Evaluation of principles of motor learning in speech and non-speech-motor learning tasks

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Abstract

Principles of motor learning (PMLs) refer to a set of concepts which are considered to facilitate the process of motor learning. PMLs can be broadly grouped into principles based on (1) the structure of practice/treatment, and (2) the nature of feedback provided during practice/treatment. Application of PMLs is most evident in studies involving non-speech-motor tasks (e.g., limb movement). However, only a few studies have investigated the application of PMLs in speech-motor tasks. Previous studies relating to speech-motor function have highlighted two primary limitations: (1) Failure to consider whether various PMLs contribute equally to learning in both non-speech and speech-motor tasks, (2) Failure to consider whether PMLs can be effective in a clinical cohort in comparison to a healthy group. The present research was designed to shed light on whether selected PMLs can indeed facilitate learning in both non-speech and speech-motor tasks and also to examine their efficacy in a clinical group with Parkinson's disease (PD) in comparison to a healthy group.

Eighty healthy subjects with no history of sensory, cognitive, or neurological abnormalities, ranging 40-80 years of age, and 16 patients with PD, ranging 58-78 years of age, were recruited as participants for the current study. Four practice conditions and one feedback condition were considered in the training of a speech-motor task and a non-speech-motor task. The four practice conditions were (1) constant practice, (2) variable practice, (3) blocked practice, and (4) random practice. The feedback was a combination of low-frequency, knowledge of results, knowledge of performance, and delayed feedback conditions, and was paired with each of the four practice conditions. The participants in the clinical and non-clinical groups were required to practise a speech and a non-speech-motor learning task. Each participant was randomly and equally assigned to one of the four practice groups. The speech-motor task involved production of a meaningless and temporally modified phrase, and the non-speech-motor task involved practising a 12-note musical sequence using a portable piano keyboard.

Each participant was seen on three consecutive days: the first two days served as the acquisition phase and the third day was the retention phase. During the acquisition phase, the participants practised 50 trials of the speech phrase and another 50 trials of the musical tune each day, and each session lasted for 60-90 min. Performance on the speech and non-speech tasks was preceded by an orthographic model of the target phrase/musical sequence displayed on a computer monitor along with an auditory model. The participants were instructed to match their performance to the target phrase/musical sequence exactly. Feedback on

performance was provided after every 10th trial. The nature of practice differed among the four practice groups. The participants returned on the third day for the retention phase and produced 10 trials of the target phrase and another 10 trials of the musical sequence. Feedback was not provided during or after the retention trials. These final trials were recorded for later acoustic analyses.

The analyses focused on spatial and temporal parameters of the speech and non-speech tasks. Spatial analysis involved evaluating the production accuracy of target phrase/tune by calculating the percentage of phonemes/keystrokes correct (PPC/PKC). The temporal analysis involved calculating the temporal synchrony of the participant productions (speech phrase & tune) during the retention trials with the target phrase and tune, respectively, through the phi correlation. The PPC/PKC and phi correlation values were subjected to a series of mixed model ANOVAs.

In the healthy subjects, the results of the spatial learning revealed that the participants learned the speech task better than the non-speech (keyboard) task. In terms of temporal learning, there was no difference in learning between the speech and non-speech tasks. On an overall note, the participants performed better on the spatial domain, rather than on the temporal domain, indicating a spatial-temporal trade-off. Across spatial as well as temporal learning, participants in the constant practice condition learned the speech and non-speech tasks better than participants in the other practice conditions. Another interesting finding was that there was an age effect, with the younger participants demonstrating superior spatial and temporal learning to that of the older participants, except for temporal learning on the keyboard task for which there was no difference. In contrast, the PD group showed no significant differences on spatial or temporal learning between any of the four practice conditions. Furthermore, although the PD patients had poorer performances than the healthy subjects on both the speech and keyboard tasks, they showed very similar pattern of learning across all four practice conditions to that of the healthy subjects.

The findings in the current study tend to have potential applications in speech-language therapy, and are as follows: (1) a constant practice regime could be beneficial in developing speech therapy protocols to treat motor-based communication disorders (e.g., dysarthria), (2) speech therapists need to exercise caution in designing speech therapy goals incorporating similar PMLs for younger and older adults, as the application of similar PMLs in younger and older adults may bring about different learning outcomes, (3) and finally, it could be beneficial for patients to practise speech tasks which would require them to focus either on the spatial or temporal aspect, rather than focussing on both the aspects simultaneously.

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Last but not the least, I thank ‘God Almighty’ who has protected all of us and continues to protect with his blessings.

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Preface

This PhD thesis conforms to the referencing style recommended by the American Psychological Association Publication Manual (5th ed.) and to the spelling conventions recommended by Oxford Dictionary (http://oxforddictionaries.com/).

The research for this PhD project was carried out between September 2010 and July 2012 while the student was enrolled as a PhD candidate at the Department of Communication Disorders in the University of Canterbury. Research expenses incurred for the purchase of equipment (keyboard) and participants' travel expenses were funded by the Department of Communication Disorders.

Currently, aspects of this PhD research have resulted in three presentations at national and international conferences

1. **Kaipa, R**., Robb, M. P., Huckabee, M. L., & Jones, R. (2011). Application of motor learning principles in speech & non-speech tasks. Paper presented at the *Annual Convention of American Speech and Hearing Association*, San Diego, November 17th-19th.
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Abbreviations

AD	Alzheimer’s disease
ANOVA	analysis of variance
AOS	apraxia of speech
ASHA	American Speech, Language and Hearing Association
CAS	childhood apraxia of speech
CI	contextual interference
CPF	challenge point framework
CV	consonant-vowel
EEG-EMG	electroencephalography-electromyography
HD	Huntington’s disease
PD	Parkinson’s disease
PMLs	principles of motor learning
PPC	percentage of phonemes correct
PKC	percentage of keystrokes correct
KR	knowledge of results
KP	knowledge of performance
UPDRS	Unified Parkinson’s disease rating scale
min	minutes
ms	milliseconds
NASA	National Aeronautics and Space Administration
NSOMSE	Non-speech-oromotor speech exercises
s	seconds

SAT	spatial-accuracy trade-off
SLP	Speech Language Pathologist
UK	United Kingdom
USA	United States of America
VC	vowel consonant
VMT	visuomotor tracking

Chapter 1. Introduction

Speech-motor control is broadly defined as the neuronal actions that initiate and regulate muscle contractions for speech production (Netsell, 1983). The speech-motor system refers to the neural mechanisms used to produce speech. The efficient functioning of the speech-motor system is affected in a sub-group of speech disorders referred to as motor-speech disorders (MSDs) (Darley, Aronson, & Brown, 1975; Duffy, 2005). MSDs may be caused by disruption at high levels of neural (cerebral) activity or at lower levels such as the point of neuro-muscular junctions. MSDs include both developmental and acquired forms of dysarthria and apraxia of speech. Individuals with MSDs represent a substantial proportion among individuals with speech disorders (Duffy, 2005). As MSDs represent deficits in motor control, treatment modalities focussing on aspects of motor learning/re-learning could be useful to treat the speech deficits associated with MSDs.

Motor learning

The process of motor learning is essential for either learning new skills (e.g., a baby learning to walk) or re-learning the lost skill(s) (e.g., an adult re-learning to walk after a stroke). Motor learning refers to 'a set of processes associated with practice or experience leading to relatively permanent changes in the capacity for movement' (Schmidt & Lee, 2005, p. 302). Often the terms 'performance' and 'learning' are used interchangeably within the scope of motor learning, and it is essential to distinguish them. According to Magill (2004), performance is a behaviour which can be observed and refers to the act of executing a motor skill. Performance is not indicative of permanent acquisition of a motor skill. Learning is a behaviour which cannot be observed but can be inferred based on a person's performance. Learning results in permanent acquisition of a particular motor skill. Motor learning is usually assessed through tests of retention and transfer. Retention refers to the persistence in the performance of an acquired motor skill, whereas transfer is indicative of ability to perform a particular task as a result of practising another task (Schmidt & Lee, 2005).

Principles of motor learning

Even though there is no agreed standard definition of Principles of Motor learning (PMLs), in a general context, PMLs refer to a set of guided principles thought to facilitate learning/re-learning of motor skills when applied systematically. PMLs can be broadly classified into two types: (1) principles pertaining to the structure of practice and,

(2) principles pertaining to the nature of feedback (Mass et al., 2008). Structure of practice refers to the act of rehearsing behaviour repeatedly for the purpose of improving or mastering it (Poole, 1991). A practice regime can be structured based on variables such as practice amount, practice distribution, practice variability, practice schedule, source of attention, and complexity of the practising task (Bislick et al., 2012). Nature of feedback refers to information related to the sensation associated with the movement itself (e.g., feel, sound), as well as information related to the result of the action with respect to the environmental goal (Kawashima et al., 2000). Efficient feedback can be provided based on frequency, type, and timing (Bislick et al., 2012).

Application of PMLs in non-speech-motor learning

PMLs have largely emerged from studies involving non-speech-motor tasks (e.g., keyboard entry tasks). Among the practice conditions, constant practice vs. variable practice and, random practice vs. blocked practice have received considerable attention. Constant practice refers to the practice of the same target repeatedly (e.g., practising a golf swing), whereas variable practice targets more than one variant of a given target (e.g., practising a golf swing over varying distances from the hole) (Shoenfelt, Synder, Maue, McDowell, & Woolard, 2002). The benefit of variable over constant practice (for retention) has been confirmed for a variety of tasks (e.g., Lee, Magill & Weeks, 1985; Wulf & Schmidt, 1997; Shoenfelt et al., 2002).

Random practice refers to a practice condition in which target movements with different motor plans are practised in such a manner that the learner is unable to predict the target for the upcoming trial (Knock et al., 2000). Blocked practice refers to a practice condition in which the learner practices a set of target movements and then practises another set of target movements successively (Knock et al., 2000). Numerous studies have shown the benefits of random over blocked practice (for retention) across a wide range of tasks (e.g., Lee & Magill, 1983; Shea & Morgan, 1979; Wright, Black, Immink, Brueckner, & Magnuson, 2004; Wulf & Lee, 1993).

Among the feedback conditions pertaining to PMLs, feedback frequency and feedback timing have received considerable attention. Feedback frequency refers to how often feedback is provided during practice (Hula et al., 2008). Studies investigating frequency of feedback have shown an advantage for low-frequency feedback (e.g., Winstein & Schmidt, 1990). Feedback timing refers to when feedback is provided relative to the completion of the motor movement (Hula et al., 2008). Studies have shown that providing feedback immediately after a task is less effective for learning than delaying it for a few seconds (e.g., Swinnen, Schmidt, Nicholson, & Shapiro, 1990).

Application of PMLs in speech-motor learning

Limited studies have experimentally applied and validated PMLs to speech-motor learning. Studies examining practice conditions have shown variable practice to be beneficial over constant practice (e.g., Adams & Page, 2000), and random practice to be beneficial over blocked practice (e.g., Knock et al., 2000). A more recent study comparing random vs. blocked practice conditions in children with childhood apraxia of speech (CAS) revealed both practice conditions to be beneficial in treatment of CAS (Mass & Farinella, 2012).

In terms of feedback condition, Hula et al. (2008) investigated the effect of feedback frequency and timing on acquisition, retention and transfer of speech skills in adults with apraxia of speech (AOS). They found that a low frequency and delayed feedback seemed to facilitate acquisition, retention, and transfer of speech skills.

Most of the above studies related to speech-motor learning pose two primary limitations. First is the failure to directly compare the effects of PMLs on both speech and non-speech-motor learning tasks within the same individual. As PMLs are largely based on studies related to non-speech tasks (e.g., finger tapping, keyboard entry), it is essential to examine the role of PMLs in speech-based tasks to be considered as a valid approach to the treatment of MSDs. There have been few attempts to include PMLs on the execution of speech-motor tasks. As there are limited studies which directly compare the effects of PMLs on speech and non-speech-motor learning tasks, it is difficult to determine whether the PMLs found to be effective in non-speech-motor learning are also effective for speech-motor learning. The second limitation is that past studies have not considered the combined effects of practice and feedback variables on speech-motor tasks. It is likely that providing optimal practise, as well as feedback conditions might assist an individual to learn a motor task better than providing either practise or feedback condition alone. In an attempt to address these two limitations, the purpose of the current study was to investigate the effect of selected PMLs (practice conditions, as well as feedback conditions) on both non-speech and speech-motor learning in individuals with normal speech-motor control and impaired speech-motor control.

Chapter 2. Review of Literature

Motor learning

Motor learning is an important psychophysiological phenomenon. It is through motor learning we learn a variety of motor skills necessary for our daily activities. Magill (2004) defined learning in general, and motor learning in particular, as 'a change in the capability of a person to perform a skill that must be inferred from a relatively permanent improvement in performance as a result of practice or experience' (p. 193). Two important aspects of learning can be deduced from this definition. First, learning indicates that an individual has acquired a new skill permanently. Second, learning cannot be observed directly, rather it has to be inferred based on the changes in the behaviour that can be observed.

Performance during practise vs. performance during retention/transfer

In the context of motor learning, it is important to distinguish performance during practice and performance during retention and/or transfer. Performance, in general, refers to any behaviour that is observable. Specifically, performance refers to execution of a specific motor skill in a specific environment (Briseno, Diaz, Romo, & Ruiz, 2010). Performance during practice is also referred to as the acquisition phase of learning. It could be easy to gauge an individual's ability to learn a motor skill by observing his/her performance during the practice regime; however, it does not provide information about the motor learning ability of an individual. For example, observing a person hitting a baseball would imply that the person's performance of the skill of hitting a ball is being observed, but it does not provide information on whether the person has learned to hit the ball correctly or not. Performance of a motor skill during the practice regime is influenced to a large extent by performance variables. These include factors like the alertness of the individual, the practising environment, and the fatigue caused by practice (Magill, 2004). In summary, three important aspects of performance during practise are: (1) performance of a motor skill during practice is observable, (2) the effect of performing a motor skill during practice is temporary (i.e., it does not result in learning of the skill), and (3) performance is influenced by practice variables.

Performance during retention/transfer determines the extent of learning. Learning would indicate that there is a permanent change in an individual's performance as a result of practice, and is not affected by the performance variables. Assessing learning through retention examines the persistence of improved performance as a result of practice. The usual way of administering a retention test is to have an individual perform a practised motor skill after a certain time interval during which the individual has not practised the skill. Assessing learning through transfer tests examines the extent to which practice on one skill generalizes to other skills (e.g., practising the forehand shot in tennis and assessing whether the backhand shot improves). In summary, the term 'motor learning' implies that: (1) learning is permanent, (2) learning can be observed directly, (3) learning is not affected by performance variables, and (4) learning is typically assessed by retention and/or transfer tests.

Nature of the skill

An important factor which could determine the outcome of motor learning is the nature of the skill to be learned. Motor skills can be classified in three categories based on: (1) the stability of the environment (open or closed), (2) precision of the movement (gross or fine), and (3) the distinctiveness of the beginning and end points (continuous, serial, or discrete) (Galligan, 2000; Davis, 2000). Each of the three categories has been summarised below:

Closed and open skills – This classification is based on the effect of the stability of the environment on motor skills (Knapp, 1967). Stability would refer to whether the environmental features are stationary (e.g., a tree) or in motion (e.g., escalator). Skills performed in stable environment are called closed skills (e.g., lifting a pen from the table, throwing a dart at a target). On the other hand, skills performed in a changing (unstable) environment are called open skills (e.g., stepping onto a moving escalator, driving).

Gross and fine motor skills – Gross motor skills require large muscle groups for execution (e.g., sitting, walking, running). Fine motor skills require relatively smaller muscle groups for execution (e.g., writing, operating scissors) (Davis, 2000).

Continuous, serial, and discrete skills – Skills can also be classified based on their start and end point. A skill is said to be discrete if it has well defined starting and finishing points. (e.g., throwing a ball). Skills which have an arbitrary start or end point are called continuous motor skills (e.g., swimming, walking). In the case of discrete motor skills, the start and end points are determined by the performer and not by the task. When a series of discrete motor skills are put together, it results in a serial motor skill. (e.g., bowling a cricket ball). In the case of serial motor skill, a series of movements must be performed in a specific order to complete the task (Galligan, 2000).

Performance characteristics of skill learning

Generally four performance characteristics are evident as skill learning takes place (Magill, 2004). First, is the improvement in the performance of the skill. The second characteristic is the development of consistency, and this implies that movement characteristics across the multiple practice trials of the same task tend to be fairly similar. The third characteristic is persistence; this indicates that the individual is able to demonstrate the improved capability in performance over a longer period of time. The fourth and final performance characteristic is adaptation. This would mean that an individual who has demonstrated improved capability in the performance of motor skills can generalize and adapt to a variety of other performance characteristics.

The stages of motor learning

An individual trying to learn a novel motor skill achieves proficiency in that skill only through repeated practice. Every individual who masters a novel motor skill, typically goes through three distinct stages of motor learning: cognitive stage, associative stage, and the autonomous stage (Fitts & Posner, 1967). The three stages are summarized below as described by Fitts and Posner.

Cognitive stage – In this stage, the learner spends a considerable amount in trying to understand what needs to be done and the nature of the skill. Considerable cognitive activity is required during this stage, as the novel learner is initially unsure of what needs to be done. The attentional demand for the movement production is very high. The performance during this stage is highly variable in nature, the movements are gross and large number of errors is observed. Even though, the learner is aware that the movements are incorrect, he/she is not sure of how to correct the movements. The learner consciously controls majority of the movements. During this stage, the learner is heavily dependent on feedback in the form of verbal instructions, demonstrations, and guidance. The gains in performance are largest during this stage as the learner constantly explores the strategy that improves the performance. There is a tendency for learner to become easily frustrated if success is not achieved quickly.

Associative stage – Once the basic movement pattern is achieved, the learner enters the associative stage of motor learning. During this stage, the performance is less variable and is more consistent. Less cognitive activity is required, and the learner is dependent on proprioceptive feedback rather than visual or auditory feedback. The errors are reduced and the movements become more refined. The learner develops an ability to detect his/her errors during the movement, even though this ability is not perfect. The attentional demand for movement production reduces. During this stage, some parts of the movement are controlled consciously, whereas some are automatically performed. The learner begins to concentrate on perfecting the skill. This stage may last between few days to months.

Autonomous stage – After an extensive period of practice, the learner enters the autonomous stage of learning. This stage reflects the highest level of proficiency, and not all learners reach this stage. Here, the performance becomes consistent and reliable. The movements are automatic and do not require any cognitive effort or attention. The movements are effortless, and are free of errors most of the time. Usually it takes years of practise to reach this stage of learning. The learner develops an ability to detect his/her errors during the movements and tends to correct those errors. To retain the skill at this stage, the skill must be repeatedly practised.

In summary, motor learning cannot be strictly delineated into these three stages, as the process of motor learning reflects a continuum. However, these stages of motor learning best explain the trajectory of learning of a novel motor skill. The learner gradually proceeds from one stage to another instead of an abrupt change.

Theories of motor learning

Within the context of motor learning, theories serve to explain the exact process of motor learning. There are two important theories which have had a significant impact on understanding motor learning and are discussed below.

Closed-loop theory

Adams (1971) was the proponent of the closed-loop theory of motor learning. He developed this theory through a series of experiments involving slow lever-operating tasks. Adams suggested that the principles of performance and learning applicable to these experiments could be generalized to other motor movements as well. This theory emphasized the importance of feedback to learn a motor task and suggested that motor learning proceeds through the gradual refinement of perceptual-motor feedback loops (hence the name closed-loop theory). When performing a novel motor task, the initial movements are crude and are not effective to achieve the intended outcome. During further practice trials, the perceptual feedback associated with the motor movements provide information about the particular location of the limbs in space, and whether the movements were able to achieve the target motor goal. This information provided by perceptual feedback is referred to as the "perceptual trace". With each subsequent practice trial, the perceptual trace guides the individual to produce motor movements which resemble the correct motor goal (also known as the correct trace). Eventually, through a combination of movements guided by the perceptual trace, the individual achieves the correct motor goal. The basic premise of the closed-loop theory is that feedback guides an individual to perform tasks more accurately. When people learning new tasks are told explicitly about their performance, they tend to do better than people who do not receive such feedback. Thus, the basic function of feedback is to guide the novice learner to achieve the intended motor goal through subsequent practice. The process involved in learning a novel motor skill as explained by closed-loop theory is shown in Figure 1 (a-c). During the early learning phase (Figure 1a), the individual produces an equal number of correct as well incorrect movements. The movements tend to be inconsistent and highly variable during this phase. During the subsequent phase (Figure 1b), the individual guided by the verbal feedback learns to produce movements which begin resembling the correct motor trace, but some of the motor movements still continue to be inaccurate. During the third phase (Figure 1c), the individual starts producing more movements which are closer to the correct trace, and in this process the number of incorrect movements are reduced to a substantial extent.

One of the important implications of the closed-loop theory is the error detection capabilities developed by the learners during the course of practice. Each time a movement is made, the learner compares the accuracy of his/her movements to the target motor goal through the feedback provided by the perceptual trace. This difference between the performed movement and the target movement is referred to as the ‘error’. If there is a large error during the initial stages of practice, the learner attempts to reduce these errors during subsequent practice trials by producing motor movements which are close to the target goal. This error detection capability eventually helps an individual to learn a novel motor task efficiently. The closed-loop theory has been criticized for not accounting for two major aspects of movement. First, the closed-loop theory is based on slow, lever positioning tasks. It does not intend to explain the motor control/learning of rapid action movements. Research has shown that feedback acts too slowly for learning rapid tasks like throwing and ball-striking (Henry and Rogers, 1960; Keele, 1968). The second criticism is that the theory does not account for generality (Schmidt, 1975b). For example, an action can be performed in many non-identical yet similar ways.

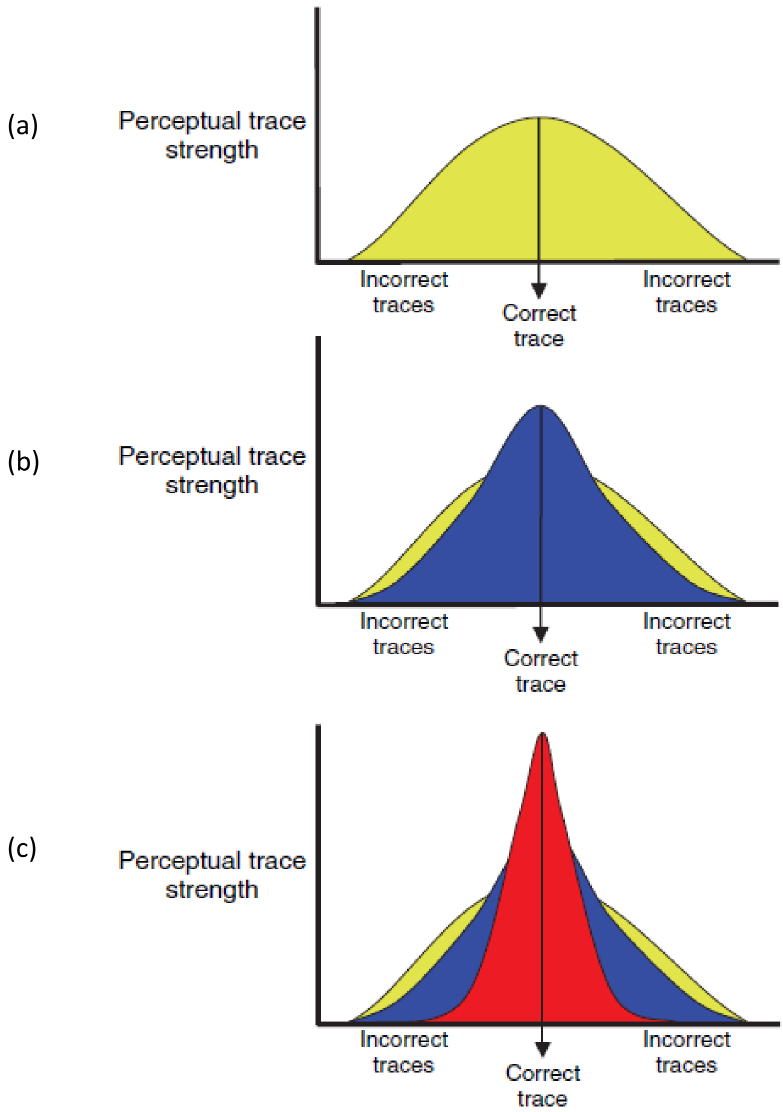


Figure 1. An illustration of Adam's closed-loop theory (from Schmidt & Lee, 2005, p.411). As repetitions accumulate, the perceptual trace starts approximating the correct trace. With many repetitions, the shape of the distribution becomes more peaked at the mode. Panels a-c depict the early, middle, and late phase of motor learning, respectively as described by Adam.

The schema theory of motor learning

Dissatisfied with Adam's closed-loop theory, Schmidt (1975b) formulated the schema theory. This theory is based on an open-loop process which was not accounted by the closed-loop theory. Adams proposed that when an individual trying to learn a new movement makes an error, the feedback loop guides him/her to correct his/her error(s) during the subsequent practice trials. On the other hand, Schmidt and his colleagues provided evidence that it takes about 120-200 ms for the whole process of sensory error detection, and initiating appropriate corrections in response to those errors (Schmidt & White, 1972; Schmidt & Wrisberg, 1973). These researchers also noted that some of the sensory channels like proprioception operate at a speed of about 110 ms (time taken to respond to an external stimulus). Based on this evidence, Schmidt argued that even though feedback is important for motor learning, the feedback loop advocated by the closed-loop theory cannot account for learning rapid motor movements. Owing to this shortcoming, Schmidt proposed that motor movements are performed based on a set of pre-defined motor commands called generalized motor programs (GMPs) which are not dependent upon feedback loop. GMPs are assumed to be a set of pre-structured commands designed to execute a range of motor movements if response specifications are provided. These response specifications are parameters that can be varied before the movement begins that enable the motor program to be performed at a different speed or a different force. For example, a motor program for hitting a ball can be modified to be performed slow or fast based on the response specifications (Schmidt, 1975b; Schmidt & Lee, 2005).

According to the schema theory, an individual is able to generate novel motor movements based on the notion of "schema". In order to generate novel motor movements, it is essential that the schema stores information about four important aspects related to the motor movement: (1) the initial conditions, (2) the response specifications of the motor program, (3) the sensory consequences of the outcome, and (4) outcome of the movement. Each of these aspects is summarised below as described by Schmidt (1975b).

Initial conditions - This would refer to the environmental conditions in which the individual performs the motor movement. The initial conditions comprises (though not limited to) the individual's pre-muscular state, and the information received from various receptors about the surrounding environment (e.g., proprioceptive information about the position of limbs in space, visual, and auditory information) (Keele, 1968; Pew, 1974). Once the movement is executed, the initial conditions used to plan the movement are stored.

Response specifications - The motor program required for the generation of motor commands is rather general, so the commands are fine-tuned and refined by response specifications. Response specifications (parameters) govern the manner in which the motor commands are executed. For example, response specifications are responsible for changing aspects like speed, force, and direction of the motor movements. Once the movement is executed, these specifications associated with the movement are stored for further use.

Sensory consequences - These refer to the information (feedback) received from the eyes, ears, and proprioceptors after the execution of the movement. This sensory information received after the execution of movement is also stored for further use to develop appropriate schemas related to motor movement.

Response outcome - This is the fourth aspect of information stored after the movement and it provides information about the success of the response in relation to the original intended outcome. This is commonly referred to as knowledge of results (KR), such as "you kicked the ball 2 feet away from the centre of the goal post". Thus, this KR provides information as to how successful the response outcome was and is stored after the completion of the movement.

Schema formation - The initial conditions, response specifications, sensory consequences, and response outcomes are stored together after a movement is performed. When the same movement is performed repeatedly, then the individual begins to draw information about the relationship among these four sources of information. The strength of this relationship among the four sources of information increases with each subsequent movement, and this relation is the schema for that particular movement. Thus the knowledge of particular movements is stored as 'motor schemas' by individuals.

When an individual is required to perform a motor movement for which he already has a motor plan, then the movement is initiated with information received from two types of schema: the recall schema and the recognition schema (Schmidt, 1975b). The recall schema encodes the relationship between initial outcome, response specifications, and the intended outcome. When the recall schema is supplied with information about the initial conditions and the intended outcome, then it formulates the appropriate response specification necessary to generate the specific motor movement. On the other hand, recognition schema encodes the relation between the initial outcome, sensory consequences, and the intended outcome. When the recognition schema is supplied information about the initial condition, and the intended outcome then it computes the appropriate sensory consequences associated with a specific motor movement (Schmidt & Lee, 2005). The recognition schema generates two types of expected sensory consequences: (1) the expected proprioceptive feedback, and (2) the expected exteroceptive feedback which consists of visual and auditory feedback. If there is a mismatch between the expected sensory consequences and the actual sensory consequences, then this represents an error signal which is used to update the recall schema. Thus, the recall and recognition schemas work in unison to ensure the smooth ongoing execution of motor movements (Schmidt, 2003).

Even though the schema theory explains the generation of novel motor movements through a generalized motor program (GMP), a drawback of this theory is that it does not explain how the GMP is formed in the first place. This theory also does not take into account as to how the rules about response specification and sensory consequences are formulated (Schmidt & Lee, 2005).

In summary, closed-loop theory (Adams, 1971) and schema theory (Schmidt, 1975b) explain the process of motor learning from different perspectives. Closed-loop theory mentions that an individual trying to learn a new motor skill makes a number of errors to begin with. However, through constant refinement of the perceptual feedback loop during the practice regime, the individual is able to learn the correct movement pattern of the motor skill. The schema theory was basically formulated to account for some of the shortcomings of the closed loop theory which were not effective to explain the entire aspects of motor learning. Schema theory contradicts the notion of motor learning through perceptual feedback as some of our sensory channels (like proprioception) operate at an extremely rapid pace which is much faster than the time taken to receive the perceptual feedback. Hence, Schmidt proposed that motor movements are learned and executed based on a set of pre-structured motor commands – GMPs – and GMPs are refined by response specifications (parameters).

Critical examination of closed loop and schema theories suggest that the contribution from both the theories could be relevant in motor learning. Even though Schmidt mentioned the role of GMP in motor learning, no explanation was provided as to how the GMP is developed in the first place. It is likely that an individual trying to learn a new motor skill might initially rely on perceptual feedback to develop a prototype of the correct movement pattern of the practising skill. This prototype can serve as a comparator model to guide the learner to detect his/her errors during each practice trial and refine his/her movement patterns to resemble the original movement pattern. Once the prototype has been well developed, it can in turn facilitate the formation of a GMP corresponding to the original movement pattern and thereby reducing the learner’s dependency on perceptual feedback. Thus, the role of both theories needs to be acknowledged within the scope of motor learning.

Principles of Motor Learning

Previous research has established that motor learning is indicative of permanent acquisition of new skills (Poole, 1991). However, the extent of learning a motor skill is guided by structured application of certain PMLs. PMLs refer to a set of principles intended to facilitate the process of motor learning (Magill, 2004). PMLs have their roots from the closed-loop (Adams, 1971) and schema theories (Schmidt, 1975b), and since then have been used extensively to study the behavioural aspects of motor learning and also in clinical settings. Most of our knowledge regarding PMLs is derived from experiments pertaining to limb-based tasks (Lee & Magill, 1983; Lai & Shea, 1998). The application of PMLs in learning novel speech tasks and to treat speech disorders has been emerging in recent years (Mass et al., 2008; Bislick et al., 2012). The PMLs are divided based on the structure of practice and nature of feedback.

Application of PMLs in non-speech tasks

There have been a number of studies pertaining to the application of motor learning in non-speech tasks and these studies have helped to evaluate the efficacy of PMLs in learning/re-learning various motor skills. A review of several studies in regards to practice and feedback conditions is provided below.

Practice condition

A primary reason for practising a skill is to attain mastery or to perfect the skill (Gentile, 1972). Practice, in a general context of motor learning would refer to the repeated rehearsal of a motor behaviour. The practice conditions consist of (1) amount of practice, (2) practice distribution, (3) practice variability, (4) practice schedule, (5) attentional focus and (6) holistic practice (Mass et al., 2008). The various practice conditions used in learning/re-learning of non-speech as well as speech-motor skills are shown in Table 1. Each of these conditions is described below as applies in non-speech tasks.

Practice amount - The amount of practice an individual devotes to a skill is critical for learning a motor skill (Magill, 2004). Practice amount refers to the time spent practising movements (Mass et al., 2008). To learn a motor skill, it is essential that some amount of practice has to be undertaken by the learner. The amount of practice needed depends on the complexity of the task and how much expertise is needed. Some research has even proposed that specific motor skill expertise is gained through accumulating an average of 10,000 practice hours (i.e., typically 10 years) (Ericsson, Krampe, & Tesch-Romer, 1993). It is essential to estimate the amount of practice needed by an individual to learn a particular

Table 1. Practice conditions with appropriate examples for application in non-speech and speech tasks (adapted from Mass et al., 2008).

Practice condition	Options (bolded options are more desirable for motor learning)	Relationship to non-speech (learning to play tennis)	Relationship to speech (learning to say "aeroplane")
Amount	Small vs. **Large**	Practising a serve 5 times vs. 50 times	Practising to say the word "aeroplane" 5 times vs. 50 times
Distribution	Massed vs. **Distributed**	Practising 50 serves in 10 min vs. 50 serves in 25 min	Practising to say the word "aeroplane" 50 times in 5 min vs. 50 times in 10 min
Variability	Constant vs. **Variable**	Practising the serve in the same spot vs. practising in different spots	Practising to say the word "aeroplane" at a constant rate of speech vs. saying it at different rates
Schedule	**Random** vs. Blocked	Practising forehand and backhand shots randomly vs. practising forehand shot 20 times and then proceeding to backhand shot	Practising the words "aeroplane" and "ship" randomly vs. practising "aeroplane" 20 times and then proceeding to "ship"
Focus	Internal vs. **External**	Focusing on the hand grip vs. watching the movement of the racket	Focusing on the lips vs. trying to hear the word while saying it
Holistic	Simple vs. **Complex**	Practising a straight drive vs. a spin shot	Practising individual syllables in the word "aeroplane" vs. the whole word

motor skill. One of the common problems encountered in determining the amount of practice is that it might result in over-learning or under-learning of the task. Magill (2004) suggests that in order to achieve expertise, more practice is better than less.

