MOTOR LEARNING AND TRANSFER ALONG TWO CONTINUA OF COMPLEXITY FOR NONSPEECH ORAL GESTURES: QUANTITY AND CONSISTENCY OF INTRAORAL PRESSURE PEAKS

by

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The purpose of this study was to determine the point at which a minimally complex well-trained nonspeech task transfers to other nonspeech tasks of varying complexity. Participants included ten normal adult speakers. The nonspeech training task included bilabial production of a single intraoral pressure peak at either 7 or 15 cm H2O. Participants received random training on the two pressure targets, with Knowledge of Results provided on 50% of the trials. Complexity of the transfer tasks was manipulated by varying both the number of intraoral pressure peaks and the consistency of pressure targets. Only 4 participants demonstrated learning of the single peak task. For these four participants, transfer occurred from the training task to the more complex transfer tasks at roughly the same time. Findings suggest that there were no differences in complexity between the number of pressure peaks or between the consistency of the pressure targets.

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PREFACE

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1.0 INTRODUCTION

In the motor speech literature, ongoing controversy exists in determining if there are shared or common neural systems for the production of speech and volitional nonspeech oral motor behaviors. Theorists in support of a shared mechanism find nonspeech oral tasks to be useful in assessing the motor speech system (Luschei, 1991; Robin, Solomon, Moon & Folkins, 1997). It was postulated that even though nonspeech vegetative movements have separate patterned circuitry, overlapping control is observed in the voluntary control over sequenced movements (Franz, Zelaznik, & Smith, 1992). Contrary to this view is the theory that speech and nonspeech production are controlled independently. This was supported by research assessing kinematic and electromyographic activity during both speech and nonspeech tasks, in which different patterns of movement were seen for each (e.g., Ruark & Moore, 1997; Moore, Smith & Ringel, 1988; Ziegler, 2003). Ziegler (2003) described the concept of a "task-dependent" motor control system in which speech and nonspeech oral behaviors are subserved by different sensory-motor systems with distinct neural pathways (page 3). This theory suggests that speech is unique in how it is controlled. Additional research has also supported the concept of independent nonspeech and speech motor pathways (Ruark et al., 1997; Weismer, 1997; Weismer & Liss, 1991). Ballard, Robin, and Folkins (2003) responded to Ziegler's (2003) "task-dependent" model, instead detailing an "integrative model" in which speech would not be considered a unique motor act. Ballard and colleagues (2003) suggested that "some nonspeech motor tasks share principles with speech," suggesting the existence of "overlapping neural and behavioural systems for the control of speech and volitional nonspeech tasks" (page 38).

Weismer (1997; 2006) suggested that a definitive demonstration of a link between oromotor and speech production would be to provide a patient with training on a nonspeech variable, and then observe that variable's generalization to speech production. Ballard et al. (2003) indicated that skill transfer should occur among behaviors "that have overlapping properties or principles of control." (page 39). Previous research has attempted to determine the similarity or overlapping nature of neural and behavioral systems for speech and volitional nonspeech behaviors, often with negative results (e.g. Dworkin, Abkarian, & Johns, 1988; Christensen and Hanson, 1981). A study by Schulz, Dingwall and Ludlow (1999) utilized a task in which participants were told to "open mouth, pucker lips, smile" (page 1161). Schulz et al. (1999) concluded that practice on an oral movement task had no influence on speech motor control in a group of patients with cerebellar atrophy. However, in this and many related studies, the nonspeech tasks were not similar enough to the speech tasks to which they attempted transfer. For example, in the Schulz et al. (1999) study, participants were not instructed to produce the gestures as a smooth, overlapping sequence, as is commonly observed in normal speech production. Additionally, many similar studies used nonspeech tasks that placed significantly different demands on the participants than would be required in order to execute a speech act (e.g., Bunton & Weismer, 1994; Moore et al., 1988). Several researchers have discussed the need for nonspeech tasks which emulate portions of the desired speech transfer task or are similar in complexity and organization to speech (e.g., Ballard, Granier & Robin., 2000; Folkins, Moon & Luschei., 1995; Forrest, 2002; Moon, Folkins, Smith & Luschei, 1993). These differences highlight the initial need to develop nonspeech tasks that meet specific criteria that will allow for a valid comparison of speech and nonspeech gestures. Once nonspeech tasks have been developed that are truly comparable to speech tasks in the level of organization and complexity, it will be possible to evaluate the evidence for a shared underlying control mechanism. Subsequently, Weismer's suggested "acid test" can then be performed with confidence that comparable tasks are being used.

In an attempt to explore the association and disparities between volitional nonspeech oral movements and speech, Shaiman and McNeil (2004) and Shaiman, McNeil and Szuminsky (2004) developed a nonspeech task to equate the level of complexity and organization between speech and nonspeech gestures. This nonspeech task was distinct from previous tasks in the literature because it was constructed to be comparable to speech in three ways. First, the nonspeech task utilized a sequence of potentially overlapping, coarticulated gestures. Second, the nonspeech task involved the goal of intraoral air pressure production. Saltzman and Munhall (1989) noted that the purpose of speech gestures is to "control air pressures and flows in the vocal tract so as to produce distinctive patterns of sound" (p.338). Thus, one potential intermediate control variable may be intraoral air pressure (Pio), which is maintained during bilabial plosive production despite airway leaks (e.g., Kim, Zajac, Warren, Mayo & Essick, 1997; Moon et al., 1993; Müller & Brown, 1980; Warren, Dalston & Dalston., 1990). Third, the nonspeech task was implemented within a motor learning paradigm to facilitate adequate learning of the nonspeech task. Research into motor learning has demonstrated that the kinematic characteristics of novel movements are quantitatively and qualitatively different from those of well-learned, highly-skilled movements (e.g., Gordon, Casabona & Soechting, 1994; MacKay, 1982; Moore & Marteniuk, 1986; Nagasaki, 1989). Studies of speech coordination in normal adults typically have examined well-learned or practiced behaviors (Smith & Zelaznick, 1990).

Conversely, most studies of voluntary nonspeech oral gestures have examined novel behaviors. The comparison of speech and nonspeech behaviors should therefore attempt to equate the nonspeech task to speech on the level of automaticity (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Schneider et al, 1984).

The results of the Shaiman et al. (2004) study indicated that participants improved their ability to produce the targeted intraoral pressures in this highly complex nonspeech task. While retention and transfer (to both speech and other nonspeech tasks) were demonstrated, both were limited. There are a variety of potential explanations for the limited retention and transfer observed in the Shaiman et al. studies. Among the possibilities, Shaiman and colleagues suggested that their nonspeech task may have been too complex, given the small number of repetitions over only two days of training and the selected conditions of practice. The nonspeech task used in that study was developed to equate the level of complexity, organization and goal between speech and nonspeech gestures. The task consisted of a sequence of 15 overlapping, coarticulated gestures, with four intraoral air pressure peaks produced during each repetition of the sequence. Three different intraoral pressure targets were utilized. Shaiman and colleagues suggested that improved retention and transfer may be observed in a different nonspeech task which is still comparable to speech, as described above, but not as complex (given the amount and conditions of practice).

The current study attempted to explore learning in a nonspeech task that was reduced in complexity relative to the earlier Shaiman et al. task. Wulf and Shea (2002) described that when "multiple tasks are carefully constructed along the continuum of interest, no one continuum is satisfactory in quantifying the complexity of the wide variety of motor tasks" (page 185) that have been previously examined in the literature. While there are potentially a wide variety of ways in which complexity for speech and nonspeech behaviors may be viewed and manipulated, the current study attempted to systematically control two parameters of complexity which may have contributed to the limited retention and transfer of the earlier studies: the number of intraoral pressure peaks and the intraoral pressure consistency.

The number of intraoral pressure peaks is of interest in that the stimuli in the Shaiman et al. studies contained a sequence of four pressure peaks, embedded within a longer sequence of nonspeech gestures. Developmental speech production research has documented that pre-speech begins with shorter primitive consonant-vowel (CV) syllables, later followed by the development of strings of repeated CV sequences (Steffens, Eilers, Fishman, Oller, Eilers, Steffens, Lynch & Urbano, 1994; Oller, 1980; Stark, 1980). The "Frame/Content" theory of MacNeilage, Davis and colleagues (1998; 1999; 2000a; 2000b) supports these findings, and concludes that the mandibular cycle of a CV sequence "is a key component of the form of adult speech" (MacNeilage, 2000a, page 440). These findings suggest that production of a single pressure peak should be less complex than the reduplicative production of multiple peaks. Additionally, there have been few studies that have explored target accuracy of intraoral air pressure production (e.g., Zajac, 1998). The production and target accuracy training of a single intraoral pressure peak permits both the evaluation of target accuracy as well as the evaluation of learning a relatively simple nonspeech task. Upon training, transfer can then be explored to untrained productions with multiple pressure peaks.

Intraoral pressure consistency is of interest is of interest in that the Shaiman et al. studies did not manipulate pressure target values within a sequence. While three different pressure levels were trained in that study, the target pressure levels were kept constant for each of the four pressure peaks in any given production of the sequence. Constant intraoral pressure levels are generated through the maintenance of a constant alveolar pressure, involving both active and passive forces of the lungs and chest wall. Changes in alveolar pressure require alterations in respiratory muscle function in order to accommodate the rapid pressure changes that are commonly observed in speech production (Zemlin, 1998). This suggests that production of a constant intraoral air pressure across multiple peaks should be less complex than production of varied intraoral air pressure.

Manipulations in complexity of the nonspeech tasks, as described above, are important for exploring potential reasons as to why retention and transfer were limited in the Shaiman et al. studies. Ballard observed that "response generalization is more likely to occur to related behaviors that are of similar or lesser complexity" (Ballard, 2001, p. 12). Likewise, motor control literature has shown that one of the main goals of learning is to transfer skills to "similar but novel tasks" (Schmidt, 1975; Schmidt & Lee, 1999). However, the complexity continuum has not been addressed to lend an understanding to when something is really of such a "similar" complexity. In manipulating both the number and the consistency of the intraoral pressure peaks, the current study permits an initial evaluation of the similarity among tasks as the complexity is systematically increased.

Naylor and Briggs (1963) identified both task complexity and task organization as relevant variables in learning and transfer. Task complexity was explained as "the demands placed on S's information-processing and/or memory-storage capacities by each of the task dimensions independently" (page 217). They defined task organization as "the demands imposed on S due to the nature of the interrelationship existing among the several task dimensions" (page 217). In further research by Naylor and Briggs (1965), it was found that breaking a complex task apart into smaller (and less complex) bits was only effective if the original task was made up of smaller, independent tasks. If the task was not composed of smaller tasks, breaking a task into smaller parts was not an effective way to reduce the complexity of a task. This finding has been widely repeated in the literature (Adams, 1987, Marmie & Healey, 1995; Schmidt & Young, 1987). Wightman & Lintern (1985) discussed the concept of segmentation by explaining a specifically delineated start and completion point to a task. Forrest (2002) expanded on the concept of segmentation to include dividing a speech task down into, for example, an isolated phone. Considering the difficulty that the participants in the Shaiman et al (2004) study had with learning the complex nonspeech task, Wightman and Lintern's (1985) work provide a method of reducing the task's complexity.

The current study was designed to train a less complex or part task, and observe its transfer to more complex or whole tasks, as complexity was systematically manipulated along the two continua. While this direction of training and transfer is not in agreement with much of the motor learning literature, there are a few studies indicating that factors such as the continuous nature of the task may result in part training being effective to transfer of the whole task (e.g., Briggs and Brogden, 1945; Kurtz and Lee, 2003). However, these studies suggested that, while training on the part task did transfer to the whole task, it was less effective than training of the whole task (see Schmidt and Lee (2005) for a detailed review of this literature). The intent of the current study was not to determine the effectiveness of part versus whole training. Rather, this study was designed to evaluate the point at which transfer occurred along the two manipulated continua.

Given the limited retention and transfer noted in the Shaiman et al (2004) research, the current study explored a simplification of the nonspeech training task from which transfer and retention to more complex tasks were intended. The purpose of this study was to determine at what point along two continua of complexity a minimally complex well-trained nonspeech intraoral task will transfer to nonspeech tasks of varying complexity. The complexity of the transfer tasks was manipulated in two ways. First, the length of the transfer tasks was manipulated. The transfer tasks consisted of both two intraoral pressure targets and three intraoral pressure targets. Second, the complexity was manipulated by using transfer tasks containing both repeating (that is, constant) intraoral pressure targets and varying intraoral pressure targets.

It was hypothesized that transfer to untrained tasks would be evidenced more rapidly to tasks on the simple end of the continuum and more slowly to those that were considered higher in complexity. Transfer was expected to occur to those tasks with fewer intraoral pressure peaks (two peaks) more rapidly than to tasks with more intraoral pressure peaks (three peaks). Additionally, transfer was expected to occur more rapidly in the tasks that have multiple pressure peaks of the same value, while tasks with variable pressure peaks were expected to transfer the most slowly.

2.0 METHODS

2.1 PARTICIPANTS

Ten normal, native American English speakers ranging in age from 20 to 33 years, with a mean age of 26.4 years, participated in the study. Five of the participants were male and 5 were female. Participants were screened in order to exclude individuals with neurologic, speech and/or hearing problems. Several minutes of conversation were used to informally evaluate speech production. Participants were given an oral mechanism examination and a pure-tone audiometric screening before beginning the study on Day 1.

2.2 STIMULI

2.2.1 Training Stimuli

The simple nonspeech task on which the participants were trained involved bilabial production of a single intraoral pressure peak (1P). Presented on the monitor in front of them, participants viewed a five-step sequence, instructing them on movement of the lips: 1) Relax; 2) Apart; 3) Together (pressure); 4) Apart; 5) Relax. The sequence was created in order to parallel bilabial movements for a simple speech task in which intraoral pressure is necessary (/apa/).

Participants were instructed to produce one of two intraoral pressure target levels presented on the monitor for the “Together” gesture: 7cm H2O or 15 cmH2O. These pressure targets were chosen as they are typical of intraoral pressures used during speech production for soft-to-normal and loud speech, respectively (Holmberg, Hillman & Perkell, 1988; Stathopoulos, 1986).

2.2.2 Transfer Stimuli

The purpose of the current study was to explore transfer to other nonspeech behaviors along a continuum of complexity. This study focused on two manipulations: the number of intraoral pressure peaks and the intraoral pressure consistency. Although participants were trained on only a single pressure peak task (1P), transfer was evaluated to more complex, multiple peak tasks consisting of either two or three pressure peaks (2P and 3P, respectively). Additionally, these multiple pressure peaks were presented with the 7 and 15 cmH2O target pressures being either constant (C, meaning each of the multiple pressure targets was of the same value—e.g. 7 cmH2O-7 cmH2O-7 cmH2O) or varied (V, meaning the multiple pressure targets were not of the same value—e.g. 7 cmH2O-15 cmH2O-7 cmH2O). Similar to the 1P condition described above, sequences containing the appropriate number of multiple “Apart-Together-Apart” gestures were presented to the participants.

