference between the two tasks, [$t(24) = 4.085$, $p < 0.05$]. A longer ST in non speech could be due to an additional processing of the choices that were required which inturn required much more time since the choices carry more information load than an alerting signal which does not have sufficient information.

Table 2. *Mean (in msec) and Standard Deviation (SD) for speech ST and RT across subjects in speech tasks*

Experimental condition	Group	N	Mean	SD	F value
SST	Normal	25	821.02	397.60	5.853*
	PWS No Tx	10	1273.92	338.72	
	PWS with Tx	15	974.70	277.88	
SRT	Normal	25	894.17	250.97	2.646
	PWS No Tx	10	1046.67	276.46	
	PWS with Tx	15	1060.23	219.70	

*p< 0.05

SST = Speech Study Time, SRT = Speech Reaction Time, Tx = Treatment

This created a significant difference between ST and RT of non speech task. The table also shows that there was no significant difference between ST and reaction time of speech task, [$t(24) = 0.905$, $p = 0.375$]. In the speech task subjects were made to artificially associate a visual cue with a verbal response. This association might have created an additional load on processing the visual stimuli and this could have inturn affected the online retrieval of the individual syllables. Hence, there was no significant difference in the ST and the reaction time.

b] Within group comparison in PWS with no treatment: From Table 4 it is evident that the ST and RT is different in non speech and speech tasks and they were significantly different from each other at 0.05 level of significance in the non speech task for PWS with no treatment, [$t(9) = 3.181$, $p < 0.05$]. An evident significant difference between the ST and the RT in the speech tasks for PWS with no treatment was seen and this was also found to be significant [$t(9) = 2.635$, $p < 0.05$]. It can thus be inferred that PWS with no treatment took longer time in programming the spatio temporal parameters of the key pressing as well as in programming syllable /pa/ which inturn is reflected as a longer ST. A shorter RT shown by this group in the speech tasks compared to ST reveals that they had problem in retrieving the programmed sequences since normals did not show differences between ST and RT in speech task.

c] Within group comparison of PWS with treatment: Table 5 shows no significant differences in ST and RT of both non speech [$t(14) = 1.925$, $p > 0.05$] and speech task [$t(14) = 0.941$, $p > 0.05$]. An increased arousal level after improved speech fluency can be attributed for the insignificant changes seen across tasks.

Table 3. *Mean (in msec), Standard Deviation (SD) and paired t test values of normals for non speech and speech tasks*

Experimental condition	N	Mean	SD	t-value (24)
Non speech task				
NSST	25	1049.79	331.66	4.085*
NSRT	25	815.90	227.86	
Speech task				
SST	25	821.03	397.60	0.905
SRT	25	894.17	250.87	

*p< 0.05

NSST = Non Speech Study Time, NSRT = Non Speech Reaction Time, SST = Speech Study Time, SRT = Speech Reaction Time

Table 4. *Mean (in msec), Standard Deviation (SD) and paired t test values of PWS with no treatment within non speech and speech tasks*

Experimental condition	N	Mean	SD	t-value (24)
Non speech task				
NSST	10	1472.71	324.71	3.181*
NSRT	10	1121.61	360.06	
Speech task				
SST	10	1273.92	338.72	2.635*
SRT	10	1046.67	276.46	

*p< 0.05

NSST = Non Speech Study Time, NSRT = Non Speech Reaction Time, SST = Speech Study Time SRT = Speech Reaction Time

C] Within subject comparison for different conditions

a) Normal controls: In the non speech tasks the results of Repeated measure ANOVA revealed that all the conditions across the ST and RT were significantly different from one another respectively [$F(3, 72) = 2.868, p < 0.05$, $F(3, 72) = 11.882, p<0.05$].

Paired t test run on the ST revealed that only the conditions 4S and 1S [$t(24) = 2.117, p < 0.05$)], 4L and 1S [$t(24) = 2.088, p < 0.05$)] were significantly different with each other ST, and none of the other pairs were significant. Boneferroni's multiple group comparison checked the individual differences in RT and revealed 4S and 4L are significantly different than 1S and 1L. A sequence length effect of increased response latency with increase in response complexity was evident. No duration effect was seen i.e. there were no differences between 1S, 1L and 4S, 4L.