The context of 'overlearning' has received considerable attention in motor learning over the past years. Overlearning refers to the continuation of practice even after attaining mastery over the skills. Past research has proven overlearning to be beneficial in learning novel skills (Dirskell, Willis, & Cooper, 1992; Bromage & Mayer, 1986). Dirskell et al. reviewed 15 studies from 1929 to 1982 investigating the role of overlearning on motor learning. The 15 studies involved 3,771 participants. The participants in some of the studies practised only physical tasks (e.g., balancing a stabilometer), whereas participants in other studies practised only cognitive tasks (e.g., remembering verbal information). They found that the degree of overlearning in these 15 studies ranged from 0% overlearning to 200% overlearning, and the benefits gained from overlearning were reduced by one-half after 19 days of practice. Based on their findings, the researchers suggested four important aspects related to overlearning: (1) overlearning is beneficial in terms of enhancing the retention of the tasks, (2) overlearning is effective in learning both physical and cognitive based tasks, (3) the retention benefits are directly proportional to the degree of overlearning (e.g., 150% overlearning enhances results in more learning than 50% overlearning), (4) the benefits of overlearning may disappear at longer retention intervals.

The effect of overlearning on long-term retention was studied by Rohrer, Taylor, Pashler, Wixted, and Cepeda (2005). The researchers recruited 218 college students as participants for two experiments. The first experiment involved 130 students who studied 10 city-country pairs (e.g., Moscow-Russia), one group of students practised this task four times more (high learners) than the other group (low learners). The participants came back for the retention tests at one and nine weeks after the initial practice. Results revealed that, after one week, the high learners recalled much more than the low learners. However, after nine weeks the retention of the high learners reduced by about two-thirds (from 70% at week 1 to 24% at week 9), while the retention of the low learners reduced by less than half during the same period (from 31% at week 1 to 17% at week 9). In the second experiment, 88 students studied a word-definition task (e.g., cess-tax). Similarly, the learners were divided into low learners and high learners. The participants returned for retention tests at intervals of one week and four weeks. The results revealed that the high learners had a significant advantage over the low learners after one week. However, this advantage disappeared after four weeks. Specifically, the retention of the high learners declined by about two-thirds (from 64% at week 1 to 22% at week 4), whereas the retention of the low learners declined by about one-half (from 38% at week 1 to 18% at week 4). The results of this study were in agreement with the findings of Dirskell et al. (1992), and suggests that overlearning could be beneficial for short-term retention but not for long-term retention.

With regards to a clinical population, Kwakkel (2009) systematically reviewed studies pertaining to intensive rehabilitation after stroke and found a dose-response relationship; that is, patients who received more practice showed improved functional outcome in comparison to patients who received less practice. Kwakkel reviewed 20 randomized control trials involving 2686 patients either in sub-acute, post-acute, and chronic stage after stroke. All the patients in the studies received either physical or occupational therapy to improve their activities of daily living. Among these 2686 patients, some of the patients received more intensive rehabilitation compared to other patients. On average, the patients in the intensive rehabilitation groups received about 959 minutes more rehabilitation than the control groups. Results revealed that the patients who received higher intensive rehabilitation improved significantly more than the control groups.

Dirskell et al. (1992) suggested that overlearning provides more opportunity for attaining initial proficiency in learning a task. However, the more important aspect is that practice beyond this initial proficiency allows the learner to receiver further feedback about the correctness of the response and this feedback helps in longer retention of the task. Overlearning (or a large amount of practice) helps in retention but the exact duration of the beneficial effects of overlearning remains to be investigated.

In summary, there is clear indication from past studies that more practice or overlearning is beneficial in learning motor skills. However, the term ‘overlearning’ has been used arbitrarily in past studies (Dirskell et al., 1992; Rohrer et al., 2005). There is no clear specification as to how much practice (in terms of practice trials or number of hours) constitutes overlearning. Further research could possibly investigate the threshold (in terms of number of practice trials or hours spent in practice) which clearly delineates learning from overlearning of a range of motor skills.

Practice distribution - Practice distribution refers to how a given practice regime is spaced across time. This ranges from massed to distributed practice. In massed practice, an individual practises a certain number of trials within a shorter time frame with no rest or a very short rest interval between the practice sessions or trials (Schmidt, 1991). In a distributed practice, the individual practises the same number of trials across a longer period of time and the rest interval between the practice sessions or trials is also relatively longer (Burdick, 1977).

Past studies have indicated that distribution practice tends to be beneficial over massed practice in learning skills (Baddely & Longman, 1978; Rohrer & Taylor, 2006). Baddely and Longman compared the effect of massed and distributed learning on a keyboard task. The training time limitations were a total of 60 hours and five days each week. The practice sessions were distributed in four different ways. Two groups practised one hour in each session. Among these two groups, one group practised only one session each day, thus prolonging the total practice session for 12 weeks; whereas, the other group practised two sessions each day, resulting in a practice regime which lasted for 6 weeks. Two other groups practised two hours each session. One of these groups practised only one session each day, resulting in a practise regime for 6 weeks, and the other group practised two sessions each day, thereby reducing the practise span to 3 weeks. The most distributed practice regime required the participants to practise for 12 weeks, and the most massed practice regime required the participants to practise for 3 weeks. The outcome measures were based on the number of hours required to learn the keyboard task, and typing speed. Results indicated that the most distributed practice group required the least amount of time to learn the keyboard task and had the fastest typing speed. The most massed practice group required the longest time to learn the task and was the slowest in terms of the typing speed.

Rohrer and Taylor (2006) investigated the benefit of massed vs. distributed practice on solving mathematical problems. The participants were 216 college students who were randomly assigned to massed and distributed practice groups. The students in the massed practice group solved 10 mathematical problems in one single session, and students in the distributed practice group solved the 10 problems in two separate sessions separated by one week. Retention tests after one week revealed that there was no difference between the two groups. However, a retention test after four weeks revealed that students in the distributed practice group were more efficient in solving the problems compared to the students in the massed practice group.

There are three possible reasons suggested by Magill (2004) to explain the beneficial effects of distributed practice. First, individuals involved in massed practice tire easily, and fatigue negatively influences learning. Second, the continuous nature of practice involved in massed practice reduces the cognitive resources of the learner if the practice continues beyond a certain critical amount. The third reason pertains to the memory consolidation process. Memory consolidation facilitates long-term storage, and for memory consolidation to happen it is essential that there is an adequate rest interval between practice sessions. Distributing the practice across days facilitates memory consolidation than massing the practice within a day or two (Brashers-Kug, Shadmehr, & Bizzi, 1996). Thus, distributed practice seems to be more beneficial than massed practice in learning new motor skills.

Practice variability - Practice variability involves practising the different movement variations of a motor skill. A practice situation can involve an individual practising only one variant of a skill, which is referred to as the constant practice. A practice session can also involve an individual practising more than one variation in the dimensions of a skill, which is referred to as the variable practice. In the case of variable practice, there is a scaling of the motor skill (i.e. variation in the dimensions of the motor skill).

Research has revealed that variable practice tends to benefit learning over constant practice for a variety of tasks. (e.g., Shea & Kohl, 1991; Shoenfelt et al., 2002; Wulf & Schmidt, 1997). Shoenfelt et al. compared the effects of constant and variable practice on shooting a basketball. The researchers found that that the constant as well as variable practice groups improved during the acquisition phase. However, the variable practice group demonstrated significantly better performance than the constant practice group on a retention test after two weeks. Kerr and Booth (1978) compared the beneficial effects of constant vs. variable practice on learning a tossing skill. Thirty-six children were recruited to learn a bean bag tossing skill at one or more targets for a period of 12 weeks. One group of participants practised tossing the bean bag at a target three feet away (constant practice), whereas the other group of participants practised tossing the bean bag at two targets which were two and four feet away, respectively (variable practice). Both groups of participants were required to toss the bean bag at a target three feet away as a part of the post-test. The results revealed that the variable practice group was significantly better on the post-test than the constant practice group.

The beneficial effect of variable practice is attributed to the "Elaboration Hypothesis" (Shea & Morgan, 1979). These researchers suggest that the effect is due to the elaboration of the memory representations of the skill variations. In the case of variable practice, the learner can compare and contrast the skill variations which make them distinct from one another and thus help in better retention of the skill. In the case of constant practice, the individual practises the same variation of the skill thereby not giving an opportunity to compare and contrast the various skill variations. This could account for the decreased beneficial effects offered by constant practice as suggested by past studies.

There are studies which have disproved the beneficial effects of variable practice over constant practice in learning motor skills (Dick, Beth, Shankle, Dick-Muehlke, Cotman, & Kean, 1996; Breslin, Hodges, Steenson, & Williams, 2012). Breslin et al. compared constant vs. variable practice in learning to shoot a basketball. Ten students in the constant practice group practised 300 trials of basketball shooting from a constant distance of 15 feet. Alternatively, 10 students in a variable practice group practised 300 trials of basketball shooting across five different distances. The practice took place over two consecutive days, and the retention test took place on the third day. Results revealed that the constant practice group performed better than the variable practice group. Dick et al. also compared constant vs. variable practice in learning a tossing skill. Twenty-four healthy adults and 28 patients with Alzheimer's disease (AD) participated in the study. The participants were required to learn tossing a bean bag at an archery type target, and practised the task for a total of 10 weeks with two practice sessions each week. During each practice session, the participants practised 32 trials of the tossing task. Participants in the constant practice condition practised the task at a constant distance, whereas participants in the variable practice condition practised at four different distances. Retention tests were conducted one week and one month after training. The results revealed that healthy participants were benefited by constant as well as variable practice conditions. On the contrary, participants with AD were benefitted only by constant practice. A likely explanation for the better performance of the AD participants in the constant practice condition is that practising multiple variations of a skill could have overburdened their cognitive system in comparison to practising a single variation of the skill. It is possible that constant practice could be more beneficial than variable practice to learn motor skills in clinical populations like individuals with AD.

In summary, studies comparing constant vs. variable practice have found equivocal results. It remains unclear as to whether constant or variable practice tends to be more beneficial in learning/re-learning motor skills. Further research across a range of motor skills will be helpful to determine whether variability of practice is indeed beneficial in motor learning.

Practice schedule - Practice schedule refers to the order in which the practice stimulus is presented to the learner. Practice tasks can either be scheduled in a random manner or a blocked manner (Schmidt & Lee, 2005). In blocked practice, the practice trials of one particular task are performed together, uninterrupted by practice on any other sequences. For example, in the case of learning to play tennis, it would involve practising 10 trials of a forehand serve, followed by practising another 10 trials of a backhand serve. However, in random practice, the practice trials are intermixed and the upcoming practice trials are not predictable. Referring to the tennis example, practising multiple trials of forehand and backhand serves in an unpredictable and random manner within the same practice session.

The advantage of random over blocked practice has been proven in a number of studies (Shea & Morgan, 1979; Shea & Wright, 1991; Wright, 1991). The benefit offered by the random practice has been mainly attributed to the ‘contextual interference’ effect. Contextual interference (CI) is a learning phenomenon wherein the interference caused due to practising different tasks within the same practice session proves to be beneficial (Magill & Hall, 1990). The concept of CI was first mentioned by Battig (1972) in a verbal learning task (paired-word associations) for what he initially referred to as ‘intra-task interference’. Shea and Morgan (1979) were among the first researchers to demonstrate the advantage of CI effect in learning limb-based motor tasks. The researchers recruited 72 right handed students as participants for the study. The participants were required to knock down three barriers in three different sequences. The participants were randomly assigned to either a high CI group (random practice) or a low CI group (blocked practice). The participants practised the task for a total of 54 trials divided in three sets of 18 trials (for the three different sequences, respectively). Participants in the blocked practice group practised one sequence of trials before proceeding to the next sequence. Participants in the random practice group practised all three sequences in an unpredictable manner during each practice set of 18 trials. Retention tests were conducted after a 10 min delay and a 10 day delay under random and blocked practice sequences. Results of the retention tests revealed that participants in the random practice group had fewer sequence errors, and demonstrated faster reaction and movement time.

Sherwood (1996) also found random practice to facilitate motor learning. Twenty-four college students were required to learn a rapid lever reversal movement so that the reversal point was 20°, 40°, 60°, or 80°. The participants were assigned to either random or blocked practice groups. All the participants practised 90 trials of the task. Retention tests immediately after the acquisition phase and after 24 hours revealed that participants in the random practice group showed more spatial accuracy in comparison to the blocked practice group.

However, there are studies which suggest that the beneficial effects of random practice cannot be generalized to all motor tasks (Brady, 2008; Maslovat, Chua, Lee, & Franks, 2004; Meira & Tani, 2001; French, Rink & Werner, 1990). Maslovat et al. (2004) compared the effect of random vs. blocked practice on learning a bimanual coordination task. A bimanual task requires manipulation from both the hands (Guiard, 1987). Thirty right-handed participants were assigned either to a blocked practice group, random practice group, or a control group. The participants in random and blocked practice groups practised two bimanual coordination tasks in a random and blocked practice schedule, respectively. Participants in the control group practised a single bimanual coordination task only. All the participants performed a total of 200 acquisition trials over two consecutive days. Retention tests were conducted immediately following the second day, and after one week. The results revealed that the random practice group demonstrated better performance than the blocked practice group. However, neither the random nor blocked practice groups demonstrated better performance than the control group, suggesting that the use of a random practice schedule could be beneficial for learning only one task.

French, Rink, and Werner (1990) compared the benefits of random vs. blocked practice in learning three volleyball skills among high-school students. The participants were required to learn the forearm pass, the set, and the overhead serve (i.e., the basic arm moves in a volleyball game). The participants were assigned to either a random practice group, blocked practice group, or a random-blocked practice group. Retention results revealed that even though there was significant improvement in all three groups, there were no differences between groups.

With regards to a clinical population, Lin, Sullivan, Wu, Kantak, and Winstein (2007) compared random vs. blocked practice conditions in learning a movement task. Twenty healthy adults and 20 adults with mild PD served as participants. The participants were required to operate a lever and move it horizontally at a specific speed and distance to learn a goal movement task. The goal movement task was displayed on the computer screen before each trial which the participants were required to replicate. Three versions of the movement task were used. Participants in the blocked practice condition practised the three movements in a blocked sequence for a total of 135 trials, whereas participants in the random practice condition practised the three movements in a random order for a total of 135 trials. The experiment lasted for two consecutive days. The first day was allotted for the practice phase (acquisition phase) and the second day was the retention phase. Results of the retention test revealed that the healthy participants in the random practice condition performed better than the participants in the blocked practice condition. However, the results were the opposite for the participants in the clinical group. Thus, the above studies suggest that random practice may not be the ideal practice schedule, especially when considering a learning task for clinical population.

In summary, past studies have revealed mixed findings with respect to the beneficial effects of blocked vs. random practice in motor learning. It was long thought that CI offered by random practice might benefit motor learning (Shea & Morgan, 1979; Magill & Hall, 1990). However, studies over the recent years have disproved this notion (Brady, 2008; Maslovat et al., 2004). Further research is required to identify the best practice schedule that would facilitate motor learning across a range of motor skills and clinical populations.

Attentional focus - Attentional focus refers to the source of attention during the process of motor skill learning (Wulf, 2007). The focus of attention can be either an internal source or an external source. An internal focus of attention refers to the attention directed by the learner towards his/her own body movements. An external focus of attention refers to directing attention to the role of learner's body movements on the surrounding environment (Vance, Wulf, Tollner, McNevin, & Mercer, 2004). Usually an external focus of attention is considered to be more beneficial in learning motor skills rather than an internal focus of attention (e.g., Wulf, HÖb, & Prinz, 1998; Wulf & McNevin, 2003). For example, Wulf et al. compared the effects of internal vs. external focus of attention on learning a skiing task. Thirty-three participants were recruited to learn slalom-type movements on a ski-simulator. The participants were randomly assigned to one of the three groups (internal focus group, external focus group, and a control group). The internal focus group received instructions to focus on their feet while performing the task. The external focus group received instructions to focus on the wheels of the platform located directly under the feet, while the control group was given no focus instructions. The participants practised the task on two consecutive days and a retention test was conducted on the third day. The results revealed that the external focus group demonstrated better learning than the internal focus and control group. There was no difference in learning between the internal focus and the control group.

The benefits of external attentional focus have been attributed to a ‘constrained action hypothesis’ (McNevin, Shea, & Wulf, 2003; Wulf, McNevin, & Shea, 2001). According to this hypothesis, when individuals are asked to focus on their body movements (internal focus), they tend to constrain body movements, which serves to disrupt automatic control processes. When individuals are asked to focus on the effect of the movement (external focus), this manner of attention facilitates automatic processes to control the movement resulting in effective learning. In summary, it is generally agreed that an external focus of attention tends to be more beneficial than internal focus in motor skill learning.

Holistic practice - A motor skill can be either practised in whole or in part (Park, Wilde, & Shea, 2004). In general, part practice is considered to be simpler in nature in comparison to whole practice which is considered to more complex. The concept of whole vs. part practice in learning a motor skill has been debated since the early half of the 20th century (Barton, 1921; Knapp & Dixon, 1952; Wickstrom, 1958). Naylor and Briggs (1963) hypothesized that the influence of whole vs. part practice would depend on two factors: (1) skill complexity, and (2) skill organization. The complexity of a skill would refer to the number of parts in the skill as well as the attention demands of the skill (Magill, 2004). Wulf and Shea (2002) considered a task to be complex if it could not be mastered in a single session and had several degrees of freedom. Degrees of freedom refer to the number of independent elements of a movement system. For example, a lever which can be pushed forward or backward has only two degrees of freedom. A task was considered to be simple if it could be mastered in a single session and had only one degree of freedom. Organization of a skill would refer to the extent of relationship among the subcomponents of a skill. A skill is said to have a high organization if the subcomponents are interdependent on one another. A skill with low organization will consist of subcomponents which are relatively independent of one another (Coker, 2009). The Naylor and Briggs hypothesis has provided certain guidelines to determine the effectiveness of part vs. whole practice in learning a motor skill. A whole skill practice is recommended if the skill is low in complexity and high in organization. A part practise approach is recommended if the skill has a high complexity and low organization.

Park et al. (2004) compared part-whole vs. whole practice on learning a movement sequence task. The researchers randomly assigned 18 university students to either a part-whole practice group or a whole-practice group. Participants in both the groups were required to learn a 16 movement sequence using a lever. Participants in the part-whole practice group practised only the first 8 elements on the first day (100 repetitions of the first 8-elements) and all 16 elements on the second day of practice (100 repetitions of all the 16 elements). On the other hand, the whole-practice group had to practise all 16 elements on both days (100 repetitions of the 16-element sequence per day). On transfer tests during which the first and second 8 elements were tested separately, the participants in the part-whole practice group revealed better performance than the whole practice group, especially on the second 8-elements .

Dean, Kovacs, and Shea (2008) compared the transfer from smaller spatial movement sequence to a larger sequence and larger sequence to a smaller sequence. Twenty-eight college students participated in the study. The participants had to either operate a lever through a bigger movement sequence (targets space at 20°, 40°, 60°, and 80°) or through a smaller movement sequence (20°, 26.7°, 33.3°, and 40°). Transfer from bigger to smaller movement sequence was more effective than the other way around. Thus, this study provides support for the whole practice approach.

With regards to a clinical population, Nettlebeck and Kirby (1976) used part or whole-task methods to train mild mentally retarded workers to thread a sewing machine. The researchers found that the part-practice approach helped the participants to learn the sewing task better than the whole practice approach.

In summary, there is no clear indication directing the use of part practice or whole practice approach to learn a motor skill. On the other hand, a part practise approach is recommended if the skill has a high complexity and low organization. Caution should be exercised in generalizing these guidelines to learn a variety of motor skills. It is likely that the effectiveness of part practice or whole practice depends on the complexity of the skill being practised. Further research is required to determine the role of part practice vs. whole practice in learning simple as well as complex skills.

Feedback condition

Feedback refers to the information individuals receive about their performance of a motor skill. This information can be provided either during or after the performance (Wulf, Chiviacowsky, Schiller, & Ávila, 2010). In other words, feedback pertains to performance-related information. When an individual performs a motor task, two types of feedback are available to the individual. The first type of feedback gained by an individual through his/her sensory channels (e.g., vision, audition, proprioception) is referred to as “inherent” or “task-intrinsic” feedback. A major extent of motor control and learning is achieved by information received through our sensory channels (Schmidt & Lee, 2005). Proprioception, vision and audition are generally regarded as the main sources of feedback during the process of motor learning (Saunder & Knill, 2003; Perkell et al., 2000; Haith, Mial, & Vijayakumar, 2008). The ability to sense body position and movement is known commonly as proprioception (Grey, 2010). Through proprioceptive knowledge, we are able to sense the position of our body and limbs in space without having to look at them. Proprioception includes the senses of movement, vibration, position, deep pain, and equilibrium (Webb & Adler, 2008). Thus, proprioception integrates information from other systems like somatosensory, vestibular and visual systems. The sensory receptors of the proprioception called as the proprioceptors, are located in the muscles and joints throughout the body. During movement, sensory signals from the proprioceptors are conveyed to the spinal cord and higher cortical centres via the afferent fibres (sensory fibres), and provides information about the location of our limbs in the surrounding environment. This information conveyed to the central nervous system is termed as the proprioceptive feedback, which is used to regulate activity in the neuronal systems generating the commands to muscles (Grey, 2010).

Vision provides information about the performed motor movements in the environment, and this guides our subsequent motor behaviour. Two visual systems have been implicated in visual stimulus processing and feedback: focal vision and ambient vision (Trevarthen, 1968), and they are briefly described. Focal vision is responsible for processing images in the central part of the visual field, and is affected by decreasing levels of illumination. Focal vision tell us ‘what the object is’. Ambient vision is responsible for processing images in the entire visual field, and is not affected by decreasing levels of illumination. Ambient vision tells us ‘where the object is’. The role of vision in motor learning has been documented as early as 1934 (Melcher, 1934). Saunders and Knill (2005) mentioned that continuous visual feedback of the hand is essential in learning fast reaching movements. Laguna (2008) described the importance of visual observation in developing memory representation of the practising task, which in turn facilitates motor learning.

Auditory feedback has also proved to be essential in motor learning, especially with regards to speech-motor learning (Perkell et al., 2000). The researchers describe an internal auditory model which is used to learn novel speech sounds. This internal model is a representation of the articulatory configurations associated with various sounds produced in the vocal tract. The importance of auditory feedback in re-learning speech sounds across various clinical conditions has also been emphasized by previous studies (Ménard et al., 2007; Kaipa, Robb, Beirne, & Allison, 2012).

The second type of feedback received from an external source in addition to the intrinsic feedback is referred to as "extrinsic" or "augmented" feedback (e.g., verbal instructions provided by an instructor to a student who is learning gymnastics). Augmented feedback is further divided into three categories based on: (1) the type of feedback, (2) the feedback frequency, and (3) the timing of feedback. All the three feedback categories can interact among one another as shown by previous studies (Adams & Page, 2000; Hula et al., 2008). The various feedback conditions used in learning/re-learning of non-speech as well as speech-motor skills are shown in Table 2.

Feedback type - There are two types of augmented feedback: (1) knowledge of results (KR), and (2) knowledge of performance (KP) (Schmidt & Lee, 2005). KR refers to externally presented information about the outcome of a movement and is provided verbally (Winstein, 1991) (i.e., whether the learner achieved the goal of the performance or not). For example, a golf instructor advising the learner that the ball missed the hole. In contrast, KP provides information about the movement pattern made by the learner that led to the outcome (Gentile, 1972). For example, a golf instructor advising the student that the ball missed the hole because he/she did not perform the backswing adequately before the downswing was made. In addition to providing the KP verbally, it can also be provided visually through video replay showing the learner's performance. There are limited studies comparing the efficacy of KR vs. KP in learning motor skills and the results have been equivocal. In some instances, providing KR might be redundant with the inherent feedback (Weeks & Kordus, 1998). For example, if an archer does not hit the target, the intrinsic feedback (in the form of visual feedback) tells him/her that the outcome was not favourable. In such an instance, providing KR might be redundant. However, if the outcome of the performance cannot be determined by the learner, then providing KR might prove beneficial. For example, while performing some types of the motor skills (like gymnastics), the learner might not be able to determine the outcome of the performance, and in such cases verbal KR could be useful.

Kernodle and Carlton (1992) compared the effects of KR and KP (in the form of videotape relays and verbal statements) in an experiment which required the participants to throw a soft, spongy ball as far as possible with the non-dominant arm. Results revealed that KP facilitated learning better than KR. Another experiment conducted by Zubiaur, Ona, and Delagado (1999) comparing KR vs. KP revealed similar results. In this experiment, students with no prior volleyball experience practised overhead serve. KP provided information about the most important error which needed attention, whereas KR provided information about the ball's

Table 2. Feedback conditions with appropriate examples for application in non-speech and speech tasks.

Feedback Conditions	Options (bolded options are more desirable for motor learning)	Relationship to non-speech (learning to play tennis)	Relationship to speech (learning to say “aeroplane”)
Type	Knowledge of performance vs. **Knowledge of results**	How did I swing the racket? vs. did the ball land on the correct spot?	How did the lips move? vs. Was it said correctly?
Frequency	High vs. **Low**	Feedback after every shot vs. feedback after every 20 shots	Feedback after every attempt vs. feedback after every 20 attempts
Timing	Immediate vs. **Delayed**	Providing feedback immediately after the serve vs. delaying by 10 s	Providing feedback immediately after production vs. delaying by 10 s

spatial precision, flight and rotation. Results revealed that KP helped the students to learn the overhead serve better than KR. Magill (2004) summarised that KR tends to be beneficial in motor learning when: (1) learners use KR to compare with the inherent feedback about their performance, and (2) learners are unable to determine the outcome of their performance based on the inherent feedback. Whereas, KP might be beneficial when: (1) skills must be performed according to certain movement characteristics (e.g., gymnastics), (2) KR is redundant with the inherent feedback, and (3) skills with complex coordination movement need to be improved. In summary, there have been equivocal findings with regards to the beneficial effects of KP vs. KR in learning motor skills. It is likely that the effect of KP vs. KR is dependent on the type of task being learned to a large extent. Further research is required to determine the beneficial effects of KP vs. KR across a range of motor skills.

Feedback Frequency - Feedback frequency refers to how often feedback is presented during the practice regime. The feedback frequency ranges from high (e.g., after every single practice trial) to low (e.g., after every 20 practice trials). It was long thought that high frequency feedback is beneficial during motor learning (Bilodeau, Bilodeau, & Schmusky, 1959). However, beginning with the seminal work of Salmoni, Schmidt, and Walter (1984), studies have proved the other way around. The phenomenon of reversal effect with respect to feedback frequency has been demonstrated in past studies (Winstein & Schmidt, 1990; Vickers, 1994). In the case of reversal effect, high feedback frequency facilitates acquisition but degrades learning.

For example, Weinstein and Schmidt (1990) compared the effects of high vs. low frequency in learning a lever positioning task. Participants had to practise a complex movement pattern using a lever on a tabletop. Participants practised the task for two consecutive days. One group of participants received feedback after every single practice trial (100% feedback), whereas the other group received feedback only for 50% of the trials. The retention test after one day revealed that the group which received feedback on 50% of the trials performed much better than the group which received 100% feedback. The detrimental effect of high frequency feedback is attributed to the guidance hypothesis (Salmoni, Schmidt, & Walter, 1984; Winstein & Schmidt, 1990). According to this hypothesis, when learners receive feedback after every practice trial (100% feedback), they become highly dependent on the feedback to perform the motor skill. When feedback is no longer available to the learners, it results in degrading their performance.

However, this reversal effect has not been demonstrated in some studies (Wulf, Shea & Matschiner, 1998; Marschall, Bund, & Wiemeyer, 2007). For example, Wulf et al. studied the effect of high vs. low frequency feedback on learning a complex ski simulation task. Twenty-seven participants practised the production of slalom-type movement on a ski simulator for two days. The participants were randomly assigned to either a high feedback frequency group (100%) or a low feedback frequency (50%) or a control group who received no feedback. The outcome parameters were force onset and movement amplitude. A retention test was performed on the third day. The retention test results revealed that the high frequency group demonstrated the best performance, the low frequency feedback demonstrated intermediate performance, and the control group showed the least performance. Thus, the researchers suggested that the reversal effect of feedback frequency might not be applicable in learning complex tasks.

In summary, low feedback frequency, as well as high feedback frequency, has been demonstrated to be useful in learning a range of motor skills. It is likely that a high frequency feedback schedule could be useful in learning complex motor skills, whereas low frequency feedback could be useful in learning simple tasks.

Feedback Timing - Feedback timing refers to the time period in which feedback is provided after the completion of the task. The timing of feedback can be either immediate or delayed. The beneficial effect of delayed feedback has been demonstrated by past studies (Swinnen, Schmidt, Nicholson, & Shapiro, 1990; Guadagnoli & Kohl, 2001). For example, Swinnen et al. instructed the participants to learn a lever operating task to achieve a specific movement-time goal. The participants received three types of feedback: immediately after completing the task, or, 3.2 s, or 8 s after completing the task. Results revealed that providing feedback immediately after the task completion had a negative influence on learning the lever task. A reason attributed to the negative effect of immediate feedback is that it blocks the learners' own analysis of inherent feedback which is essential for the development of error-detection capabilities (Swinnen et al., 1990; Guadagnoli & Kohl, 2001). Thus, past studies suggest that delayed feedback seems to be more beneficial than immediate feedback.

In summary, with regards to practice condition, there is sufficient evidence to support large amount of practice, distributed practice, and external focus of attention to be more beneficial than less practice, massed practice, and internal focus of attention, respectively. There have been equivocal findings in the case of constant vs. variable practice, random vs. blocked practice, and part vs. whole practice. Within the feedback condition, past studies favour delayed feedback over immediate feedback, and there has been mixed findings with respect to KP vs. KR, and high vs. low feedback frequency.

Application of PMLs in speech tasks

The research related to the application of PMLs in learning speech tasks and to treat speech disorders has been gradually increasing since the last decade (Adams & Page, 2000; Knock et al. 2000; Adams, Page, & Jog, 2002; Steinhauer & Grayhack, 2000; Mass et al. 2002; Mass et al. 2008; Mass & Farinella, 2012; Bislick et al. 2012). A summary of some of these past studies is provided in Table 3. There have been limited studies investigating the application of PMLs in speech-motor learning and are heavily drawn from the limb-based tasks. As the beneficial effect of a number of PMLs is yet to be determined in speech-motor learning, only the PMLs which have proved to be beneficial in learning speech tasks or treating speech disorders are discussed below.

Practice condition

Practice amount – There has been a recent spur of interest in investigating the amount of practice required to learn/re-learn various speech and language tasks. A recent issue of the Journal of International Speech Language Pathology was dedicated to the discussion of amount of practice required for treatment of various speech disorders (Baker, 2012a, 2012b; Packman & Onslow, 2012; To, Law, & Cheung, 2012; Roy, 2012; Yoder, Fey, & Warren, 2012; Enderby, 2012; Manes & Robin, 2012). The above studies address practice amount in terms of frequency of intervention for various speech and language disorders like stuttering, aphasia, motor-speech disorders, voice disorders, reading disorder, and speech sound disorders. Warren, Fey, & Yoder (2007) mentioned that the intensity of an intervention programme is based on a number of factors like: (1) what is being carried out in intervention sessions (active ingredients), (2) the number of times the active ingredients occur in a therapy session (dose), (3) number of intervention sessions per unit time (e.g., per day/per week), (4) the duration of individual intervention sessions, (5) and the length of the entire intervention programme (total intervention duration). Thus, it might be logical to deduce that the intensity of an intervention programme might vary based on all the above factors. In addition, most of the above studies seem to suggest that it is always not possible to prescribe an ideal amount of practise in speech language pathology, as the amount of practise is dependent on extraneous variables like what is being carried out in intervention, type of disorder, cognitive status of the client, family environment of the client, financial status of the client.

Table 3. Summary of various studies related to application of PMLs in speech-motor learning

Study	Participants	Practice task	Practice condition investigated	Outcome
Adams & Page (2000)	40 healthy participants	Temporal learning of a speech utterance	Constant vs. Variable, Random vs. Blocked, and Low frequency vs. High frequency feedback	Variable, random and low frequency feedback were beneficial in learning the utterance
Knock et al. (2000)	Two adults with aphasia and AOS	Learning CV and VC syllables (treatment study)	Random vs. Blocked	Random practice was beneficial over blocked
Adams, Page & Jog (2002)	18 participants with PD	Temporal learning of a speech utterance	Low frequency vs. High frequency feedback	Low frequency was beneficial over high frequency
Steinhauer & Grayhack (2000)	30 healthy participants	Vowel nasalization task	Low frequency vs. High frequency feedback	Low frequency facilitated the vowel nasalization task
Mass et al. (2002)	Two adults with aphasia and AOS	Learning monosyllable words (treatment study)	Simple vs. Complex stimuli practice	Complex stimuli practise was more beneficial
Mass et al. (2008) (review paper)				Provided information regarding the application of PMLs in speech related tasks and treatment
Wong, Ma & Yiu (2011)	21 participants with vocal hyperfunction	Sentence reading task	Constant, random, and blocked practice	No significant difference between the three conditions
Edeal & Neumann (2011)	Two children with AOS	Treatment of consonant targets	High production frequency vs. Low production frequency	High frequency production was beneficial over low frequency
Maas & Farinella (2012)	Four children with AOS	Treatment of various speech stimuli like monosyllables, bisyllable words	Random vs. blocked practice	Mixed findings
Bislick et al. (2012) (review paper)				Provided information regarding the scientific rigour of the past studies related to PMLs in SLP.

Study	Participants	Practice task	Practice condition investigated	Outcome
To, Law, & Cheung (2012)	102 SLPs	Survey study	A survey related to treatment intensity provided for speech sound disorders was investigated	The treatment intensity provided by SLPs varied depending on their work settings and in most cases it was not sufficient.
Baker (2012a) (discussion paper)			Practice amount	Provided information about ways of determining frequency intervention in SLP practise.
Yoder, Fey, & Warren (2012a) (commentary paper)			Practice amount	The authors reviewed one of their past studies and suggested that spacing the treatment sessions can have an impact on treatment intensity
Roy (2012) (commentary paper)			Practice amount	Discussed regarding the harmful effects involved in excess practise of vocal exercises.
Enderby (2012) (commentary paper)			Practice amount	Amount of therapy provided to clients must be based on factors like impairment, psychosocial aspects.
Manes & Robin (2012) (commentary paper)			Practice amount	Provided information regarding different practice and feedback conditions which can have an impact on deciding the practise amount (e.g., practice variability can affect the practice amount).
Packman & Onslow (2012) (commentary paper)			Practice amount	Provided information about Lidcombe programme, and mentioned that since Lidcombe is mainly parent-driven, it is difficult to prescribe the exact practice amount in such cases.
Baker (2012b) (discussion paper)			Practice amount	The author reviewed all the above studies related to practice amount and concluded that recommending ideal practice amount is dependent on extraneous factors like the client's impairment, psychosocial status, financial status.