Table 1 presents the stimuli used in this study. As two variables were manipulated for the transfer tasks (i.e., number of peaks and pressure consistency), transfer stimuli are separated and coded by both the number of peaks (2P or 3P) and the consistency of the pressure targets across multiple peaks (C or V). For example, “2PV” represents a two peak task in which the two pressure targets were varied; “3PC” represents a three peak task in which the three pressure targets remained constant (that is, the three pressure targets were all of the same value).

Table 1. The stimuli utilized in the study are shown below. The varying levels of complexity are organized by number of peaks and variability of peaks, with detail provided in regard to the specific target presented to participants and if training was provided.

Stimulus Code	Gesture Sequence	Number of Pressure Peaks	Pressure Consistency	Pressure Targets (cm H2O)	Training Provided
1P	A-T-A*	1	na	7	Yes
1P	A-T-A	1	na	15	Yes
2PC	A-T-A-T-A	2	Constant	7-7	No
2PC	A-T-A-T-A	2	Constant	15-15	No
2PV	A-T-A-T-A	2	Varied	7-15	No
2PV	A-T-A-T-A	2	Varied	15-7	No
3PC	A-T-A-T-A-T-A	3	Constant	7-7-7	No
3PC	A-T-A-T-A-T-A	3	Constant	15-15-15	No
3PV	A-T-A-T-A-T-A	3	Varied	7-15-7	No
3PV	A-T-A-T-A-T-A	3	Varied	15-7-15	No

* A = lips "Apart"
T = lips "Together"

As detailed in the Introduction, these stimuli were developed utilizing the assumptions that the 3P tasks would be more complex than the 2P tasks, and that the V tasks would be more complex than the C tasks. Additionally, the interaction between the two main effects (number of peaks and pressure consistency) utilizes the assumptions that 3PV would be more complex than 3PC, and that 3PV would be more complex than 2PV.

2.2.3 Intentional Deception

Participants were intentionally deceived as to the purpose of the study, to ensure that they did not conceive of the nonspeech stimuli as being speech-like; such awareness would invalidate the nonspeech task. Subjects were informed that the purpose of the study was to compare the ability to generate pressure for finger movements to the ability to generate intraoral pressure for lip movements. Participants were told that they were being assigned "randomly" to either a finger pressure group or a lip intraoral pressure group. Participants were assigned only to the intraoral pressure group, and were be briefed as to the reasons for the deception upon completion of the study.

2.2.4 Instrumentation

Intraoral air pressure was transduced using a pressure transducer (Glottal Enterprises, Model MSIF-2) attached to a 6 cm long polyethylene tube inserted into the oral cavity between the lips at the oral angle. The bandwidth of the transducer was from DC to 36.6 Hz ±3%. Calibration was performed with both a U-tube manometer and the Glottal Enterprises Pneumotach Calibration Unit (Model MCU-4). Target intraoral pressure levels were displayed on a computer monitor positioned in front of the participant. Data were digitized on-line at a sampling rate of 1000 Hz.

2.3 PROCEDURES

Data were collected over three days (24 to 48 hours apart), in order to provide ample opportunities for learning and the assessment of retention and transfer.

2.3.1 Pre-Training

On Day 1, participants were seated at a computer monitor, on which the sequence of gestures for the 1P tasks was presented, as described above. The experimenter provided participants with both verbal instructions and a model of the nonspeech sequence. Participants were instructed to produce the sequence of gestures in a smooth and overlapping manner, rather than as isolated lip gestures. After correct production of the 1P sequence, the intraoral pressure transducer was positioned and the participants were instructed to produce intraoral pressure during the single "Together" gesture. Participants were not instructed in the details of pressure build-up (e.g., velopharyngeal port closure). However, instructions were provided, as necessary, to expel air from the lungs and trap the air briefly behind the lips. Upon the successful generation of intraoral pressure, the participants were provided with a graphic display of the low pressure target (7 cm H2O), as seen in Figure 1. The x-axis provided a time display and the y-axis provided amplitude of the intraoral pressure target. A green horizontal line indicated the target pressure level. Participants were given two trials to produce the low intraoral pressure target, with Knowledge of Results (KR[1]) provided after each production. KR was provided so that the participant had an understanding of the scaling of the target value. KR consisted of a red diamond indicating the extent of the error and the direction in which it was produced relative to the green line of the target pressure level, in a method similar to that used by Shea and Kohl (1991). Subsequently, participants were given two trials to produce the high intraoral pressure target (15 cm H2O), with KR provided.

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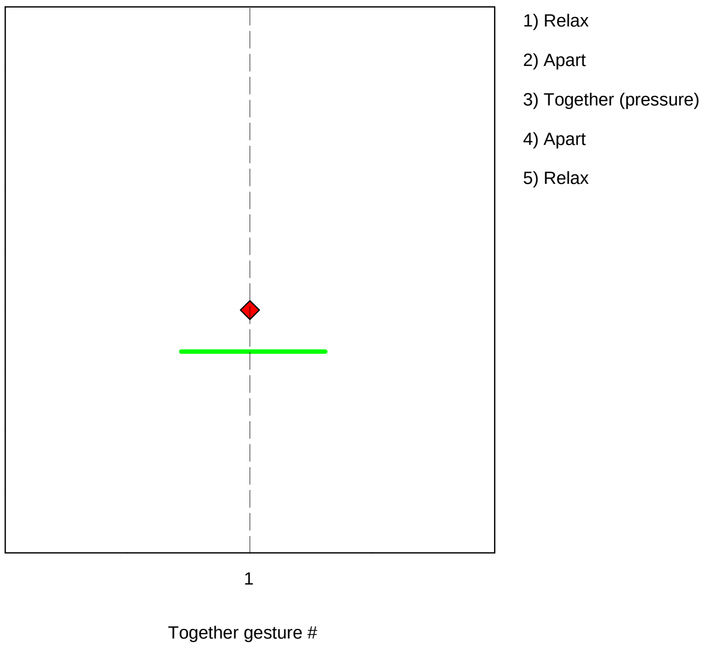
[1] "KR is … terminal (i.e., postmovement) feedback about the *outcome* of the movement in terms of the environmental goal." (Schmidt and Lee, 2005, page 367).

Figure 1. This figure shows the display of Knowledge of Results (KR) that was provided to participants during training. The x-axis is a time display while the y-axis provides the amplitude of the intraoral pressure target. The green line represents the target level (e.g. 7 cm H2O or 15 cm H2O) and the red diamond represents the amount of intraoral pressure produced by the participant.



2.3.2 Baseline

Baseline data were then collected for 10 productions of the 1P task (5 productions at each target level, randomly presented). No KR was provided during the baseline condition. Subsequently, the 2P tasks were presented and explained to the participants. Baseline data were collected for 20 productions (5 productions at each of the 4 pressure and consistency target level combinations, randomly presented), with no KR. Baseline data were then collected for the 3P tasks, as described for the 2P tasks.

Participants received training on only the 1P task. Training consisted of multiple sets of 40 repetitions of the 1P task; the two target pressure levels were evenly distributed and pseudo-randomly presented (no more than twice in a row) during each set. Six sets were presented on Day 1, and six sets were presented on Day 2, for a total of 480 repetitions of the 1P task across two days. Knowledge of Results was provided, as described above, with a relative frequency of 50%, as previous studies have demonstrated improved retention and transfer with low frequency KR (Adams & Page, 2000; Steinhauer & Grayhack, 2000). The KR-delay interval was three seconds, and the post-KR-delay interval was 5 seconds, as studies have shown improved learning with a 3 to 5 second delay (Swinnen, Schmidt, Nicholson & Shapiro., 1990). These conditions of practice were chosen based on well-established limb research (c.f. Schmidt & Lee, 1999), research specific to speech production (Adams & Page, 2000; Knock, Ballard, Robin & Schmidt, 2000), and pilot data using a nonspeech task which was more complex than the current nonspeech task (Shaiman & McNeil, 2004; Shaiman et al., 2004).

Following each set of 40 repetitions of the 1P training task, participants were probed for their ability to produce the 1P, 2P and 3P tasks, respectively, with no KR presented. The 1P task consisted of 6 randomly-presented repetitions, while the 2P and 3P tasks consisted of 12 randomly-presented repetitions each. While it is not typical of motor learning studies to assess retention and transfer so frequently, the frequent probing of the 2P and 3P tasks was deemed necessary in order to determine the precise point in the learning of the simple 1P task at which transfer potentially occurred to the more complex tasks. Since transfer may occur rapidly, infrequent probes may miss the point of transfer.

Previous studies (Shaiman & McNeil, 2004; Shaiman et al., 2004) have suggested that participants potentially became bored with the extensive practice of each experimental session.

In order to maintain participants' interest and attention, participants were informed that they would receive a monetary bonus of $10 each day (in addition to payment for participation) if they performed within +/- 5% of the targets by the completion of the study. In actuality, all participants received this bonus regardless of performance.

2.3.3 Retention and Transfer

Retention of the trained 1P task and transfer to the untrained complex 2P and 3P tasks were assessed at the completion of Day 1, at both the beginning and end of Day 2, and at the beginning of Day 3; no training occurred on Day 3. During retention and transfer, no KR was provided.

A post-experimental questionnaire was administered (and audio-recorded) to participants upon completion of data collection on Day 3. The questionnaire contained several items which assessed the participant's knowledge of the nonspeech tasks as being "speech-like." Such awareness may invalidate the nonspeech study, as the realization could lead the participant to produce the nonspeech tasks as though they were speech. These target questions were embedded within several foil questions, in order to ensure that the questionnaire itself did not lead participants to the awareness of the similarity between speech and nonspeech production. (See "Intentional Deception", above.) The questionnaire is provided in Appendix A.

2.3.4 Data Analysis

The values (in cm H2O) of the intraoral pressure peaks for each "Together" gesture were automatically computed utilizing custom-designed software. Overall performance accuracy was established by computing the Absolute Error (AE), which is the absolute deviation (in cm H_2O) between the participant's production and the target pressure level (cf., Schmidt & Lee, 2005). Lower values indicate that the participant was closer to the target level. Means and standard deviations of the AE were computed for each complexity level, individually for each participant. The initial analysis involved the determination of learning of the 1P task for each participant. Learning was defined as a decrease in AE from the Day 1 baseline condition to the retention conditions at either the end of Day 2 or the beginning of Day 3. Nonparametric statistical analyses were conducted, due to the small sample size. Utilizing difference scores, a 95% upper directional confidence interval (CI) was calculated. Data for those participants whose difference scores were beyond the 95% CI were then subjected to further descriptive analyses.

While training was provided on the 1P task, transfer was explored to the more complex, multiple-peak tasks. Results for each main effect (number of intraoral pressure peaks and intraoral pressure consistency) are provided, followed by the results exploring the potential interaction between the main effects. 1P data are presented simultaneously, in order to allow for the comparison of learning on the 1P task to transfer on the complex tasks.

The initial hypothesis was that AE would decrease for the 1P task with learning. It was also hypothesized that transfer would be observed (as lower AE values) to all complexity levels. However, it was expected that transfer would be observed earlier in the 1P learning process for the 2P tasks than for the 3P tasks, as the smaller number of gestures in the 2P sequence was predicted to be less complex. Similarly, it was expected that transfer would be observed earlier in the 1P learning process for C than for V tasks, as constant pressure levels were predicted to be less complex than varied pressure levels.

3.0 RESULTS

Of the ten participants enrolled in this study, data analysis indicated that only four of the participants demonstrated learning of the trained, one-peak task (1P). These results are presented in detail in the first section, below. The second section below addresses the subsequent analysis of performance on the more complex transfer tasks, limited to the four participants who demonstrated learning on the 1P task. For these participants, there was a trend toward transfer of learning from the simple one-peak task to each of the more complex, untrained multiple-peak tasks.

3.1.1 Trained, One-Peak Condition

The 1P task was the condition in which participants produced a single intraoral pressure peak (Apart-Together-Apart), with a target pressure of either 7 or 15 cmH2O. Participants received training on only this one-peak task. Training consisted of multiple sets of random practice over two days, with Knowledge of Results (extent and direction of the participant's production from the target value) provided on 50% of the trials. Learning was defined as a decrease in AE from the Day 1 baseline condition to the retention conditions at either the end of Day 2 or the beginning of Day 3[2].

Of the ten participants in this study, only four participants demonstrated learning of the 1P task. Table 2 presents the mean AE values (with standard deviations in parentheses) for individual participants at the Day 1 baseline condition and at the two final retention conditions (end of Day 2 and beginning of Day 3). The four participants who demonstrated learning are marked with an asterisk in Table 2.

Table 2. Mean absolute error (AE) values and standard deviations (in parentheses) for all participants 1-10 on Day 1 baseline and Days 2 and 3 retention conditions. The asterisk notes the participants that demonstrated successful learning of the 1P task.

	Day 1		Day 2		Day 3	
Participants	Baseline		Retention		Retention	
1	4.38	(2.56)	3.34	(2.85)	4.58	(2.86)
2*	12.40	(4.21)	4.25	(3.25)	6.11	(2.58)
3	11.13	(4.63)	12.16	(4.00)	12.34	(4.21)
4	3.15	(2.04)	8.09	(3.14)	3.96	(2.99)
5	7.10	(4.85)	7.49	(3.19)	5.93	(5.33)
6	6.18	(4.86)	5.07	(3.57)	5.06	(4.45)
7*	8.01	(4.87)	3.15	(1.44)	5.23	(4.01)
8*	11.29	(4.53)	4.90	(3.53)	6.05	(3.55)
9*	12.25	(4.11)	3.03	(2.04)	3.45	(2.09)
10	8.43	(3.48)	9.27	(5.11)	10.92	(4.24)

Nonparametric statistical analyses were conducted, due to the small sample size. Difference scores were calculated by subtracting the AE values for Day 1 baseline from the end of Day 2 retention, and subtracting Day 1 baseline from Day 3 retention. The difference scores for Day 2 and Day 3 retention were then pooled and rank-ordered, from smallest to largest, with

[2] Baseline and retention conditions were collected with 0% KR.

the corresponding rank numbers of 1 to 20. A 95% upper directional confidence interval[3] was calculated, using the equation:

$$U = 0.5*n - Z_{\alpha}* \mathit{sqrt}(0.5*n* (1 - 0.5))$$

where $n = 20$, $Z_{\alpha} = 1.645$ and 0.5 stands for the median. The upper boundary of this confidence interval was determined to be a rank order of $U = 13.648$. This indicates that the 95% CI covered the ordered differences with the rank numbers 1 to 13. The rank numbers 14 to 20, corresponding to the seven largest difference scores, were beyond the 95% CI. These largest difference scores came from participants 2, 7, 8 and 9. These findings indicate that participants 2, 7, 8, and 9 demonstrated a decrease in AE from the Day 1 baseline condition to the retention conditions at either the end of Day 2 or at the beginning of Day 3, for the 1P task. While it is recognized that this was a lenient measurement of retention, the results acquired were the same as would have been in the sole comparison of Day 1 at baseline to Day 3 of retention. The remaining participants did not demonstrate a decrease in AE with training for the 1P task, as their rank-ordered difference scores fell within the 95% CI. Table 3 presents the rank-ordered difference scores. It is important to note that the same participants would have demonstrated significant improvement for the 1P task even if difference scores were composed of only Day 1 to Day 3 (retention).