Table 5. *Mean (in msec), Standard Deviation (SD) and paired t test values of PWS with treatment within non speech tasks*

Experimental condition	N	Mean	SD	t-value (24)
Non speech task				
NSST	15	1155.52	402.23	1.925
NSRT	15	941.91	283.70	
Speech task				
SST	15	974.70	277.88	0.941
SRT	15	1060.23	219.70	

In speech ST task showed that there was an absence of sequence length effect. Also, there were no differences between the responses requiring same sequences i.e. 4S, 4L and 1S, 1L, revealing once again that there was no duration effect on the ST of speech task. Further repeated measure ANOVA showed no significant difference across different conditions in ST task, [$F(3, 72) = 1.155, p > 0.05$]. Absence of sequence length effect suggests that all the units, irrespective of the length seemed to be preprogrammed as a single chunk in the ST task and the absence of duration effect suggests that the addition of the syllable duration did not tax the speech motor system. In RT task only sequence length effect was evident with the absence of duration effect.

b) PWS with no treatment: Repeated measure ANOVA revealed no significant difference across conditions for ST measures [$F(3, 27) = 2.620, p > 0.05$] and RT measures [$F(3, 27) = 1.177, p > 0.05$] of non speech task in PWS without treatment there was no significant difference across conditions also in ST measures [$F(3, 27) = 2.300, p > 0.05$] of speech task. There was however a significant difference between the conditions in RT measures [$F(3, 27) = 7.422, p < 0.01$] of the speech task. There was also a lack of duration effect in all the tasks. Lack of sequence length effect in both ST of non speech and speech tasks in PWS with no treatment shows no differences in programming a shorter or a longer chunk.

c) PWS with treatment: Repeated measure ANOVA revealed no significant differences between conditions in ST of non speech task, [$F(42, 3) = 0.956, p > 0.05$]. When compared to PWS with no treatment the reaction time of PWS with treatment was much shorter. This could be attributed to the treatment variable but, it is not statistically significant. There was no sequence length or duration effect on the responses indicating that treatment had a positive effect on motor programming, it could not rectify completely the deficit seen in PWS.

Repeated measure ANOVA across conditions revealed that there was no significant difference between conditions in the ST of the speech task [$F(3, 42) = 2.056, p > 0.05$]. There was no statistically significant difference between shorter and longer sequences suggesting that the motor programming of speech was aberrant even after PWS had undergone therapy. But the reaction time of PWS with treatment was shorter compared to the PWS with no treatment. Repeated measure ANOVA revealed a significant difference across the conditions in the RT of speech task [$F(3, 42) = 4.121, p < 0.05$].

There was a sequence length effect and an absence of duration effect which again revealed that PWS have difficulty in integrating the individually programmed chunks into a single cohesive unit and the presence of duration as a complex factor did not tax their motor system.

D] Within condition comparison across groups

To understand the within subject differences across the groups, Multivariate Analysis of Variance i.e. MANOVA was carried out. Since the subject size was less, the MANOVA results were cross verified with Kruskal-Wallis test. The MANOVA results revealed that both the ST and RT in all the four conditions (4S, 4L, 1S, 1L) of non speech task were significantly different across the groups. In the ST of speech task, conditions like 4L, 1S and 1L were significantly different across the groups and in the RT, only 1L was significantly different across the groups. This was also supported with the earlier findings that non speech ST and RT showed a significant difference between groups owing to the sequence length effects.

The ST of speech task produced significant differences between the groups in conditions like 4L, 1S and 1L. In the RT of speech task there was no significant difference across groups found. This could be due to the fact that all hearing adults are highly skilled in sequencing and controlling the syllable duration due to continuous practice in speaking over their lifetime. Also, it has been reported in the motor learning literature that a sequence of units may completely get reorganized as a single unit due to extensive random practice (Klapp, 1995; Sakai, Hikosaka & Nakamura, 2004; Wright et. al., 2004) Though, different stimulus varying in length and complexity was presented, it could have been reorganized as a single chunk, because of which there was no significant difference in various conditions across groups.

Duncan's Post hoc analysis test was carried out to know the factors that accounted for the group difference. Few of the dependent variables of ST (4L, 1S, 1L) , RT (4S, 4L, 1S, 1L) of non speech task and RT (1L) of speech task were significantly different between normal controls and PWS with no treatment. These findings show that normals and PWS with no treatment behaved like two different groups across various conditions taken in the experiment but, PWS with treatment were falling between the normal controls and PWS with no treatment.