The literature pertaining to the practice amount in non-speech tasks recommend 'overlearning' to be beneficial in motor learning. However, the same recommendation might be harmful for some patients with certain speech disorders. For example, Roy (2012) mentioned that overdose of voice therapy might result in vocal fold tissue damage rather than benefitting the patient. In summary, the results of recent studies would indicate that that there is no universal prescription for the amount of practise in speech language pathology, and the recommended amount of practise should be based on the factors discussed above. This is in contrast with studies considering the amount of practise in non-speech learning tasks (Dirskell et al., 1992; Bromage & Mayer, 1986).

Practice variability – Adams and Page (2000) compared constant vs. variable practice in a group of 40 healthy participants. This experiment also investigated the effects of practice schedule and feedback frequency on learning a novel speech utterance recruiting the same cohort of participants. The participants were assigned to one of four different groups. One group of participants practised 50 trials of the utterance "Buy Bobby a Poppy" with the target duration of 2.4 s (constant practice), and the other group practised 50 trials of the same utterance with the target durations of 2.4 s and 3.6 s (variable practice). The performance feedback was provided after every practice trial for participants in both groups through graphing the utterance durations. The participants underwent a retention test two days after the acquisition phase and produced the target utterance without further practise. The outcome measure was the absolute error (AE), which was determined by calculating the absolute difference between the target utterance duration and the participants' utterance durations. Each participant's AE score was based on the last five trials of the retention phase. The AE score was obtained for the 2.4 s target duration. The results revealed that both groups demonstrated similar performance during the acquisition phase, but the retention test results indicated that the variable practice group had significantly lower AE in comparison to the constant practice group. The results of this study suggest that variable practice is beneficial in learning speech tasks which is in close agreement with some of the studies related to non-speech-motor learning (Shea & Kohl, 1991; Shoenfelt et al., 2002; Wulf & Schmidt, 1997).

Practice schedule – The findings of the studies which have compared random vs. blocked practice conditions have been equivocal. Adams and Page (2000) compared random vs. blocked practice conditions on learning the same utterance task "Buy Bobby a Poppy" (as noted above). The same participants and experimental protocol were used to carry out this experiment. The retention results two days after the training revealed that the random practice group had significantly lower AE in comparison to the blocked practice group. The results of this experiment suggests that random practice is favourable in learning speech tasks and is in agreement with some of the findings related to non-speech tasks (Shea & Morgan, 1979; Shea & Wright, 1991; Wright, 1991).

In regards to a clinical population, Knock et al. (2000) compared random vs. blocked practice in treating speech deficits in two adult males who presented with AOS, as well as aphasia. A single-subject alternating treatment design was chosen for the study, so that each participant served as his own control. The first participant underwent two phases of treatment. In phase 1, the production of CV syllables (e.g., /pa/, /ba/, /ta/) were treated, and in phase 2 the production of VC syllables (e.g., /ap/, /ab/, /at/) were treated. The second participant underwent only one phase of the treatment. The treatment stimuli for the second participant included six CVC words (e.g., cat, tap, vase). Each treatment phase comprised of 12 treatment sessions and each treatment session consisted of a blocked practice condition and a random practice condition. The order of the practice conditions was counterbalanced across the 12 treatment sessions. The practice stimuli used during the treatment sessions were also tested during the retention phase. Results of the retention test revealed that stimuli trained using random practice had greater retention than the stimuli trained using blocked practice. The retention effects were more pronounced after four weeks of treatment. This trend was noticed in both participants. The results of this study suggest that random practice may be more beneficial over blocked practice in treating certain speech disorders.

Recently, Mass and Farinella (2012) compared the effect of random vs. blocked practice condition in treating CAS. Four children with CAS participated in the study. A two-phase alternating treatment design with multiple baselines across behaviours and a withdrawal/maintenance component was used as the experimental design. The Dynamic Temporal and Tactile Cueing method (DTTC) was used in the treatment. The DTTC method uses PMLs for speech practice and feedback delivery, and also incorporates auditory, visual, and tactile cueing by using a specific hierarchy of temporal delay between stimulus delivery and response. Each treatment session contained random and blocked practice conditions and the conditions were counterbalanced across sessions. The treatment targets varied for the four participants depending on the severity of CAS. The treatment lasted for four weeks and each treatment condition (using blocked or random practice) was followed by a two-week maintenance interval to measure retention. In addition to retention, transfer was also assessed on untreated but related words. The results were mixed, with two participants benefitted by blocked practice, one participant by random practice, and another participant did not show an improvement in either condition. The findings of the Mass and Farinella are not in agreement with the findings of Knock et al. (2000). Mass and Farinella attributed the difference in findings to the age of the participants in both the studies. Specifically, Knock et al. recruited adult participants as opposed to Mass and Farinella who recruited children.

Wong, Ma, and Yiu (2011) compared random, blocked, and constant practice in learning of relaxed phonation in patients with vocal hyperfunction. Twenty-one patients with hyperfunctional voice problems were randomly assigned to one of the three above mentioned practice conditions. Participants in the constant practice condition practised reading sentence stimuli with four Chinese characters. Participants in the random practice condition practised reading sentence stimuli varying in length from two to five characters in a random manner, and participants in the blocked practice condition read the sentence stimuli in increasing length starting from two to five characters. Surface EMG feedback from the orofacial and thyohyoid region was provided to the participants after reading every two sentence stimuli. The participants underwent eight sessions of training which lasted for four weeks. A retention test after one week of training revealed that considerable voice motor learning was demonstrated by participants in all of the practice conditions, and there was no significant difference in learning between the three practice groups. Similar to the findings of non-speech-motor learning (Brady, 2008; Maslovat, Chua, Lee, & Franks, 2004; Meira & Tani, 2001; French, Rink & Werner, 1990), recent studies related to speech-motor learning have also revealed equivocal findings with regards to the beneficial effects of random vs. blocked practice conditions.

Holistic practice - Mass et al. (2002) compared the effect of part (simple) vs. whole (complex) stimuli in treating speech deficits associated with AOS. A withdrawal design along with a multiple baseline design across behaviours was used in treating speech deficits in two patients with combined AOS and aphasia. The researchers used the framework of part-whole syllable structure to define the stimuli complexity. The stimuli used for the treatment were non-words. A whole syllable structure with three-element s-clusters comprised the complex condition (e.g., spleem), whereas the part syllable structure (singletons) comprised the simple condition (e.g., leem). Both patients were subjected to two counterbalanced treatment phases (a simple stimuli phase and a complex stimuli phase). The transfer effect of treatment speech targets was investigated by using untrained real word stimuli which were related to the treatment targets. For the first participant, treatment using complex (whole) stimuli resulted in overall improvement in production of simple and complex real as well as nonwords. The same effect was also observed for the treatment carried out using simple (part) stimuli but to a lesser extent. For the second participant, the treatment using simple as well as complex stimuli resulted in an improvement in the production of simple real and nonwords but not in the production of complex real and nonwords. The results of this study suggest that speech-motor learning may be most beneficial when using complex stimuli compared to simple stimuli as part of the practice condition.

Feedback condition

Feedback frequency – Studies comparing high vs. low frequency feedback in learning speech tasks and to treat speech disorders have found that low frequency feedback tends to be more beneficial over high frequency feedback (Adams & Page, 2000; Adams, Page, & Jog, 2002; Hula et al., 2008; Mass et al., 2012), which is similar to the findings of some of the studies related to non-speech tasks (Salmoni et al., 1984; Weinstein & Schmidt, 1990).

Adams and Page (2000) compared low frequency vs. high frequency feedback in learning the utterance task "Buy Bobby a Poppy". Participants in the high frequency group practised 50 trials of the speech utterance with target duration of 2.4 s and received feedback after very single trial. Participants in the low frequency group also practised 50 trials of the same task, but received feedback after every five trials. Participants were given feedback about their performance through graphing the utterance duration values. Retention test results two days post-training revealed that participants in the low frequency feedback group performed better than participants in the high frequency group.

Hula et al. (2008) examined low vs. high frequency feedback in treating speech deficits associated with AOS. Four participants with AOS participated in this experiment. A single-subject alternating treatment design was used, so that each participant received both the treatment condition (high frequency feedback and low frequency feedback) and also served as his/her control. Each participant received two phases of treatment. In phase 1, CV combinations beginning with fricatives (e.g., /fa/, /vu/) were treated using high frequency feedback, and CV combinations beginning with plosives (e.g., /pa/, /ba/) were treated using low frequency feedback. In phase 2, this arrangement was reversed. The order of sessions during the treatment was counterbalanced across the participants. There was also a four-week maintenance phase following the treatment phase. Weekly probes administered throughout the 16 weeks (treatment and maintenance phases) served to assess the retention when treatment was removed. Learning was also assessed through transfer using untrained stimuli probes. The results revealed that low frequency feedback enhanced retention in two participants, and transfer effects were seen in only one participant. The results reveal that some of the participants were able to benefit from treatment using low frequency feedback. The main reason for the difference in treatment outcome could have been due to differences in the severity of AOS among the four participants.

In a recent study, Mass et al. (2012) investigated the effect of high frequency vs. low frequency feedback frequency in treating speech deficits in four children with CAS. The children ranged in age from 5;4 (years;months) to 8;4. The treatment targets were chosen depending on each child's speech and language status. The DTTC was used in the treatment. An alternating treatment design with multiple baselines across behaviours was used. Each child received high frequency feedback as well as low frequency feedback within a single session, with the order of feedback conditions counterbalanced across sessions. The post-treatment results revealed mixed findings, with two children benefitted from low frequency feedback, one child benefitted from high frequency feedback (to a small extent), and the other child not benefitting from either condition. The researchers suggested that although reduced feedback might benefit children with CAS in general, it may vary with the child's age and the severity of the apraxia.

Feedback timing – There are few studies comparing immediate and delayed feedback in speech-related tasks. Hula et al. (2008) conducted a second experiment which compared immediate vs. delayed feedback. The two participants who completed the feedback frequency experiment also took part in this experiment. There was a gap of one week between both experiments. Feedback was provided for both the participants after every trial either immediately (immediate feedback) or after a delay of 5.0 s (delayed feedback). Retention and transfer results revealed that only one participant demonstrated treatment gains. Based on the findings of this experiment, it is difficult to assess the benefits of delayed feedback in speech-motor learning. Further research using a larger cohort of participants is required to compare the benefits of immediate vs. delayed feedback in learning speech tasks.

In summary, studies investigating various practice and feedback conditions in speech-related tasks are limited in number in comparison to the studies related to non-speech tasks. With regards to practice condition, variable practice, and complex stimuli practice are considered beneficial over constant practice and simple stimuli practice, respectively. There have been equivocal findings with respect to random vs. blocked practice condition. In feedback condition, low frequency feedback, and delayed feedback are considered to be beneficial over high frequency feedback, and immediate feedback, respectively. The efficacy of other practice and feedback conditions remains to be investigated in speech-motor learning.

As speech is also a motor activity, it is plausible that the PMLs applicable to limb-based tasks might also be applicable for speech-related tasks. However, previous research has shown that speech and non-speech activities differ based on the degree of movement coordination (Grimme, Fuchs, Perrier, Schoner, 2011), neural resources (Smith, 2006), and cognitive demands (Grimme et al., 2011). So it is unclear whether the PMLs found to be effective for non-speech motor learning would also be effective for speech motor learning

Role of pre-practice in motor learning

Pre-practice helps an individual to prepare for the upcoming practice sessions/trials (Edwin, Karyll, Lise, & Gary, 1981). The role of pre-practice in motor learning has been gaining considerable attention in recent years (Schmidt & Lee, 2005; Murray, McCabe, & Ballard, 2011; Bricker-Katz, McCabe, Lincoln, & Ballard, 2011). The aim of a pre-practice session should be to assure that the person understands the importance of the task to be learned and performs the task in the correct manner. The three important aspects of pre-practice are: (1) to build adequate motivation for learning the task, (2) providing correct information about the task to be learned, and (3) modelling the task to be learned (Sherwood & Lee, 2003), and they are described below.

Motivation for learning

It is essential that an individual remains motivated while learning a motor task. If the motivation level decreases, then the individual might not find the task engaging, resulting in decreased learning outcomes. Two ways to motivate an individual who is learning a task are by (1) making the task seem important, and (2) setting appropriate and achievable goal (Mass et al., 2008). When an individual is trying to learn a task, he or she should be informed about the importance of learning the task and the benefits involved in learning the task. For example, a person with dysarthria who is attending speech therapy, should be informed about the importance of speech therapy and the associated benefits of treatment activities. Setting specific goals which are achievable is also very important in motivating an individual who is learning a new task. It is recommended to avoid “do your best goals” as they tend to be very general rather than being specific (Mass et al., 2008). For example, in the case of a person with cluttering, it is better to set the goal of reducing the rate of speech to a specific number of words per minute rather than telling the person “to do your best”.

Verbal information

Orienting a novice learner about the task through effective verbal instructions has proven to be an important precursor to motor learning (Schmidt & Lee, 2005). Instructions can be provided regarding the task to be performed, how to perform the task, what are the outcome measures to be achieved, and the possible error detection strategies after the task is performed. Care should be exercised that the exact amount of information is provided to the learner through verbal instructions. Providing too much or too little instructions can prove to be detrimental in learning the task.

Modelling

Another important aspect of pre-practice is modelling. The task which is to be learned can be modelled in many ways. An effective way of modelling is to demonstrate the skill directly to the learners so that they can observe the specific steps involved in executing the task. The task can also be modelled through videotapes or photographs of skilled performers (Svinin, Riken, Goncharenko, Hosoe, & Kanou, 2007).

Effect of age on motor learning

Aging is an inevitable biological process experienced by every living organism. Aging is accompanied by a gradual decrease in physiological output (Partridge & Mangel, 1999). Mild irreversible changes in the functioning of most of the body organs start by the third or fourth decade of our lives with progressive deterioration in aging (Boss & Seegmiller, 1981). Some of the age-related systemic changes include decreased cardiac output, hypertension, decreased lung volume, decreased renal functioning (Boss & Seegmiller, 1981), and decrease in the number of neurons in the cortex (Brody, 1955). Aging is also accompanied by changes in the sensory system (Shimokata & Kuzuya, 1995). Old age results in a decrease in visual acuity (Shinomori, Schefrin, Werner, 2001), hearing acuity (Tremblay, Piskosz, & Souza, 2003), taste, and smell perception (Schmall, 1993).

A hallmark characteristic of old age is the decline in cognitive-motor performance. Past research has revealed that aging is characterized by impairments in motor (Ketcham & Stelmach, 2001) as well as cognitive functioning (Dixon & Raz, 2000; Salthouse, 1985; Cook & Woollacott, 2000). Old people tend to perform motor tasks with less precision and more slowly in comparison to their younger counterparts (Voelcker-Rehage, 2008). Fozard, Verryyssen, Reynolds, Hancokc, and Quilter (1994) showed that the reaction to an auditory stimulus decreases by 0.5 ms between 20 and 96 years. Myerson, Hale, Hirschman, Hansen and Christiansen (1989) measured reaction time of the older and younger participants in three different cognitive-motor tasks (letter classification, abstract matching-to-sample, and choice reaction time). The researchers found that the performance of the younger group was better than the older group in the cognitive-motor tasks. The researchers suggested that age has a direct effect of physical slowing of movements. A number of models have been developed to explain the decline of motor skill with age.

A popular model which explains the decreased and slower motor performance among elderly individuals is the “information loss model” (Myerson, Hale, Wagstaff, Poon, & Smith, 1990). According to this model, response planning requires several processing stages, and a certain amount of time is dedicated to each stage. More time is required to plan a response, if there is a loss of information at any particular stage. Aging is accompanied by increased information loss at each processing stage, and hence more time is spent in planning the movement responses. Another model explains the decreased motor output among the elderly based on changes in “attitudes and preferences” (Verhoff, Reuman, & Feld, 1984). A critical assumption is that elderly people approach a task differently than their younger counterparts and are more resistant to novel and unfamiliar tasks, thus resulting in a decreased motor output.

Crossman and Szafran (1956), and others (Welford, 1985) attributed the decreased and slower motor performance of the elderly group to brain-based changes. This “neural noise model” model mentions that as people age, there is increased random activity in the brain referred to as noise. In the case of complex learning tasks, the noise activity is further heightened. Due to this increased noise, additional time is required to integrate incoming information from the external world involved in producing a response.

The “reduced working memory model” is well supported by previous studies (Kester, Benjamin, Castel, & Craik, 2002; Jost, Bryck, Vogel, & Mayr, 2011). The reduced working memory in elderly individuals is attributed to the inhibitory deficit hypothesis. According to this hypothesis, older individuals are unable to inhibit interference from task-irrelevant information; this irrelevant information interferes with the essential information and reduces the memory capacity of the aged individuals (Hasher & Zacks 1988; Hasher, Zacks, & Rahhal, 1999; Zacks, Hasher, & Li, 2000).

Despite the changes in motor ability and learning that accompany old age, previous research has well established that elderly individuals are capable of learning/re-learning motor skills (Seidler 2006; Ketcham & Stelmach, 2001). However, the extent and the style of learning might differ between elderly and younger individuals (e.g., Strickgold & Walker, 2005). Walker, Brakefield, Morgan, Hobson, and Strickgold (2002) demonstrated that elderly individuals are capable of retaining and improving their skills after a period of delay. Various studies related to motor learning of non-speech and speech-motor tasks in elderly individuals are mentioned below.

Non-speech motor learning

Research investigating the effect of age on non-speech-motor learning tasks suggests that older individuals tend to demonstrate decreased motor learning in terms of precision and speed in comparison to the younger individuals (Baron & Menich, 1985; Seidler, 2006; Breitenstein, Daum, & Schugens, 1996). Seidler (2006) examined younger (18–31 years) and older participants (65–80 years) in their ability to learn different joystick aiming tasks. Older adults exhibited poorer precision and took longer time to learn the joystick aiming task as compared to younger adults. Anshel (1978) compared the learning ability of younger (22–26 years) and older (70–80 years) participants on a limb repositioning task. Younger adults performed more accurately than older adults. However, with practice, the older participants showed significantly greater improvement than younger participants. The findings of this study suggested that the elderly individuals were capable of learning the limb repositioning task but performance was affected by age-related changes.

Breitenstein, Daum, and Schugens (1996) compared the performance of younger and older participants on simple and mirror-reversed tracking tasks. In the simple tracking task, the extent of improvement in performance was similar between the younger and older participants. But in the more complex mirror reversed tracking task, the performance of the younger participants was much better than the older counterparts. This suggests that with increase in complexity of the tasks, the age difference in motor learning is more pronounced. Similarly, other studies have found that even though older participants tend to learn complex motor skills, performance accuracy is lower in comparison to younger participants (Wishart, Lee, Cunningham, & Murdoch, 2002; Wright & Payne, 1985).

The task complexity has been considered a major factor in determining the amount of motor learning in elderly individuals. Welford (1985) demonstrated that for simple tasks, the elderly participants learned the task quickly and there was not much difference in terms of performance accuracy between the younger and older participants. However, Falduto and Baron (1985) found that on a complex card sorting task, the performance of the younger participants was much better than the older participants.

Speech motor learning

Old age is accompanied by changes like deterioration in the physiological functioning of oral motor structures (e.g., tongue) (Calhoun, Gibson, Hartley, Minton, & Hokanson, 1992), breakdowns in speech production (Searl, Gabel, & Fulks, 2002), decreased breath support for speech (Hoit & Hixon, 1987), atrophy of the vocal folds (Takeda, Thomas, & Ludlow, 2000), and decrease in articulation rate (Jacewicz, Fox, O'Neil, & Salmons, 2009). The studies which have compared the performance of younger vs. older adults on speech-motor learning tasks also suggest that older participants tend to perform poorly in comparison to their younger counterparts (Sadagopan, 2008; Ballard, Robin, Woodworth, & Zimba, 2001; Schulz, Stein, & Micallef, 2001). Sadagopan compared the novel speech learning ability in younger vs. older age groups. A physiological measure (i.e., kinematic analysis) and behavioural measures (production accuracy and duration) were assessed on two consecutive days for 16 young and elderly participants during the production of six novel nonwords increasing in length and complexity. Behaviourally, clear differences were noted between young and elderly participants in the ability to accurately produce the longer, more complex nonwords. Older speakers' productions revealed a significantly greater percentage of articulatory errors than young adults for four-syllable nonwords, suggesting that important age-related differences are present for repetition of long, complex novel nonwords. Elderly individuals also demonstrated longer durations for nonword production than young adults, and this effect was magnified for longer, more complex nonwords. Very few elderly individuals were able to produce the requisite number of accurate productions for kinematic analysis of the two most complex nonwords, and these were excluded from statistical analyses.

Ballard et al. (2001) investigated the age-related changes in a visuomotor tracking (VMT) task. In a VMT task related to an articulator, the participant is required to trace the movement of the target signal using an articulator of interest (like the tongue). In this study, the control of, lower lip, jaw, and larynx was studied across the life span using the VMT task. A total of 52 females and 35 males ranging in age from 8 to 84 years participated. For the lip and jaw, then VMT performance was studied using a strain gauge cantilever system. To study the control of larynx, the participants were required to sustain a vowel (/a/). Results revealed that the movement accuracy was better in the younger participants in comparison to the older participants.

Schulz et al. (2001) studied performance of healthy younger and older participants on a novel speech utterance with respect to the kinematic measurement of the articulators. Three younger males (22-24 years) and three older males (54-68 years) participated in the study. All the participants practised producing a novel meaningless speech utterance in five blocks of 10 repetitions each. The kinematic movements of the tongue, lower lip, and jaw were measured during this practice task. The results suggested older, as well as younger, participants demonstrated learning capabilities of the utterance. However, the younger males were more accurate in the production of the utterance, made fewer errors, and showed better retention in comparison to the older participants. The results of this study were in agreement with the findings of the non-speech-motor learning, suggesting that elderly individuals are capable of learning motor skills but tend to be less accurate in performance compared to the younger individuals (Wishart et al. 2002; Wright & Payne, 1985).

Past studies suggest that old age leads to decreases and slower performance of non-speech, as well as, speech-motor learning tasks. Various brain-based and cognitive models have been implicated to explain the reduced motor performance of old aged individuals. Past studies have proven that older individuals are capable of learning novel motor skills but they do it at a much slower pace than their younger counterparts. A drawback of past studies is that aging has not been considered in the application of PMLs in speech, as well as, non-speech tasks. It is possible that systematic application of PMLs in elderly population might facilitate motor learning to a major extent. It remains to be determined whether the application of PMLs that facilitates non-speech and speech motor learning in young adults are similar to those for older individuals.

Spatial and temporal aspects of motor learning

Spatial learning in general, refers to learning the movement characteristics of novel motor movements in relation to the learner's surrounding environment and spatial orientation (e.g., learning to articulate the sounds of a word correctly, learning to kick a football accurately). Temporal learning would refer to learning the duration and/or pacing required to perform the motor skill (Schmidt & Lee, 2005) (e.g., learning to say a phrase within the specified duration, performing a throwing task at a certain pace). Most studies applying PMLs in speech and non-speech-motor learning tasks have investigated either the spatial (e.g., Shoenfelt at al., 2002; Wulf & Schmidt, 1997; Mass & Farinella, 2012; Hulla et al., 2008; Knock et al., 2000) or temporal aspects of motor learning (Shea, Lai, Wright, Immink, & Black, 2001; Sekiya, Magill, & Anderson, 1996; Adams & Page, 2000). However, it is important to recognize that movements possess both spatial and temporal characteristics. Even though, spatial and temporal aspects can be dissociated separately (e.g., drawing a square in different sizes and at different speeds), the entirety of motor learning is captured by measuring both the spatial and temporal aspects of motor learning. To date, there have been no attempts to apply PMLs to the learning of both spatial and temporal speech or non-speech movements.

An important concept within the framework of motor learning is the 'speed-accuracy trade-off' (SAT) (Wickelgreen, 1977). In a typical SAT, the speed of the motor skill is reduced when focus is on accuracy and vice-versa (Schmidt & Lee, 2005). In other words, movements can be performed very quickly with compromised accuracy, or they can be performed accurately at the expense of being slower. For example, when a person tries to insert a key into a keyhole to open a door, he needs to perform the task at a slower pace so that the accuracy is not compromised. However, many tasks have both speed and accuracy requirements. An ideal way to approach these tasks is to make movements as fast as possible without compromising the accuracy. For example, this might be applicable to tasks like kicking a football or swinging a tennis racket. Both these tasks must be done quickly but also with precision (Fairbrother, 2010).

The notion of SAT has been implicated in non-speech tasks (Keramati, Dezfouli, & Piray, 2011), as well as in speech tasks, (Goozee, Stephenson, Murdoch, Darnell, & Lapointe, 2005; Parnell & Amerman, 1996). For example, Goozee et al. compared the lingual kinematics in a group of younger and older participants. Eight younger females (M = 26.7 years) and eight older females (M = 67.1 years) were required to repeat /ta/ and /ka/ at a moderate rate and as fast as possible. Electromagnetic articulography was used to track the lingual movements during these speech tasks. The results revealed that during the fast speaking condition, both groups reduced the distance travelled by the tongue. However, older participants demonstrated a SAT to maintain the accuracy in articulating the sounds. SAT might provide important information about the approach (spatial vs. temporal) adapted by individuals while learning a certain motor skill. This information could be useful in teaching novel motor skills or in designing treatment protocols for various motor disorders. Most studies related to motor learning have focussed solely on either spatial or temporal learning, thereby not having an opportunity to observe the SAT situation. Hence, measuring the outcomes of motor learning in terms of both spatial and temporal aspects would provide a more complete picture about the process of motor learning.

Statement of the Problem

The notion that PMLs facilitate learning/re-learning of motor skills has largely emerged from studies involving non-speech-motor tasks (e.g., finger tapping, keyboard entry, arm stretching and lever positioning tasks) which have been conducted over the past 40 years (Adams, 1971; Schmidt, 1975b). Identifying the PMLs which tend to be the most effective in learning non-speech-motor skills or treating motor disorders has been a matter of debate. Still, the general consensus is that PMLs tend to be effective in learning various facets of motor skills (e.g., Steinhauer & Grayhack, 2000; Murray & Udermann, 2003; Emanuel, Jarus, & Bart, 2008). Past studies have validated the usefulness of PMLs in learning non-speech-motor skills in healthy individuals (Breslin et al., 2012; Rohrer et al., 2005; Murray & Udermann, 2003; Emanuel, Jarus, & Bart, 2008) as well as in clinical populations (Kwakkel, 2009; Verschueren, Swinnen, & Dom, 1997; Dick et al., 1996; Lin et al., 2007).

Since the last decade, there has been considerable interest to investigate the benefits of PMLs in relation to speech-motor learning (e.g., Adams & Page, 2000; Knock, et al., 2000; Steinhauer & Grayhack, 2000; Adams et al., 2002; Ballard et al., 2007; Hula et al., 2008; Maas et al., 2008; Katz et al., 2010; Wong et al., 2011; Mass & Farinella, 2012; Bislick et al., 2012). All of the aforementioned studies have been responsible for shifting the focus of application of PMLs from non-speech tasks to speech tasks. In addition, they have also provided evidence that PMLs are useful in learning speech-motor tasks, as well as in treating MSDs. In spite of these advances, there are a number of limitations in past studies that need to be addressed. Some of the limitations serve as the basis for the present study.

The first major limitation is that past studies have failed to directly compare the effects of PMLs on both speech *and* non-speech-motor learning tasks in the same individual. Because PMLs have been drawn heavily from non-speech (limb-based) tasks, it may be reasonable to deduce that the PMLs applicable to non-speech-motor learning will also be applicable to speech-motor learning, as both are motor skills. However, research has shown that limb-motor control and speech-motor control differ in terms of their physiological nature (Smith, 2006), degrees of freedom, and cognitive requirements (Grimme et al., 2011). Therefore, it is uncertain whether non-speech motor control and speech-motor control will respond to PMLs in a similar manner.

A second limitation with past studies of non-speech and speech-motor learning is that they have failed to consider the combined effects of practice and feedback variables on motor learning. It is possible that motor learning is effective in situations where an individual receives both practice and feedback simultaneously, so addressing only one of these issues (i.e., either practice or feedback) in learning a motor skill will limit the motor learning ability of an individual.

A third limitation is that the past studies have not investigated the effects of PMLs on aging population. Decreased motor performance is a typical finding in studies on normal aging (Mattay et al., 2002; Perrot & Bertsch, 2007). It is likely that the PMLs might affect the elderly individuals in a different manner than the younger age group. Research related to age effects and PMLs is yet to be undertaken.

The fourth limitation is that past studies have not compared the effects of PMLs in healthy and in individuals with motor-based disorders. Past studies have revealed that individuals with motor-based disorders (e.g., Parkinson's disease) tend to have difficulty in executing motor activities (Marsden, 1989). It is likely that the application of PMLs in individuals with motor-based disorders and healthy individuals might influence motor learning to varying degrees in both the groups. Addressing this issue might help in designing therapy protocols incorporating PMLs for individuals with motor-based disorders.

Finally, past studies have not addressed motor learning in terms of both spatial and temporal learning abilities. It is well known that a motor skill is comprised of a spatial and a temporal domain (Kelso, 1992). Some of the past studies related to temporal learning have found that participants learn temporal skills at the expense of spatial accuracy (e.g., Goozee et al., 2005). It is essential to estimate motor learning within the scope of spatial and temporal domains to fully appreciate the effectiveness of PMLs.

In conclusion, the goals of the current study were: (1) to investigate the effect of selected principles of motor learning on non-speech and speech-motor learning in individuals with normal speech-motor control and impaired speech-motor control, and (2) to compare the spatial and temporal learning of speech, as well as non-speech tasks, in older and younger age groups.

To achieve these goals the following hypotheses were posed:

Hypothesis 1 – The PMLs that best facilitate spatial learning of a novel musical keyboard entry task (non-speech task) will also best facilitate spatial learning of a novel speech utterance (speech task) in a group of healthy individuals.

Hypothesis 2 – The PMLs that best facilitate temporal learning of a novel musical keyboard entry task (non-speech task) will also best facilitate temporal learning of a novel speech utterance (speech task) in a group of healthy individuals.

Rationale for H1 & H2: Speech is considered to be a dynamic motor system essential for human communication. The speech and skeletomuscular systems share common neural control modes despite fundamental biomechanical differences (Perrier, Ostry & Laboissière, 1996). Recent research reveals that that coordination among limb and articulatory effectors share common physiological framework and have been investigated with similar experimental methods (Perrier, Ostry & Laboissière, 1996). Hence, the practice and feedback conditions inducing changes in the non-speech-motor system can be expected to influence the speech-motor system in a similar manner. Therefore, it is reasonable to hypothesize that speech production as a motor skill is governed by similar principles of motor learning as the non-speech-motor system.

Hypothesis 3 – The PMLs that best facilitate spatial learning of a novel speech utterance task will not be similar between a group of healthy younger individuals and a group of healthy older individuals.

Hypothesis 4 – The PMLs that best facilitate spatial learning of a novel musical keyboard entry (non-speech) task will not be similar between a group of healthy younger individuals and a group of healthy older individuals.

Hypothesis 5 – The PMLs that best facilitate temporal learning of a novel speech utterance task will not be similar between a group of healthy younger individuals and a group of healthy older individuals.

Hypothesis 6 – The PMLs that best facilitate temporal learning of a novel musical keyboard (non-speech) entry task will not be similar between a group of healthy younger individuals and a group of healthy older individuals.

Rationale for H3-H6: Past studies have revealed differences of the speech and non-speech-motor systems between younger and elderly individuals (Mattya et al., 2002; Perrot & Bertsch, 2007). Some common examples of motor performance deficits in older individuals include difficulty in coordination (Seidler et al., 2002), increased movement variability (Vidal, Teulings, & Stelmach, 1998) in comparison to younger individuals. Previous research investigating motor learning in older and younger individuals suggests that the extent of motor learning tends to vary between older and younger individuals (Fraser, Li & Penhune, 2009). It is possible that the speech and non-speech-motor systems of the younger and elderly individuals might be influenced to varying extent upon application of PMLs. Although, investigating the age effect on speech-motor learning seems to be pertinent to the current study, a parallel investigation of the age effect on non-speech-motor learning might provide valuable evidence pertaining to the aging motor system in general.

Hypothesis 7- The PMLs that best facilitate spatial learning of a novel speech utterance task will be similar between a group of healthy individuals and a group of individuals with hypokinetic dysarthria due to PD.

Hypothesis 8 - The PMLs that best facilitate spatial learning of a novel musical keyboard (non-speech) entry task will be similar between a group of healthy individuals and a group of individuals with hypokinetic dysarthria due to PD.

Hypothesis 9 - The PMLs that best facilitate temporal learning of a novel speech utterance task will be similar between a group of healthy individuals and a group of individuals with hypokinetic dysarthria due to PD.

Hypothesis 10 - The PMLs that best facilitate temporal learning of a novel musical keyboard entry (non-speech) task will be similar between a group of healthy individuals and a group of individuals with hypokinetic dysarthria due to PD.

Rationale for H7-H10: There is evidence to show that individuals with PD are also capable of motor learning (Soliveri, Brown, Jahanshahi, & Marsden, 1992; Behrman, Cauraugh, & Light, 2000). It is likely that the PMLs which influence the speech and non-speech-motor systems of healthy individuals will also influence the speech and non-speech-motor systems of individuals with PD to a similar extent. However, the performance of individuals with PD can be expected to be reduced in comparison to the healthy counterparts.

Chapter 3. Methods

Participants

Non-clinical group - The study involved two experiments. The first experiment involved recruitment of a non-clinical group of 80 healthy individuals (21 males & 59 females) in the age range of 40-80 years (M = 59 years). The inclusion criteria for the participants were (1) no reported history of sensory and cognitive abnormalities, (2) native speaker of New Zealand English, (3) completion of a high school diploma, and (4) right-hand dominance. The right hand dominance was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971) prior to the start of the data collection. The inventory provides a quantitative index of handedness. Details of the inventory are provided in Appendix 3. The participants for the non-clinical group were recruited through a convenience sampling procedure from the database of control participants registered with the New Zealand Brain Research Institute (Christchurch, NZ) and also from the wider community of Christchurch. The demographic details of the participants in the non-clinical group are presented in Table 4.

Clinical group - The second experiment involved recruiting a clinical group of 16 individuals (12 males & 4 female) in the age range of 58-84 years (M = 70 years) with hypokinetic dysarthria due to PD. The participants were recruited from a list of patients receiving support services from the Parkinson's Society of New Zealand (Canterbury Division). Based on the examination of medical records, the condition of PD was diagnosed as a chronic progressive syndrome with two of three cardinal features of rest tremor, bradykinesia, and rigidity, without evidence of a secondary cause or atypical features. The onset of the PD for the participants ranged from 4-12 years. All participants were on dopamine replacement therapy. The data collected in the present study occurred while the participants were in a self-reported 'on' state, 1 to 4 hours after taking medications. The 'on' state refers to the time period following medication which represents the best motor ability of patients with PD (Goberman & Coelho, 2002). The Movement Disorder Society–Unified Parkinson's Disease Rating Scale (MDS-UPDRS) 'motor examination' subsection scores (Goetz., et al, 2007), and modified Hoehn and Yahr staging (Goetz et al., 2004) were recorded for each participant with PD on the first day of the experiment. The 'motor examination' subsection of the MDS-UPDRS consists of 18 evaluation parameters.