[3] The confidence interval was estimated, and not a strict 95% CI. The actual CI was 94.2%.

Table 3. Rank ordering of participant difference scores, calculated by viewing the decrease in absolute error (AE) from Day 1 to Day 2 or from Day 1 to Day 3 during the production of the 1P task.

Rank Order	Difference Score	Participant Number	Retention Day 1 vs. Day 2 or Day 3
20	**9.22**	**9**	**Day 2**
19	**8.80**	**9**	**Day 3**
18	**8.15**	**2**	**Day 2**
17	**6.39**	**8**	**Day 2**
16	**6.29**	**2**	**Day 3**
15	**5.24**	**8**	**Day 3**
14	**4.86**	**7**	**Day 2**
13	2.78	7	Day 3
12	1.17	5	Day 3
11	1.12	6	Day 3
10	1.11	6	Day 2
9	1.04	1	Day 2
8	-0.20	1	Day 3
7	-0.39	5	Day 2
6	-0.81	4	Day 3
5	-0.84	10	Day 2
4	-1.03	3	Day 2
3	-1.21	3	Day 3
2	-2.49	10	Day 3
1	-4.94	4	Day 2

The purpose of the current study was to explore transfer to tasks that were constructed to be more complex than the trained task. As six of the ten participants failed to demonstrate learning of the trained 1P task, their transfer data were subjected to only limited analyses, as seen in Appendix B. Potential explanations for the lack of learning in these participants are explored in the Discussion section. The remainder of the Results focuses on transfer from the 1P task to the more complex multiple-peak tasks, utilizing the data from only participants 2, 7, 8, and 9.

3.1.2 Transfer, Multiple-Peak Conditions

While training was provided on the 1P task, transfer was explored on the more complex, multiple-peak tasks. On the transfer tasks, participants produced either 2 (2P) or 3 (3P) intraoral pressure peaks. These tasks were presented with the 7 and 15 cmH2O target pressures being either constant (C, meaning all one target value) or varied (V, meaning varied target values) across the multiple peaks. Participants received 0% KR on these trials. Transfer was defined as a decrease in AE from the Day 1 baseline condition.

The results for each main effect are provided below, followed by the results exploring the potential interaction between number of peaks and pressure consistency. 1P data are presented simultaneously, in order to allow for the comparison of learning on this trained task to transfer on the complex tasks. Data are presented descriptively, for each of the four participants individually (participants 2, 7, 8 and 9), as an *n* of 4 results in statistical power too small for a meaningful pooled analysis.

3.1.3 Main Effect: Number of Intraoral Pressure Peaks

Figure 2 (a through d) presents the individual participant mean AE values for the 1P, 2P and 3P conditions, across time; data are presented for only the 0% KR conditions. Time #1 represents Day 1 baseline conditions, prior to the initiation of training on the 1P condition. Time #2 represents the first probe on Day 1 immediately following the first 1P training set. Time #7 represents the end of Day 1; Time #14 represents the end of Day 2; and Time #15 represents Day 3. Further detail related to the trials represented by the various "time" labels can be viewed in Table 4, below.

Table 4. Explanation of x-axis "time" labels #1-15. No knowledge of results was provided to participants during any baseline/probe/retention trials. Each probe condition followed a 1P training session.

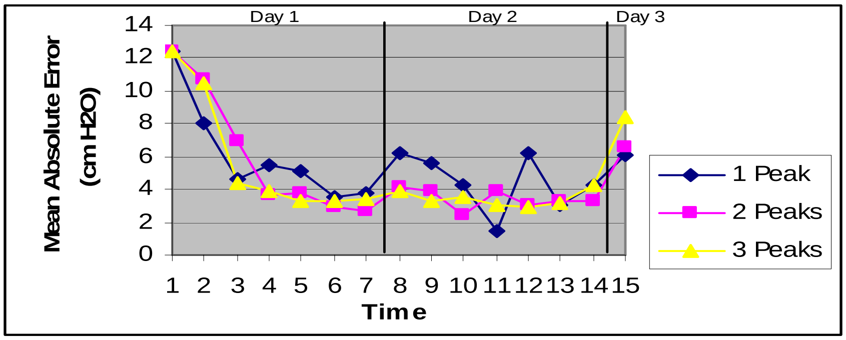
Time	Condition
Time #1	Day 1, Baseline
Time #2	Day 1, Probe #1
Time #3	Day 1, Probe #2
Time #4	Day 1, Probe #3
Time #5	Day 1, Probe #4
Time #6	Day 1, Probe #5
Time #7	Day 1, Probe #6
Time #8	Day 2, Probe #1
Time #9	Day 2, Probe #2
Time #10	Day 2, Probe #3
Time #11	Day 2, Probe #4
Time #12	Day 2, Probe #5
Time #13	Day 2, Probe #6
Time #14	Day 2, Retention
Time #15	Day 3, Retention

The four participants showed a similar trend: As training of the 1P task resulted in the demonstration of learning (a smaller mean AE), transfer occurred to both untrained 2P and 3P tasks. Transfer occurred quite early in the 1P training process for participants 2, 7 and 9, as evidenced by decreased mean AE values immediately following the first or second 1P training sets (Times #2 and #3). Participant 8 did not demonstrate either learning of the 1P task or transfer to the 2P or 3P tasks until the beginning of Day 2, prior to the initiation of training on that day. For all four participants, Times #14 and/or #15 demonstrated retention of the trained 1P task, as well as transfer to the 2P and 3P tasks. In general, differences in the time of transfer between the 2P and 3P tasks appeared to be negligible. That is, at each time interval, the mean AE values for the 2P and 3P tasks were quite similar.

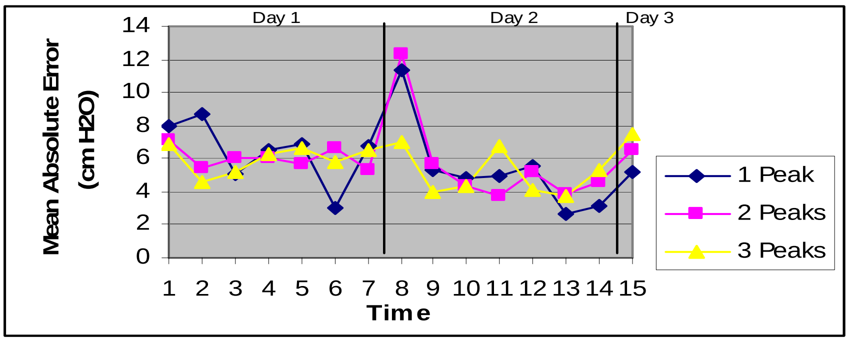
Standard deviations of the AE for 1P, 2P and 3P tasks are presented in Figure 3, and were analyzed in order to explore variability with learning and transfer. While there were some differences in variability across time between the tasks, in general, standard deviations of the AE decreased with learning of the 1P task, and transferred to relatively similar amounts for both 2P and 3P tasks. The only specific pattern to emerge was for participants 2 and 9 on Day 3, who demonstrated the least variability for the 1P task, slightly increased variability for the 2P task, and greater variability for the 3P tasks; the other two participants did not demonstrate this pattern.

Figure 2: Individual participant mean absolute error values for 1P, 2P and 3P conditions, utilizing 0% KR.

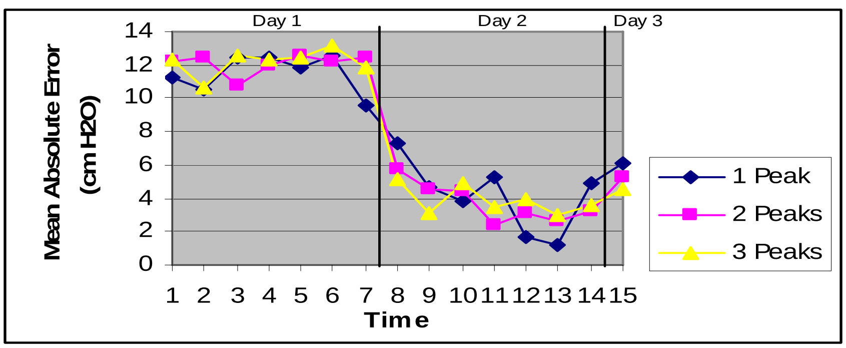
a. Participant 2



b. Participant 7



c. Participant 8



d. Participant 9

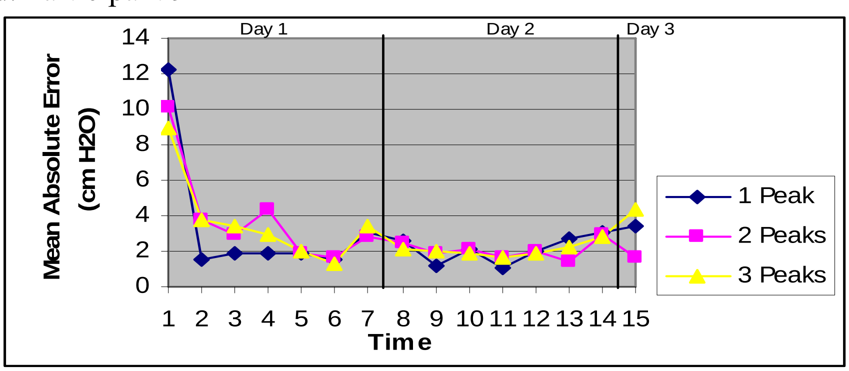
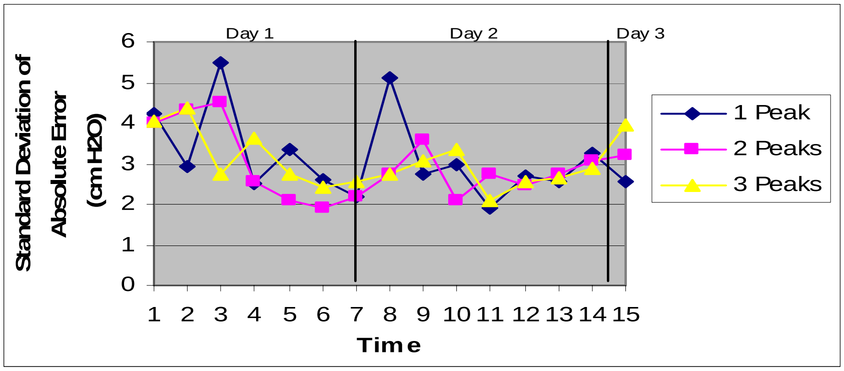
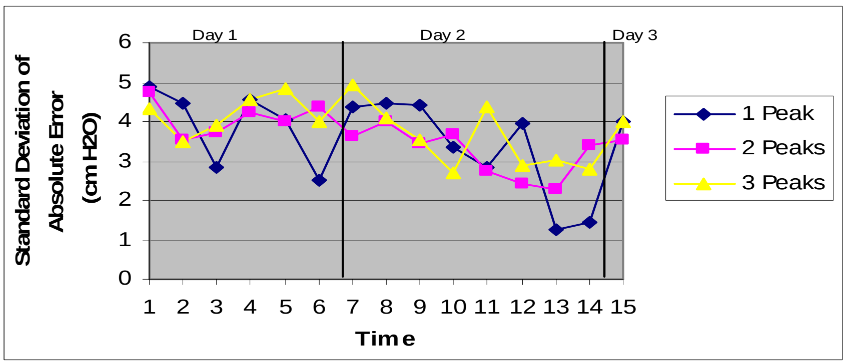


Figure 3. Individual participant standard deviation values for 1P, 2P and 3P conditions, utilizing 0% KR.

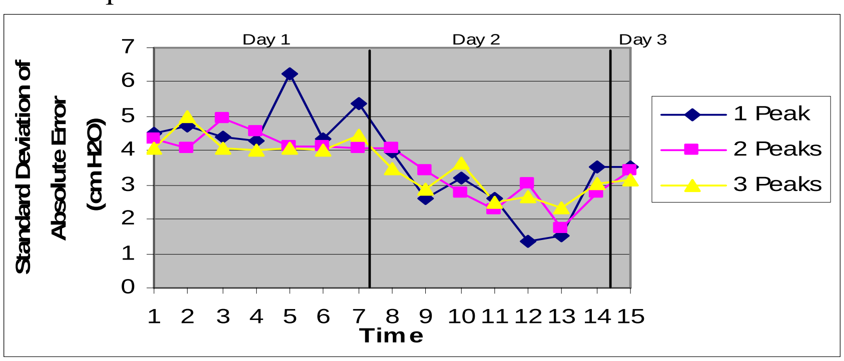
a. Participant 2



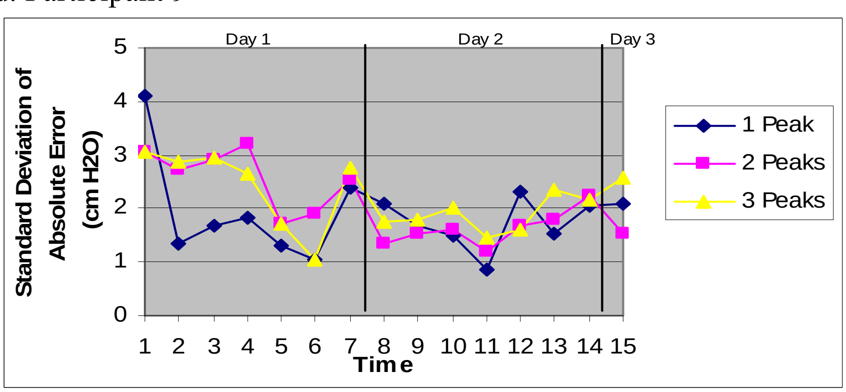
b. Participant 7



c. Participant 8



d. Participant 9



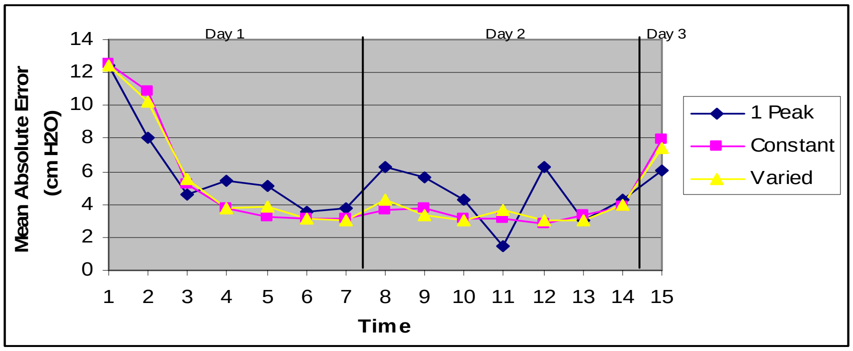
3.1.4 Main Effect: Intraoral Pressure Consistency

Figure 4 presents the individual participant mean AE values for the 1P, C and V conditions, across time. Similar to the manipulation for the number of peaks, manipulation of pressure consistency also resulted in transfer to both C and V conditions with learning of the 1P task. Transfer appeared to occur early in the 1P training process for the same participants (2, 7 and 9), with participant 8 demonstrating learning and transfer only at the beginning of Day 2. In general, differences in the time of transfer between the C and V tasks appeared to be negligible. That is, at each time interval, the mean AE values for the C and V tasks were quite similar. A modest trend was observed on Day 3, with three participants (2, 7 and 8) demonstrating larger AE values for the C task than for the V task. However, participant 8 also demonstrated larger AE values for the 1P task than for both the C and V tasks on Day 3.