The results of Kruskal- Wallis test revealed that all the conditions in the ST of non speech task were significantly different across groups but, no significance was seen within all the conditions of RT of non speech task. Also, the findings of both MANOVA and Kruskal-Wallis test matched the ST of speech task where significant results across groups were revealed. The findings of MANOVA and Kruskal-Wallis are showing contradictory results with respect to the RT of the non speech task. But going by findings of within subject comparison of different conditions, it can be stated that there was no significant difference between RT of non speech across subject groups.

Also, the results should be explained by keeping the findings of Kruskal-Wallis test, since it has more statistical power than MANOVA when the subject size varies significantly. Hence a deficit at the stage of INT leaving SEQ process intact best explains the non speech motor programming errors seen in PWS. Both MANOVA and Kruskal-Wallis revealed significant differences in ST of speech task, the findings can be interpreted that the PWS have deficit at the INT stage of speech motor programming. In the RT of speech task, few of the conditions are found to be significantly different by MANOVA such as 4S, 4L and 1S and Kruskal-Wallis revealed significant difference across 4L and 1S. Hence, these two tasks were found to be significantly different from each other whereas the other two were not.

It is however difficult to conclude whether PWS have deficits in the RT of speech task. This variable has to be studied further in greater detail to delineate the presence of programming errors in the speech task. Mann-Whitney U test was used to understand the difference between the groups across conditions.

Table 6. *Chi-square and its significance of Kruskal-Wallis test within conditions across groups*

Conditions	X^2 (2)	Sig.
nspST4S	7.649	0 .022*
nspST4L	6.819	0.033*
nspST1S	9.222	0.010*
nspST1L	7.344	0.025*
nspRT4S	3.699	0.157
nspRT4L	3.234	0.198
nspRT1S	4.817	0.090
nspRT1L	4.872	0.088
spST4S	9.734	0.008*
spST4L	14.889	0.001*
spST1S	11.088	0.004*
spST1L	15.164	0.001*
spRT4S	6.487	0.039*
spRT4L	2.066	0.356
spRT1S	4.067	0.131
spRT1L	6.011	0.040*

*$p < 0.05$

nspST= Non speech study time, nspRT= Non speech reaction time, spST= Speech study time, spRT= Speech reaction time

Normals vs. PWS with no treatment: Mann-Whitney U test revealed significant differences across all the conditions in the ST and RT of non speech tasks and ST of speech tasks across groups but, no significant difference was obtained in the RT of speech task across three conditions such as 4L, 1L, and 1S.Hence these findings support modality independent deficit in PWS in INT stage and modality dependent SEQ difficulty in the non speech task.

Normals vs. PWS with treatment: No significant differences across all the conditions except for the conditions of 4L of ST, 1L and 4S of RT of speech task was found. No significant difference across most of the conditions between the two groups could be attributed to the treatment variable. The significant differences seen in the above said conditions should be tested further to understand the group differences.

PWS with treatment vs. PWS with no treatment: Mann-Whitney U test revealed no significant differences across the two groups in majority of the conditions but, there were few conditions which were significantly different across the groups which included 4S in ST of non speech task and 4L, 1S and 1L of ST of speech task. It can be concluded that PWS with and without treatment did not differ on the majority of the variables but, when it comes to the ST of speech task, there was a significant difference in three out of four conditions suggesting an INT deficit in PWS irrespective of the treatment variable.

Conclusions

There was a significant difference between normal controls and PWS in the motor programming stages outlined by Klapp (1995, 2003) in both non speech and speech tasks irrespective of the treatment variable in effect. PWS with treatment and without treatment were significantly different from the normal controls in the ST of both non speech and speech task. This suggests a modality independent deficit in ST which in turn points to a deficit in the INT process. There was no significant difference in the RT in the non speech task revealing an intact SEQ and aberrant INT process in the non speech task. But, the findings of the study in terms of Speech Reaction Time did not show any consistent trend across the groups hence it should be explored further. Also, treatment variable has a positive effect on both speech and non speech motor programming even though the therapy was addressed only with respect to speech remediation. All these findings suggest that there are few common neuromotor control strategies which subserves two unrelated motor systems.

In conclusion, though treatment showed favorable effect on the speech motor programming as inferred through the Self Study Reaction Time paradigm used in this study, all the effects could not be attributed to treatment. Some of the similarities seen between normals and PWS with treatment group could be attributed to the motivation factors, arousal, practice effects along with some uncontrolled processing at the central level which cannot be addressed with the design used in this study.

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