Table 4. Descriptive data of the participants in the non-clinical group including age, sex, and practice conditions. Mean age of the participants is indicated at the bottom of the table.

Participants	Age	Sex	Practice condition
1	78	F	Constant
2	73	F	Constant
3	71	F	Constant
4	71	F	Constant
5	71	F	Constant
6	67	F	Constant
7	64	F	Constant
8	64	F	Constant
9	62	F	Constant
10	61	F	Constant
11	60	M	Constant
12	57	F	Constant
13	57	F	Constant
14	56	F	Constant
15	56	F	Constant
16	53	F	Constant
17	51	F	Constant
18	48	F	Constant
19	46	F	Constant
20	46	M	Constant
21	72	F	Variable
22	71	F	Variable
23	70	M	Variable
24	65	M	Variable
25	64	M	Variable
26	63	F	Variable
27	62	M	Variable
28	61	F	Variable
29	60	F	Variable
30	59	F	Variable
31	57	F	Variable
32	56	F	Variable
33	55	F	Variable
34	55	F	Variable
35	54	M	Variable
36	52	F	Variable
37	51	F	Variable
38	49	F	Variable
39	44	F	Variable
40	42	F	Variable

Participants	Age	Sex	Practice condition
41	73	F	Random
42	73	M	Random
43	72	M	Random
44	71	F	Random
45	70	M	Random
46	65	F	Random
47	65	M	Random
48	63	F	Random
49	62	F	Random
50	62	F	Random
51	57	M	Random
52	55	F	Random
53	55	F	Random
54	52	F	Random
55	52	F	Random
56	52	M	Random
57	50	F	Random
58	49	M	Random
59	46	F	Random
60	44	M	Random
61	75	F	Blocked
62	72	F	Blocked
63	72	F	Blocked
64	71	M	Blocked
65	64	F	Blocked
66	64	M	Blocked
67	64	M	Blocked
68	63	F	Blocked
69	62	F	Blocked
70	61	M	Blocked
71	59	M	Blocked
72	58	F	Blocked
73	58	F	Blocked
74	57	F	Blocked
75	57	F	Blocked
76	57	F	Blocked
77	52	F	Blocked
78	48	F	Blocked
79	45	F	Blocked
80	44	M	Blocked
M	59.5		

Each parameter is evaluated by the clinician and given a score ranging from '0' (normal) to '4' severe) based on the performance of the participant on a particular task. The total score for the 'motor examination' subsection ranged from '0' (normal) to '82' (severe). The average UPDRS score during the 'on' state was 45.3 (range = 21-61, SD = 12.2) indicating moderate motor impairment, and the average speech UPDRS subscale rating was 1.56 (range = 1–3, SD = 0.62) indicating mild-moderate speech impairment. The modified Hoehn and Yahr staging scale evaluates the severity of PD based on five separate stages, with 0.5 increments between each stage. Stage one indicates unilateral signs and symptoms and stage five indicates severe impairment requiring total assistance. The average Hoehn and Yahr stage during the 'on' state testing was 1.8, indicating the stage of bilateral involvement. In addition, all the participants were administered the Frenchay Dysarthria Assessment (FDA) (Enderby, 1983) to arrive at a diagnosis of dysarthria. The FDA provides a standardized assessment of speech neuromuscular activity, involving respiration, phonation, resonance and articulation, and speech-related reflex activity. The FDA allows the clinician to rate the ability of each speech subsystem using a 9-point scale, and thus provides a profile that contributes to the differential diagnosis of dysarthria. The results of FDA indicated that all the participants exhibited hypokinetic dysarthria, which is usually associated with PD (Duffy, 2005). Demographic details, UPDRS scores and modified Hoehn and Yahr staging scores of the participants collected prior to the start of the experiment are presented in Table 5.

Procedure

Four practice conditions and a combination of feedback conditions were applied to the speech and non-speech-motor learning tasks. The same conditions and tasks were evaluated in both experiments. The four practice conditions were (1) constant practice, (2) variable practice, (3) blocked practice, and (4) random practice. The feedback which was provided constituted a combination of low-frequency, KR, KP, and delayed feedback conditions. The four practice conditions were paired with feedback conditions in both experiments.

Experiment I: Non-clinical group

Speech Task

Four different groups were organized on the basis of the practice condition (constant, variable, blocked, & random). Each of the 80 participants was randomly and equally assigned to one of the four practice conditions, thus constituting 20 participants in each practice condition (see Table 4). The participants in each practice condition were trained

Table 5. Descriptive data of the participants in the clinical group including age, sex, UPDRS scores, Hoehn & Yahr staging scores, and practice conditions. Mean scores are indicated at the bottom of the table.

Participants	Age	Sex	Motor UPDRS	Speech UPDRS	Hoehn & Yahr	Practice conditions
1	84	M	48	2	2	Constant
2	80	M	53	1	1.5	Constant
3	69	M	60	3	2	Constant
4	71	F	61	2	2	Constant
5	74	M	41	1	1.5	Variable
6	62	M	59	2	3	Variable
7	71	M	34	2	1.5	Variable
8	57	F	32	1	1	Variable
9	71	M	32	2	1.5	Random
10	67	M	42	2	1.5	Random
11	71	M	39	1	2	Random
12	69	M	40	1	1.5	Random
13	71	F	21	1	1	Blocked
14	58	M	61	2	2.5	Blocked
15	81	M	55	1	2.5	Blocked
16	64	M	48	1	2	Blocked
M	70		45.3	1.57	1.8	

speech phrase "*Thak glers wur vasing veen arad moovly*". A meaningless phrase was chosen as the stimulus for training based on the Challenge Point Framework (CPF) (Guadagnoli & Lee, 2004).

According to CPF, a more challenging environment facilitates better motor learning in comparison to a less challenging environment. To make the speech task challenging, a speech phrase containing a string of non-words which followed the phonotactic rules of the English language was created. Moreover, learning a meaningless material has shown to be more difficult in comparison to learning a meaningful material (Epstein, 1962). In addition, the temporal spacing between the non-words was also altered in an attempt to make the phrase more challenging. In total, the speech phrase used for training (also called the target phrase) consisted of 7 non-words and 28 phonemes, in total. Among the 7 non-words, 3 were bi-syllabic and the rest were monosyllabic. The whole phrase was split into three segments based on temporal pauses which served as the boundaries. The first segment consisted of two non-words (of eight phonemes), the second segment consisted of three non-words (of 11 phonemes) and the third segment consisted of two non-words (of nine phonemes). Between the first two segments there was a pause of 4 seconds (s) and between the second and third segments there was a pause of 2 s. The temporal durations of the first, second and third segments were 1 s, 3.1 s and 1.6 s, respectively. The overall duration of the target phrase was 11.7 s. The target phrase used for the purpose of training across all four practice groups is depicted in Figure 2. The study took place in a sound-treated laboratory in the Department of Communication Disorders. The procedures used for practising the speech task were similar across the four practice conditions, although the nature of practise varied. Participants were seated comfortably in a chair in front of a 19 inch computer screen.

Participants in each of the four practice groups were involved in a practice regime of 50 trials per day, for a two-day period to learn the target phrase.[1] The practice trials on each day began after a pre-practice session. During the pre-practice session, the participants were well motivated, and were provided with clear instructions on specific goals to be achieved during the practice regime. During the practice regime, the production of each trial by the participants was always preceded by the provision of orthographic and auditory representations of the target phrase. The orthographic representation of the target phrase was displayed on the computer screen along with the auditory representation. The auditory representation of the phrase was provided through loud-speakers using a pre-recorded adult male voice. To assist the participant in the practice regime, the speech phrase was presented

[1]An initial pilot study was conducted by engaging the participants in a practice regime of 100 trials each day during the two-day period. It was found that the participants found it difficult to practise 100 trials each day due to fatigue. Hence, it was determined that 50 practice trials were adequate to engage the participants in a practice regime.

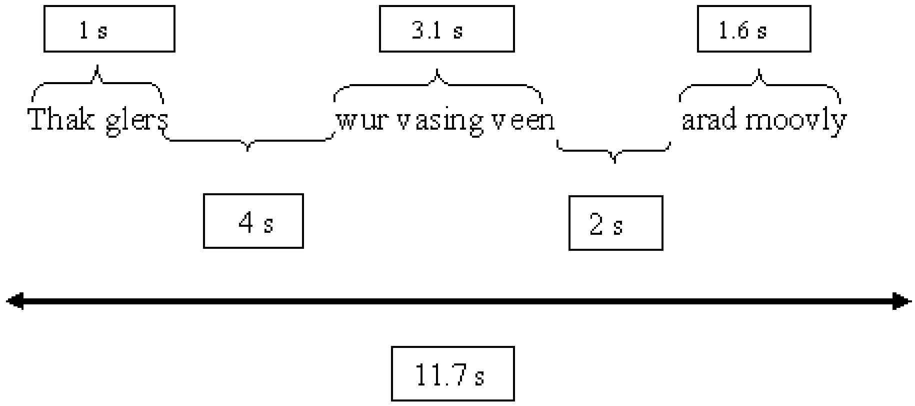


Figure 2. Target phrase used for training the participants in each practice condition. The target phrase consisted of 3 bi-syllabic and 4 monosyllabic non-words. In total, there were 28 phonemes. The temporal components of the phrase are shown.

via a Power Point format along with the orthographic and auditory representations displayed on the computer monitor. The initiation of the Power Point presentation enabled the participants to see and hear the orthographic and auditory representation of the speech phrase, respectively. The complete production following the provision of orthographic and auditory representations comprised one practice trial. Once the researcher judged a trial to be performed, he pressed the ‘return’ key on the computer keyboard which resulted in the initiation of the next practice trial. This was carried out until the completion of 50 trials on each day during the two-day period. Instances of false start allowed the participants to re-start the production of speech phrase during any particular practice trial. The general equipment layout for the speech task is shown in Figure 3.

The participants were instructed to match their production to the target phrase as accurately as possible. At the conclusion of every 10th trial, there was a break of approximate five minutes during which the researcher performed an acoustic analysis of the participant’s production of the 10th trial and provided feedback on their performance and accuracy of production. The researcher measured the overall duration of the phrase, as well as the individual duration of each segment and pause duration between the segments. In addition to this temporal analysis, the researcher also perceptually assessed the articulatory accuracy of the phonemes produced by the participants. The feedback was provided to the participants by displaying the target phrase on a sheet of A4 paper as shown in Figure 2. The researcher indicated whether the participant’s production matched the target phrase in terms of temporal and articulatory accuracy. When providing verbal feedback to the participant on each temporal feature (overall duration, segment duration and pause duration), the researcher used terms like “accurate”, “too long” and “too short” in reference to the orthographic rendition of the phrase. In terms of feedback on articulatory accuracy, the researcher perceptually analysed the participants’ productions and indicated whether the individual phonemes were articulated correctly in comparison to the target phrase. Thus, the nature of feedback provision was low-frequency and delayed, and also included information about KR and KP.

Participants were also informed if there were any instances of misarticulation. Across the two days there were a total of 100 trials, and each participant received 10 feedback trials of the target phrase. The participant utterances after each practice trial were audio-recorded using a desktop condenser microphone (DSE-PC). The output acoustic signal from the microphone was fed into a laptop computer (Lenovo ideapad S10e) running Audacity 1.3 (Beta version) acoustic analysis software program. The entire experiment took place over three consecutive days. The first two days served as the acquisition phase of speech-motor

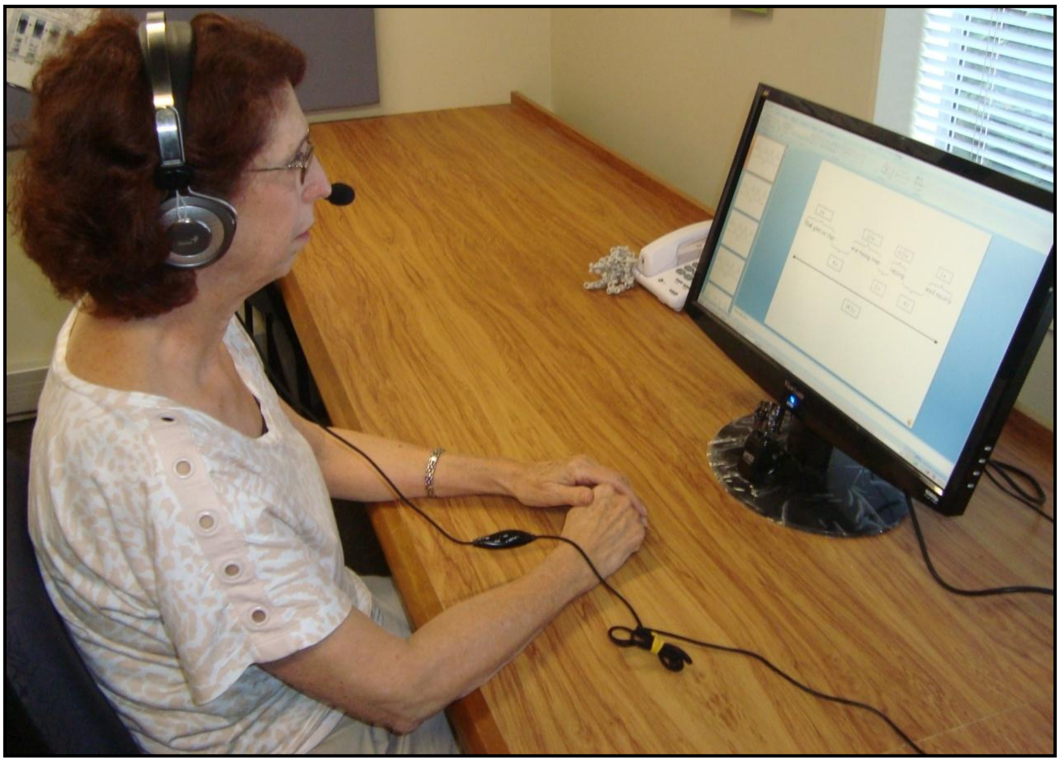


Figure 3. Experimental set up for the speech learning task. The computer monitor and the headphones are used for the purpose of visual and auditory representations of the speech phrase, respectively.

learning, during which the participants practised 50 trials of the target phrase each day. The acquisition phase lasted for 60-90 min on each of the first two days. On the third day, the participants returned to the laboratory and were seated in front of the computer screen. However, the participants were not provided with any sort of visual or auditory representations of the target phase and were required to produce 10 trials of the target phrase without any further practice or feedback. This formed the retention phase and lasted for 10-15 min. These trials were recorded and stored for later acoustic analyses.

Practice Design for constant practice group - Constant practice was defined as practice on only one variant of a movement (Mass et al., 2008). During the acquisition phase, the participants practised 50 trials of the target phrase in a repeated manner each day. After each ten trials, the participants were provided with feedback as described previously. This resulted in provision of five feedback trials to participants on each day of the acquisition phase. Participants returned to the lab on the third day for the retention phase. The participants were required to recall and produce the previously practised target phrase. The participants produced 10 trials of the target phrase and no feedback was provided during or after the retention trials. These trials were recorded for later acoustic analyses.

Practice Design for variable practice group - Variable practice was defined as practice on more than one variant of a given movement (e.g., practising a golf swing over varying distances from the hole). Variable practice consists of practising motor tasks which share the same motor plan but differ in parameter (Mass et al., 2008). In an attempt to include tasks of similar motor plan but of different parameters, an alternate phrase of different temporal duration was chosen. Participants practised 25 trials of the target phrase and 25 trials of an alternate phrase (50 trials in total) during each day of the acquisition phase. The alternate phrase used the same sequence of non-words; however, the phrase was modified temporally by changing the duration of the non-words and inter-segment pauses. The phrase was temporally modified by inserting a pause of 3 s between the first two segments and a pause of 5 s between the second and third segments. The durations of the first, second and third segments were 2 s, 2 s and 1.6 s, respectively. The overall duration of the target phrase was 13.6 s. The target and alternate phrase used by the participants undergoing variable practice is shown in Figure 4. The target and alternate phrases were randomized across 100 trials.

Feedback was provided after every 10 trials and the procedure of feedback provision was similar to constant practice. At the conclusion of 50 practice trials on the first day, there were three instances when the 10^{th} trial was the target phrase and another two instances when the

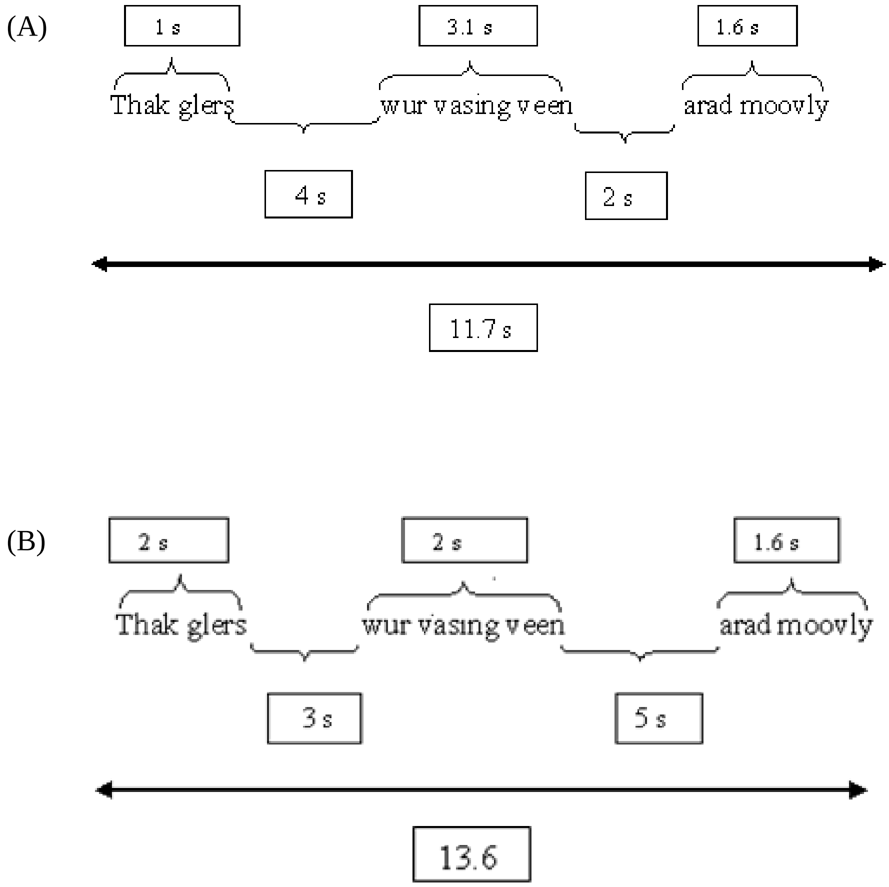


Figure 4. The target and alternate phrases used for the variable practice condition. The top panel (A) depicts the target phrase and the bottom panel (B) depicts the alternate phrase. The temporal components of both the phrases are also shown.

10th trial was the alternate phrase. Similarly, at the end of the 50 trials on the second day, there were three instances when the 10th trial was the alternate phrase and another two instances when the 10th trial was the target phrase. This arrangement resulted in each participant receiving five feedback trials of the target phrase and another five feedback trials of the alternate phrase during the acquisition phase. The order of the feedback trials for the target and alternate phrases was randomized and counterbalanced across both days of the acquisition phase and also across the participants to avoid order effect. Participants returned to the lab on the third day for the retention phase. Participants were required to recall and produce the previously practised target and alternate phrases. Participants produced 10 trials of the target phrase and 10 trials of the alternate phrase. Feedback was not provided during or after the retention trials. These trials were recorded and stored for later acoustic analyses. The recall order of the retention trials for the target and alternate phrases was counterbalanced across the 20 participants.

Practice Design for random practice group - Random practice was defined as a practice schedule in which different movements are produced on successive trials, and where the target for the upcoming trial is not predictable to the learner (Mass et al., 2008). All the participants assigned to this group practised 25 trials of the target phrase and 25 trials of a second alternate phrase during each day of the acquisition phase. The alternate phrase used for random practice was called the 'second alternate phrase' to distinguish this phrase from the alternate phrase used in the variable practice condition. The second alternate phrase was "*Ang haky deebs reciled tofently roovly*". The nature of random practice involves practising tasks of a different motor plan. In an attempt to change the motor plan, the second alternate phrase differed from the target phrase in terms of phonemic composition and temporal duration. The second alternate phrase consisted of six non-words and 29 phonemes, in total; of which two were monosyllabic, three were bisyllabic and one was trisyllabic. The whole phrase was split into three segments based on temporal pauses which served as the boundaries.

The first segment consisted of two non-words (of seven phonemes), the second segment consisted of three non-words (of 17 phonemes), and the third segment consisted of one non-word (of five phonemes). Between the first two segments there was a pause of 2 s and between the second and third segments there was a pause of 3 s. The temporal duration of the first, second and third segments were 1.95 s, 2.1 s and 0.57 s, respectively. The overall duration of the target phrase was 9.62 s. The target and second alternate phrases used for training participants is shown in Figure 5. An equal number of target and second alternate phrases were randomized across 100 trials. The manner of feedback provision was similar to the other practice conditions. The organization of the feedback trials was similar to the variable practice condition. At the end of the acquisition phase, there were five instances when the 10th trial was the target phrase and another five instances when the 10th trial was the second alternate phrase. This arrangement resulted in each participant receiving five feedback trials of the target phrase and another five feedback trials of the alternate phrase during the acquisition phase. The order of the feedback trials was randomized and counterbalanced across both days of the acquisition phase and also across the participants. The retention phase on the third day also followed a similar procedure as the variable practice condition. The recall order of the retention trials for the target and second alternate phrases was counterbalanced across all the 20 participants.

Practice Design for blocked practice group – Blocked practice was defined as a practice schedule in which the learner practises a group of the same target movements before beginning practice on the next target (Mass et al., 2008). The participants practised the target phrase and the second alternate phrase in blocks of 25 trials each. This resulted in participants practising the target phrase from trials 1 through 25, and the second alternate phrase was practised from trials 26 through 50, and vice-versa on the second day. Due to this arrangement of blocked practice, the feedback at the end of the 30th trial was based on the phrase which was practised from trials 25 through 30. For example, if the target phrase was practised from trials 26 through 30, then the feedback for the target phrase was provided at the end of the 30th trial, and this was reversed on the second day. The procedure of feedback provision was similar to the other practice conditions. This resulted in each participant receiving five feedback trials of the target phrase and five feedback trials of the second alternate phrase at the end of the acquisition phase. The order of the feedback trials for the target and second alternate phrases was randomized and counterbalanced across both days of the acquisition phase and also across the participants to avoid order effect. The retention phase on the third day followed a similar procedure as the random practice condition.

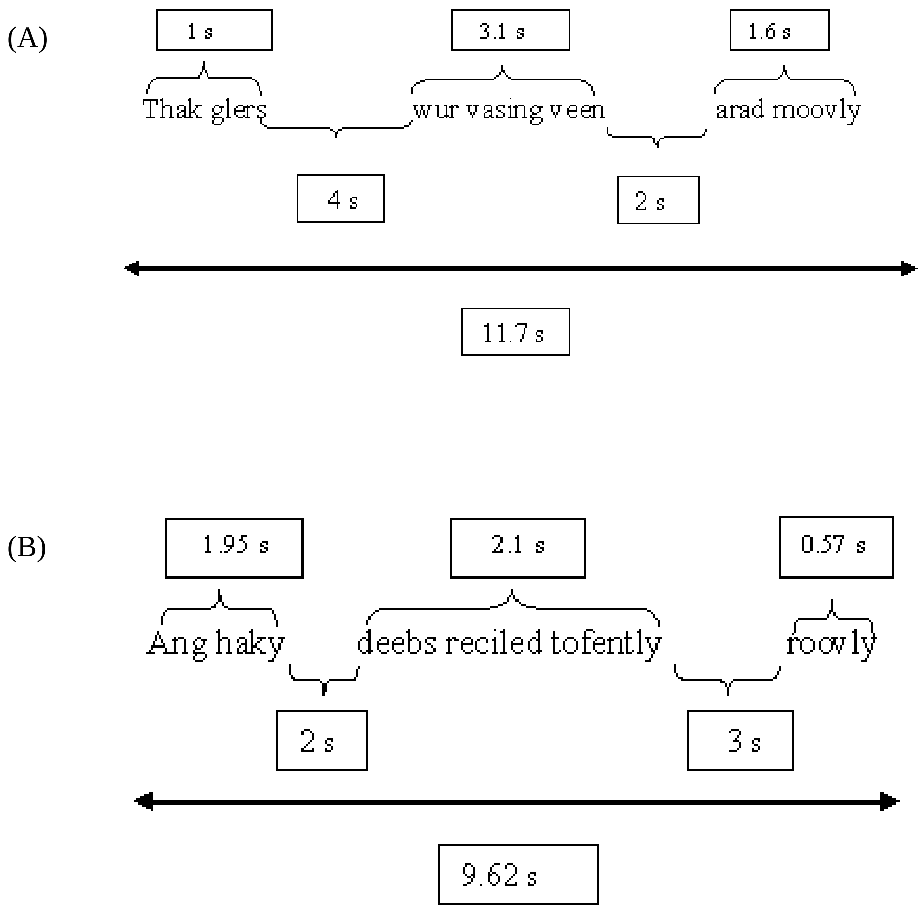
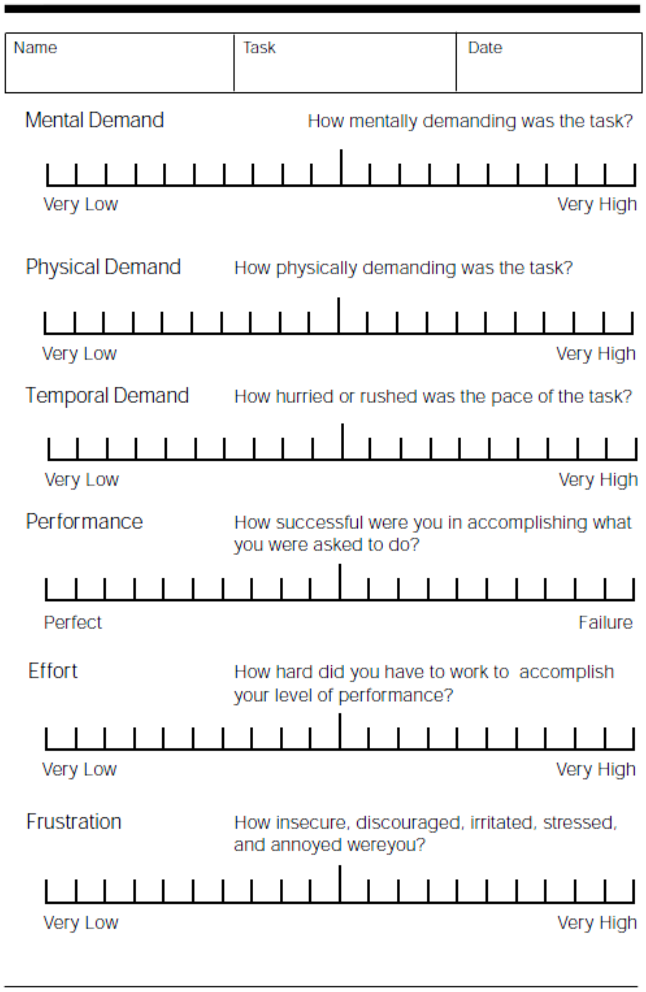


Figure 5. The target and second alternate phrases used for the random practice condition are shown. The top panel (A) depicts the target phrase and the bottom panel (B) depicts the second alternate phrase. The temporal components of both the phrases are also shown.

NASA Task Load Index - Following the retention phase on the third day, each of the 80 participants were required to complete the NASA Task Load Index (Hart & Staveland, 1988) to assess the complexity of the speech task. The NASA Task Load Index is a multi-dimensional rating scale used to assess the overall workload associated with a given performance situation. The index evaluates the workload in terms of six different subscales: mental demand, physical demand, temporal demand, own performance, effort, and frustration. Each subscale consists of 21 gradations with one extreme representing 'very low demand' and the other extreme representing 'very high demand'. The index provides an overall workload score based on an average of these six subscales. The participants were instructed to indicate their preference across each subscale by putting a check across the appropriate gradation. The ratings across these six subscales were averaged to obtain a mean perceived difficulty rating score. The index is shown in Figure 6.



Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Figure 6. NASA Task Load Index (Hart & Staveland, 1988) which assesses workload on six 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Non-speech Task

Each participant also completed a non-speech task and was assigned to the same practice groups as the speech task. The non-speech task involved training on a musical keyboard. The task required the participants to use the index finger of the (dominant) right hand to practise a musical tune (also called the target tune) comprised of a sequence of musical notes. The non-speech task occurred on the same days and session as the speech task. The sequence of practising the speech and non-speech tasks was counterbalanced across the participants to avoid any order effect. The target tune was "$FBG^{\#}A^{\#}$ $FG^{\#}AA^{\#}$ $FG^{\#}A^{\#}B$". Similar to the target (speech) phrase, the entire target tune was organized into three musical segments. Each segment consisted of three musical notes, with a total of 12 notes across the tune. The duration of the first, second and third segments were 1.75 s, 1.7 s and 1.8 s, respectively. There was a pause of 4 s between the first and second segments and a pause of 2 s between the second and third segments. The entire duration of the target tune was 11.29 s. For the purpose of visual representation, the musical notes in each segment were depicted by dots of increasing size on the keys. The size of the dots indicated the order of keys to be pressed on the keyboard (e.g., the smallest dot on the key would indicate the first key to be pressed, and so on). The target musical tune is illustrated in Figure 7.

Similar to the speech task, participants in each of the four practice conditions were required to undergo a practice regime of 50 trials during each day of the acquisition phase to learn the target tune. The practice trials on each day began after a pre-practice session. During the pre-practice session, the participants were instructed about the nature of the task and the expected outcomes during the practice regime. The non-speech task followed the same procedure as the speech task. The production of each trial by the participants was always preceded by the provision of visual and auditory representations of the target tune. The visual representation of the target tune was displayed on a computer monitor along with an auditory representation of the tune. A pre-recorded target musical tune delivered through loud-speakers served as the auditory representation.

The 50 practice trials during each day of the practice regime were visually presented to each participant on a Power Point format along with an auditory representation of the target tune. The complete production of the keyboard tune after the provision of visual and auditory representations comprised one practice trial. Once the researcher judged a trial to be performed, he pressed the 'return' key on the computer keyboard which resulted in the initiation of the next practice trial. This was carried out until the completion of 50 trials on each day during the two-day period. If a participant was observed to exhibit a false start,

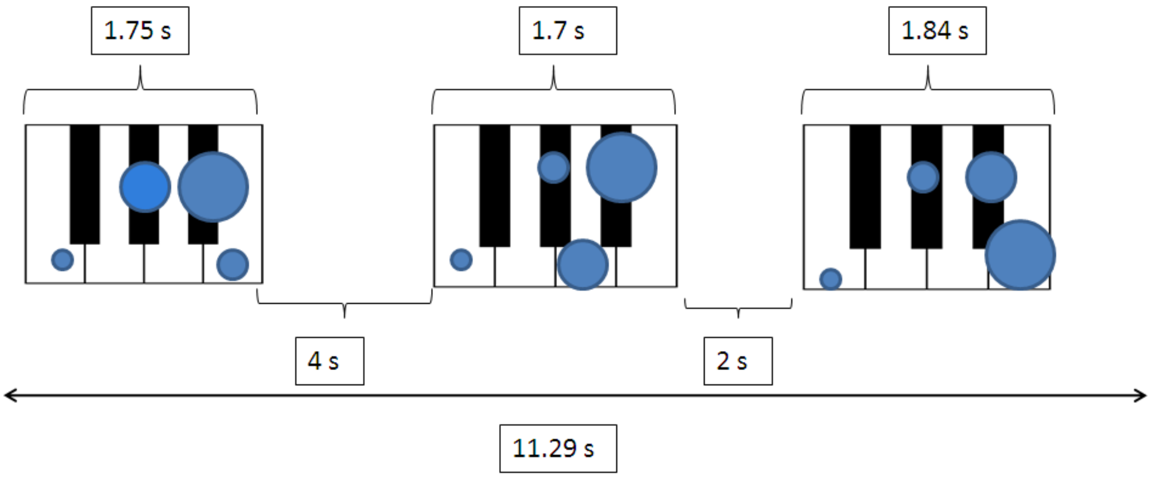


Figure 7. Target musical tune used for training the participants in each practice condition. The size of the dots indicates the playing order of the musical notes in each segment. The smallest dot on the key indicates the first key to be pressed, and so on. The temporal components of the tune are also shown.

he/she was allowed to re-play the musical tune during any particular practice trial. Keyboard entry productions after every practice trial were audio-recorded in a manner similar to the speech task. At the conclusion of every 10 practice trials, the participants received an approximate five minutes break during which they received feedback which was low-frequency and delayed in nature, and also included information about KR and KP. The feedback on temporal accuracy was similar to the speech task. Feedback on production accuracy involved the researcher perceptually analyzing the keyboard entry productions and informing the participants of any incorrect keyboard entry productions. The acquisition phase lasted for 60-90 min on each of the first two days and the retention phase lasted for 10-15 min. The retention phase was identical to the speech task. The experimental setup for the keyboard task is shown in Figure 8.

Practice design for constant practice group - During each day of the acquisition phase, the participants practised 50 trials of the target tune in a repeated manner. The nature and provision of feedback was provided in a manner similar to the constant practice condition in the speech task. Participants returned to the lab for the retention phase and were required to recall and reproduce 10 trials of the target tune without further practice or feedback. These trials were recorded for later acoustic analyses.

Practice design for variable practice group - The participants practised 25 trials of the target tune and 25 trials of an alternate tune during each day of the acquisition phase. An alternate tune of different duration was chosen in an attempt to practise tasks of similar motor plan but of different parameters. The alternate tune used for variable practice consisted of the same number and sequence of musical notes in each segment as the target tune, but differed in duration. The durations of the first, second and third segments were 1.75 s, 1.7 s and 1.84 s, respectively. There was a pause of 3 s between the first and second segments and a pause of 5 s between the second and third segments. The entire duration of the target tune was 13.29 s. The target and alternate tunes were randomized across 100 trials. The target and alternate tunes used for training participants is shown in Figure 9. Randomization of the feedback trials and the procedure for feedback provision was similar to the variable practice condition in the speech task. During the retention phase, participants produced 10 trials of the target tune followed by another 10 trials of the alternate tune. These trials were recorded and stored for later acoustic analyses. The recall order of the retention trials for the target and alternate tunes were counterbalanced across the 20 participants.