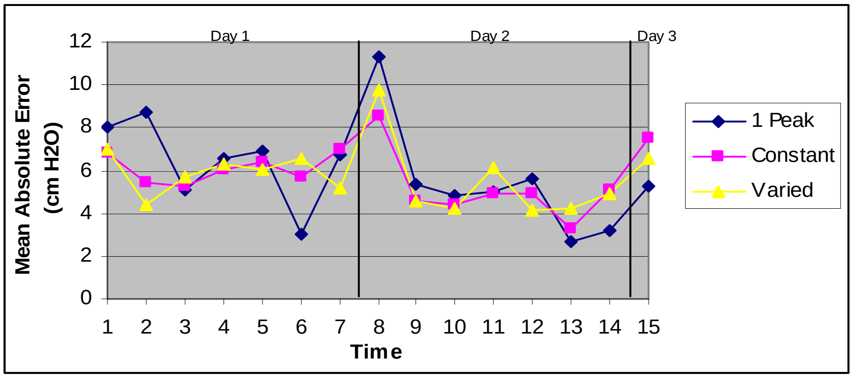
Standard deviations of the AE for 1P, C and V tasks are presented in Figure 5. In general, standard deviations decreased with learning of the 1P task, and transferred to relatively similar amounts for both 2P and 3P tasks. The exception was participant 9, who demonstrated increased variability for the V task.

Figure 4. Individual participant mean AE values for the 1P, constant (C) and variable (V) conditions, across time, utilizing 0% KR.

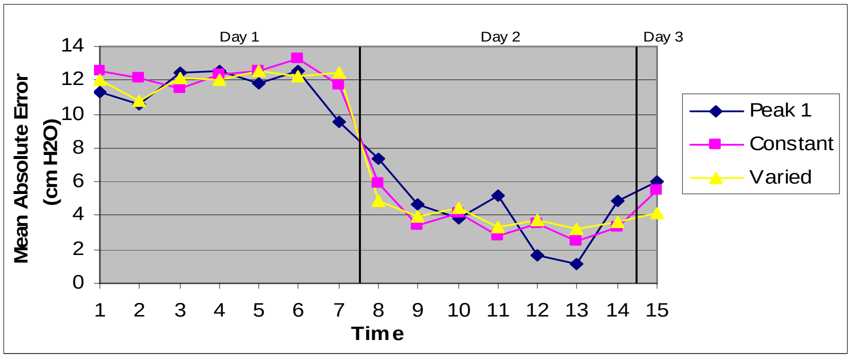
a. Participant 2



b. Participant 7



c. Participant 8



Participant 9

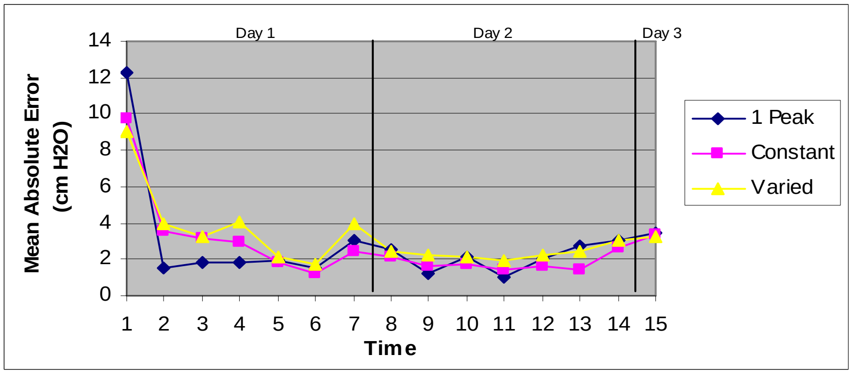
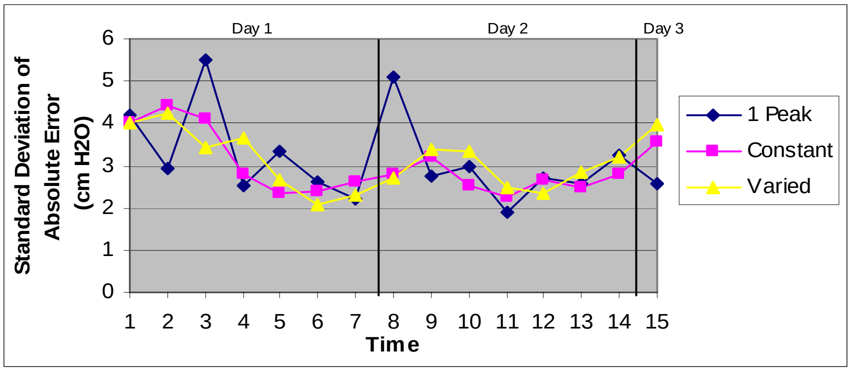
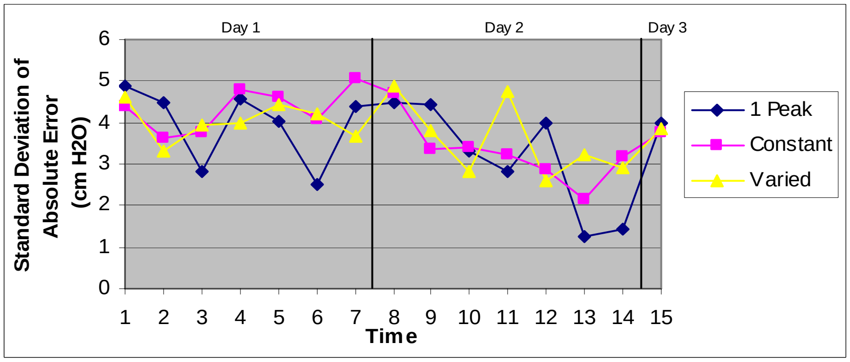


Figure 5. Standard deviations of the absolute error for one-peak, constant (C) and varied (V) tasks, utilizing 0% KR.

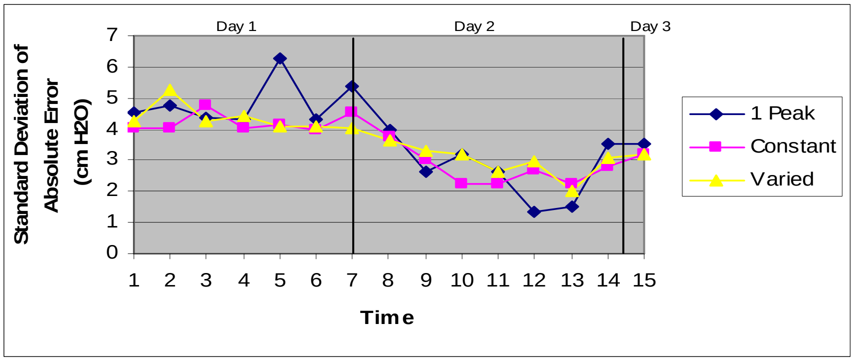
a. Participant 2



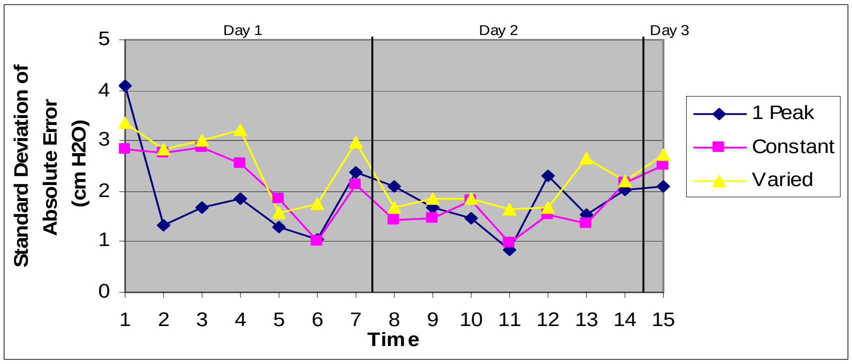
b. Participant 7



c. Participant 8



d. Participant 9



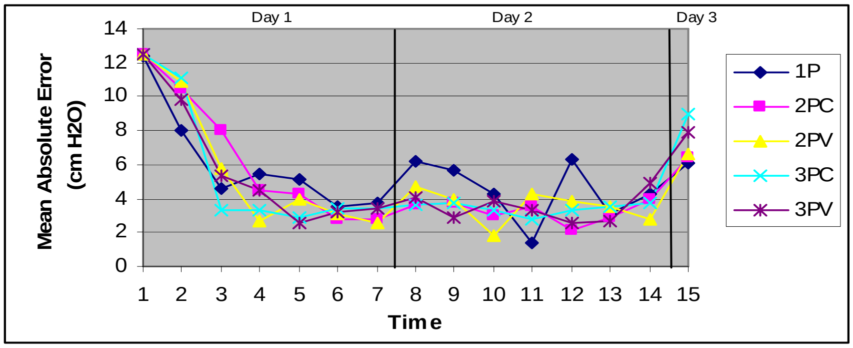
3.1.5 Interaction of Number of Peaks and Consistency

Figure 6 presents the individual participant mean AE values for the following conditions across time: 1P, two peaks constant (2PC), two peaks varied (2PV), 3 peaks constant (3PC) and 3 peaks varied (3PV) conditions. Examination of the data for participants 2, 7, 8 and 9 suggests no distinct pattern of transfer across the four complex tasks. While mean AE values varied somewhat across these tasks, in general, it appeared that transfer to these complex tasks occurred at approximately the same point in time during the 1P training. These findings are similar to those observed, above, for the manipulations of both the number of intraoral pressure peaks and the intraoral pressure consistency. Thus, no interaction was observed between the number of peaks and the pressure consistency.

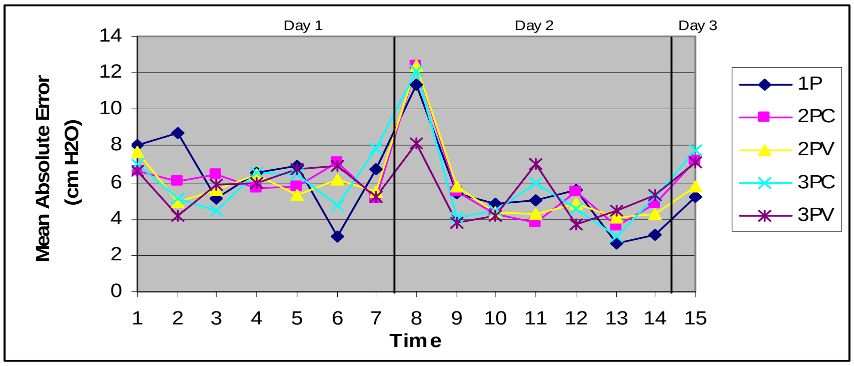
Standard deviations for the 1P, 2PC, 2PV, 3PC and 3PV tasks are presented in Figure 7. As with the standard deviations reported for both the number of peaks and pressure consistency, no distinct patterns emerged in the variability for the four complex transfer tasks. In general, participants demonstrated a decrease in variability across time, with no one task evidencing earlier transfer or substantially different variability.

Figure 6. Individual participant mean AE values for the following conditions across time: 1P, two peaks constant (2PC), two peaks varied (2PV), 3 peaks constant (3PC) and 3 peaks varied (3PV) conditions, utilizing 0% KR.

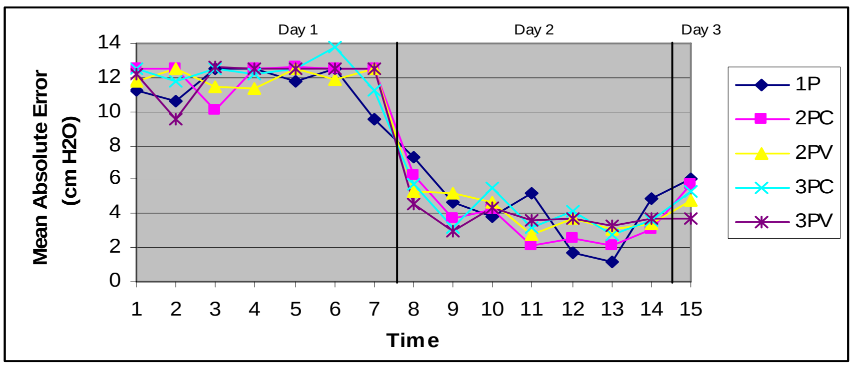
a. Participant 2



b. Participant 7



c. Participant 8



d. Participant 9

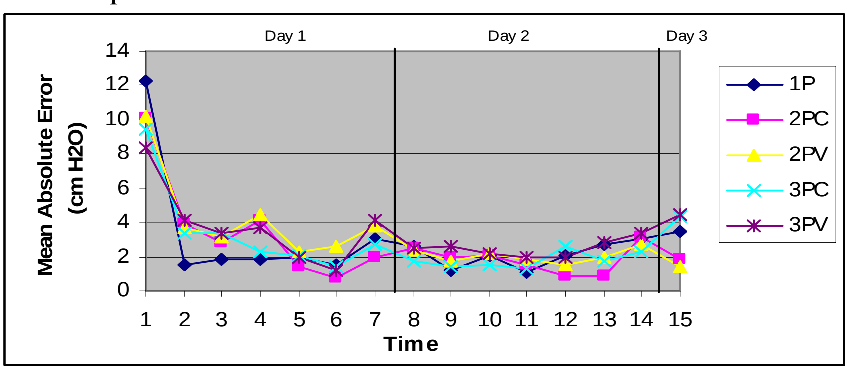
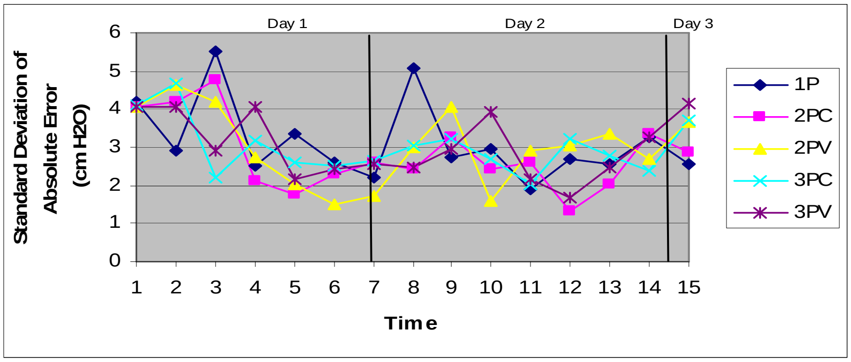
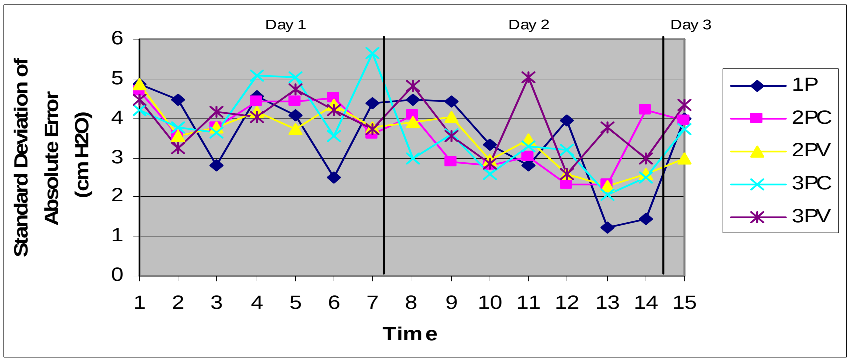


Figure 7. Standard deviations for the 1P, 2PC, 2PV, 3PC and 3PV tasks, utilizing 0% KR.

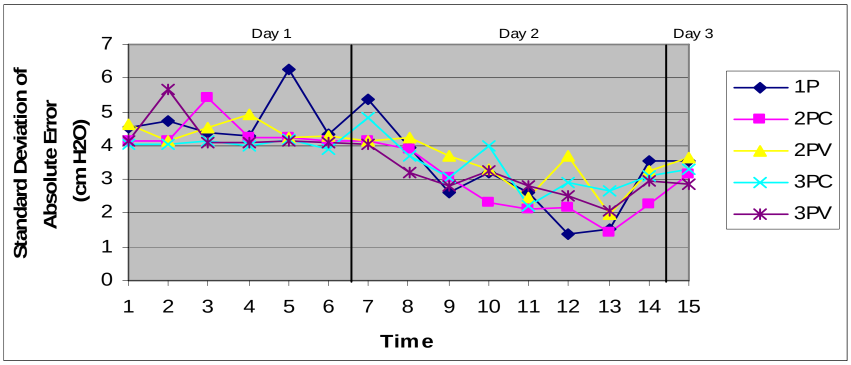
a. Participant 2



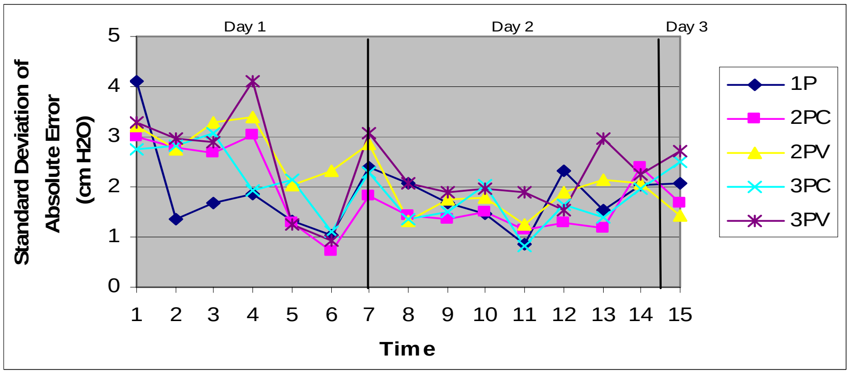
b. Participant 7



c. Participant 8



d. Participant 9



3.1.6 Intentional Deception

Participants were intentionally deceived as to the purpose of the study, to ensure that they did not conceive of the nonspeech stimuli as being speech-like. Participants' responses to the questionnaire, administered at the completion of data collection on Day 3, provided evidence of the effectiveness of the deception. Of the 10 participants in the study, only three indicated awareness of the nonspeech stimuli as being speech-like or thinking of specific speech sounds during the production of the nonspeech tasks (participants 3, 4 and 8). The remaining seven participants expressed no awareness of the nonspeech tasks as being speech-like, until they were informed of this at the completion of data collection on Day 3.

Of the participants who demonstrated learning of the 1P task, participants 2, 7 and 9 reported no awareness of the similarity to speech. Participant 2 indicated, "… I was just trying to hit the targets." Participant 7 reported, "I didn't think of them as speech movements…I was just thinking of that sound that makes (popped lips)…" Participant 9 reported, "I know that it's similar… I was just thinking more to control the pressure." Participant 8, however, indicated awareness of the nonspeech task as being speech-like. This participant reported, "I feel like as I was getting better at it, more towards the end of the study, and then today, when I sat down today, as I was thinking a "p" sound, I was trying to remember the sort of shape of my mouth and I was not making pressure on the tube." Participant 8, as indicated in the data above, did not demonstrate learning of the 1P task or transfer to the more complex tasks during Day 1 of training. However, during baseline data collection at the beginning of Day 2, this participant demonstrated a substantial decrease in the AE for both the 1P task and the transfer tasks.

Of the remaining participants who did not demonstrate learning of the 1P task, participants 1, 5, 6, and 10 provided responses consistent with other participants who demonstrated no awareness of the similarity to speech. Participants 3 and 4, while reporting that they were producing “p” or “b” sounds during the nonspeech tasks, demonstrated no decease in AE values with learning.

4.0 DISCUSSION

The purpose of this study was to determine at what point along two continua of complexity a minimally complex, trained nonspeech task would transfer to nonspeech tasks of increasingly varied complexity. The trained task consisted of production of a single pressure peak, targeting one of two intraoral air pressure values. Complexity of the transfer tasks was manipulated by varying both the number of intraoral pressure peaks (2 peaks or 3 peaks) and the consistency of the intraoral pressure peaks (constant or varied). Results indicated that 4 of the 10 participants demonstrated learning of the trained 1P task, as evaluated by a decrease in the mean Absolute Error of intraoral pressure production from baseline to retention conditions. For these 4 participants, while transfer to the increasingly complex nonspeech tasks did occur, transfer appeared to occur at roughly the same point in time in the learning of the 1P task, across manipulations of both number of pressure peaks and consistency of the pressure peaks. That is, there appeared to be no difference in the time of transfer across the various levels of complexity. It was predicted that transfer would occur earlier to the tasks which were less complex along the two manipulated continua. The results did not support this prediction. There are several potential explanations as to why transfer appeared to occur roughly at the same time for the various complexity levels.

First, the manipulation of both number of peaks and consistency of peaks may not have resulted in one task being more complex than another. This failure to differentiate across the various levels of complexity could be a result of several reasons. The manipulation of the number of pressure peaks may have been inadequate to differentiate one versus two versus three peaks. That is, the production of reduplicative pressure peaks may be no more complex than production of a single pressure peak. While the developmental literature (Steffens et al., 1994; Oller, 1980; Stark, 1980) suggests that a reduplicative utterance is more complex, this may not necessarily be the case for productions by normal adults. Future studies may consider placing multiple pressure peaks within an embedded context of other nonspeech gestures, such as those used in the original Shaiman et al. (2004) study. Similarly, the reduplicative bilabial productions in the current study were similar to Alternating Motion Rates (AMRs) commonly used in the assessment of motor speech disorders. Future studies may embed the multiple bilabial pressure peaks within the context of Sequential Motion Rates (SMRs), which are considered to be more difficult, due to the heavy sequencing demands of moving from one articulatory position to another (Duffy, 2005).

Similar to the manipulation of number of peaks, manipulation of the consistency of the peaks (constant versus varied) may not have been adequate to differentiate complexity. This finding may be due to the manner in which Absolute Errors were computed. Mean AE values and standard deviations were computed for both target pressure levels together. However, it would be interesting to compare accuracy of pressure production for the two target pressure levels separately. It is possible that the lower target level (7 cm H2O) was produced with greater accuracy than the high target level (15 cmH2O), as the low target is typically produced during soft-to-conversational speaking levels, while the high target is produced during loud speech (Holmberg et al., 1988; Stathopoulos, 1986). Separating the data based on target value may provide insight into the complexity of the pressure consistency manipulation. Future studies should also assess differences in the production accuracy for the 7 cmH2O targets versus the 15 cmH2O targets in multiple peak productions (e.g. 7 cmH2O-7 cmH2O; 15 cmH2O-15 cmH2O-15 cmH2O).

Another possible explanation for why the manipulations did not appear to differentiate complexity levels is that probing of the transfer tasks may have been too infrequent. Transfer tasks were probed after every 40 training repetitions of the 1P task. In fact, transfer may have occurred differentially across the complex tasks, but the points of transfer may have occurred during the first or second 40 training trials. Future studies should probe the transfer tasks more frequently, to determine when transfer first occurs for the different levels of complexity.

An additional possibility is that the participants in the study were tapping into their underlying speech knowledge in order to produce the complex tasks. That is, the complex transfer tasks were not differentiated because participants were able to utilize a motor program (or some equivalent structure) that is commonly used during the production of speech, thus enabling accurate pressure production in what was presumed to be a nonspeech task. However, if this had been the case, these participants should have achieved lower absolute error values during Day 1 baseline. Also, three of the participants reported that they did not recognize the nonspeech tasks as being speech-like while they produced the tasks.

Clearly, transfer did occur from a relatively simple trained nonspeech task to more complex untrained nonspeech tasks. This is particularly interesting in that much of the motor learning literature suggests that transfer should not occur in this direction. Rather, it suggests that transfer should occur from more complex trained tasks to less complex, untrained tasks, the opposite of our findings. It is important to consider factors that may have influenced these results. First, it is possible that the training task was of a comparable complexity level to the transfer tasks. Since no continuum yet exists to detail what makes something simple or complex, perhaps length and consistency of pressure peaks are not accurate identifiers of the simplicity or complexity of a task. In this case, it is possible that we selected incorrect or less than optimal parameters when attempting to classify complexity. Another possibility relates back to the literature in which Naylor and Briggs (1963) showed that the learning of complex tasks with autonomous parts was carried out by training separate parts of the task. However, Naylor and Briggs (1963) also stated that the learning of tasks with highly integrated parts would not benefit from breaking apart these tasks during training. Viewing the nonspeech training task utilized in the present study, the possibility exists that the nonspeech training task was so simplified that it was not *as* integrated a task as speech or a higher complexity nonspeech task. None-the-less, this task seems to have followed the pattern of skill acquisition in which the training of separate parts of a task did, in fact, facilitate the learning of the complex task.

In regard to the intentional deception, it is important to assess if recognition that the nonspeech tasks were speech-like did improve performance on the 1P task, or provide for better transfer to the untrained tasks. Since only one participant of three realized the speech parallel of the nonspeech training task improved performance on the 1P training task, this realization does not seem to account for the generalization to the other nonspeech tasks. The only participant that appeared to benefit from this awareness was participant 8. It is possible that being in a "speech mode" allowed this participant to produce more accurate pressure peaks at the beginning of Day 2. However, the other participants who were aware demonstrated no benefit (e.g. quite high AE values all along for S3). Participant 8 stated that he/she had realized that he/she had been producing the task incorrectly throughout the first day of training, explaining that the first day he/she had been "blowing" on the tube. Upon his/her return to the second day of training, he/she explained that he/she understood how to produce pressure independent of "blowing" and later revealed during the questionnaire on Day 3 that he/she realized it was speech before returning on Day 2. It is possible that this participant was utilizing a well-established "speech motor program" or some equivalent motoric structure to achieve such high accuracy beginning on Day 2. Participant 3, while indicating an awareness of the speech deception, did not produce accurate intraoral pressure peaks during any point in the learning, presenting with a consistently high absolute error. Participant 4 was relatively low the entire way through (although high at the end of Day 2), also not showing any related learning curve during the realization of the speech deception. Future studies are being planned to determine if possessing knowledge of a nonspeech task as being "speech-like" results in a change in target accuracy.

There are several limitations to the present study that should be considered when interpreting the results. First, the sample size was extremely small, with only four participants demonstrating learning of the 1P training task. However, additional data are currently being collected from new participants in order to have adequate power for additional analyses. It is expected that future analyses will consist of both individual (single-subject) and group comparisons. This combined individual and group data analysis strategy has been described in Bryk and Raudenbush (1987).

The lack of learning is a large area of concern to this study. This may have been caused by several factors. First, it is possible that the directions provided to participants were not sufficient to perform the task. Of note, toward the end of the study, participants 7, 8, and 9 consecutively demonstrated learning, perhaps indicating that the manner in which the investigator delivered instructions, or the content of the instructions, improved over time. In future studies, this limitation could be addressed by using standardized participant instructions, utilizing video instructions to maintain consistency of instruction delivery. Another possibility for the lack of learning may be due to the participants not being sufficiently motivated to perform the task over such a long period of time (three hour sessions for both Day 1 and Day 2). While participants were motivated with an monetary incentive bonus, this bonus may not have been large enough or offered frequently enough to motivate accurate performance. Therefore, it is possible that boredom may have played a role in the participants' lack of learning. The lack of participant learning may also have been explained by a floor effect. Several participants started at Day 1 baseline with a low absolute error, leaving little room for any further substantial decrease in intraoral pressure peak absolute error.

It is also necessary to examine exactly what participants learned when becoming increasingly accurate during pressure peak production. Participants learned to build intraoral pressure to certain target levels. It can be assumed that they learned to coordinate timing of the respiratory and articulatory systems, as well as to close both the lips and the velopharyngeal port for the build-up of intraoral pressure. However, the lack of kinematic or airflow data limits the ability to identify specific movement characteristics that may have been learned in order to generate the intraoral pressure values. In the future, kinematic data would help to provide insight into specifically learned characteristics of intraoral pressure production.

An additional limitation regards the baseline data collection and presentation. Insufficient baseline data were collected to fully document the variability in both the simple and complex productions of the pressure peaks before training began. In future studies, it would be necessary to have participants produce additional baseline data. An additional constraint existed in the presentation of baseline data in graphs. The baseline data were presented as single data points on the graphs, which does not provide knowledge of participant intraoral pressure peak variability.

In future studies, baseline data should be shown as individual productions rather than an average across baseline production.

Perceptual judgments were utilizing to determine whether transfer occurred. Specific parameters by which these perceptual judgments are made should be identified and defined. Potential parameters of measurement include slope, magnitude and variability of AE decrease. Inter-rater reliability should be established to align investigator and naïve rater perceptions of transfer.

A further limitation regards the maximum pressure measurement of the intraoral pressure peaks. The pressure transducer utilized in this study was capable of measuring pressures up to 23 cmH2O. In some instances, participants produced intraoral pressures in excess of 23 cm H2O. This typically occurred during attempts to reach the 15 cm H2O target. The limitation of the pressure transducer thus resulted in invalid AE measurements on these specific trials, presenting a smaller AE than the participant actually produced. In addition, this inaccurate AE information provided participants with erroneous KR regarding the magnitude of their production relative to the target. Data should be reanalyzed to exclude these productions. Additionally, future studies should aim to either use a transducer with a higher ceiling for pressure measurement or else fine tune participant productions of intraoral pressure production below the maximum transducer reading of 23 cmH2O.

In futures studies, it may also be important to examine a speed-accuracy trade-off in the production of the intraoral pressure peak task. Although analyses have not been performed to determine if speed of production of the pressure peaks increased from beginning to end of the study, informal observation from the investigator did indicate that there was an increase in the speed of production. However, the speed-accuracy trade-off appears not to apply in that participants became increasingly accurate throughout the study.