Figure 8. Experimental set-up for the keyboard task. The computer monitor and the headphones are used for the purpose of visual and auditory representations of the musical tune, respectively.

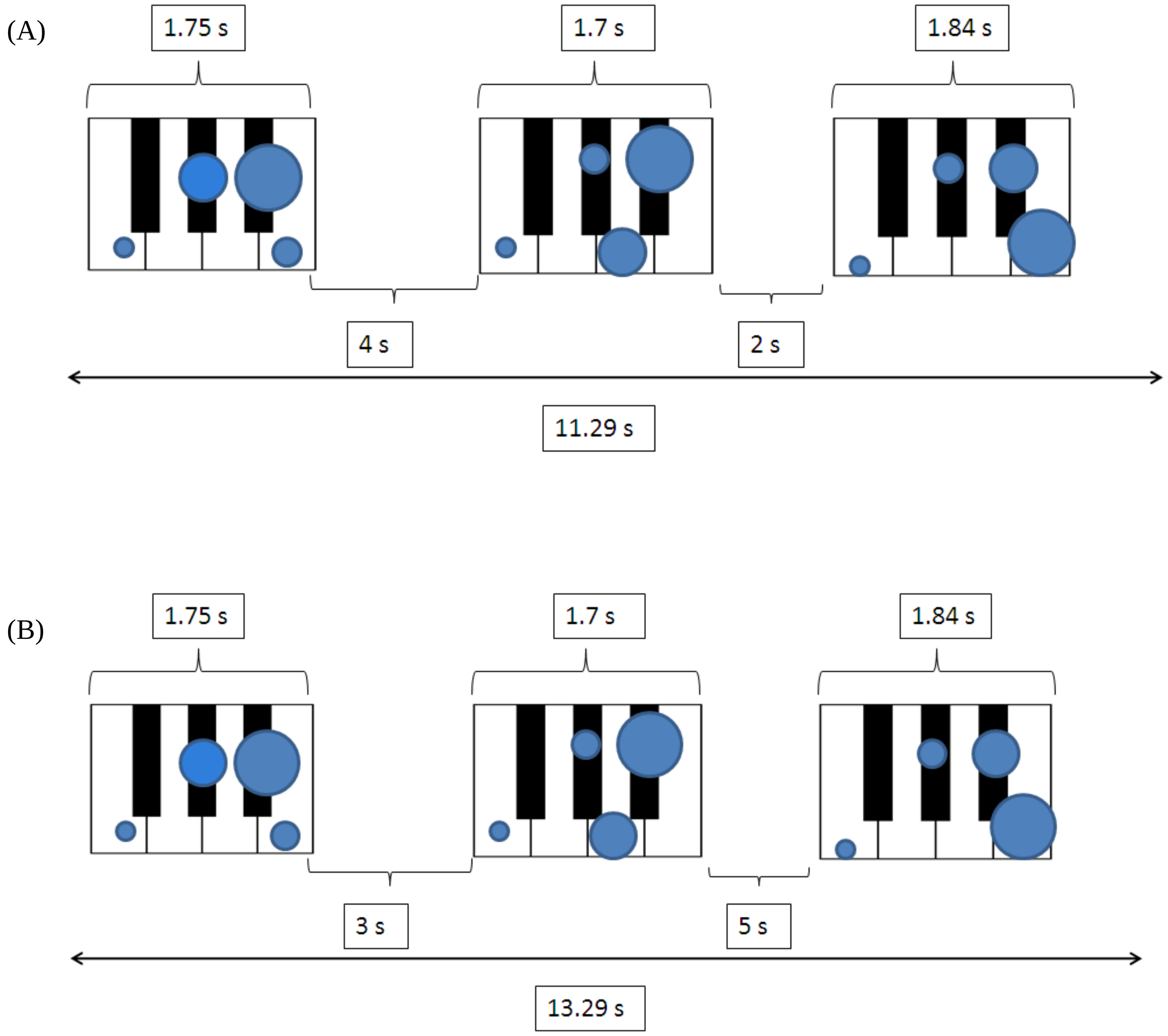


Figure 9. The target and alternate tunes used for the variable practice condition. The top panel (A) depicts the target tune and the bottom panel (B) depicts the alternate tune. Both tunes consist of same sequence of four musical notes in each segment. The size of the dots indicates the playing order of the musical notes in each segment. The smallest dot on the key indicates the first key to be pressed, and so on. The temporal components of both the tunes are also shown.

Practice Design for random practice group - Participants practised 25 trials of the target tune and 25 trials of a second alternate tune during each day of the acquisition phase. To distinguish the alternate tune used in the variable practice condition, the alternate tune in the random practice condition was called the ‘second alternate tune’. The second alternate tune was “$FA^{\#}G^{\#}G$ $A^{\#}G^{\#}FF^{\#}$ $GAFA^{\#}$”. The second alternate tune differed from the target tune in terms of musical notes and temporal duration. The alternate tune consisted of three segments separated by pauses. Each segment in turn consisted of a sequence of four musical notes. Between the first two segments there was a pause of 2 s and between the second and third segments there was a pause of 3 s. The durations of the first, second and third segments were 1.87 s, 2.17 s and 2.05 s, respectively. The overall duration of the second alternate tune was 11.09 s. The target and second alternate tunes used for training participants is shown in Figure 10. An equal number of target and alternate phrases were randomized across 100 trials. Feedback was provided in a manner similar to the random practice condition in the speech task. The retention phase on the third day also followed the same procedure as the speech task.

Practice design for blocked practice group - Participants practised the target tune in a block of 25 trials followed by a block of 25 trials comprising the second alternate tune (used for the random practice condition) or vice versa during each day of the each day of the acquisition phase. The order of blocked practice was counterbalanced across 20 participants to avoid an order effect. The feedback provision was of the same nature as the blocked practice condition in the speech task. The retention phase on the third day also followed a similar procedure as the blocked practice condition in the speech task.

NASA Task Load Index - Similar to the speech task, each participant was required to complete the NASA task load index following the retention phase to assess the complexity of the non-speech task.

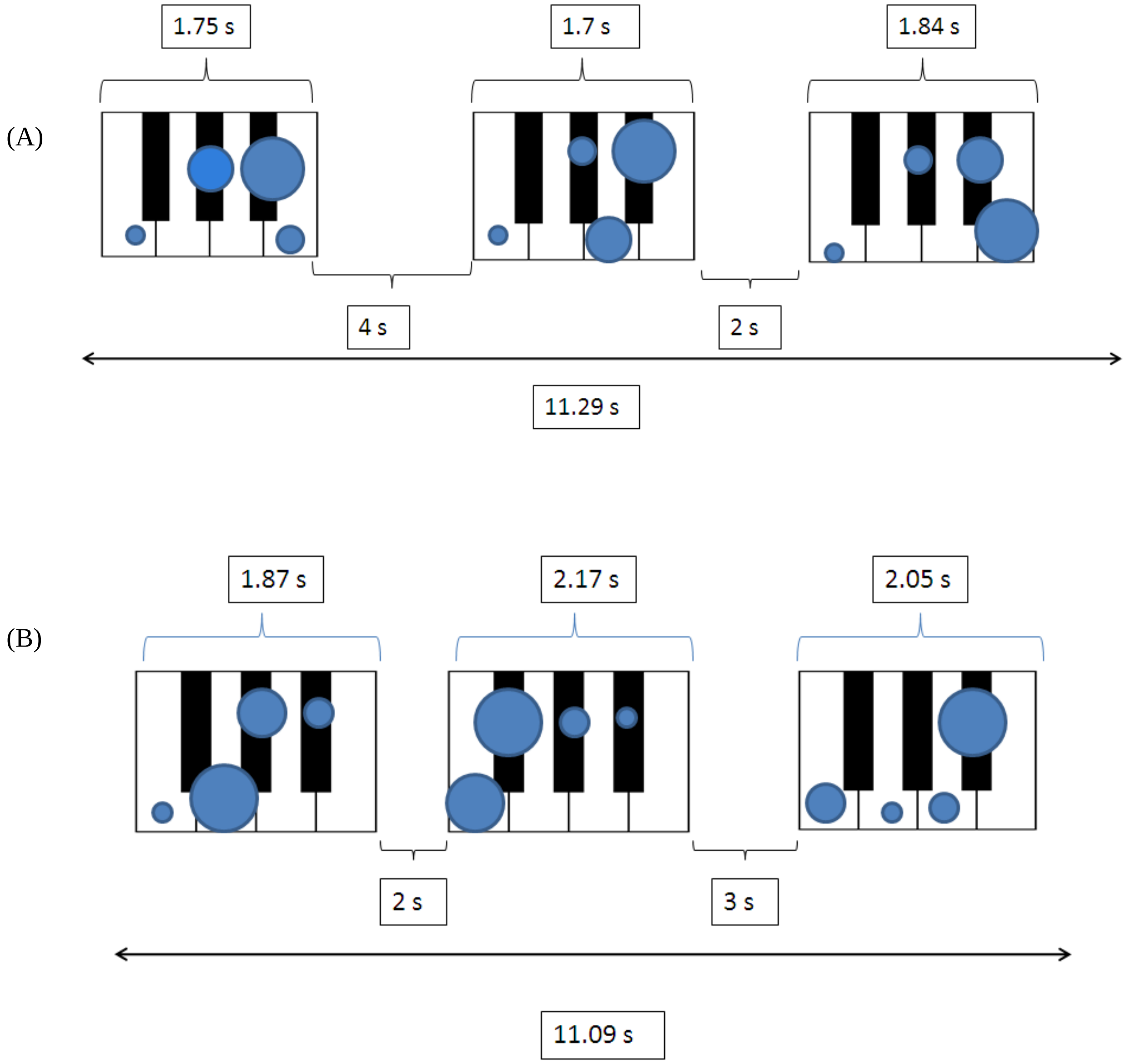


Figure 10. The target and second alternate tunes used for the random practice condition. The top panel (A) depicts the target tune and the bottom panel (B) depicts the second alternate tune. The second alternate tune differs from the target tune in terms of the musical notes and temporal duration. The size of the dots indicates the playing order of the musical notes in each segment. The smallest dot on the key indicates the first key to be pressed, and so on. The temporal components of both the tunes are also shown.

Experiment II: Clinical group

Experiment II involved a clinical group of 16 participants with PD. The experiment procedures were identical to Experiment I. The 16 participants were randomly and equally assigned to the four practice conditions, resulting in four participants in each practice group. The speech and non-speech tasks were carried out in the same fashion as Experiment I. The speech and non-speech tasks occurred on the same days and the order of the learning tasks was counterbalanced across the 16 participants to avoid any order effect. The experiment took place over three consecutive days. The first two days of the experiment served as the acquisition phase and the third day was the retention phase.

Data Analyses

The final five trials of the 10 trials obtained from each participant for the speech and non-speech tasks during the retention phase were analysed. The reason for including only the final five retention trials for data analysis was that of all the ten trials produced by the participants during the retention phase, the last five trials represented better production accuracy in comparison to the first five trials as judged by the researcher. Also, this method of including the final five trials of the participant productions for data analysis has been previously reported in a study (Adams & Page, 2000). The data were analysed according to (1) spatial and (2) temporal features of production accuracy. The data analysis procedures were similar for clinical and non-clinical groups.

Spatial analysis

Speech task - Spatial analysis of the speech task involved evaluating the production accuracy of the target speech phrase by calculating the Percentage of Phonemes Correct (PPC) (Dollaghan & Campbell, 1998). The production accuracy of the alternate and second alternate phrases was not evaluated as the focus of the study was on the learning outcome of the target phrase alone. The PPC is calculated by dividing the number of correct phonemes produced by the total number of phonemes produced and multiplying by 100. The mean PPC obtained from the final five retention trials was calculated for each participant. The individual mean values were then averaged across the 20 participants in each practice group to obtain a grand mean PPC.

Keyboard task - Spatial analysis of the keyboard learning task was based on the calculation of Percentage of Keystrokes Correct (PKC). The PKC was devised in a manner similar to PPC to evaluate the production accuracy of the target tune during the retention trials. The PKC is calculated by dividing the number of correct keystrokes produced by the total number of keystrokes produced and multiplying by 100. The final five retention trials for each participant were used in the calculation of a mean PKC for each participant. The individual mean values were then averaged across the 20 participants in each practice group to obtain a grand mean PPC.

Temporal analysis

Temporal analysis focused on calculating the temporal synchrony of the participant productions during the retention trials of the speech phrase and keyboard tune in comparison to the original examples of the target phrase and tune, respectively. The final five trials of the target phrase/tune produced by each participant during the retention phase were submitted to acoustic analysis. The acoustic analysis was carried out using Audacity 1.3 (Beta version). The participant productions during the retention trials, as well as the original examples of the target phrase and tune were digitized at a 44 kHz sampling rate and simultaneously displayed one below the other on a computer monitor as amplitude-by-time waveforms. To determine the synchrony between the participants' production of the target phrase/tune in comparison to the original examples of the target phrase/tune, the participants' productions of the target phrase/tune were acoustically aligned to the original phrase/tune. The alignment of the participant productions and the original example of the target phrase/tune occurred at the onset point of the acoustic waveform. The participant productions and the original target waveform shared the same onset point. The offset point was based on offset of the original target waveform. So if the participant's production was longer than the target waveform, then the part of the waveform that exceeded the offset point was excluded from the analysis. Once the waveform of participants' production and the original target waveform were aligned according to the onset and offset points of the original target phrase/tune, a pair of vertical cursors was placed at the onset and offset points. The part of the two waveforms between the vertical cursors was converted to binary values. The process of converting the waveforms to binary plots was carried out through a Matlab based program. The steps involved in converting the acoustic waveforms to binary variables were as follows:

a. The waveforms of the target phrase and tune as well as the waveforms of the participant productions during the retention trials were digitized at a sampling rate of 44 KHz. This yielded 514800 samples and 496760 samples for the target phrase and tune, respectively. The number of samples for the participant productions ranged from 264,000 to 500,000.

b. The next step involved rectifying and smoothing the target waveforms and that of the waveform of the participant productions.
c. Following the rectification and smoothing, a threshold was set at 10% of the whole waveform's amplitude (i.e. for the entire utterance/keyboard tune) to arrive at the binary values. The portion of the waveform that was above the threshold was converted to 1's and part of the waveform below the threshold value was converted to 0's. The amplitude of the extraneous noises (like heavy breathing) was revealed to exceed the 10% of the waveform's amplitude, so setting a cut-off threshold of 10% limited the inclusion of the extraneous noises in the signal.
d. The binary values yielded a plot for the original target phrase/tune and participant's production. These binary values were used to calculate the phi correlation between the participant productions and the target phrase/tune. The steps (a-d) involved in converting an acoustic waveform of a keyboard entry production to a binary plot is depicted in Figure 11.

A phi correlation was used to assess temporal relation (synchrony) between the two signals. The phi correlation is a measure of the degree of association between two binary variables (Field, 2010). A phi correlation was obtained from each of the final five responses and these values were averaged to obtain a mean phi correlation for each participant. A grand mean phi correlation value was calculated for the 20 participants in each of the four practice conditions. The temporal synchrony between the waveform of a keyboard production during the retention trial and the waveform of the target tune is illustrated in Figure 12.

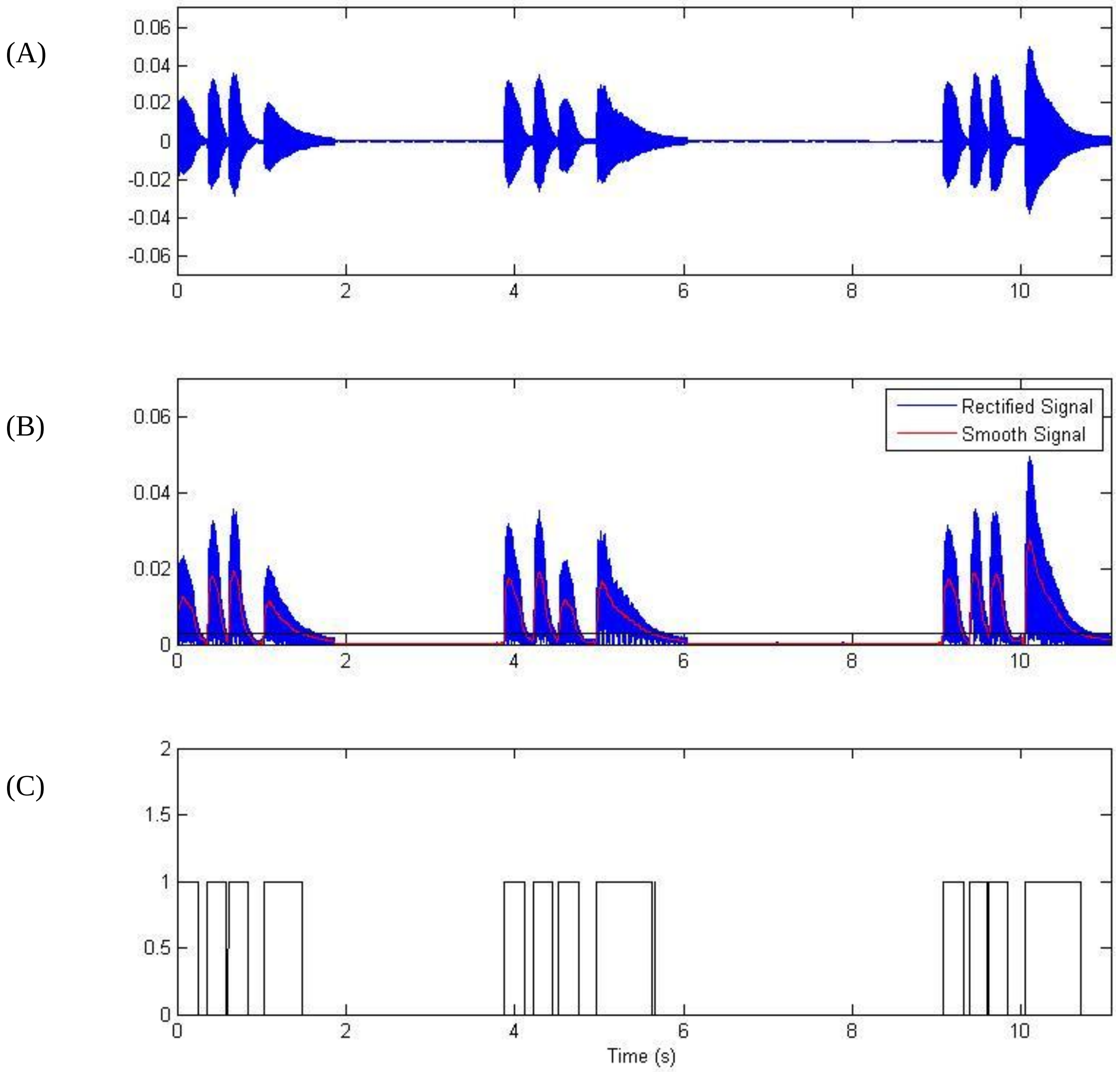


Figure 11. Conversion of acoustic waveform to binary variables for calculation of phi correlation. The top panel (A) depicts the raw acoustic waveform of a keyboard entry production. The middle panel (B) depicts the waveform after being subjected to rectification, low-pass filtering, and smoothing. The horizontal black line denotes the threshold set at 10% of the waveform's amplitude. The bottom panel (C) shows the binary plot used to calculate the phi correlation.

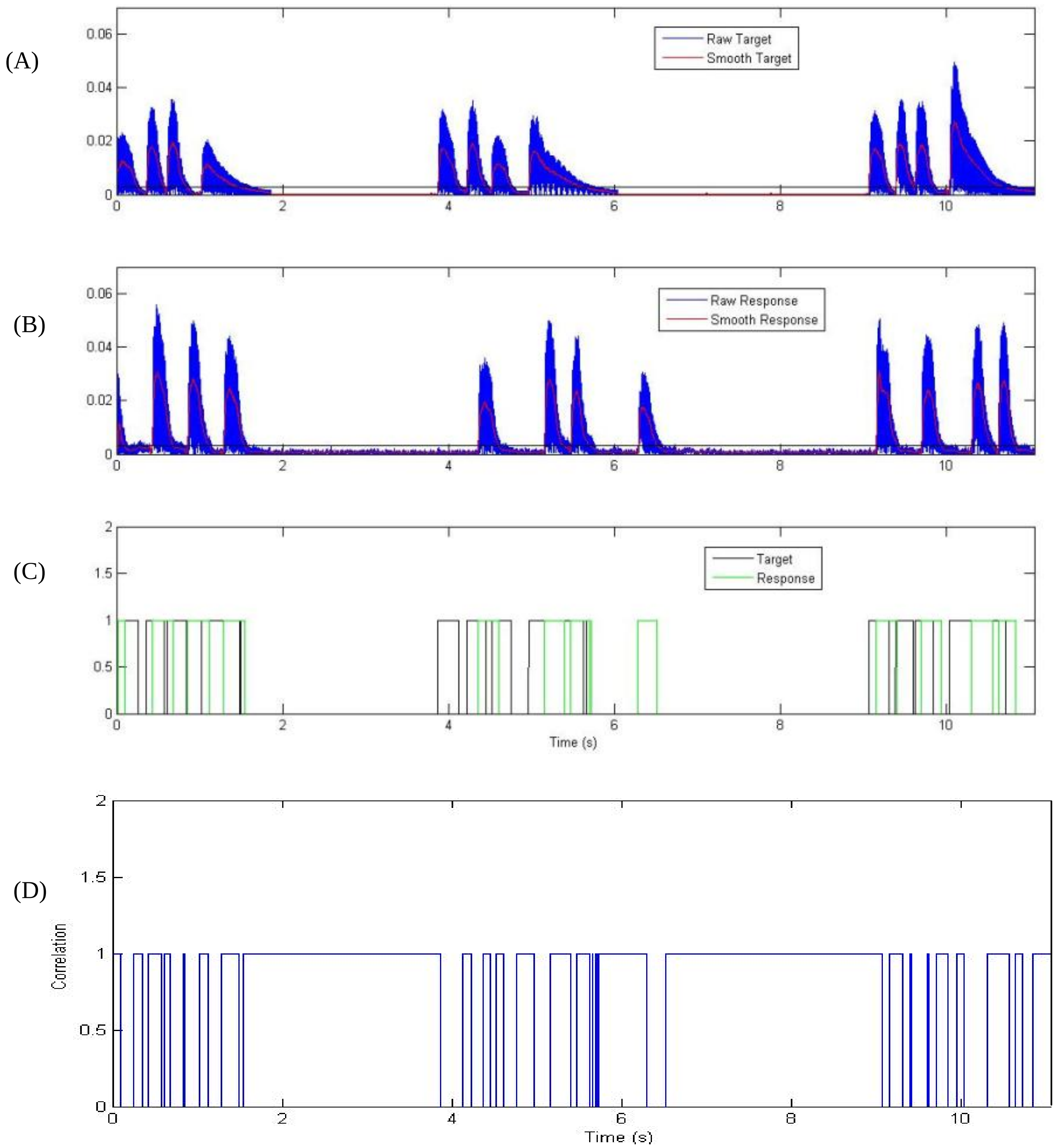


Figure 12. An illustration of temporal synchrony between the waveform of a keyboard production during the retention trial and the waveform of the target tune. Panel (A) depicts the waveform of the target musical tune after rectification and low-pass filtering, the red trace indicates the smoothed version of the waveform, and the black horizontal line depicts the 10% threshold. Panel (B) depicts the waveform of the keyboard entry production after rectification and low-pass filtering, the red trace indicates the smoothed version of the waveform, and the black horizontal line depicts the 10% threshold. Panel (C) depicts the binary plots of the waveforms of the target tune and the keyboard entry production during the retention trial. Panel (D) depicts the binary plots of the temporal match between the two waveforms. This binary plot yielded a phi correlation of 0.48.

Statistical analyses

Four different analyses were carried out. The first set of analysis compared the spatial and temporal learning among the practice conditions for speech and keyboard tasks. For the spatial analysis, the mean PPC and PKC scores obtained during the retention phase trials across all the participants were subjected to a series of two-way mixed model ANOVAs (2 practice tasks X 4 practice conditions). The between group factor was the practice condition (constant, variable, random, & blocked practice conditions) and the within-group factor was the practice task (speech & keyboard tasks). Similarly for the temporal analysis, the mean phi correlation values for the speech and keyboard learning tasks obtained during the retention phase trials across the participant groups were subjected to a series of two-way mixed model ANOVAs.

The second analysis compared the effect of older and younger age groups on speech and keyboard tasks with regard to spatial and temporal learning. A median split was performed to split the participants into younger and older age groups. The spatial analysis involved subjecting the mean PPC/PKC of the older and younger age groups to a two-way ANOVA (2 age groups X 4 practice conditions). Similarly, the temporal analysis involved subjecting the mean phi correlation values of the younger and older age groups to a two-way ANOVA (2 age groups X 4 practice conditions).

The third analysis compared the clinical and non-clinical groups on speech and keyboard learning tasks by subjecting the PPC/PKC and phi correlation values to a two-way ANOVA (2 groups X 4 practice conditions). The fourth and final analysis compared the perceived difficulty among the practice conditions in speech and keyboard learning tasks by subjecting the mean NASA task load index scores of the younger and older age groups to a two way ANOVA. In addition, to compare the perceived difficulty of speech vs. keyboard learning tasks, the index scores across all the four practice conditions were collapsed and were compared using a paired sample t- test.

The ANOVA tests yielded a F value, p value, and a partial eta squared value to calculate the effect size. Partial eta squared is the ratio of variance accounted by an effect and that effect plus its associated error variance within an ANOVA study (Brown, 2008). The guidelines recommended by Barnette (2006) were used to relate the partial eta squared values to effect size. One percent of the variance accounted by the predictor variable relates to small effect size (0.2), a variance of 6% accounted by the predictor variable relates to medium effect size (0.5), and a variance of 14% accounted by the predictor variable relates to large effect size (0.8).

Measurement reliability

Intra-rater reliability was judged for the spatial and temporal analyses. Specifically, for the spatial analysis, the mean PPC and PKC values during the retention phase were re-analysed, and for the temporal analysis, mean phi correlation values during the retention phase were re-analysed. The measurement reliability was performed for the non-clinical as well as clinical groups by randomly choosing 20% of the data (i.e., 16 of 80 participants in the non-clinical group, and 4 of 16 participants in the clinical group).

The Pearson Product Moment Correlation was used to calculate the intra-judge reliability. For the non-clinical and clinical groups, the intra-rater reliability of the spatial analysis ranged from $r = 0.91$ to $r = 0.99$. The intra-rater reliability of the temporal analysis ranged from $r = 0.99$ to $r = 1.00$ for the non-clinical and clinical groups. All the correlations were significant ($p < 0.05$). The correlation values for spatial and temporal across the clinical and non-clinical are presented in Table 6.

Table 6. Pearson Product Moment Correlation values depicting the intra-judge measurement reliability for the spatial and temporal analysis across non-clinical and clinical groups.

Measure	Pearson Product Moment Correlation values*
Spatial analysis	
Non-clinical group	
PPC	0.95
PKC	0.97
Clinical group	
PPC	0.95
PKC	0.99
Temporal analysis	
Non-clinical group	
PPC	0.99
PKC	1.00
Clinical group	
PPC	1.00
PKC	1.00

*All the correlation values were significant ($p < 0.05$)

Chapter 4. Results

The results are presented in four sections. The first section reports the results of spatial analysis for the non-clinical and clinical groups. The second section reports the results of the temporal analysis for the non-clinical and clinical groups. The third section deals with the effect of age on spatial and temporal learning of speech and keyboard learning tasks in the non-clinical group. The fourth and final section reports the results of the NASA task load index.

Spatial learning

Non-clinical group - The results of the spatial analysis for speech and non-speech (keyboard) learning tasks are shown in Table 7. The speech and keyboard tasks are indicated in terms of PPC and PKC, respectively. The mean PPC values ranged from 77.5% to 91.6% across the four practice conditions. The mean PKC values ranged from 59.3% to 96.1% across the four practice conditions. To evaluate the participant performance on the speech and keyboard tasks across the four practice conditions, a two-way mixed model analysis of variance (ANOVA) (2 practice tasks X 4 practice conditions) was performed. The between group factor was the practice condition (constant, variable, random, & blocked practice conditions) and the within-group factor was the practice task (speech & keyboard tasks). Results revealed that there was a significant main effect for practice condition, F (3, 76) = 11.52, $p = 0.004$, $\eta_p^2 = 0.313$. Post hoc analysis using Tukey HSD criterion revealed that the constant practice condition was significantly better than the random ($p = 0.007$) and blocked practice conditions ($p < 0.001$). The variable practice condition was also significantly better than random ($p = 0.034$) and blocked practice conditions ($p < 0.001$). There was a significant main effect for the practice task with the speech task showing better performance than the keyboard task, $F(1, 76) = 8.632$, $p = 0.004$, $\eta_p^2 = 0.102$. There was a significant interaction between the practice conditions and the practice tasks, $F(3, 76) = 9.70$, $p < 0.001$, $\eta_p^2 = 0.277$. Follow-up post hoc tests for the interaction effect revealed that in the speech task, constant practice condition was better than the blocked practice condition ($p = 0.049$), and random practice condition revealed a marginal significance over blocked practice conditions ($p = 0.06$). In the keyboard task, constant practice condition was better than random ($p < 0.001$) and blocked practice conditions ($p < 0.001$), variable practice condition was also better than random ($p < 0.001$) and blocked practice conditions ($p < 0.001$). The PPC and PKC values for speech and keyboard tasks, respectively across the four practice conditions are depicted in Figure 13.

Table 7. PPC and PKC values (%) of the participants in the non-clinical group for the speech and non-speech learning tasks. 20 participants were assigned to each practice condition. Mean (M) and standard deviation values (SD) are shown at the bottom of the table.

Participants (N = 80)	**Constant** (N = 20)		**Variable** (N = 20)		**Random** (N = 20)		**Blocked** (N = 20)	
	Speech (PPC)	Keyboard (PKC)	Speech (PPC)	Keyboard (PKC)	Speech (PPC)	Keyboard (PKC)	Speech (PPC)	Keyboard (PKC)
1	93	100	96	100	100	100	100	100
2	79	100	100	100	100	100	82	28.4
3	93	100	100	100	69.48	2.4	93	43.2
4	96	100	91.4	100	82	100	69	38.4
5	83	100	100	100	69	25.8	95.4	100
6	90	100	96.4	100	86	82.6	29	75
7	100	92	69.4	42	85.2	100	61	26.6
8	93	100	100	100	100	29.8	30	46.8
9	100	96.6	93	100	96	73.4	100	54.4
10	100	100	86	100	93	100	100	66.6
11	80.6	100	89	100	75	71.6	100	100
12	96	100	64	100	100	34.2	68	25
13	93	100	96	100	93	14.2	86	42
14	54	100	89	100	100	100	55	34.6
15	100	100	88.8	80	89	100	100	100
16	89.4	100	79	100	100	38.2	96	100
17	100	56.8	42.2	100	89	35.4	33.2	44.8
18	100	100	99.4	83.2	100	58	100	46.4
19	100	100	82	100	99.2	46.8	61	69.2
20	93	78.4	75	100	97	53	93	45.2
M	91.6	96.1	86.8	95.2	91.1	63.2	77.5	59.3
SD	11	10.5	14.9	13.7	10.4	33.4	25.1	27.3

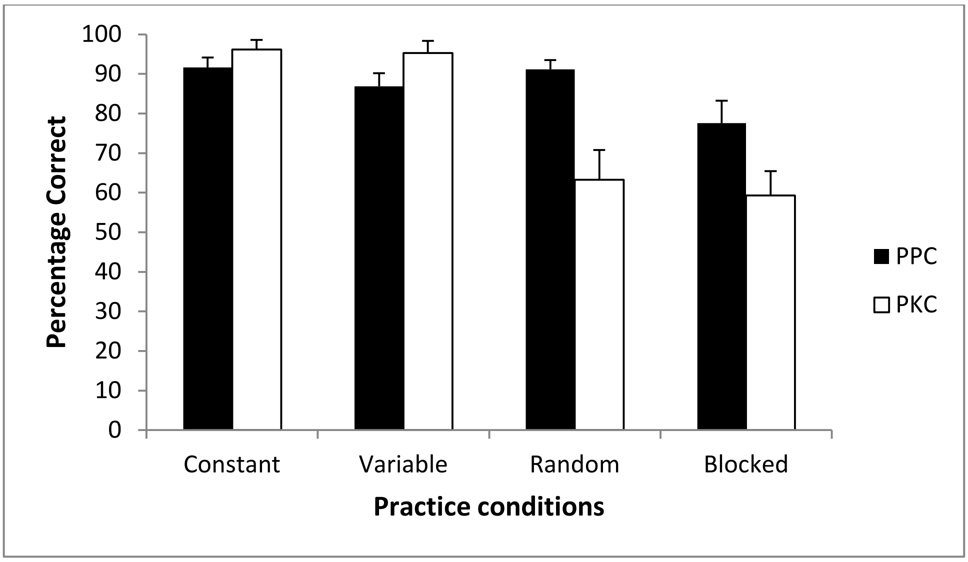


Figure 13. Percentage of Phoneme Correct (PPC) and Percentage of Keystrokes Correct (PKC) values for speech and keyboard tasks across four practice conditions in the non-clinical group. Error bars show 95% confidence interval.

Clinical group - The results of the spatial analysis for speech and non-speech-motor learning tasks for the clinical group are shown in Table 8. The mean PPC values ranged from 72.5% to 78.1% across the four practice conditions. The mean PKC values ranged from 49.55% to 82.2% across the four practice conditions. The PPC and PKC values were subjected to a two-way mixed model ANOVA (2 practice tasks X 4 practice conditions) to determine the participant performance on the speech and keyboard tasks across the four practice conditions. Results revealed that there was no main effect for the practice condition, $F(3, 12) = 1.325$, $p = 0.312$, $\eta_p^2 = 0.249$. There was no main effect for the practice task, $F(1, 12) = 1.759$, $p = 0.209$, $\eta_p^2 = 0.128$. There was also no interaction effect, $F(3, 12) = 1.297$, $p = 0.320$, $\eta_p^2 = 0.245$.