Finally, it is important to consider how the results of the current study relate to the limited retention and transfer which was observed in the Shaiman et al. (2004) study. The fact that only 4 participants in the current study demonstrated retention of the trained task suggests individual differences in learning. Equally important, however, is that of the participants that demonstrated learning, all showed retention of this learning. Issues such as task instructions, number of training trials, motivation of participants, as well as the conditions of practice (e.g., percent KR, KR delay interval, etc.) should be systematically manipulated in future studies. Better understanding of the variables involved in training may permit improved learning and retention for all participants. The observation that transfer did occur to the more complex tasks for all participants that demonstrated learning suggests that a nonspeech task, developed to equate the level of complexity, organization and goal between speech and nonspeech gestures, can be learned and transferred. This finding provides a foundation for continued examination of the complexity of nonspeech oral behaviors, and their potential relationship to speech production.

APPENDIX A

POST-EXPERIMENTAL QUESTIONNAIRE

A.1 DURING THE EXPERIMENT, DID YOU THINK THERE WAS ANY PARTICULAR PATTERN TO WHEN YOU WERE GIVEN FEEDBACK FOR THE MOVEMENTS? IF SO, WHAT WAS THE PATTERN?

A.2 DURING THE EXPERIMENT, WHAT DID YOU THINK WAS THE POINT OF THE TRIALS WHERE YOU WERE NOT GIVEN FEEDBACK ON YOUR PERFORMANCE?

A.3 WHILE YOU WERE PERFORMING THE LIP MOVEMENTS, DID YOU THINK THERE WAS ANYTHING SPECIAL ABOUT THESE MOVEMENTS? IF SO, WHAT DID YOU THINK WAS SPECIAL?

A.4 DURING THE EXPERIMENT, DID YOU DO ANYTHING DIFFERENTLY ON THE TRIALS IMMEDIATELY FOLLOWING FEEDBACK? IF SO, WHAT DID YOU DO DIFFERENTLY?

A.5 DURING THE EXPERIMENT, DID YOU THINK YOU WERE SUPPOSED TO MAKE THE LIP MOVEMENTS IN ANY PARTICULAR WAY OR DID YOU CHANGE THE WAY IN WHICH YOU MADE THE MOVEMENTS? IF SO, HOW?

A.6 HOW ACCURATE DO YOU THINK YOU WERE ON GETTING CLOSE TO THE GREEN TARGET LINE ON THE LIP TASK?

A.7 WERE YOU FAMILIAR WITH THE SEQUENCE OF THE LIP MOVEMENTS BEFORE THE EXPERIMENTAL SESSION? IF SO, HOW?

A.8 WOULD INSTRUCTIONS TO DEVELOP A RHYTHM TO THE MOVEMENTS HAVE MADE A DIFFERENCE IN YOUR PERFORMANCE? IF SO, HOW?

A.9 DO YOU THINK THAT THE LIPS MOVEMENTS WERE AT ALL SPEECH-LIKE?

A.10 WHILE YOU WERE DOING THE EXPERIMENT, BEFORE I ASKED YOU IF THE LIP MOVEMENTS WERE LIKE SPEECH, DID YOU AT ALL THINK OF THE LIP MOVEMENTS AS BEING SPEECH-LIKE?

A.11 WHEN YOU WERE DOING THE LIP MOVEMENTS, WERE YOU THINKING OF THEM AS SPEECH MOVEMENTS? OR DID YOU MERELY RECOGNIZE THAT THEY WERE LIKE SPEECH?

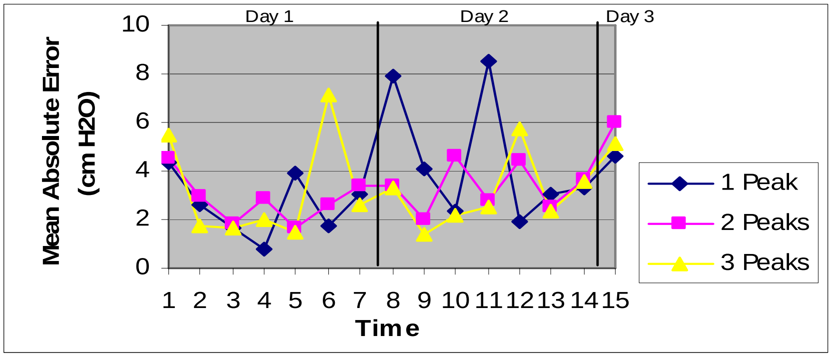
A.12 WERE YOU THINKING OF ANY SPECIFIC SPEECH SOUNDS WHILE YOU WERE PRODUCING THE MOVEMENTS? IF SO, WHAT SOUNDS WERE YOU THINKING OF?

APPENDIX B

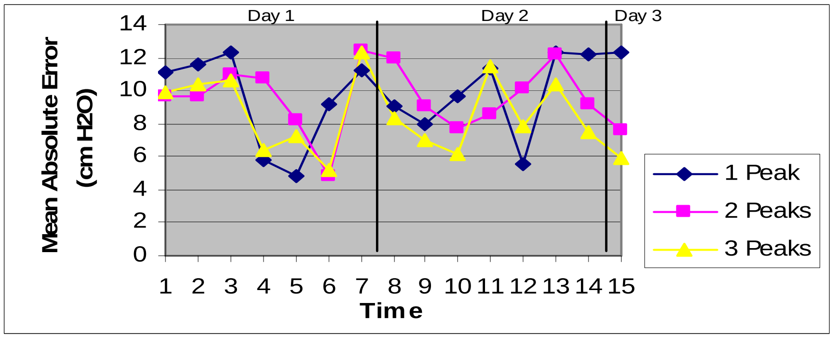
PARTICIPANTS 1, 3, 4, 5, 6, 10: 1P AND TRANSFER TASK RESULTS

Individual participant mean absolute error values for 1P, 2P and 3P conditions, utilizing 0% KR.

Participant 1



Participant 3



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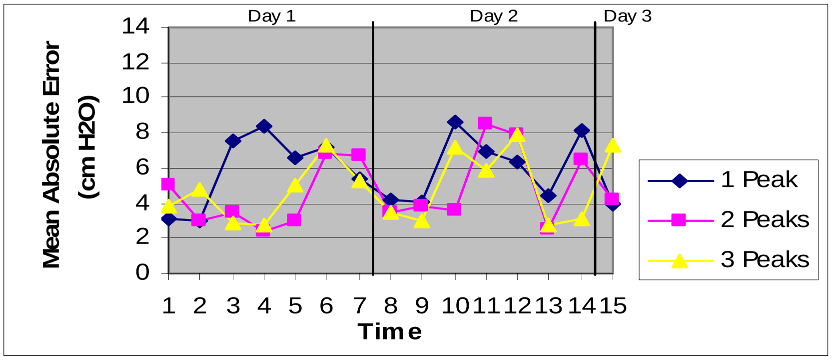
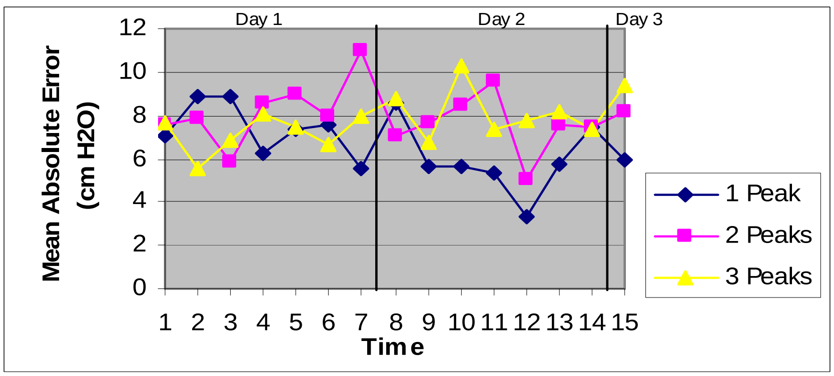


Participant 5



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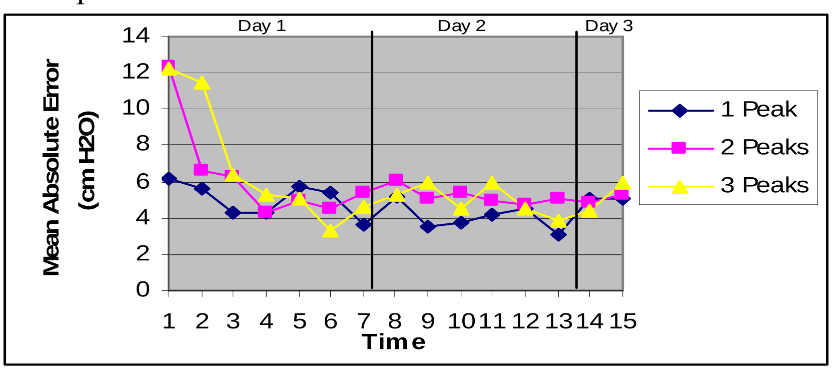
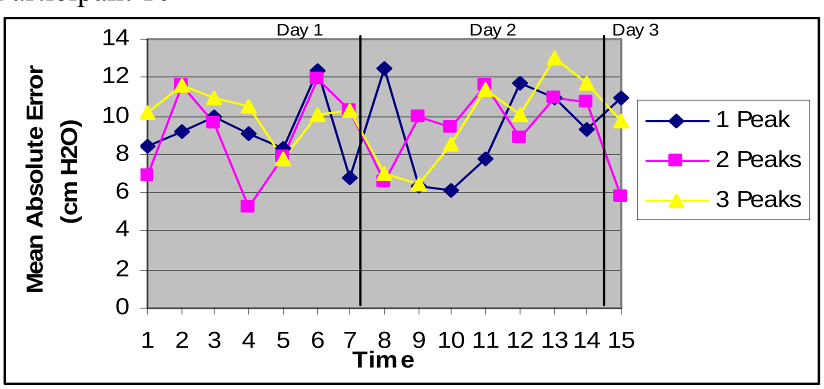
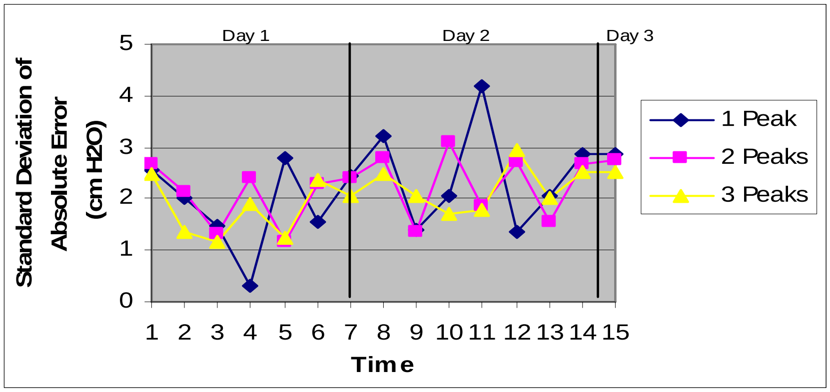


Participant 10



Individual participant standard deviation values for 1P, 2P and 3P conditions, utilizing 0% KR.

Participant 1



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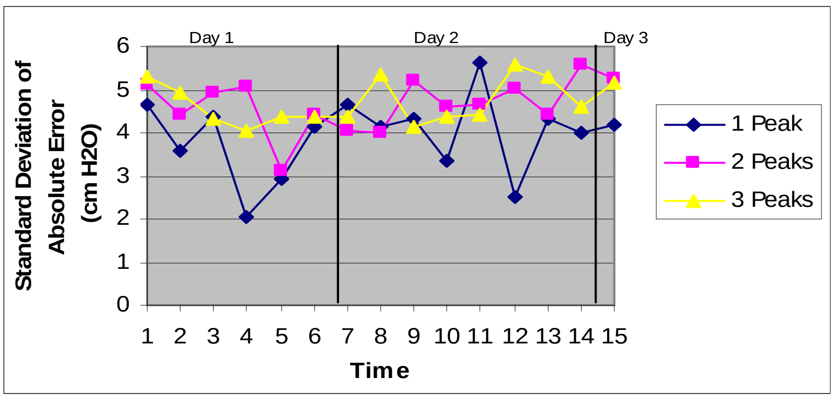

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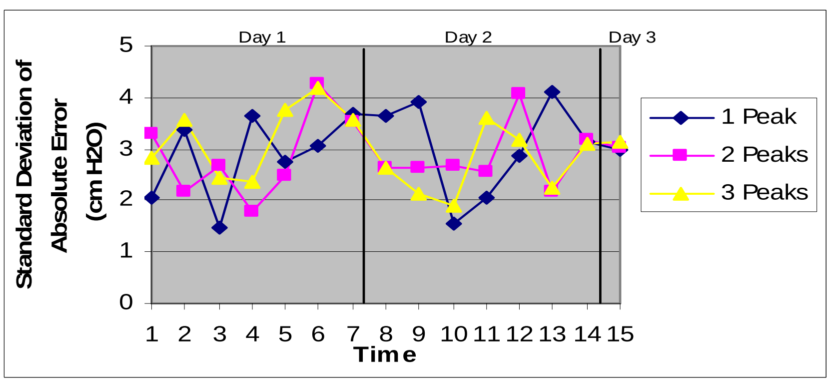
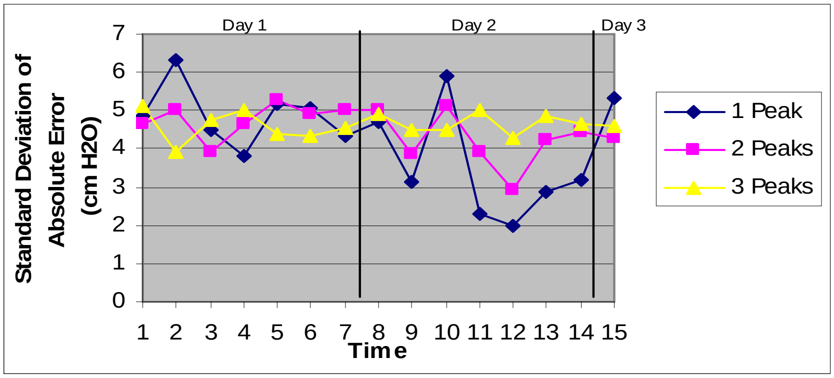
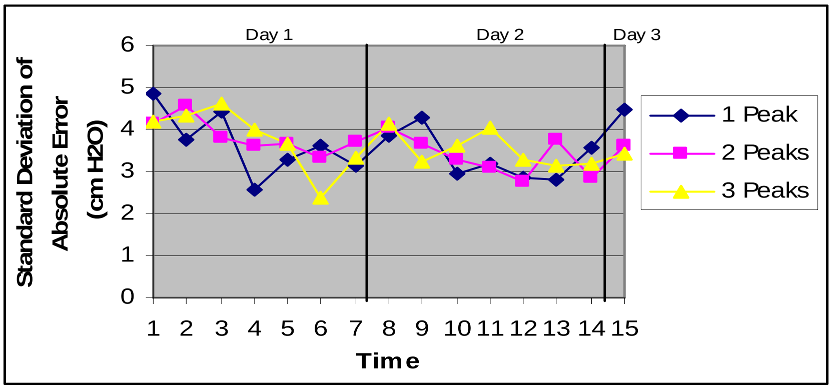