Non-clinical vs. clinical

Speech task - The mean PPC values for the non-clinical and clinical groups are shown in Table 9. The mean PPC across the four practice conditions was higher in the non-clinical group in comparison to the clinical group. In the non-clinical group, the mean PPC was highest for the constant practice condition (91.6%) and lowest for the blocked practice condition (77.6%). In the clinical group, the mean PPC was highest for the constant practice condition (78.1%) and lowest for the variable practice condition (72.5%). To determine the effect of group (non-clinical vs. clinical) on performance of the speech task, the PPC values across the four practice conditions were subjected to a two-way ANOVA (2 groups X 4 practice conditions). There was a main effect for group, $F(1, 48) = 5.658$, $p = 0.02$, $\eta_p^2 = 0.06$. There was no main effect for the practice condition, $F(3, 48) = 0.502$, $p = 0.682$, $\eta_p^2 = 0.017$, and there was no significant interaction between the group and the practice condition, $F(3, 48) = 0.641$, $p = 0.682$, $\eta_p^2 = 0.021$.

Keyboard task - The mean PKC for the non-clinical and clinical groups are shown in Table 9. The mean PKC across all the four practice conditions was higher in the non-clinical group in comparison to the clinical group. In the non-clinical group, the mean PKC was highest for the constant practice condition (96.1%) and lowest for the blocked practice condition (59.3%). The mean PKC for the clinical group was highest for the constant practice condition (82.2%) and lowest for the blocked practice condition (49.5%).The PKC values across the four practice conditions were subjected to a two-way ANOVA (2 groups X 4 practice conditions) to determine the effect of group on spatial learning of the keyboard task. There was a main effect for group, $F(1, 48) = 3.925$, $p = 0.049$, $\eta_p^2 = 0.043$. There was also a

Table 8. PPC and PKC values (%) of the participants in the clinical group for the speech and keyboard tasks across four practice conditions. Four participants were assigned to each practice condition. Mean (M) and standard deviation (SD) values are shown at the bottom of the table.

Participants (N = 16)	**Constant** (N = 4)		**Variable** (N = 4)		**Random** (N = 4)		**Blocked** (N = 4)	
	Speech (PPC)	Keyboard (PKC)	Speech (PPC)	Keyboard (PKC)	Speech (PPC)	Keyboard (PKC)	Speech (PPC)	Keyboard (PKC)
1	40.2	72.2	71	81.6	52.8	46.8	83.6	55
2	92.2	100	75.2	68	60.6	96.6	100	44.8
3	96	56.6	83	100	90	36.8	62.4	25
4	84.2	100	61	61.6	96	36.8	64.2	73.4
M	78.1	82.2	72.5	77.8	74.8	54.2	77.5	49.5
SD	25.7	21.5	9.1	17	21.3	28.6	17.7	20.2

Table 9. Mean PPC and PKC values (%) for non-clinical and clinical groups. The standard deviation values are indicated in parentheses.

Groups	**Constant**		**Variable**		**Random**		**Blocked**	
	Speech (PPC)	Keyboard (PKC)	Speech (PPC)	Keyboard (PKC)	Speech (PPC)	Keyboard (PKC)	Speech (PPC)	Keyboard (PKC)
Non-Clinical	91.6 (11)	96.1 (10.5)	86.8 (14.9)	95.2 (13.7)	91.1 (10.4)	63.2 (33.4)	77.5 (25.1)	59.3 (27.3)
Clinical	78.1 (25.7)	82.2 (21.5)	72.5 (9.1)	77.8 (17)	74.8 (21.3)	54.2 (28.6)	77.55 (17.8)	49.5 (20.2)

main effect for practice condition, $F(3, 48) = 8.210$, $p < 0.001$, $\eta_p^2 = 0.219$. Post hoc analysis using Tukey HSD criterion revealed that the constant practice condition was better than the random ($p < 0.001$) and blocked practice conditions ($p < 0.001$). The variable practice condition was also better than random ($p < 0.001$) and blocked practice conditions ($p < 0.001$). There was no significant interaction between the group and the practice condition, $F(3, 48) = 0.343$, $p = 0.794$, $\eta_p^2 = 0.021$.

Summary of key findings for the spatial learning

Non-clinical group

- The retention performance on the speech task was better than on the keyboard task.
- The retention performance of the participants in different practice conditions was influenced by the type of task practised (i.e. there was an interaction between practice task and practice conditions).
- In the speech task, constant practice condition was better than blocked practice condition. In the keyboard task, constant and variable practice conditions were better than random and blocked practice conditions.

Clinical group

- There was no difference in retention performance between the speech and keyboard tasks, or between the four practice conditions, and the retention performance of the participants in different practice conditions was not influenced by the practice task (i.e. no interaction effect).

Non-clinical vs. clinical group

- For the speech task, the retention performance of the non-clinical group was better than the clinical group, there was no difference in retention performance between the four practice conditions, and the retention performance of the participants in different practice conditions was not influenced by the practice group (i.e. clinical or non-clinical group).
- For the keyboard task, the retention performance of the non-clinical group was better than the clinical group, the performance of participants (in both groups) in the constant and variable practice conditions was better than random and blocked practice conditions, and the retention performance of the participants in different practice conditions was not influenced by the practice group (i.e. clinical or non-clinical).

Temporal learning

Non-clinical group - The results of the temporal analysis for speech and keyboard tasks are shown in Table 10. The results are indicated in terms of phi correlation values. The mean phi correlation values for speech task ranged from 0.21 to 0.34 across the four practice conditions. The mean phi correlation values for keyboard task ranged from 0.16 to 0.27 across the four practice conditions. To evaluate the participant performance on the speech and keyboard tasks, the phi correlation values across the four practice conditions were subjected to a two-way mixed model ANOVA (2 practice tasks X 4 practice conditions). The between-group factor was the practice condition (constant, variable, random & blocked practice conditions) and the within-group factor was the practice task (speech & keyboard tasks). Results revealed that there was no significant main effect for the practice task, $F(1, 76) = 0.341$, $p = 0.56$, $\eta_p^2 = 0.004$. There was a significant main effect for the practice condition, $F(3, 76) = 2.901$, $p = 0.04$, $\eta_p^2 = 0.103$. Post hoc tests using Tukey HSD criterion revealed that the constant practice condition was significantly better than the random practice condition ($p = 0.03$). There was no significant interaction between the practice conditions and the practice tasks, $F(3, 76) = .986$, $p = 0.40$, $\eta_p^2 = 0.37$. The phi correlation values for speech and keyboard tasks across four practice conditions are shown in Figure 14.

Clinical group - The results of the temporal analysis for the clinical group indicated in phi correlation values are shown in Table 11. The mean phi correlation values for speech task ranged from 0.05 to 0.13 across the four practice conditions. The mean phi correlation values for the keyboard task ranged from 0.10 to 0.24 across the four practice conditions. To evaluate the participant performance on the speech and keyboard tasks across the four practice conditions, a two-way mixed model ANOVA (2 practice tasks X 4 practice conditions) was performed. There was no main effect for the practice task, $F(1, 12) = 3.305$, $p = 0.094$, $\eta_p^2 = 0.189$, and no significant main effect for the practice condition, $F(3, 12) = 0.612$, $p = 0.620$, $\eta_p^2 = 0.116$. There was also no significant interaction between the practice conditions and practice tasks, $F(3, 12) = 0.363$, $p = 0.781$, $\eta_p^2 = 0.055$.

Table 10. Phi correlation values of the participants in the non-clinical group for the speech and keyboard tasks across four practice conditions. 20 practice conditions were assigned to each practice condition. Mean (M) and standard deviation (SD) values are shown at the bottom of the table

Participants (N = 80)	**Constant** (N = 20)		**Variable** (N = 20)		**Random** (N = 20)		**Blocked** (N = 20)	
	Speech (Phi)	Keyboard (Phi)	Speech (Phi)	Keyboard (Phi)	Speech (Phi)	Keyboard (Phi)	Speech (Phi)	Keyboard (Phi)
1	0.18	0.49	0.42	0.29	0.12	0.35	0.41	-0.06
2	0.43	0.58	0.49	0.41	0.19	0.57	0.20	0.33
3	0.22	0.00	0.41	0.47	0.35	0.57	0.45	0.51
4	0.49	0.39	0.36	0.16	0.06	0.08	0.14	0.18
5	0.23	0.31	0.36	0.47	0.04	0.08	0.53	-0.08
6	0.00	0.37	0.30	0.03	0.48	0.06	0.30	0.00
7	0.22	0.10	0.55	0.42	0.34	-0.05	0.49	-0.03
8	0.08	0.43	0.22	0.11	0.13	0.28	0.12	0.01
9	0.46	0.17	0.17	0.27	0.33	0.13	0.26	0.47
10	0.40	0.52	0.30	0.54	0.39	-0.10	0.23	0.34
11	0.45	0.16	-0.12	0.04	0.02	0.10	-0.06	0.09
12	0.38	0.00	0.08	0.11	0.17	-0.04	-0.02	0.51
13	0.49	0.24	0.03	0.18	0.27	0.10	0.14	0.21
14	0.49	0.24	-0.04	0.06	0.42	-0.02	0.46	0.29
15	0.00	0.05	0.21	0.32	0.15	0.32	-0.03	0.19
16	0.51	0.28	0.35	0.46	0.28	0.15	-0.03	0.19
17	0.61	0.16	0.05	0.51	0.28	0.27	0.17	0.07
18	0.31	0.31	0.15	0.08	-0.11	0.08	0.00	0.15
19	0.30	0.44	0.28	0.26	0.36	0.19	0.40	0.38
20	0.52	0.23	-0.27	0.30	-0.04	0.11	0.25	0.46
M	0.34	0.27	0.21	0.27	0.21	0.16	0.22	0.21
SD	0.18	0.17	0.21	0.17	0.16	0.19	0.19	0.19

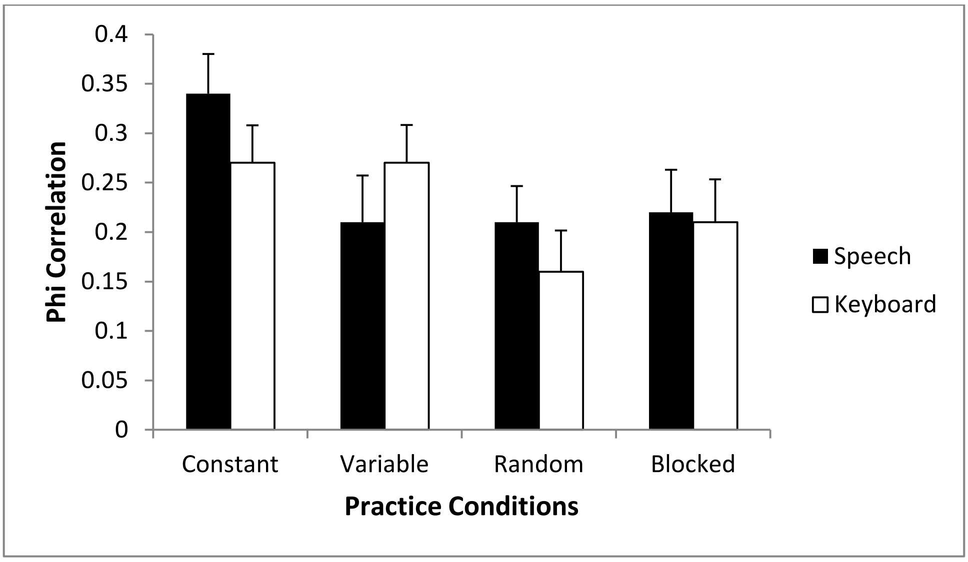


Figure 14. Phi correlation values of the non-clinical group for speech and keyboard tasks across the four practice conditions. Error bars show 95% confidence interval.

Table 11. Phi correlation values of the participants in the clinical group for the speech and keyboard tasks across four practice conditions. Four participants assigned to each practice condition. Mean (M) and standard deviation (SD) values are shown at the bottom of the table.

Participants (N = 16)	**Constant** (N = 4)		**Variable** (N = 4)		**Random** (N = 4)		**Blocked** (N = 4)	
	Speech (phi)	Keyboard (phi)	Speech (phi)	Keyboard (phi)	Speech (phi)	Keyboard (phi)	Speech (phi)	Keyboard (phi)
1	0.14	0.06	0.33	0.28	0.04	0.12	0.27	0.25
2	0.04	0.28	0.14	0.21	0.05	0.01	0.24	0.31
3	0.15	0.27	-0.05	0.31	-0.01	0.18	-0.17	0.05
4	0.17	0.02	0.01	0.16	0.14	0.09	0.03	0.00
M	0.13	0.16	0.10	0.24	0.05	0.10	0.09	0.15
SD	0.06	0.14	0.17	0.07	0.06	0.07	0.20	0.15

Non-clinical vs. clinical

Speech task - The mean phi correlation values of speech and keyboard tasks for the non-clinical and clinical groups are shown in Table 12. As seen from Table 12, the mean correlation values for the speech task were higher across all four practice conditions in the non-clinical group in comparison to the clinical group. In the non-clinical group, the mean correlation value was highest for the constant practice condition (0.34) and lowest for the variable practice (0.21) and random practice conditions (0.21). The mean correlation value for the clinical group was highest for the constant practice condition (0.13) and lowest for the random practice condition (0.05). To determine the effect of group on temporal learning of the speech task, the phi correlation values across the four practice conditions were subjected to a two-way ANOVA (2 groups X 4 practice condition). Results revealed a main effect for group with the non-clinical group performance being better than the clinical group, $F(1, 48) = 4.534$, $p = 0.038$, $\eta_p^2 = 0.086$. There was no significant main effect for practice condition, $F(3, 48) = 2.479$, $p = 0.072$, $\eta_p^2 = 0.134$. There was no significant interaction between group performance and practice conditions, $F(3, 48) = 1.680$, $p = 0.184$, $\eta_p^2 = 0.095$.

Keyboard task - From Table 12, it is suggestive that the phi correlation values in the non-clinical group were highest for the constant and variable practice conditions (0.27) and lowest for the random practice condition (0.16). In the clinical group, the variable practice condition revealed the highest correlation value (0.24) and the random practice had the lowest correlation value (0.10). The phi correlation values across the four practice conditions were subjected to a two-way ANOVA (group X practice condition). There was no significant main effect for group, $F(1, 48) = 0.704$, $p = 0.405$, $\eta_p^2 = 0.014$. There was no significant main effect for practice condition, $F(3, 48) = 0.804$, $p = 0.498$, $\eta_p^2 = 0.048$. There was also no significant interaction between the groups and practice conditions, $F(3, 48) = 0.697$, $p = 0.559$, $\eta_p^2 = 0.042$.

Table 12. Mean phi correlation values for the non-clinical and clinical groups. The standard deviation values are shown in parentheses

Group	**Constant**		**Variable**		**Random**		**Blocked**	
	Speech (phi)	Keyboard (phi)	Speech (phi)	Keyboard (phi)	Speech (phi)	Keyboard (phi)	Speech (phi)	Keyboard (phi)
Non-clinical	0.34 (0.18)	0.27 (0.17)	0.21 (0.21)	0.27 (0.17)	0.21 (0.16)	0.16 (0.19)	0.22 (0.19)	0.21 (0.19)
Clinical	0.13 (0.06)	0.16 (0.14)	0.10 (0.17)	0.24 (0.17)	0.05 (0.06)	0.10 (0.07)	0.09 (0.20)	0.15 (0.15)

Summary of the key findings for the temporal learning

Non-clinical group findings

- There was no difference in retention performance between the speech and keyboard task.
- The retention performance in constant practice condition was better than the random practice condition. There was no difference between the variable, random, and blocked practice conditions.
- The retention performance of the participants in different practice conditions was not influenced by the practice task (i.e., no interaction effect).

Clinical group findings

- There was no difference in retention performance between the speech and keyboard task, no difference between the practice conditions, and the retention performance of the participants in different practice conditions was not influenced by the practice task.

Non-clinical vs. clinical group findings

- For the speech task, the retention performance of the non-clinical group was better than the clinical group, the retention performance of the participants in the constant practice condition was better than the random practice condition, and the retention performance of the participants in different practice conditions was not influenced by the practice group (i.e., no interaction effect).
- For the keyboard task, there was no difference in the retention performance between the non-clinical and clinical groups, no difference between the four practice conditions, and the retention performance of the participants in different practice conditions was not influenced by the practice group (i.e., no interaction effect).

Age effect

The effect of age on spatial and temporal learning was analysed in the non-clinical group. A similar analysis was not performed in the clinical group due to inadequate sample size. The age of the participants in the non-clinical group ranged from 42 to 78 years. To examine the effect of age on motor learning performance, a median split was performed to separate the participants into two groups (younger, older). The median split was at 59 years of age, thus placing 40 participants in each age group. The age distribution across the four practice conditions included nine younger participants in the constant practice condition, 11 younger participants in the variable practice conditions, and 10 younger participants each in random and blocked practice conditions. The distribution of the participants across the four practice conditions for the spatial learning and temporal learning tasks is depicted in tables 13 through 16. The age of the participants in the younger group ranged from 42 to 59 years (M = 52.2), and in the older group, the age of the participants ranged from 60 to 79 years (M = 67.3).

Spatial learning

Speech task - The mean PPC and PKC values for the younger and older age groups are shown in Table 17. The mean PPC values across four practice conditions are higher in the younger age group except for the constant practice condition. In the younger group, the mean PPC was highest for the random practice condition (93.5%) and lowest for the constant and variable practice conditions (90.1%). In the older group, the mean PPC was highest for the constant practice condition (92.9%) and lowest for the blocked practice condition (63.8%). To determine the age effect on speech task, the PPC values across the four practice conditions were subjected to a two-way ANOVA (2 age groups X 4 practice conditions). There was a significant main effect for age with the younger group performing better than the older group, $F(1, 72) = 7.390$, $p = 0.008$, $\eta_p^2 = 0.093$. A significant main effect or the practice condition was also found, $F(3, 72) = 3.674$, $p = 0.016$, $\eta_p^2 = 0.133$. Post hoc analysis using Tukey HSD criterion revealed that the constant practice condition was better than the blocked practice condition ($p = 0.022$). There was an interaction between the age of the participants and the practice conditions, $F(3, 72) = 3.657$, $p = 0.016$, $\eta_p^2 = 0.132$. Follow-up post hoc tests for the interaction effect revealed that in the older group, the retention performance participants in the constant practice condition was significantly better than the participants in the blocked practice condition ($p = 0.01$). In the younger group, there was no difference in the retention performance between the participants in the four practice conditions. The PPC values of the younger and older age groups across four practice conditions are depicted in Figure 15.

Table 13. Distribution of Percentage of Phoneme Correct values (%) in the younger and older age groups for the speech task across four practice conditions. [2] Mean (M) and Standard Deviation (SD) values are shown at the bottom of the table.

Participants	Constant		Variable		Random		Blocked	
	Young	Old	Young	Old	Young	Old	Young	Old
1	93	93	86	100	100	69.48	100	69
2	100	96	93	91.4	85.2	86	86	100
3	89.4	100	96.4	89	93	69	100	68
4	80.6	54	64	100	100	93	100	29
5	93	90	96	69.4	100	99.2	61	55
6	79	100	89	96	100	100	93	61
7	83	100	99.4	75	100	96	95.4	93
8	93	100	100	82	82	97	82	30
9	100	100	79	42.2	100	89	96	33.2
10		96	88.8		75	89	100	100
11		93	100					
M	90.1	92.9	90.1	82.7	93.5	88.7	91.3	63.8
SD	7.7	13.3	10.9	18.6	9.4	11.2	12.3	27.6

[2]Unequal sample sizes across the four groups is a result of median split performed on the overall data

Table 14. Distribution of percentage of keystrokes correct values (%) in the younger and older age groups for the keyboard task across four practice conditions. Mean (M) and Standard Deviation (SD) values are shown at the bottom of the table.

Participants	Constant		Variable		Random		Blocked	
	Young	Old	Young	Old	Young	Old	Young	Old
1	100	100	100	100	100	2.4	100	38.4
2	100	100	100	100	100	82.6	42	100
3	100	92	100	100	14.2	25.8	100	25
4	100	100	100	100	29.8	100	54.4	26.6
5	100	100	100	42	58	46.8	43.2	34.6
6	100	96.6	100	100	100	38.2	69.2	75
7	100	56.8	83.2	100	100	53	100	45.2
8	100	100	100	100	34.2	73.4	28.4	44.8
9	100	100	100	100	100	35.4	100	46.8
10		100	80		71.6	100	66.6	46.4
11		78.4	100					
M	100	93	96.6	93.5	70.7	55.7	70.3	48.2
SD	0	13.7	7.4	19.3	34.4	32.4	28.0	22.8

Table 15. Distribution of phi correlation values in the younger and older age groups for the speech task across four practice conditions. Mean (M) and Standard Deviation (SD) values are shown at the bottom of the table.

Participants	Constant		Variable		Random		Blocked	
	Young	Old	Young	Old	Young	Old	Young	Old
1	0.18	0.40	0.42	0.08	0.12	0.02	0.41	-0.06
2	0.43	0.45	0.49	0.03	0.19	0.17	0.20	-0.02
3	0.22	0.38	0.41	-0.04	0.35	0.27	0.45	0.14
4	0.49	0.49	0.36	0.21	0.06	0.42	0.14	0.46
5	0.23	0.49	0.36	0.35	0.04	0.15	0.53	-0.03
6	0.00	0.00	0.30	0.05	0.48	0.28	0.30	-0.03
7	0.22	0.51	0.55	0.15	0.34	0.28	0.49	0.17
8	0.08	0.61	0.22	0.28	0.13	-0.11	0.12	0.00
9	0.46	0.31	0.17	-0.27	0.33	0.36	0.26	0.40
10		0.30	0.30		0.39	-0.04	0.23	0.25
11		0.52	-0.12					
M	0.26	0.41	0.31	0.09	0.24	0.18	0.31	0.13
SD	0.17	0.16	0.18	0.19	0.15	0.18	0.15	0.19

Table 16. Distribution of phi correlation values in the younger and older age groups for the keyboard task across four practice conditions. Mean (M) and Standard Deviation (SD) values are shown at the bottom of the table.

Participants	Constant		Variable		Random		Blocked	
	Young	Old	Young	Old	Young	Old	Young	Old
1	0.49	0.52	0.29	0.11	0.35	0.10	-0.06	0.09
2	0.58	0.16	0.41	0.18	0.57	-0.04	0.33	0.51
3	0.00	0.00	0.47	0.06	0.57	0.10	0.51	0.21
4	0.39	0.24	0.16	0.32	0.08	-0.02	0.18	0.29
5	0.31	0.24	0.47	0.46	0.08	0.32	-0.08	0.19
6	0.37	0.05	0.03	0.51	0.06	0.15	0.00	0.19
7	0.10	0.28	0.42	0.08	-0.05	0.27	-0.03	0.07
8	0.43	0.16	0.11	0.26	0.28	0.08	0.01	0.15
9	0.17	0.31	0.27	0.30	0.13	0.19	0.47	0.38
10		0.44	0.54		-0.10	0.11	0.34	0.46
11		0.23	0.04					
M	0.32	0.24	0.29	0.25	0.20	0.12	0.17	0.25
SD	0.19	0.15	0.18	0.16	0.24	0.11	0.23	0.15

Table 17. PPC and PKC values (%) of the younger and older age groups across four practice conditions for speech and keyboard learning tasks. The standard deviation values are shown in parentheses.

Age groups	**Constant**		**Variable**		**Random**		**Blocked**	
	Speech (PPC)	Keyboard (PKC)	Speech (PPC)	Keyboard (PKC)	Speech (PPC)	Keyboard (PKC)	Speech (PPC)	Keyboard (PKC)
Young	90.1 (7.79)	100 (0)	90.1 (10.91)	96.6 (7.48)	93.5 (9.41)	70.7 (34.40)	91.3 (12.37)	70.3 (28.06)
Old	92.9 (13.39)	93.1 (13.71)	82.7 (18.60)	93.5 (19.33)	88.7 (11.27)	55.7 (32.49)	63.8 (27.68)	48.2 (22.88)

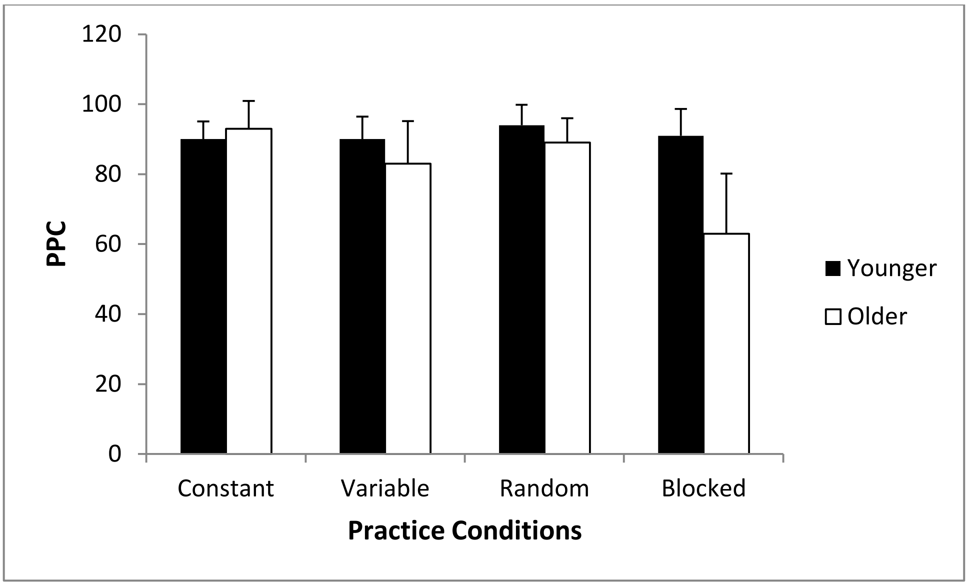


Figure 15. Percentage of Phoneme Correct (PPC) values of the younger and older age groups across four practice conditions. Error bars show 95% confidence interval.

Keyboard task - The mean PKC across all of the practice conditions was higher in the younger group in comparison to the older group. In the younger group, the mean PKC was highest for the constant practice condition (100%) and lowest for the blocked practice condition (70.3%). In the older group, the mean PKC was highest for the variable practice condition (93.5%) and lowest for the blocked practice condition (48.2%).The PKC values across the four practice conditions were subjected to a two-way ANOVA (2 age groups X 4 practice conditions) to determine the effect of age on keyboard task performance. There was a significant main effect for age with the younger group performance being better than the older group, $F(1, 72) = 5.24$, $p = 0.024$, $\eta_p^2 = 0.069$. A significant main effect for the practice condition was also found, $F(3, 72) = 15.337$, $p = 0.001$, $\eta_p^2 = 0.390$. Post hoc analysis using Tukey HSD criterion revealed that the constant practice condition was better than random ($p < 0.001$) and blocked practice conditions ($p < 0.001$), and performance on the variable practice condition was better than random ($p < 0.005$) and blocked practice conditions ($p <0.001$). There was no significant interaction between the age of the participants and the practice conditions, $F(3, 72) = 0.690$, $p = 0.561$, $\eta_p^2 = 0.028$. The PKC values of the younger and older age groups across four practice conditions are depicted in Figure 16.

Temporal learning

Speech task - The mean phi correlation values for the younger and older age groups are shown in Table 18. The mean correlation values were higher in the younger age group in comparison to the older group across practice conditions except for the constant practice condition. In the younger group, the mean correlation value was highest for the variable practice condition (0.31) and lowest for the random practice condition (0.24). In the older group, the mean correlation value was highest for the constant practice condition (0.41) and lowest for the variable practice condition (0.09). To determine the effect of age on speech task performance, the phi correlation values across the four practice conditions were subjected to a two-way ANOVA (2 age groups X 4 practice conditions). Results revealed a significant main effect for age with the performance of the younger group better than the older group, $F(1, 72) = 4.352$, $p = 0.04$, $\eta_p^2 = 0.057$. There was no main effect for the practice condition, $F(3, 72) = 2.426$, $p = 0.072$, $\eta_p^2 = 0.092$. There was a significant interaction between the age of the participants and the practice conditions, $F(3, 72) = 4.708$, $p = 0.005$, $\eta_p^2 = 0.164$. Follow up post hoc tests revealed that the retention performance of the participants in the constant practice condition was better than participants in the variable, random, and blocked practice conditions ($p < 0.05$) in the older age group but there were no

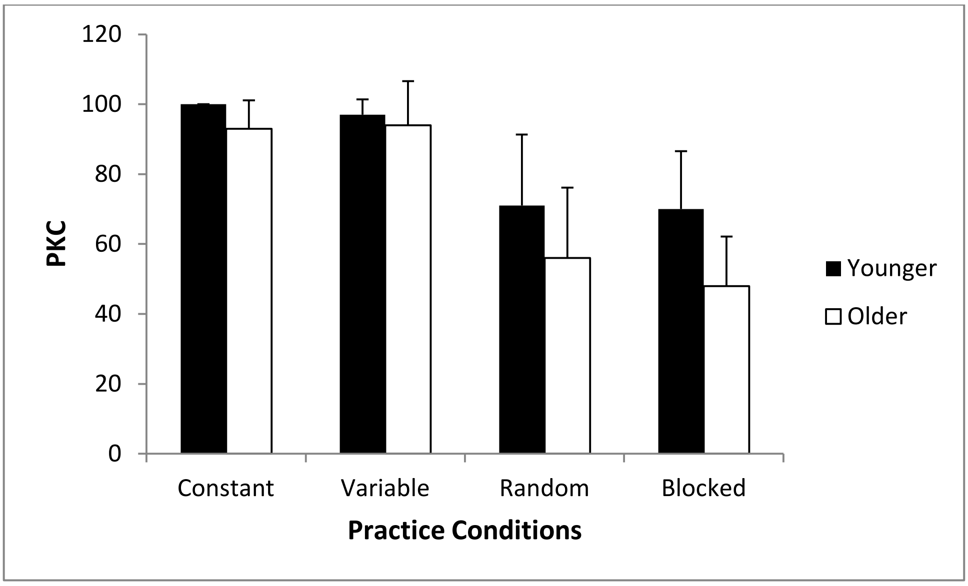


Figure 16. Percentage of keystrokes correct (PKC) values of the younger and older age groups across four practice conditions. Error bars show 95% confidence interval.

Table 18. Phi correlation values of the younger and older age groups across four practice conditions for speech and keyboard learning tasks. The standard deviation values are shown in parentheses.

Age groups	**Constant**		**Variable**		**Random**		**Blocked**	
	Speech (phi)	Keyboard (phi)	Speech (phi)	Keyboard (phi)	Speech (phi)	Keyboard (phi)	Speech (phi)	Keyboard (phi)
Young	0.26 (0.17)	0.32 (0.19)	0.31 (0.18)	0.29 (0.18)	0.24 (0.15)	0.20 (0.24)	0.31 (0.15)	0.17 (0.23)
Old	0.41 (0.16)	0.24 (0.15)	0.09 (0.19)	0.25 (0.16)	0.18 (0.18)	0.12 (0.11)	0.13 (0.19)	0.25 (0.15)

differences between the practice conditions in the younger group (*p = 0.12*). The phi correlation values of the younger and older age groups for the speech task across four practice conditions is depicted in Figure 17.

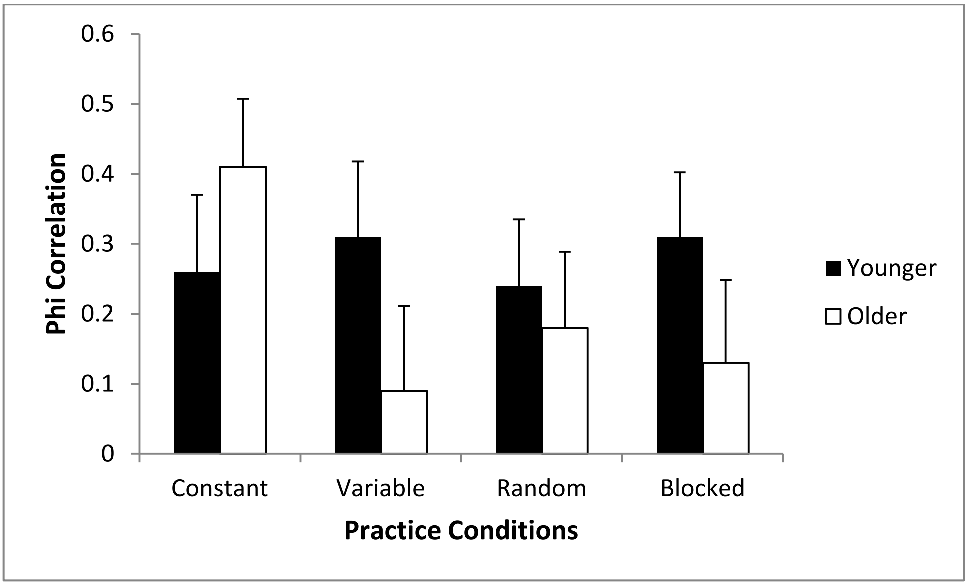


Figure 17. Phi correlation values of the younger and older age groups for the speech task across four practice conditions. The error bars show 95% confidence interval.

Keyboard task - The mean phi correlation values of the younger and older groups are shown in Table 18. The correlation values in the younger group were highest for the constant practice condition (0.32) and lowest for the blocked practice condition (0.17). In the older group, variable and blocked practice conditions revealed the highest correlation value (0.25) and the random practice had the lowest correlation value (0.12).The phi correlation values across the four practice conditions were subjected to a two-way ANOVA to determine the effect of age on temporal learning of the keyboard task. There was no significant main effect for age, $F(1, 72) = 0.370$, $p = 0.545$ $\eta_p^2 = 0.005$. There was also no significant main effect for practice condition $F(3, 72) = 1.841$, $p = 0.147$, $\eta_p^2 = 0.071$. There was no significant interaction between the age of the participants and the practice conditions, $F(3, 72) = 0.885$, $p = 0.453$, $\eta_p^2 = 0.\ 036$, indicating that the age of the participants did not affect the temporal learning of the keyboard task across practice conditions. The phi correlation values of the younger and older age groups for the keyboard task across four practice conditions is depicted in Figure 18.

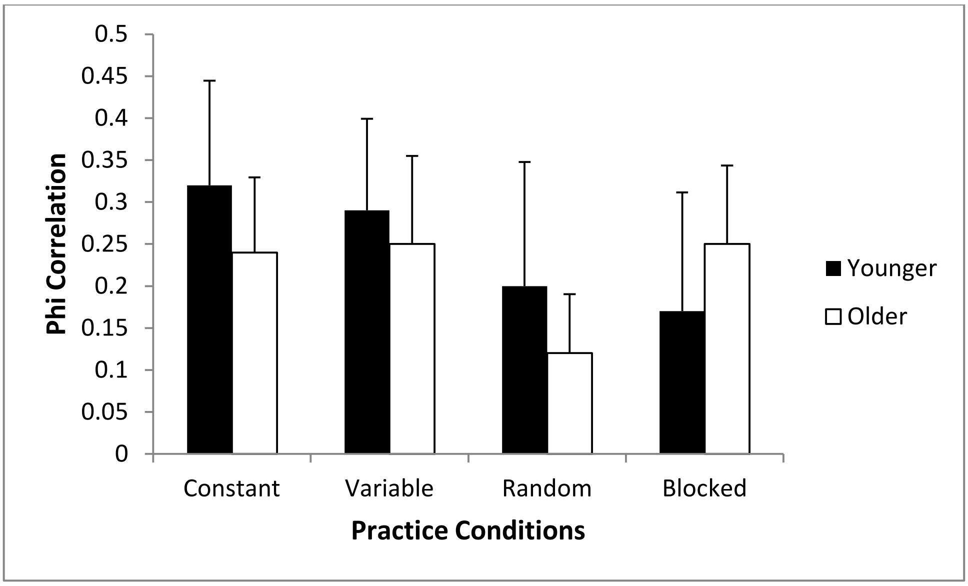


Figure 18. Phi correlation values of the younger and older age groups for the keyboard task across four practice conditions. The error bars show 95% confidence interval.

Summary of key findings of age effect on spatial and temporal learning

Speech task

- The retention performance of the younger group was better than the older group in spatial as well as temporal learning.
- The retention performance of the participants in different practice conditions was influenced by the age group for spatial and temporal learning (i.e. there was an interaction effect).
- In case of spatial learning, follow up post hoc tests revealed that the retention performance of the participants in the constant practice condition was better than the participants in the blocked practice condition in the older age group but there were no differences between the practice conditions in the younger group.
- In case of temporal learning, follow up post hoc tests revealed that the retention performance of the participants in the constant practice condition was better than participants in the variable, random, and blocked practice conditions in the older age group, but there were no differences between the practice conditions in the younger group.

Keyboard task

- The retention performance of the younger group was better than the older group in spatial but not in temporal learning.
- The retention performance of the participants in different practice conditions was not influenced by the age group for spatial as well as temporal learning (i.e. there was no interaction effect).
- In case of spatial learning, the retention performance (of the younger and older age group participants) was better in constant and variable practice conditions than random and blocked practice conditions. In case of temporal learning, there was no difference between the practice conditions.

NASA Task Load Index

Each participant completed the NASA task load index to evaluate the perceived difficulty related with performance on speech and keyboard tasks. The effect of age on perceived task difficulty was analysed in the non-clinical group alone. A similar analysis was not performed in the clinical group due to inadequate sample size. The splitting of participants into younger and older age groups was performed in a similar manner used to investigate the effect of age on speech and keyboard learning tasks. The age distribution of the participants across four practice conditions included nine younger participants in the constant practice conditions, 11 younger participants in variable practice conditions, and 10 younger participants each in random and blocked practice conditions.

Speech task

The NASA task load index scores of the younger and older age groups across the four practice conditions is shown in Figure 19. The mean index scores across four practice conditions were higher in the older group except in case of variable practice condition. In the younger age group, the mean index score was highest for the random practice condition (8.73) and lowest for the constant practice condition (5.14). In the older age group, the mean index score was highest for the random practice condition (10.53) and lowest for the constant practice condition (7.58). To determine the effect of age on the perceived difficulty of the speech task, the mean index for the four practice conditions were subjected to a two-way ANOVA (2 age groups X 4 practice conditions). There was a main effect for age, $F(1, 72) = 4.737$, $p = 0.033$, $\eta_p^2 = 0.062$. There was also a main effect for practice condition, $F(3, 72) = 4.784$, $p = 0.004$, $\eta_p^2 = 0.166$. Post hoc analysis using Tukey HSD criterion revealed that constant practice condition received lower score than random ($p = 0.006$) and blocked practice conditions ($p = 0.026$). There was no interaction between the age of the participants and the practice condition, $F(3, 72) = 1.002$, $p = 0.397$, $\eta_p^2 = 0.040$.

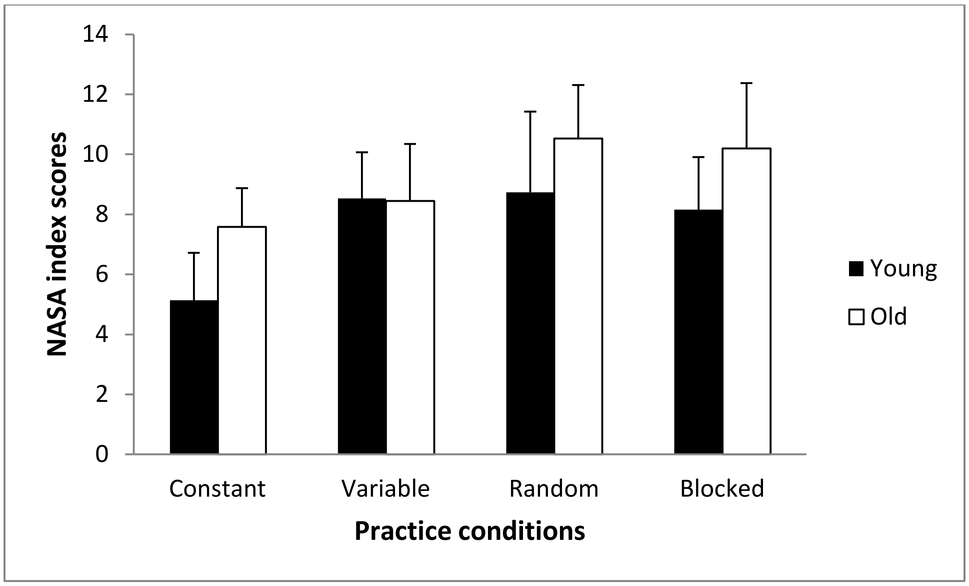


Figure 19. NASA task load index scores of the speech task across four practice conditions for younger and older groups. The error bars show 95% confidence interval.

Keyboard task

The NASA task load index scores of the younger and older age groups across the four practice conditions is shown in Figure 20. The mean index scores across four practice conditions are higher in the older group except the blocked practice condition. In the younger age group, the mean index score was highest for the blocked practice condition (12.1) and lowest for the constant practice condition (6.27). In the older age group, the mean index score was highest for the random practice condition (12.55) and lowest for the variable practice condition (7.5). To determine the effect of age on the perceived difficulty of the keyboard task, the mean index for the four practice conditions were subjected to a two-way ANOVA (2 age groups X 4 practice conditions). There was no main effect for age, $F(1, 72) = 0.25$, $p = 0.618$, $\eta_p^2 = 0.003$. However, there was a main effect for practice condition, $F(3, 72) = 11.848$, $p < 0.001$, $\eta_p^2 = 0.331$. Post hoc analysis using Tukey HSD criterion revealed that constant practice condition received lower score than random ($p < 0.001$) and blocked practice conditions ($p < 0.001$). There was no interaction between the age of the participants and the practice condition, $F(3, 72) = 1.866$, $p = 0.143$, $\eta_p^2 = 0.072$.

Speech vs. keyboard tasks

To compare the perceived difficulty of speech vs. keyboard learning task, the NASA load index scores across all the four practice conditions were collapsed in both the tasks and compared using a paired sample 't' test. On average, the index scores of the keyboard task (M = 9.85, SD = 3.25) was higher than the speech task (M = 8.44, SD = 3.52), $t(79) = -4.103$, $p < 0.001$ (two-tailed), $r = 0.59$. The mean index scores for the speech and keyboard tasks are shown in Figure 21.

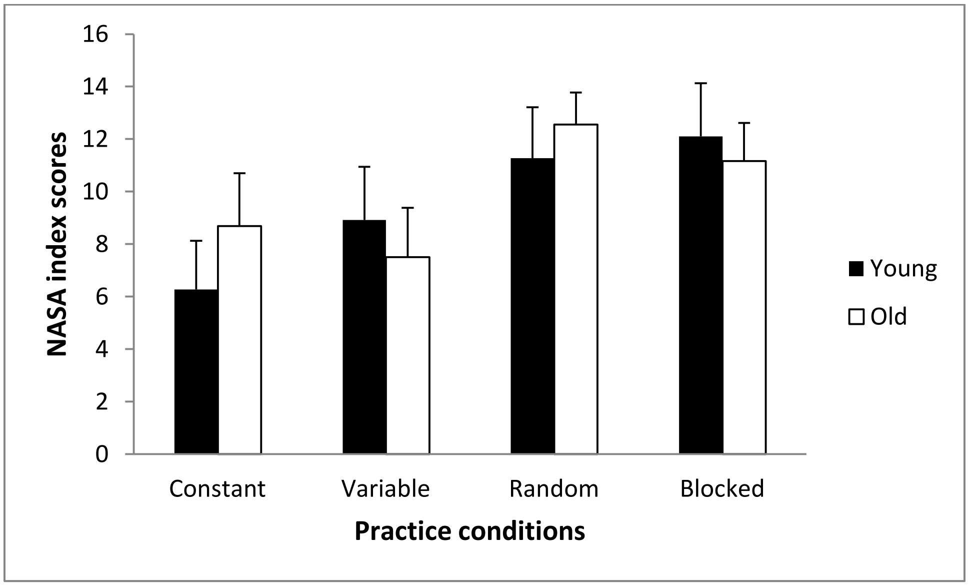


Figure 20. NASA task load index scores of the younger and older groups across four practice conditions for the keyboard task. The error bars show 95% confidence interval.

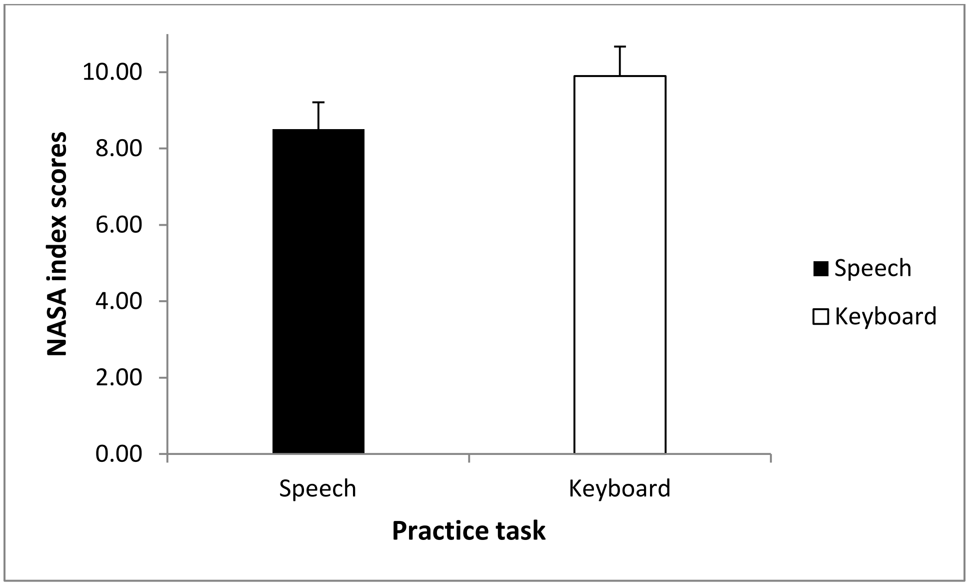


Figure 21. Mean NASA task load index scores for the speech and keyboard tasks. Error bars show 95% confidence interval.

Summary of key findings of NASA task load index

Speech task

- The older group perceived the speech task to be more difficult than the younger group.
- Across both the groups, the constant practice condition was perceived easier in comparison to random and blocked practice conditions.
- The age of the participants did not influence the participants' performance across the four practice condition (i.e. no interaction effect).

Keyboard task

- There was no difference in the mean index scores between the younger and older groups.
- Across both the groups, the constant practice condition was perceived easier than random and blocked practice conditions.
- The age of the participants did not influence the participants' performance across the four practice condition (i.e. no interaction effect).

Speech vs. Keyboard tasks

- The keyboard task was perceived to be more difficult than the speech task.

Chapter 5. Discussion

The major findings of the current study can be summarised as follows: First, in the case of spatial learning, performance on the speech task was better than the keyboard task. The constant practice was found to be better than blocked practice for the speech task. For the keyboard task, constant and variable practice conditions were better than random and blocked practice conditions. Second, in the case of temporal learning, there was no significant difference between speech and keyboard tasks. The main effect of practice condition across speech and keyboard tasks revealed that the constant practice condition was better than the random practice condition. Third, an age effect was observed, with the performance of the younger age group being better than the older age group across all of the speech and keyboard tasks. Fourth, performance of the non-clinical group was better than the clinical group on both the speech and keyboard tasks. A discussion of the results in regard to each of the major findings is provided below.

Spatial Learning

Non-clinical group

Speech task - The mean PPC values of the constant, variable, random, and blocked practice conditions were 91.6%, 86.8%, 91.1%, and 77.5%, respectively, with the constant practice condition being better than the blocked practice condition. There have been limited studies investigating the effects of PMLs on speech-motor learning, and in particular there has been no research investigating the application of PMLs in spatial learning among healthy individuals. Rosenbek, Lemme, Ahern, Harris, and Wertz (1973) explored the efficacy of the 'eight-step continuum approach' in treating speech deficits in three adults with AOS. The eight-step continuum approach is based on a hierarchical cueing procedure that begins with a high level of support providing simultaneous production of slowly spoken simple utterances with visual and tactile cues. During the course of therapy, these cues are either gradually faded or increased until the cues are completely faded and the patient begins producing delayed repetitions of increasingly complex stimulus items. The results revealed that the treatment outcome varied among the three individuals. Even though the researchers did not mention directly about the application of PMLs during the treatment protocol, they speculated that constant practice might facilitate acquisition of new utterances, whereas variable practice might help in retention. The variable nature of treatment outcome and low sample size in the Rosenbek et al. study makes it difficult to judge the effectiveness of variable practice. The elaboration hypothesis is attributed to the beneficial nature of variable practice (Shea & Morgan, 1979). An individual engaged in variable practice elaborates the memory representations of the skill variations of the practising task, and this helps the individuals to compare and contrast the skills variation and thus eventually facilitates learning the task. It is likely for this reason that variable practice might have benefitted the participants in Rosenbek et al.'s study. On the contrary, the present study found no significant difference between constant and variable practice conditions during the retention phase. The reason for this discrepancy can be attributed to Challenge Point Framework (CPF) (Guadagnoli & Lee, 2004). CPF explains the effects of various practice conditions on motor learning tasks. According to CPF, successful learning of a task depends on the skill level of the learner and the difficulty of the to-be learned task. With regards to the skill level of the learner, Rosenbek et al. recruited impaired speakers (AOS) as participants, whereas the present study examined healthy participants. In terms of the difficulty of the task to-be learned, Rosenbek at al. used meaningful words and phrases as practice stimuli, whereas the present study used complex phrase(s) consisting of non-words as practice stimulus. It is plausible that as the complexity of the practising task increases, the practice conditions which allow the participants to engage in repeated practice might facilitate the spatial learning of the task.[3] The repeated exposure to the visual and auditory representations of the target phrase offered by the constant and variable practice conditions could have equally benefited the participants in spatial learning of the target phrase.

There have been two studies of impaired speakers using random vs. blocked practice conditions and the results of these studies are equivocal (Knock et al., 2000; Mass & Farinella, 2012). Knock et al. compared random vs. blocked practice in two adults diagnosed to have aphasia as well as severe AOS, and found both the practice conditions to be equally beneficial during the acquisition phase of learning. However, during the retention phase both individuals showed poorer maintenance of blocked practice targets than random practice targets. Mass and Farinella compared random vs. blocked practice in four children diagnosed with AOS. The findings during the retention phase were mixed, with blocked practice benefitting two children, random practice benefitting one

[3]The variable practice condition involved practicing the target phrase along with an alternate phrase. Both the phrases were similar in terms of spatial representation with the only difference being the temporal organization of

the phrase. With regards to spatial learning, the participants were practising the same phrase throughout the acquisition phase, which could have facilitated the formation of an efficient cognitive representation.
child, no clear improvement in either condition was seen in another child.

The difference between the findings of Knock et al. and Mass and Farinella can be attributed to two reasons. First, is the inherent performance variability seen between individuals with AOS [American Speech, Language, and Hearing Association (ASHA), 2007)]. The diverse nature of AOS represents a situation where two individuals with the same severity might exhibit varied speech deficits and respond differently to the same therapy technique. The second reason might be due to the age of the participants. Knock et al. found random practice to be beneficial in adults, whereas Mass and Farinella found blocked practice to be better in children. It is possible that beneficial effects of practice conditions are different for children than for adults. In the present study, the random practice condition had a marginal significant advantage (p = 0.06) over blocked practice condition in terms of retention performance, similar to the findings of Knock et al. (2000). It can be speculated that as both the studies recruited adult participants, random practice might benefit adults rather than children in complex speech learning tasks.

Overall, across the four practice conditions, the results reveal that the constant practice was condition was better than the blocked practice condition. It is likely that the repeated exposure (as in the case of constant practice) to the orthographic stimulus could have been a cue to the phonological motor plan that helped in the retrieval of the speech phrase during the retention phrase. Laguna (2008) proposed that repeated practice and exposure to the visual image of the practicing task can aid in the development of memory representation of the task, called 'cognitive representation'. Past research has also proven that auditory feedback can be vital in learning new speech sounds, as speakers use auditory perceptual features as a reference for articulation of the novel speech sounds (Perkell et al., 1997). In the current study, the continuous visual and auditory representations of the target phrase offered by the constant practice could have facilitated the participants to form an accurate cognitive representation of the phrase. However, the nature of the blocked practice did not provide continuous visual and auditory representations of the target phrase as the target and alternate phrases were separated by a block of 25 trials. This sequential manner of practice could have prevented the participants from storing the target speech phrase in their working memory leading to memory trace decay. This could be attributed to the decreased spatial performance of the participants in the blocked practice condition.

Keyboard task - The mean PKC values of the constant, variable, random and blocked practice conditions were 96.1%, 95.2%, 63.2%, and 59.3%, respectively. The results indicated that the constant and variable practice conditions were significantly better than the random and blocked practice conditions. This finding differs from past research which has found variable practice to be more beneficial than constant practice for a number of non-speech tasks like basketball shooting, and target tracking tasks (Shoenfelt at al., 2002; Wulf & Schmidt, 1997). For example, Shoenfelt et al. compared the beneficial effects of constant vs. variable practice in shooting basketball free throws. The researchers found that the constant as well as variable practice groups improved during the acquisition phase. On a retention test after two weeks, the variable practice group demonstrated much better performance than during the acquisition phase. On the other hand, the constant practice group, returned to their pre-test level on the retention test. Similar to past research examining speech-motor learning, non-speech-motor learning is facilitated by variable practice. Yet, the present study found constant and variable practice conditions to be equally beneficial for non-speech-motor learning. As in the case of speech task, it is likely that the repeated exposure to the visual and auditory representations of the target tune offered by the constant and variable practice conditions could have equally benefited the participants in spatial learning of the target tune.

With regards to random vs. blocked practice conditions, numerous studies have shown the benefits of random over blocked practice conditions across a wide range of tasks like throwing balls at a target, maze tracing, and computer-based tracking (Goode & Magill, 1986; Shea & Wright, 1991). For example, Goode and Magill found that in throwing a ball to a target, random practice led to better retention in comparison to blocked practice. However, in the present study, participants in random, as well as blocked practice conditions demonstrated similar performance. It is possible that as the participants did not have prior experience in playing the keyboard, they may have required repeated exposure to the visual and auditory representations of the target tune without any interruption of the alternate tune. However, the interference of the alternate tune in the random and blocked practice conditions could have precluded the participants from learning the target tune successfully. This can possibly account for the similar performance of the participants in the random and blocked practice conditions.

Speech vs. Keyboard tasks - Examination of the PPC and PKC scores revealed that the participants performed better on the speech task compared to the keyboard task. This can be attributed to two possibilities. First, the speech task offered an orthographic representation of the target speech phrase during the practice regime. Previous research has shown that it is easier to create a mental image of lexical items than non-lexical items (Prado & Ullman, 2009). Second, as speech is a highly practised task, it is possible that the auditory feedback could have helped the participants to develop a better internal model of the target phrase in comparison to the keyboard task. The internal model is a representation of the articulatory configurations associated with various sounds produced in the vocal tract (Perkell et al., 2000). In contrast, the participants were not accustomed to the keyboard task, and this lack of familiarity could have precluded the participants from developing an internal model of the keyboard task even in the presence of auditory feedback.

The initial proposed hypothesis was *"The PMLs that best facilitate spatial learning of a novel musical keyboard entry task (non-speech task) will also best facilitate spatial learning of a novel speech utterance (speech task) in healthy individuals*". The findings of the spatial learning partially support this hypothesis. Across the speech and keyboard tasks, constant practice condition provided maximum retention whereas blocked practice conditions offered the least retention. On the whole, the findings of the spatial learning in the current study suggest that constant practice condition might prove to be beneficial in learning complex speech and non-speech-motor tasks.

Temporal Learning

Non-clinical group

Speech task - The phi correlation values for constant, variable, random, and blocked practice conditions were 0.34, 0.21, 0.21, and 0.22, respectively. Statistical analyses found no significant difference between the four practice conditions, although the highest correlation was found among the participants in the constant practice condition.

Adams and Page (2000) trained participants to practise the utterance "Buy Bobby a poppy" with a specific overall utterance duration, using either constant or variable practice conditions. Results of the training revealed that the group undergoing constant practice were less successful in their training compared to the variable practice group, despite the fact that the constant group had received twice as many practice trials as the variable practice group. These results indicated that the use of variable practice was more beneficial than constant practice for temporal learning of speech in unimpaired speakers.

The notion of 'speed-accuracy trade-off' (SAT) is commonly implicated in motor learning tasks which demands spatial and temporal accuracy (Wickelgren, 1977; Dickman & Meyer, 1988; Jelsma & Pieters, 1989). In a typical SAT situation, the speed of the motor skill is reduced when focus is on accuracy and vice-versa (Schmidt & Lee, 2005). According to Fitts (1954), there is a proportional relationship between movement time and accuracy. It means that as speed increases, accuracy decreases proportionally. In the speech-motor learning literature, the SAT situation has been reported in various studies (Gooze et al., 2005; Parnell & Amerman, 1996; Amerman & Parnell, 1990). In a recent study, Latash and Mikaelian (2011) explored the relationship between task difficulty and speech time in picture description tasks. They found that speech time scaled linearly with the increase in difficulty of the naming tasks. This was termed as the speed-difficulty trade-off situation rather than a typical speed-accuracy trade-off situation. In the present study, the speed in performing the motor tasks was not measured, but rather the temporal performance was measured via phi correlation approach. The low correlation values and similar temporal performance across the four practice conditions is suggestive of a decreased temporal learning by the participants, and this can be attributed to the 'spatial-temporal trade-off' similar to the notion of SAT. It is plausible that as the participants had to learn a novel speech task, they would have focused more on spatial accuracy, thus compromising temporal accuracy.

Keyboard task - The phi correlation values for constant, variable, random, and blocked practice conditions were 0.27, 0.27, 0.16, and 0.21, respectively, with no significant difference in the phi correlation values across the four practice conditions. Previous studies have investigated the effect of various practice conditions on learning absolute and relative timing (Shea, Lai, Wright, Immink, & Black, 2001; Sekiya et al., 1996). The results of the past studies suggest that absolute timing is enhanced by random practice and relative timing is enhanced by constant and blocked practice conditions. For example, Shea et al. (2001) compared the effects of constant, serial (practice condition in which the task variation change from trial to trial in a predictable manner), random, and blocked practice conditions on learning absolute and relative timing in a sequential keyboard pressing task. Results revealed that participants who were in the constant and blocked practice conditions demonstrated better relative timing abilities, whereas better absolute timing abilities were demonstrated by participants in the random and serial practice conditions. The researchers explained the results based on the predictability of the practice environment. Predictability of the practice environment refers to the ease with which the participants can predict the forthcoming task variations during the practice regime (e.g., a blocked practice conditions offers a highly predictive practice environment). Practice conditions which facilitated predictability of the forthcoming tasks helped in the learning of relative timing, whereas practice conditions which enhanced variability and unpredictability of the forthcoming tasks helped in learning of absolute timing.

There are two methodological differences that make it difficult to directly compare the results of the current study with the previous studies. First, the present study investigated temporal learning through the calculation of a phi correlation using absolute duration measures. In contrast, past studies have directly measured the absolute duration and relative duration values of individual motor movements (e.g., duration of a speech utterance). Second, the focus of past studies was restricted to temporal learning. In the present study, the participants were asked to focus on both spatial as well as temporal learning.

Speech vs. keyboard tasks - There was no main effect of the practice task, indicating that temporal learning was similar across the speech and keyboard tasks. The low phi correlation values on both the speech and keyboard tasks indicate that participants had considerable difficulty in synchronizing their productions with the target phrase/tune during the retention trials. There are two possible reasons for this.

First, is the possibility of a 'spatial-temporal trade-off'. The participants were required to learn the spatial as well as temporal aspects of speech and keyboard tasks. It is likely that when participants are learning tasks which are complex and novel in nature (as in the present study), they might tend to focus more on performing those tasks correctly with respect to the spatial domain rather than focussing on the temporal domain. Even in the present study, during the retention phase the participants could have been more attentive in saying the words correctly or playing the correct keys rather than timing their productions to match the temporal duration of the target phrase/tune.

The second reason could be attributed to the validity of the phi correlation approach to assessing the temporal learning. The current method of evaluating temporal learning did not parallel the approach used in previous studies, namely measurement of relative duration, syllable length, and pause duration. Instead, a broader approach was adopted by measuring the overall match between the participants' productions and target stimulus. As there have been no prior studies investigating the use of phi correlation in estimating motor learning, it is likely that this novel approach may be insensitive to certain subtle features of temporal learning that may have been present.

The initial proposed hypothesis was "*The PMLs that best facilitate temporal learning of a novel musical keyboard entry task (non-speech task) will also best facilitate temporal learning of a novel speech utterance (speech task) in healthy individuals*". This hypothesis can either be supported or rejected based on the interpretation of the current findings. Since there was no significant difference between the four practice conditions (in terms of retention) in speech as well as keyboard tasks, one line of interpretation could be that all the PMLs were equally facilitative in temporal learning of the keyboard entry as well as the speech task, thus providing support for this hypothesis. However, the current findings can also be interpreted in a different manner. As there was no significant difference between the four practice conditions across both the tasks, none of the PMLs best facilitated the temporal learning of the keyboard entry as well as the speech task, thus offering ground for rejecting this hypothesis.

Age effect

Spatial learning

Speech task - Based on a median split of the data according to age of participants, the younger age group performed better than the older age group across the four practice conditions. The PPC values across the four practice conditions indicated a similar performance among the young participants. In the older age group, the constant practice condition was better than the blocked practice condition. Considered within the context of the overall results, it appears that the difference observed in spatial learning across the practice conditions were primarily found among the older participants.

The poorer performance found among the older participants can be attributed to age-related constraints imposed by the motor and cognitive systems. Decreased motor performance is a typical finding in studies on normal aging (Mattay et al., 2002; Perrot & Bertsch, 2007). Past research has revealed that speech is affected as a result of aging (Jacewicz et al., 2009; Hoit & Hixon, 1987; Searl et al., 2002). Old age typically causes systemic deterioration of the body structures including the oral mechanism (Campbell, McComas, & Petito, 1973). Acoustic analysis has confirmed that men over 70 years speak at a rate that is slower than that of younger men (Ryan, 1972) and imprecise articulation is frequently implicated in the speech of elderly individuals (Amerman & Parnell, 1990; Hartman & Danhauer, 1976). Sadagopan (2008) compared the novel speech learning ability in younger vs. older age groups. A physiologic measure through kinematic analysis (lip aperture coordination) and behavioural measures (production accuracy and duration) were assessed on two consecutive days for 16 young and 16 elderly participants during the production of six novel non-words increasing in length and complexity. Behaviourally, clear differences were noted between young and elderly participants in the ability to accurately produce the longer, more complex non-words. Older speakers' productions revealed a greater percentage of articulatory errors than young adults for four-syllable non-words, suggesting that important age-related differences are present for repetition of long, complex and, novel non-words. Elderly individuals also demonstrated longer durations for non-word production than young adults, and this effect was more pronounced for longer, more complex nonwords. Very few elderly individuals produced the requisite number of accurate productions for kinematic analysis of the two most complex non-words, and were not subjected to statistical analyses. The results of the current study are in close agreement with the findings of Sadagopan.

Different models have been proposed to account for the cognitive-motor decline in elderly individuals. The "information loss model" (Myerson et al., 1990) attributes the decreased motor performance in the elderly population due to the loss of information at each of the various information processing stages, thereby requiring more time to plan a motor response. The "neural noise model" (Crossman & Szafran, 1956; Welford, 1985) explains the decreased motor performance in elderly individuals based on the increased random activity in the brain due to aging. Another model explaining the reduced motor output in elderly population is based on the difference in attitudes and preferences shown by the elderly people in performing novel motor tasks (Verhoff et al., 1984). Reduced working memory in older adults has been documented in past studies (Kester et al., 2002; Jost et al., 2011). According to the inhibitory deficit hypothesis, older individuals are unable to filter out task-irrelevant information from external sources, which, in turn, reduces their memory capacity (Hasher & Zacks, 1988). Hasher and Zacks found that older adults lack inhibitory control, thus allowing irrelevant information to enter their working memory and distract them during memory tasks. In the present study, it is likely that all the above models can be accounted for the decreased spatial learning (i.e., lower PPC) among the elderly individuals.

The findings with respect to the practice conditions in the older group can be explained based on similar reasons applicable for overall results of spatial learning. The advantage of constant practice over blocked practice can be attributed to the role of repeated exposure to the orthographic stimulus which could have aided in the retrieval of the phonological motor plan pertaining to the speech phrase during the retention phrase. Thus, the continuous auditory and visual representation of the target phrase offered by the constant practice could have facilitated the participants to form an accurate cognitive representation of the phrase. The sequential manner of practice in the blocked practice condition could have affected the participants in the older group to a greater extent than the younger group in forming a mental imagery of the target phrase. Past research has shown that younger adults have enhanced working memory in terms of increased cognitive processing in comparison to older adults (Kahneman, 1973). This enhanced cognitive processing may have made the younger participants less reliant on mental imagery and hence, able to perform similarly across the four practice conditions.

The initial proposed hypothesis was "*The PMLs that best facilitate spatial learning of a novel speech utterance task will not be similar between a group of healthy younger individuals and a group of healthy older individuals*". The findings of the spatial learning of the speech task support this hypothesis. In the younger group, there was no difference in learning between the participants in four practice conditions. In the older group, the participants in the constant practice condition demonstrated better learning than participants in the blocked practice condition.

Keyboard task - The mean PKC values of the younger age group during the retention phase were significantly better that the older age group. The performance of younger, as well as older, participants in the constant and variable practice conditions was better than participants in random and blocked practice conditions. As there was no interaction effect between age of the participants and practice condition, the performance of the younger and older participants across the four practice conditions could not be analysed separately.

It is well known that aging is accompanied by impairments in sensorimotor (Ketcham & Stelmach, 2001) as well as cognitive and perceptual functioning (e.g., Gunning-Dixon & Raz, 2000; Salthouse, 1985; Seidler, 2006; Perrot & Bertsch, 2007). For example, Perrot and Bertsch investigated motor learning abilities of 31 younger (20–30 years) vs. 33 older adults (61-75 years) in a ball juggling task. The participants practised the juggling task for 12 sessions of 20 minutes each. Results revealed that the younger adults learned the task faster than the older adults, and also older adults required more psychomotor ability to learn the juggling task in comparison to the younger adults.

Older people perform complex motor tasks more slowly and less accurately than they once did (Voelcker-Rehage, 2008). For example, Seidler (2006) examined young (18–31 years) and old adults (65–80 years) in their ability to learn different joystick aiming tasks. Older adults exhibited poorer performance and took longer to learn the visuomotor version of the joystick task as compared to younger adults. Apparently, with increased difficulty level, age differences in motor learning become more pronounced. The results of the present study are in agreement with past studies indicating the effect of aging on spatial learning of non-speech tasks. The reasons provided by the various models of aging could probably account for the decreased performance of the older group in comparison to the younger group.

Fraser, Li, and Penhune (2009) assessed the retention performance of younger vs. older age group on a multi-finger sequence task. Eighteen younger adults (M = 24 years) and 15 older adults (M = 65 years) practised a sequence of keys on a piano keyboard through variable practice in response to a pattern of visual stimulus that appeared on the computer monitor. The results in terms of accuracy and reaction time revealed that older and younger adults demonstrated similar performance during the retention test across days. The results of the present study also revealed similar performance of both the age groups in variable practice condition; the current study also found variable practice (along with constant practice) aided the learning of the keyboard, which is in agreement with the findings of Fraser et al. It is likely that as the complexity of the practice task increases, the need for the frequency of exposure to the visual and/or auditory representations of the task also increases to form a mental imagery of the task. In the present study, the practice conditions (i.e., constant and variable practice) which provided repeated exposure to the auditory and visual representation of the task without any interruption of the alternate tune could have facilitated in forming the mental imagery of the keyboard task.

The initial proposed hypothesis was "*The PMLs that best facilitate spatial learning of a novel musical keyboard entry (non-speech) task will not be similar between a group of healthy younger* *individuals and a group of healthy older individuals*". The findings of the spatial learning of the keyboard task do not support this hypothesis. The younger, as well as older, participants in the constant and variable practice conditions demonstrated better learning than participants in random and blocked practice conditions.

Temporal Learning

Speech task - The mean phi correlation values revealed that the temporal learning of the younger group was better than the older group across the four practice conditions. There was no difference in the performance of the young participants across the four practice conditions. Similar to the spatial learning, it is likely that the increased cognitive resources of the participants in the younger group could have facilitated temporal learning to a similar extent across all the four practice conditions. The performance of the older participants in the constant practice condition was better compared to the other three practice conditions. This can be attributed to the role of mental imagery as in the case of spatial learning of the speech task. The repeated visual and auditory representations of the speech phrase offered by the constant practice condition could have helped the participants to develop a better cognitive representation of the phrase, thereby facilitating the temporal learning. Another reason for the better performance of the participants in the constant practice condition can be accounted by a timing model described by Wing and Kristofferson (1973b). According to this model, there are two levels of timing: (1) a central time keeper level and, (2) a motor implementation level. The centrally-generated 'internal clock' brings about the movement of desired goal duration by sending pulses via the central nervous system. Wing (2002) mentioned that one of the factors affecting the internal clock and motor implementation output is the increased working memory demands due to a secondary task. It is possible that as the older participants in the constant practice condition had to practice just one target phrase, the overall working memory demands would have been lesser in comparison to the other three practice conditions which had interference from an alternate tune.