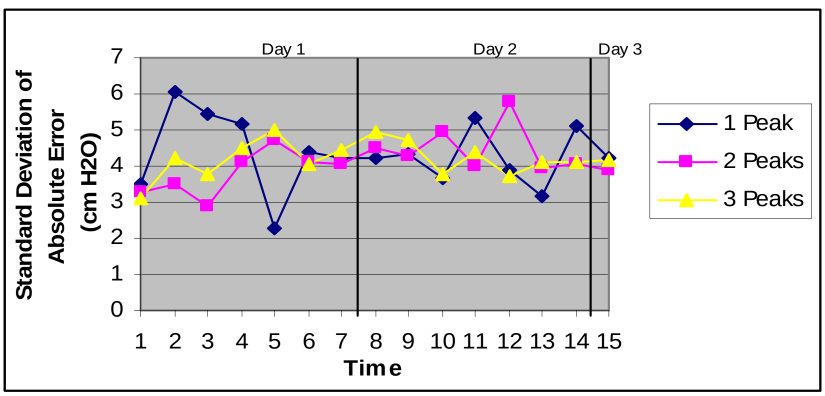
Participant 5



Participant 6

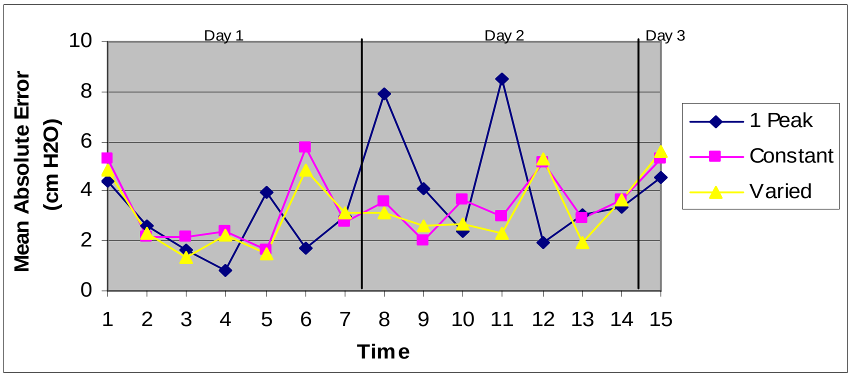


Participant 10



Individual participant mean AE values for the 1P, constant (C) and variable (V) conditions, across time, utilizing 0% KR.

Participant 1



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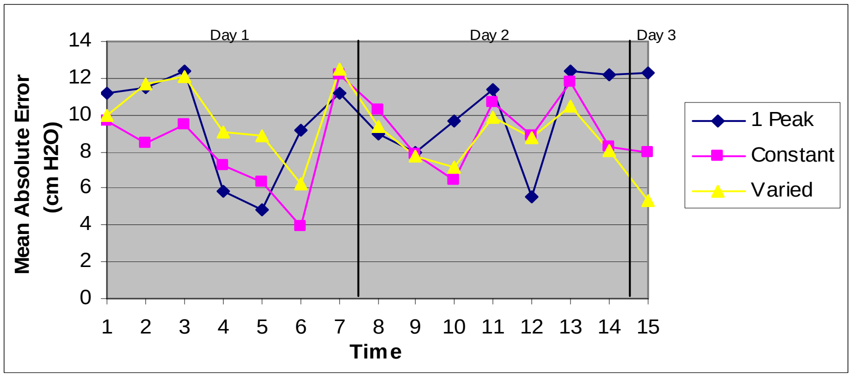
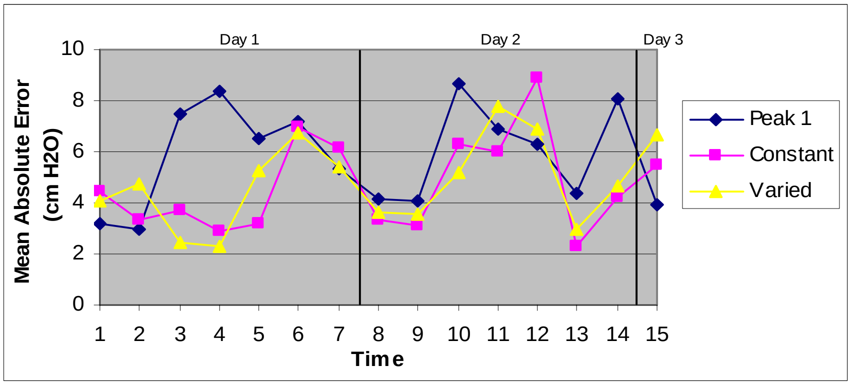
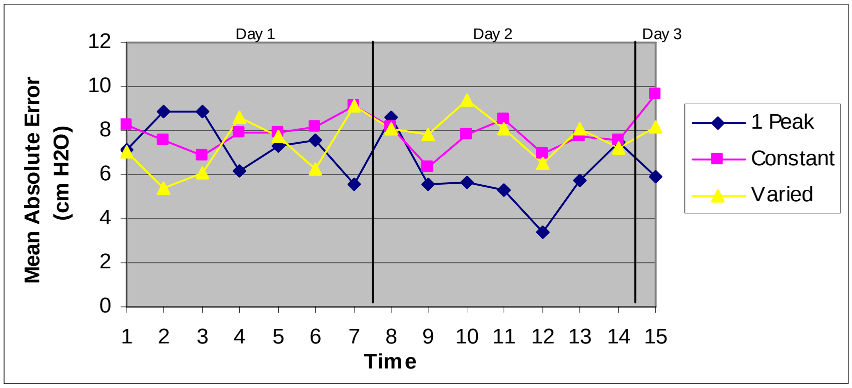


Participant 4



Participant 5



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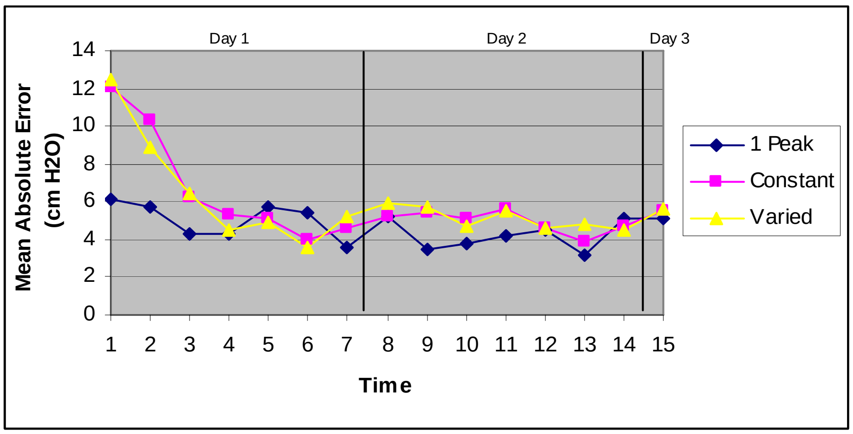

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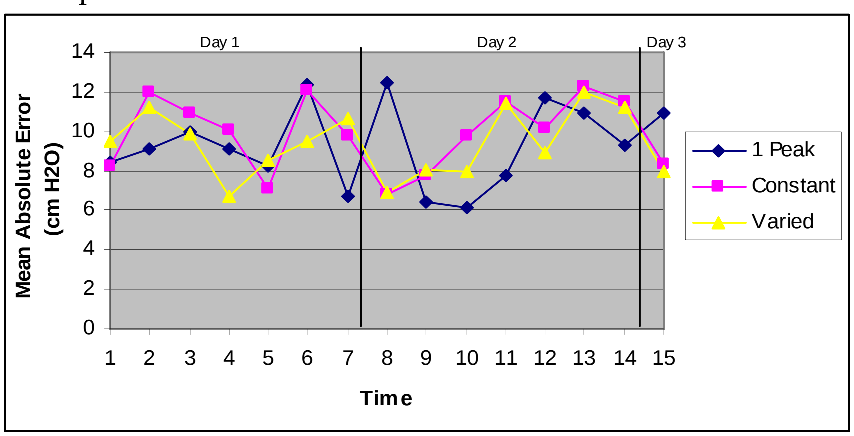
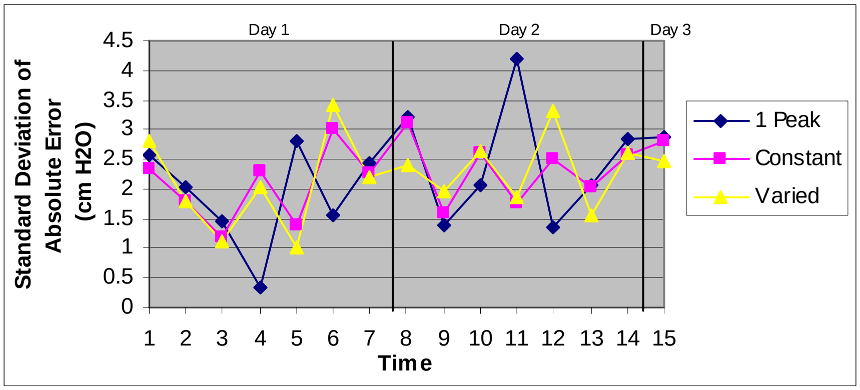
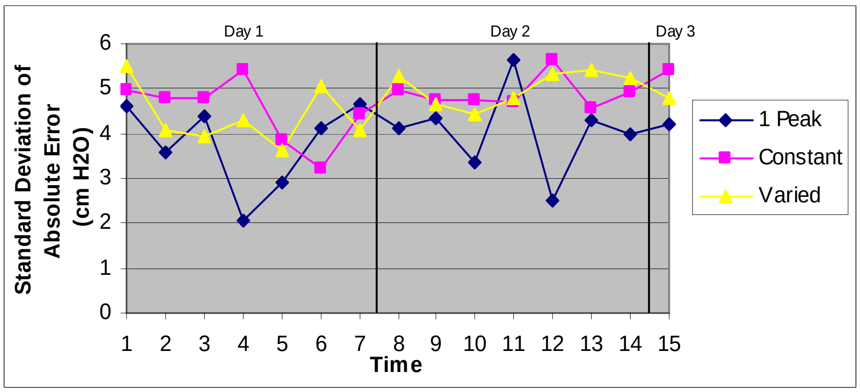


Standard deviations of the absolute error for one-peak, constant (C) and varied (V) tasks, utilizing 0% KR.

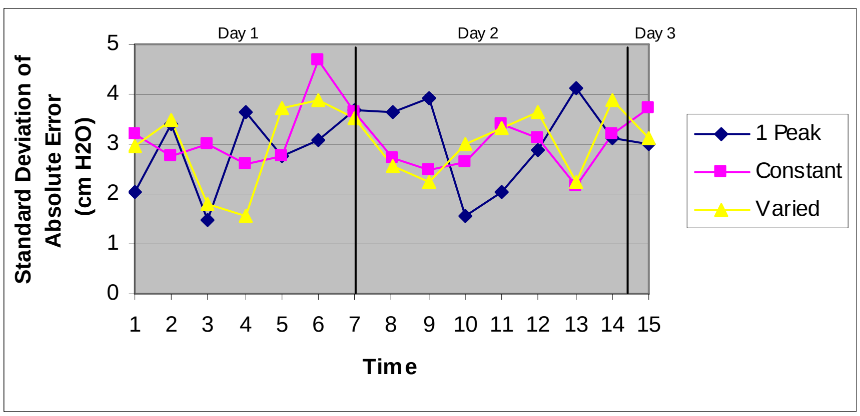
Participant 1



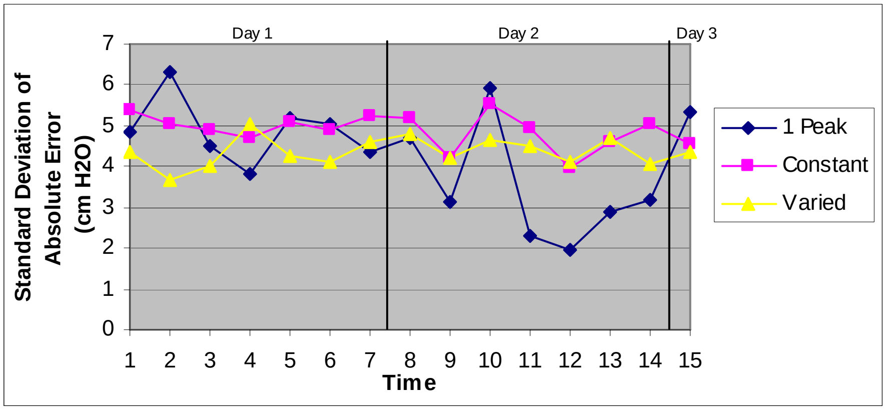
Participant 3



Participant 4



Participant 5



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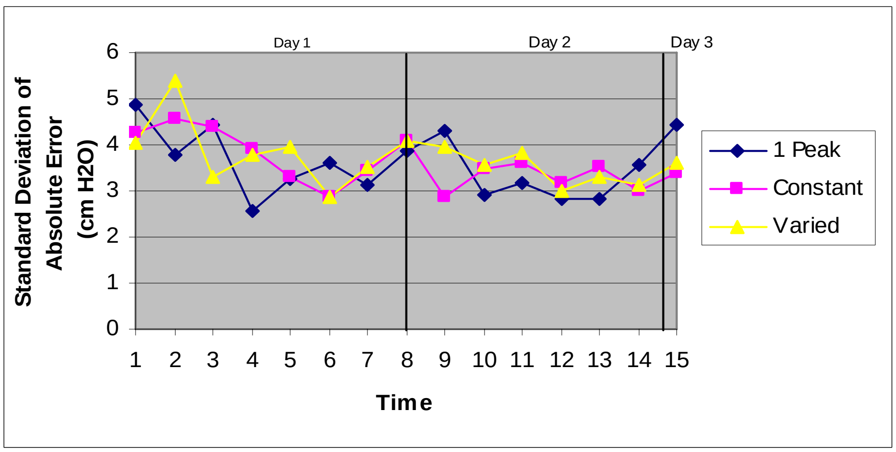
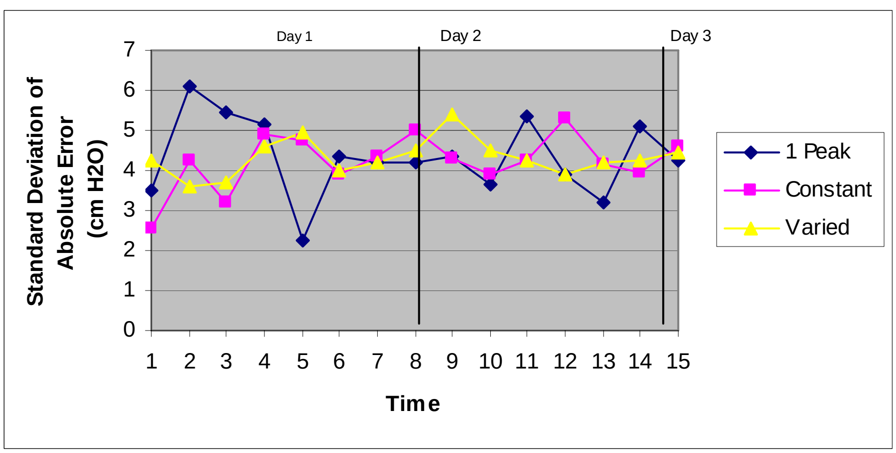
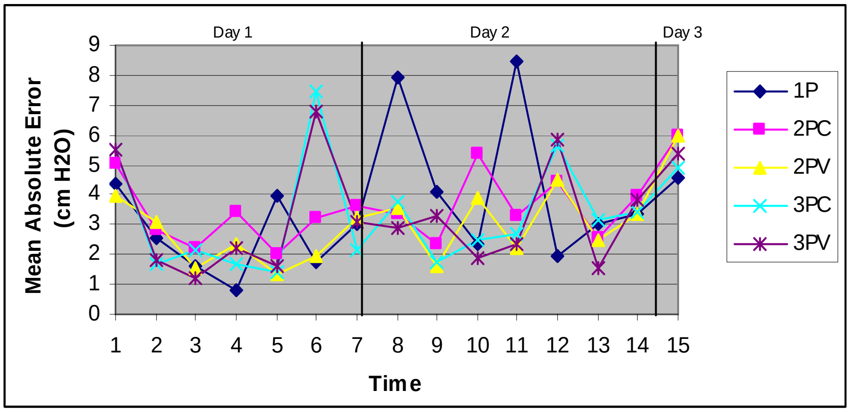


Participant 10



Individual participant mean AE values for the following conditions across time: 1P, two peaks constant (2PC), two peaks varied (2PV), 3 peaks constant (3PC) and 3 peaks varied (3PV) conditions, utilizing 0% KR.

Participant 1



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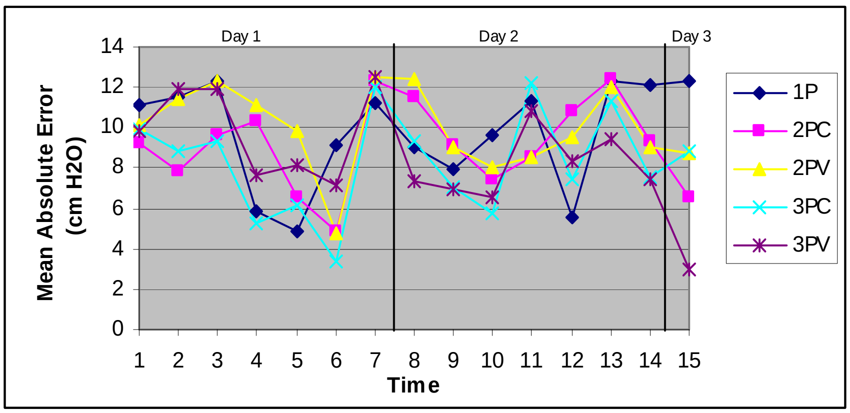

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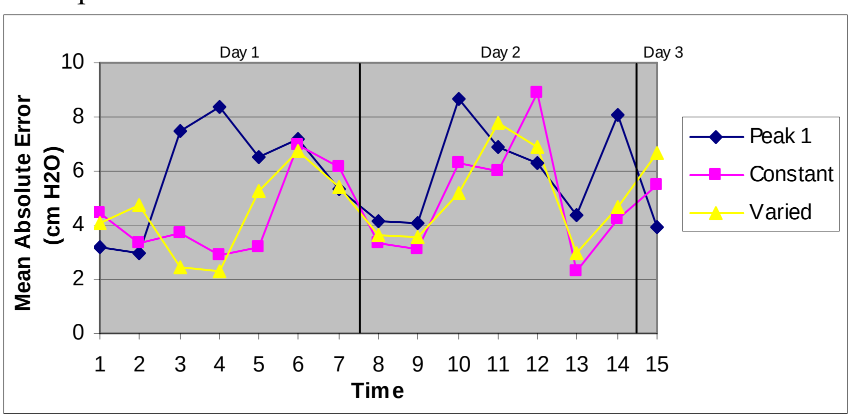
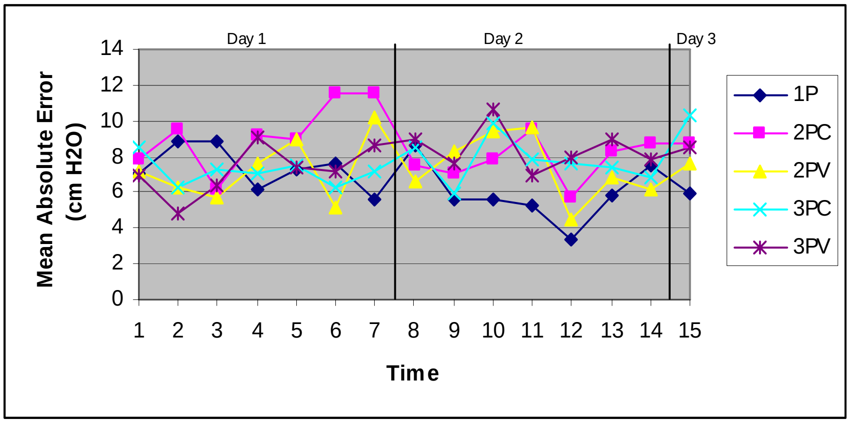
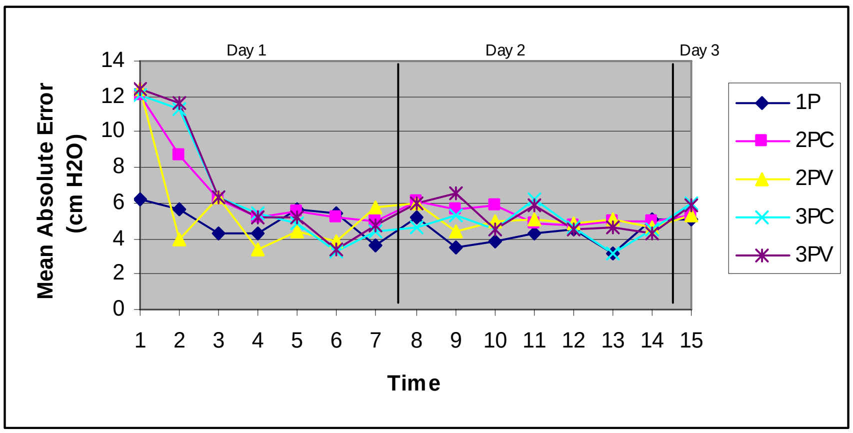


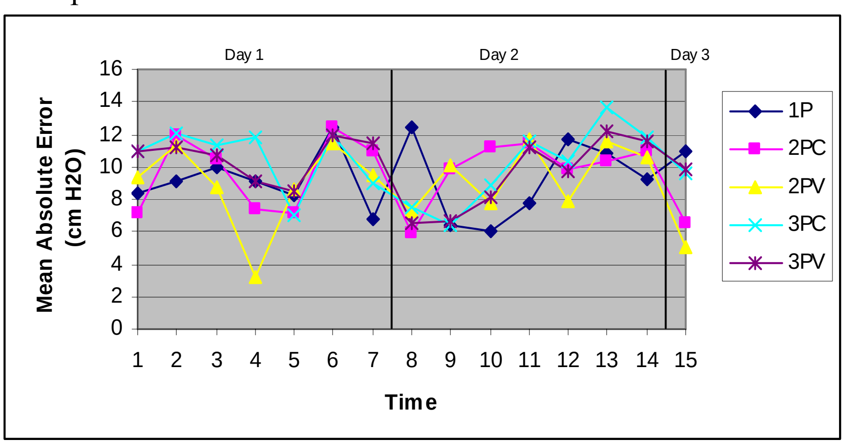
Participant 5



Participant 6

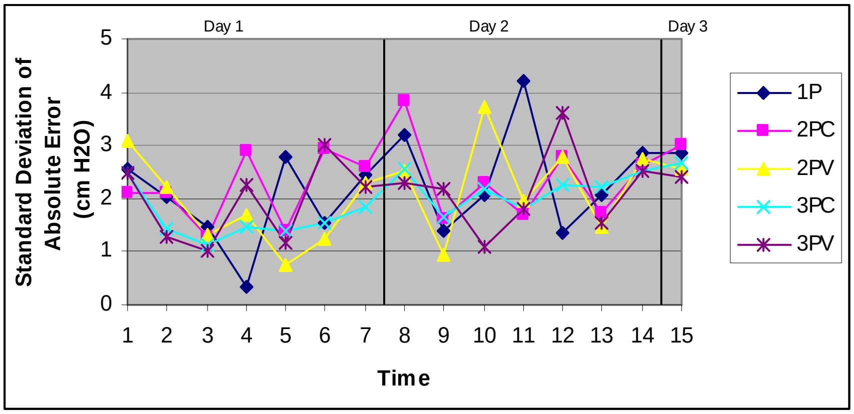


Participant 10



Standard deviations for the 1P, 2PC, 2PV, 3PC and 3PV tasks, utilizing 0% KR.

Participant 1



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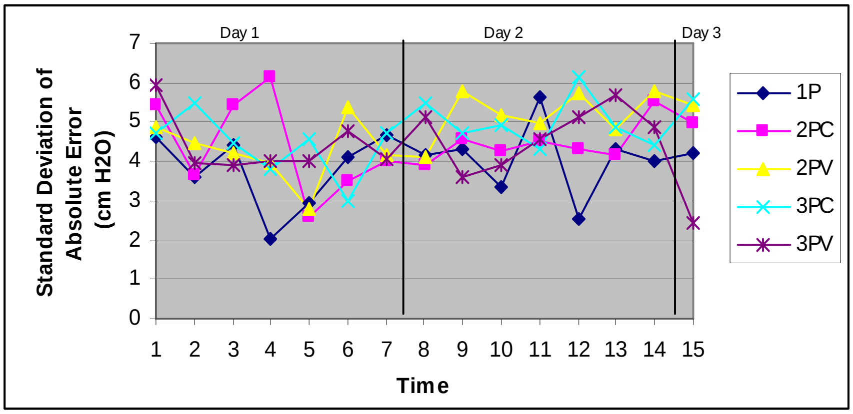
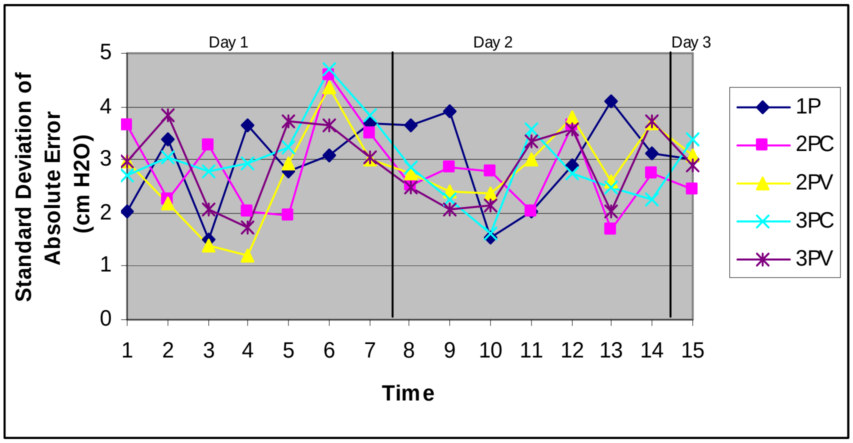


Participant 4



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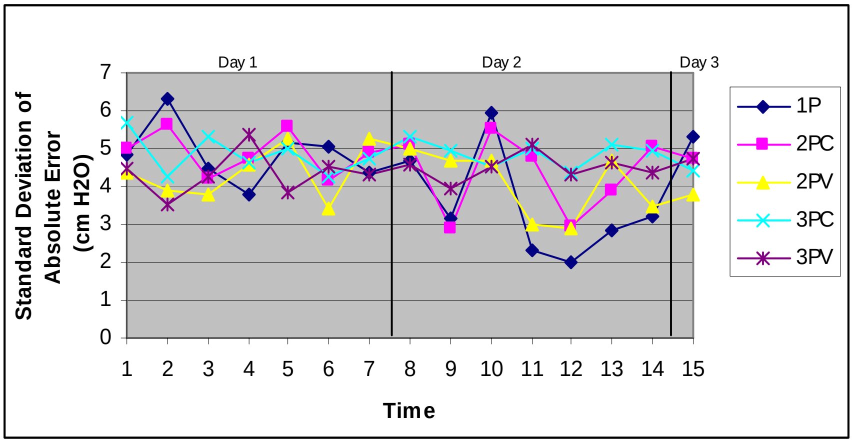

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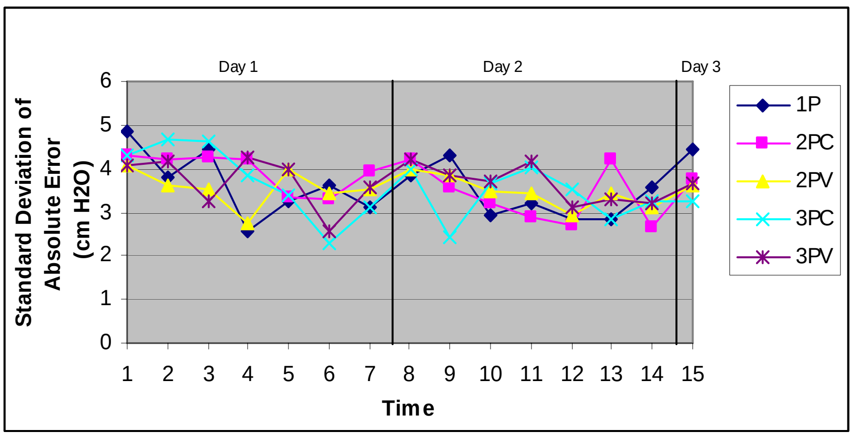
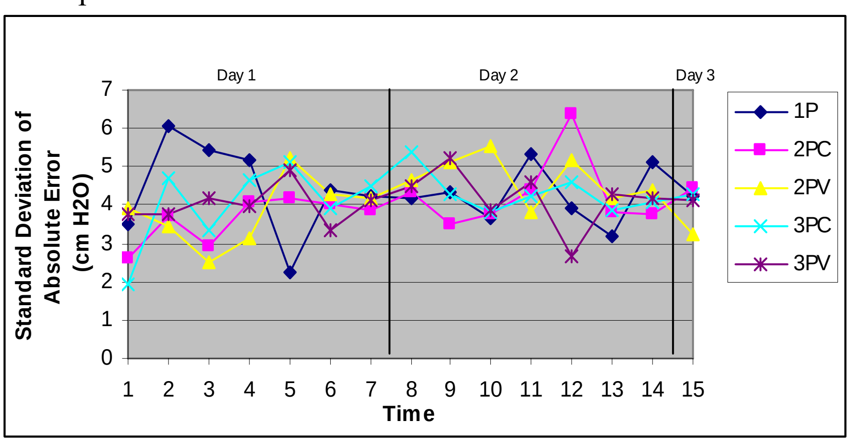


Participant 10



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