The initial proposed hypothesis was "*The PMLs that best facilitate temporal learning of a novel speech utterance task will not be similar between a group of healthy younger individuals and a group of healthy older individuals*". The findings of the temporal learning of the speech task support this hypothesis. In the younger group, there was no difference in learning between the participants in four practice conditions. On the other hand, in the older group, the participants in the constant practice condition exhibited better learning than the participants in the other three practice conditions.

Keyboard task - The mean phi correlation values revealed that there was no age effect or main effect of practice condition. It is possible that temporal learning of the keyboard task could have burdened the cognitive resources of the participants in both the age groups. This in turn could have resulted in the keyboard task being equally difficult for participants in both age groups across the four practice conditions. Two reasons for this finding are offered. First, there might not be an age difference between the younger and older age groups in temporal learning of a complex non-speech task. Second, the methodological limitations associated with calculating the phi correlation approach could have possibly missed subtle aspects of temporal learning. Previous research has measured relative and absolute durations of motor movements to investigate temporal learning in motor tasks (Shea, Wulf, Park, & Gaunt, 2001; Shea, Lai, Wright, Immink, & Black, 2001), it is likely that investigating temporal learning through such outcome measures might be more revealing about temporal learning.

The initial proposed hypothesis was "*The PMLs that best facilitate temporal learning of a novel musical keyboard entry (non-speech) task will not be similar between a group of healthy younger individuals and a group of healthy older individuals*". The current findings reveal that there is no significant difference between the participants in four practice conditions across both the groups, indicating that both the groups were similar in terms of temporal learning of the keyboard task. This offers ground to reject this hypothesis.

Non-Clinical vs. Clinical group

The clinical group examined in the present study consisted of 16 individuals with PD. The participants were randomly and equally assigned to the four practice conditions. The data analysis was similar to the non-clinical group. The results of spatial and temporal learning in the clinical group revealed no difference between the PD patients across the four practice conditions. While it is possible that the groups performed similarly across practice conditions, a more likely explanation is that the sample size was insufficient to detect small differences. Therefore, this section focuses on a general comparison of the non-clinical and clinical group performances. The results obtained through statistical comparison of the non-clinical and clinical groups are exploratory in nature as unequal sample sizes were compared. In instances, where significant differences were not obtained, both groups were compared using a descriptive statistical approach. The similarities and/or differences between the non-clinical and clinical groups for each of the major finding are discussed below.

Spatial Learning

Speech task - The mean PPC values of the constant, variable, random, and blocked practice conditions in the clinical group were 78.1%, 72.5%, 74.8%, and 77.5%, respectively. The spatial performance of the non-clinical group was significantly better than the clinical group. There was no main effect of practice condition, suggesting that there were no significant differences between the practice conditions across the clinical and non-clinical groups

A prominent characteristic of PD is hypokinetic dysarthria (Ho, Iansek, Marigliani, Bradshaw, & Gates, 1998; Logemann, Fisher, Boshes, & Blonsky, 1978). The present group of participants demonstrated hypokinetic dysarthria. The speech characteristics of hypokietic dysarthria include hypophonia, monotonicity, breathiness/ hoarseness, imprecise articulation, and speaking rate problems (Duffy, 2005). Connor, Abbs, Cole, and Gracco (1989) analysed the sequencing of upper and lower lip and jaw peak velocities during the production of the nonword ‘sapapple’ and reported decreased coordination of articulators in nine participants with hypokinetic dysarthria. The past studies suggest that the hypokinetic dysarthria in patients with PD might affect the speech output to varying extent depending on the severity (Duffy, 2005). Consistent with the findings of the past studies examining the speech of individuals with hypokinetic dysarthria, the results of the present study also indicate a decreased spatial performance of the participants with hypokinetic dysarthria in comparison to the non-clinical group.

The initial proposed hypothesis was “*The PMLs that best facilitate spatial learning of a novel speech utterance task will be similar between a group of healthy individuals and a group of individuals with hypokinetic dysarthria due to PD*”. This hypothesis can be either supported or rejected based on how the current findings are interpreted. One line of interpretation could be that as there was no significant difference between the four practice conditions in clinical as well as non-clinical groups, the PMLs equally facilitated the spatial learning of the novel speech utterance in both the groups, thus supporting the hypothesis. The other line of interpretation could be that none of the PMLs best facilitated the spatial learning of the speech utterance task, as there was no difference between the four practice conditions in both the groups, thus rejecting this hypothesis.

Keyboard task - The mean PPC values of the constant, variable, random, and blocked practice conditions in the clinical group were 82.2%, 77.8%, 54.2%, and 49.5%, respectively. The spatial performance of the non-clinical group was significantly better than the clinical group. Studies have shown that PD patients have difficulty in starting and executing movements (Wilson, 1925). In addition, rapid single-joint, simultaneous, and sequential movements are executed abnormally in PD (Marsden, 1989; Solveri, Brown, Jahanshahi, & Marsden, 1992). For example, Solveri et al. compared the motor learning abilities of 21 patients with PD and 23 age-matched controls on a buttoning task. They found that both groups improved with practice, but the performance of the control group was better than the PD group. The results of the present study are consistent with the findings of Solveri et al. The physiologic constraints of the motor system of the participants in the clinical group can possibly account for the decreased spatial performance of the PD group.

The constant and variable practice conditions were significantly better that random and blocked practice conditions across both the groups. As there was no significant interaction effect, the differences between the practice conditions in non-clinical and clinical groups could not be analysed separately. Sidaway, Gordon, Hopkins, Kershaw, Marean, & Wilkins (2006) compared random vs. blocked practice conditions in four participants with PD. The participants practised three 5-key press patterns on computer keyboard under both blocked and random practice conditions. Retention tests after one day and one week revealed that superior performance was exhibited by participants in the random practice condition. On the contrary, Lin, Sullivan, Wu, Kantak, and Winstein (2007) found that participants with PD benefited from a blocked practice in comparison to random practice on a lever movement task. Twenty adults with PD and 20 age-matched adults practised three-lever movement tasks with either a blocked or a random practice order. Retention tests revealed that participants in the control group who practised with a random order performed more accurately than participants in the control group who practised with a blocked order. However, for the PD group, the findings were reversed; participants who practised with a blocked order performed more accurately than participants who practised with a random order. The results of the current study reveal that there was no difference between the random and blocked practice conditions.

The difference in findings between Lin et al. (2007) and Sidaway et al. (2006) can be attributed to the 'challenge point framework' (CPF) (Guadagnoli & Lee, 2004). According to the

CPF, the practice conditions that facilitate the learning of a task depend on the difficulty of the task. It is likely that the difference in difficulty of the tasks used in both the studies could have resulted in different practice conditions facilitating the motor learning. The results of the present study indicate that there was no significant difference between the random and blocked practice conditions; this does not support the findings of Sidaway et al. or Lin et al. The small sample size of the clinical group can be a reason for the lack of difference between the random and blocked practice conditions in the present study. However, a comparison between random and blocked practice conditions using a descriptive approach revealed that the performance of the random practice group was slightly better than the blocked practice group, providing marginal support for Sidaway et al. It could be possible that the computer keyboard press task used by Sidaway et al. was similar to the musical keyboard task used in the present study leading to similar findings.

The initial proposed hypothesis was "*The PMLs that best facilitate spatial learning of a novel musical keyboard entry (non-speech) task will be similar between a group of healthy individuals and a group of individuals with hypokinetic dysarthria due to PD*". Since the constant and variable practice conditions were better than the random and blocked practice conditions in non-clinical as well as clinical groups, the findings support this hypothesis.

Temporal learning

Speech task - The mean phi correlation values of the constant, variable, random, and blocked practice conditions in the clinical group were 0.13, 0.10, 0.05, and 0.09, respectively. The temporal performance of the non-clinical group was significantly better than the clinical group. Basal ganglia disorders affect movement speed and rhythm of speech. (Kent & Rosenbek, 1982; Netsell, 1983). Ludlow, Connor, and Bassich (1987) investigated the effects of two different basal ganglia diseases on different aspects of speech timing (speech planning, initiation, and production). Twelve patients with PD and 12 patients with Huntington's disease (HD) were compared with normal participants on four different speech timing tasks; reaction time, syllable duration, sentence duration, and phrase duration. Results revealed that in PD as well as HD patients, the control of sentence and phrase duration was impaired. The PD patients had difficulties in altering sentence and phrase durations, but not syllables. On the other hand, HD patients exhibited a global speech timing difficulty across sentences, phrases and syllables. The researchers attributed the speech timing impairment in PD patients to the motor planning. The results of the present study are consistent with the findings of Ludlow et al. The speech timing deficits due to the impaired motor planning ability at the syllable and phrase levels could possibly explain the decreased temporal learning in participants with PD in comparison to the healthy participants. Despite the absent significant findings between the practice conditions, the general trend of the results indicated that in clinical as well as non-clinical groups, the constant practice condition facilitated spatial learning more than the other three practice conditions. In the constant practice condition, the repeated practice of the target phrase could have strengthened the formation of an internal template of a central clock as indicated by the timing model (Wing & Kristofferson, 1973b). The low sample size, and the differences in severity of PD among participants in the clinical group can be a probable reason for the lack of significant findings between the practice conditions.

The initial proposed hypothesis was "*The PMLs that best facilitate temporal learning of a novel speech utterance task will be similar between a group of healthy individuals and a group of individuals with hypokinetic dysarthria due to PD*". Again this hypothesis can either be rejected or accepted based on the direction of the interpretation of the findings. The lack of significant difference between the four practice conditions in clinical as well as non-clinical groups could mean that all the PMLs were equally facilitative in temporal learning of the speech task, which would support of the hypothesis. Alternatively, this finding could also be interpreted that none of the PMLs best facilitated the temporal learning of the speech task, thus rejecting the hypothesis.

Keyboard task - The mean phi correlation values of the constant, variable, random, and blocked practice conditions in the clinical group were 0.16, 0.24, 0.10, and 0.15, respectively. There was no significant difference in the temporal performance between non-clinical group and clinical group and also there was no main effect of practice condition. Even though there were no significant difference between the practice conditions, the general trend of the results indicate that the best performance for the clinical participants was found for those undertaking variable practice, this was also the case for the non-clinical group which showed the best performance for variable, as well as constant practice. As in the case of temporal learning of the speech phrase, the low sample size, and the differences in severity of PD among participants in the clinical group could have contributed to the lack of significant findings between the practice conditions.

The initial proposed hypothesis was "*The PMLs that best facilitate temporal learning of a novel musical keyboard entry (non-speech) task will be similar between a group of healthy* *individuals and a group of individuals with hypokinetic dysarthria due to PD*". The current findings reveal that there is no significant difference between the participants in four practice conditions across both the groups, and the descriptive comparison between the clinical and non-clinical groups indicated that both the groups were similar in terms of temporal learning of the keyboard task. Thus, the findings support this hypothesis.

NASA task load index

There were no specific hypotheses with regards to NASA task load index. However, a part of the current research focused on investigating the perceived difficulty of the speech and non-speech-motor learning tasks by the participants in relation to their retention performance by using NASA task load index.

Speech task - Based on a median split of the index scores according to the age of the participants, the results revealed that the mean index score of the older group was higher than the older group, which suggests that the older group perceived the task to be more difficult than the younger group. There was also a main effect of the practice condition, with the index scores of the random and blocked practice conditions being significantly higher than the constant practice condition. As there was no significant interaction effect, the differences in the index scores between the four practice conditions could not be analysed separately in younger and older age groups.

The decreased motor and cognitive resources as a result of aging could have resulted in the older group perceiving the speech task to be more difficult than the younger group. In regards to the practice condition, the repeated auditory and visual representations provided by the constant practice condition could probably account for the reason that it was perceived to be the least complex practice condition. In the case of random and blocked practice conditions, the additional task load of practising a second alternate phrase along with the target phrase could have made the participants in both the age groups perceive these two practice conditions as being the most difficult. Even though the variable practice condition was not significantly lower than the random and blocked practice condition, visual inspection of the data revealed that the index scores of the variable practice condition was lower than random and blocked practice condition suggesting that it may have been perceived to be less complex than random and blocked practice conditions.

Keyboard task - The results revealed that there was no age effect. The lack of experience in playing a musical keyboard could have led to the task being equally difficult by the participants in younger as well as older age groups. However, there was a main effect of practice condition, with the index scores of the random and blocked practice conditions being higher than the constant practice condition. As in the case of speech task, the additional task load of practising an alternate phrase along with the target phrase could have made the participants in both the age groups perceive random and blocked practice conditions as being the most difficult.

Speech vs. keyboard tasks - The comparison of the index scores between the speech and keyboard tasks indicated that the keyboard task was considered to be significantly more difficult than the speech task. Both the tasks offered auditory and visual representation during the practise regime. However, a major difference among these two tasks was that the speech task was linguistic in nature as it offered an orthographic representation of the target phrase. This could have helped the participants to visualize the speech task more easily than the keyboard task. The limited 'imageability effect' offered by the keyboard task could account for it to be perceived more difficult that the speech task. Also, since speech is a highly practised task in comparison to the keyboard task, the participants could have felt the speech task to be easier than the keyboard task.

The non-speech vs. speech debate

There is ongoing debate regarding the clinical basis and utility for the use of non-speech-oromotor tasks to assess and treat motor-speech disorders (MSDs) (McCauley, Strand, Lof, Schooling, & Frymark, 2009). One line of thought argues against the use of non-speech-oromotor tasks in assessment and treatment of MSDs (Forrest, 2002; Clark, 2003; Ziegler, 2003; Weismer, 2006; Lass & Pannbacker, 2008; Ruscello, 2008; Powell, 2008). According to this view, the acoustic signal is an integral part of speech-motor control. Non-speech-oromotor tasks do not involve speech production so it is unlikely that these tasks provide insight to the speech productions deficits in MSDs.

The other line of thought advocates the use of non-speech-oromotor tasks in assessment of MSDs (Folkins, 1985; Folkins, Moon, Luschei, Robin, Tye-Murray, & Moll, 1995; Ballard, Robin, & Folkins, 2003). According to this view, the underlying cause of MSDs is a motor problem. As such, the inclusion of speech tasks in the assessment may result in a failure to separate motor from linguistic factors in speech performance. Therefore, use of speech tasks exclusively to evaluate speech-motor control may not reflect the underlying motor control problem. One recurring issue in this debate is the need to evaluate parts of the speech mechanism independently of other parts. Hence, inclusion of linguistic factors in an evaluation task may impede the understanding of a suspected motor control deficit.

Ziegler (2003) opposed using non-speech tasks in the assessment and treatment of MSDs. He proposed a task dependent model of speech-motor control, whereby movements of the tongue, lips, and larynx are controlled in fundamentally different ways depending on the particular motor activity. Furthermore, the task dependent model explains that the various subsystems of speech production (respiratory, phonatory, resonatory and articulatory subsystems) are separate to the extent that each of them has unique properties, are subserved by a neural circuitry, and can be impaired selectively after brain lesions. Weismer (2006) also supports Ziegler's view on task specificity. He suggests that there is neither theoretical nor clinical support for implementation of non-speech-oromotor tasks in assessment and treatment of MSDs. Weismer further states that the relation between disordered speech and speech acoustics cannot be observed in studies of non-speech-oromotor behaviour, but rather in studies of speech production in persons with MSDs. Thus, he suggests that the underlying speech deficits in MSDS are best assessed and treated using speech tasks rather than non-speech based tasks.

The concept of task specificity is also strongly advocated by Bunton (2008). She explained the differences between the speech mechanism and non-speech mechanism based on four perspectives; (1) movement characteristics of non-speech oral motor behaviors and speech production, (2) treatment studies, (3) basis of motor learning, and (4) neuroanatomical underpinnings. Based on the data from these domains, she suggested that there is little theoretical or clinical evidence to recommend non-speech activities in the practice of Speech-Language Pathology.

The application of evidence based practice concerning the use of non-speech-oromotor treatment was studied by Lass and Pannbacker (2008). They conducted a systematic literature search using the electronic databases and reviewed a total of 45 articles/reports that were published between 1981 and 2006 in peer-reviewed and non-peer-reviewed journals. They concluded that evidence is either weak or lacking for the use of non-speech tasks in the treatment of speech disorders. Similar conclusions were reached by Ruscello (2008), Powell (2008) and Wilson, Green, Yunusova, and Moore (2008).

All the above studies are suggestive of task specificity of speech. However, the alternative line of thought promotes the use of non-speech-oromotor tasks in assessment of speech disorders. Ballard, Robin, and Folkins (2003) proposed an integrative model of speech- motor control. According to this model, speech and volitional non-speech-motor control are integrated into the functioning of a more general motor system where neural and behavioural systems demonstrate areas of overlap. Folkins (1985) postulated an integrated motor approach to speech production in which speech is organized ultimately to produce the holistic behaviour of communication. Folkins' model was developed to argue against the need to use linguistic units as organizing structures for the motor aspects of speech. The integrative model does not claim complete task-dependence or task-independence, rather it takes a stand between the two. According to this model, certain volitional non-speech tasks share principles in common with speech and therefore with speech-motor anomalies (e.g., dysarthria). At complex behavioural levels, there must be overlapping functional components and, therefore, overlapping and integrative neural pathways or networks. Folkins et al. (1995) suggested that in order to assess motoric deficits in an individual with MSD it is necessary to separate the motoric deficits from the psycholinguistic deficits if present. Non-speech tasks can be designed to measure the pure motoric deficits and give better insight to understanding the nature of the prevailing MSD.

Netsell (1986) also stressed the importance of using non-speech-oromotor tasks as valid assessment tools in individuals with MSDs. Netsell highlighted the potential benefits of non-speech tasks in differential diagnosis and as specific disease markers in order to find out the underlying neuropathophysiology of the speech-motor system. More recently, McCauley, Strand, Lof, Schooling and Frymark (2009) examined the peer-reviewed literature from 1960 to 2007 for articles on the use of non-speech-oromotor exercises (NSOMEs) that affect speech physiology, production, or functional outcomes (i.e., intelligibility). They found insufficient evidence to support or refute the use of NSOMEs to assist with improving speech-motor control.

The non-speech vs. speech debate in the context of the present study

Lof and Watson (2008) conducted a survey to investigate the usage of NSOMSEs among speech language pathologists (SLPs) in USA. They found that 85% of the SLPs who responded to the survey used NSOMEs to treat speech disorders in children. In another similar survey, Mackenzie, Muir and Allen (2010) found that 86% of the SLPs in UK who responded to the survey used NSOMEs to treat speech problems related to dysarthria. As at present, there is insufficient evidence to support or refute the use of NSOMEs; SLPs continue to use NSOMSEs to treat a wide facet of speech disorders in children as well as in adults. NSOMEs encompass a wide range of activities targeted to improve muscle strength and coordination of oral structures. Hodge (2002) indicated that NSOMEs are a collection of stimulation techniques and procedures that are designed to influence the resting posture and/or movement of the lips, jaw, and tongue.

An ideal way to resolve this ongoing debate would be to train participants using non-speech-based tasks and observe for transfer in the speech tasks. The current research was designed to assess retention benefits of selected PMLs rather than transfer benefits. However, the present study found that constant practice was beneficial for spatial and temporal learning in speech as well as non-speech tasks. So it may be that if certain PMLs are followed, one might expect transfer benefits from the non-speech to the speech domain. Admittedly, the non-speech task used in this study was not an oro-motor task; still it seems that some non-speech as well as speech tasks respond consistently to specific PMLs. As most SLPs continue to use NSOMEs of varying complexity to treat speech disorders, it would be worthwhile to explore the use of constant practice condition in implementing such complex non-speech based activities in the light of the present study. However, caution should be exercised in generalizing the results of the current study to NSOMSEs, as the present study used a limb-based task as the non-speech task instead of the usual oral-based non-speech task. Further research along the lines of the present study using an oral-based non-speech task instead of a limb-based task can contribute further evidence to support or refute the ongoing debate.

Limitations of the Study

1. One of the main limitations in the current study seems to be with regards to the approach adopted to estimate temporal learning. Temporal learning can be estimated by at least four different ways. First, through verbal estimation of the stimulus duration (e.g., verbal estimation of the duration of a tone or empty intervals). Second, through temporal discrimination tests (e.g., presenting two tones and determining whether the second tone is shorter than the first tone). The third way is through temporal production (e.g., subject is asked to produce a certain interval by pressing a button), and (4) temporal reproduction,

(e.g., subject is presented with a stimulus of certain duration and is asked to reproduce that duration) (Salman, 2002). In the current study, the temporal learning was evaluated through temporal reproduction, as this method is frequently used in the motor learning research (e.g., Wulf, Lee & Schmidt, 1994). It is likely that estimating temporal learning through any of the other three methods would have provided additional information. For example, as none of the participants had any experience in playing the keyboard, assessing temporal learning by having the participants to verbally estimate the duration of the keyboard tune could have resulted more accurate results than temporal reproduction of the keyboard tune.

2. Another limitation pertains to the use of phi correlation as a measure of temporal learning. Other measures of temporal learning, like relative and absolute duration, have been frequently reported in the motor learning literature (Lai, Shea, Wulf, & Wright, 2000; Wulf, Lee & Schmidt, 1994; Adams & Page, 2000). Adams and Page (2000) used absolute duration to compare constant vs. variable practice conditions in learning the utterance "Buy Bobby a poppy" with a specific overall utterance duration. Results revealed that the group undergoing constant practice were less successful in their training compared to the variable practice group. In the present study, absolute duration measures, like speech segment duration and pause durations, may have provided additional details regarding temporal learning. Also, to determine the synchrony between the participants' production of the target phrase/and the original examples of the target phrase/tune, the alignment of the participant productions and the original example of the target phrase/tune occurred at the onset point of the acoustic waveform. However, it could have been possible that the final segment of the participant productions could have been more synchronous to the target tune/phrase than the initial segment. In this case, aligning the participant productions and the target phrase/tune at the offset point of the acoustic waveform may have resulted in higher phi correlations.

3. The third limitation is with regards to the length of the training (i.e., acquisition phase). In the present study, retention was assessed following two consecutive days of training. Some studies that have investigated speech-motor learning assessed retention following treatment/training ranging from 2 days to one week (Adams & Page, 2000; Pendt, Reuter, & Muller, 2011; Rostami & Ashayeri, 2009). For example, Pendt et al. (2011) compared

the timing release abilities of 19 patients with Parkinson's disease and 19 healthy control group participants on a throwing task. The participants performed 200 throws per day through blocked practice and the training lasted for a period of five days. Retention test results after seven months revealed accurate temporal learning of the throwing task by the participants in both the groups. In the present study, additional training of the participants (e.g., three days) may have resulted in improved/increased temporal learning of the speech and non-speech tasks.

4. The fourth limitation was that the sample size of the PD group was small. A low sample size renders low statistical power which limits the ability to confidently reject the null hypothesis (Ellis, 2010). This is a possible reason for no significant differences being found between the practice conditions in the clinical group. Notwithstanding, the current study indicates that if there were differences between the conditions, they are small.
5. The importance of pre-practice in motor learning has been documented by previous studies (Edwin, Karyll, Lise, & Gary, 1981; Murray, McCabe, & Ballard, 2011; Bricker-Katz, McCabe, Lincoln, & Ballard, 2011. Even though pre-practice instructions were provided to participants prior to the start of the experiment, it was not done rigorously and this could have been another limitation of the study.
6. A common method of splitting the data into two groups is by performing a median split. In some occasions, a quartile split is performed, wherein the data is split into four groups such that 25% of the observations are in each group (Altman & Bland, 1994). In the current study, a median split was performed to divide the participants into two age groups, and this could have been one of the limitations of the study. It is likely that performing a quartile split instead of the median split could have placed the participants into four different age groups, thus offering more specific information on the spatial and temporal learning abilities of each age group.
7. The complexity of the tasks involved in the practice could have possibly influenced the effects of each practice condition. For example, participants in the constant practice condition had to practise one spatial pattern and one temporal pattern. Whereas, participants in the random practice condition had to practice two spatial patterns and two temporal patterns in a random manner. It is likely that the easier nature of the task in the

constant practice condition could have led to better learning outcomes in comparison to the other practice conditions.

8. The current study infers the learning outcomes of the participants in each of the four practice conditions based on the data reported at the end of the retention phase. However, there were no data reported with reference to skill mastery of the participants at the end of the acquisition phase. This could be a potential limitation because the amount of retention (or learning) of a motor skill is typically determined in reference to the skill acquisition. Without baseline data at the end of the acquisition phase, quantification of the amount of motor learning demonstrated at the end of the retention phase is likely to be less precise.
9. The final limitation is that patients with PD were selected as the clinical group. Parkinson's disease (PD) is a neurodegenerative disorder caused due to the dopamine deficiency in the substantia nigra (Duffy, 2005). This gradually affects the brain's ability to generate body movements. It may be difficult to establish the efficacy of PMLs in this clinical cohort, as the retention benefits of PML might disappear over the course of time due to neurodegeneration. Using PMLs to train/re-train motor tasks in a different clinical cohort like patients with stroke might provide more information about the efficacy of PMLs. Patients with stroke present with an impaired but stable motor system, as stroke is not a neurodegenerative condition there are more chances for the patients with stroke to retain the learned motor skills.

Directions for future research

The present research can be extended in many directions. First, the current study compared four practice conditions in learning a speech and a non-speech task. There are other PMLs with respect to attentional focus (internal vs. complex), target complexity (simple vs. complex), practice amount (small vs. large) (Mass et al., 2008) which were not addressed in the current study. It is likely that each PML may contribute to motor learning in a unique manner (Mass et al., 2008). For example, Freedman, Mass, Caligiuri, Wulf, and Robin (2007) compared the use of external vs. internal focus of attention in learning oral and limb based motor tasks. Two groups of 23 participants were administered hand and tongue impulse force control tasks. Each group was randomly assigned to either an internal or an external focus of attention. Participants were required to exert rapid pressure bursts to achieve a target force level of 20% of their maximal strength. Results revealed an advantage of an external focus over internal focus of attention for both the hand and tongue control tasks. The present study can be extended further by investigating the role of each of these principles in speech and non-speech-motor learning tasks. This line of future research might help to determine the PML which best facilitates speech-motor learning and thus can be incorporated in developing speech therapy protocols.

Second, the present study included adult participants in clinical and non-clinical groups. However, the role of PMLs in learning complex speech tasks in children has still to be investigated. Mass and Farinella (2012) treated children with AOS using random and blocked practice conditions. The researchers found contrasting results in comparison to Knock et al. (2000) who recruited adults with AOS. It is plausible that the effects of PML in learning complex speech tasks are different for children than for adults. Children with speech impairment represent a substantial percentage among the school age children (McLeod, Harrison, McAllister & McCormack, 2007). McLeod et al. analysed 4,983 parental reports and 3,276 teacher reports and found that 25.2% of the children aged between four and five years had some sort of expressive speech and language impairments. In the USA, almost 91% of SLPs in schools indicated that they saw pupils with phonological/articulation disorders (ASHA, 2006). Future research investigating the beneficial role of PMLs in speech-motor learning among children may prove useful in rehabilitating children with speech impairment.

Third, the speech task in the present study involved learning a complex meaningless speech phrase. According to CPF, the learning outcome of a task is highly dependent on the task complexity (Lee & Guadagnoli, 2004). Adams and Page (2000) compared constant vs. variable practice conditions in learning a meaningful phrase “Buy Bobby a poppy” with a specific overall utterance duration. They found that the group undergoing constant practise were less successful in their training compared to the variable practise group. The current study used a meaningless phrase to separate the effect of linguistic familiarity on speech-motor learning and found constant practise to facilitate speech-motor learning. It is likely that extending the current study by including a meaningful speech phrase as a practice stimulus might result in other practise conditions favouring speech-motor learning. Results obtained by comparing practice conditions in learning a meaningful phrase may be more representative of the speech-motor learning rather than using a non-meaningful phrase.

Fourth, further studies could include three data collection points during the motor learning process, (1) at the beginning of the practice sessions, (2) at the end of the practice sessions, and

(3) during the retention phase. This arrangement could prove useful in determining the influence of the PMLs on motor learning by tracking the participants' motor learning performance from the beginning of the practice session until the end of the retention phase.

Fifth, an important concept, which needs to be investigated, is the concept of response generalization to other motor tasks. In the current study, based on the retention data alone, it was determined that the constant practice condition was beneficial in comparison to the other practice conditions. However, it is possible that the other practice conditions, which were not responsive to the particular motor tasks in the current study, could be beneficial in learning simpler motor tasks, which are used more frequently in everyday life.

Finally, an important concept of motor learning which remains to be investigated is the transfer effect. A possible way to address the ongoing non-speech vs. speech debate would be to investigate the transfer effect of non-speech tasks across speech tasks. Caviness, Liss, Adler, and Evidente (2006) studied the task specificity of speech to address the ongoing non-speech vs. speech debate. They compared speech and non-speech tasks in healthy controls and in individuals with PD through a measure known as Electroencephalographic-Electromyographic (EEG-EMG) coherence. Coherence is based on a measure of linear relatedness between two waveforms as a function of frequency. This measure is thought to reflect coupling between neural electrophysiological mechanisms in the control of non-speech and speech movement production. They recruited 20 healthy participants and 20 individuals with PD for the study, all the participants were required to carry out two non-speech and four speech tasks. During the non-speech and speech production tasks, the EEG-EMG coherence was simultaneously measured. They found varied coherence values within both the speech and the non-speech tasks in both the groups, which supported the notion of task specificity of speech. However, the researchers did not address the issue of transfer. Future research could be designed to optimally train non-speech movements using PMLs and then observe transfer to comparable speech tasks through EEG-EMG coherence. A study of this nature should help to address "the ongoing non-speech vs. speech debate".

Clinical Implications

Based on the findings of the current study, it is likely that a constant practice regime could be possibly beneficial in learning complex and novel speech motor tasks. Secondly, the speech learning tasks incorporating certain PMLs could lead to different learning outcomes in younger vs. older participants. Finally, the results suggest that it might be easy for patients/participants to learn spatial and temporal aspects individually rather than having to learn both the aspects simultaneously due to possible spatial-temporal trade-off.

As the current study is translational in nature, caution should be exercised in generalizing the above findings to clinical situations. It is likely that the above practice conditions could interact with factors like amount of practice/treatment, length of practice, nature of speech disorders, age of the patients undergoing treatment, and severity of disorder. More research is required along these lines before generalizing the above findings to clinical conditions.

Conclusion

The summary of the findings are: First, in terms of spatial learning, the speech task was learned better than the keyboard task. Second, in general, participants in the constant practice condition learned the speech as well as non-speech tasks better than the participants in the other three practice conditions. Third, there was a spatial-temporal trade-off as indicated by low phi correlation scores in speech as well as non-speech tasks (i.e. the temporal learning was compromised in comparison to the spatial learning). Fourth, there was an age effect, with the motor learning outcomes being better in the younger age group than in the older age group, and finally, there were no apparent differences in the effects of PMLs on speech and non-speech motor learning between non-clinical and clinical groups.

Stages of motor learning

Recall, motor learning is a continuous process. An individual trying to learn a novel motor skill gradually progresses through three different stages of motor learning: the cognitive stage, the associative stage, and the autonomous stage. A logical question to be posed at the end of the current study is: in what stage of motor learning can the participants be placed with respect to spatial and temporal learning? An attempt is made to place the participants in one of the three stages of motor learning based on the retention test performance on the spatial and temporal aspects of the speech and keyboard tasks.

Spatial learning - In case of speech as well as keyboard tasks, the participants were aware of their goals, demonstrated consistent performance and, were able to detect errors during their performance. Some of the participants were even able to execute the tasks automatically to certain extent without much conscious effort. More than half of the participants were not dependent on the feedback to perform the speech and keyboard tasks. The participants had a success rate of 50-60%. Based on the movement characteristics exhibited by the participants, it is likely that the participants were in the associative stage of motor learning with respect to the spatial learning.

Temporal learning - In speech as well keyboard tasks, the participants were not aware of their goals. Some of the participants did not even attempt to temporally match their productions with the target phrase/tune. The participants exhibited highly inconsistent performance during the production trials, and were not able to detect their errors. It seemed that the participants were still heavily dependent on feedback to temporally align their productions with the target phrase/tune during the production trials. On an overall note, the participants had a success rate of 15-25%. Based on the movement characteristics exhibited by the participants, it is likely that the participants were in the cognitive stage of motor learning with respect to the temporal learning.

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APPENDICES

Appendix 1

Project information sheet

PROJECT INFORMATION SHEET FOR PARTICIPANTS

Department of Communication Disorders

Research Title:

Effect of principles of motor learning on speech and non-speech-motor learning

Principal Investigator:

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You are invited to participate in the research project entitled “Effect of principles of motor learning on speech and non-speech-motor learning”

The aim of this project is to evaluate the effects of motor learning tasks, such as amount and type of practice on the learning of novel speech and non-speech tasks.

Your participation in this project will involve attending three sessions on three consecutive days at the Communication Disorders Research Facility. The first two sessions will last approximately one hour and ten minutes each, and the third session will last approximately 15 minutes. The first two sessions will involve learning a novel speech and a non-speech task. The speaking task will require you to rehearse a phrase up to 100 times. The non-speech task will involve you to play a musical tune on an electronic key board. You will rehearse this up to 100 times. On the third day, you will return to the institute and will be required to demonstrate the speech and musical tasks you were taught on the previous day.

The entire procedure is completely non-invasive and does not pose any hazard to your safety. The entire study will take place at Communication Disorders Research Facility located at 19 Creyke Road, Ilam. **As a token of appreciation for your participation you will be given $25 of super market vouchers at the end of your participation**. In addition, your valuable participation will be very useful to investigate new management protocols to help treat speech deficits in individuals with Parkinson’s disease.

You have the right to withdraw from the project at any time, including withdrawal of any information provided. The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: the identity of participants will not be made public without their consent. To ensure confidentiality, the information gathered will be assigned a number and all identifiable information removed. Data will be kept in a locked filing cabinet within a lockable room in the Department of Communication Disorders. A summary of the results of the study will be provided upon request.

The project is being carried out as a requirement for a PhD (Doctor of Philosophy) thesis by Ramesh Kaipa under the supervision of Professor Michael Robb, Dr Maggie Lee Huckabee and Assoc Prof Richard Jones. The project has been reviewed ***and approved*** by the University of

Canterbury Human Ethics Committee. If you have any further questions about the research project, please do not hesitate to contact either my supervisor or myself at the University of Canterbury. Thank you once again.

If you have any questions or concerns about your rights as a participant in this research study, you can contact an independent health and disability advocate. This is a free service provided under the Health and Disability Commissioner Act.

Telephone (NZ wide): 0800 555 050. Free Fax (NZ wide): 0800 2787 7678 (0800 2 SUPPORT)

Email (NZ wide): advocacy@hdc.org.nz

Sincerely,

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Appendix 2

Participant consent form

Ramesh Kaipa
Department of Communication Disorders
University of Canterbury
Private Bag 4800
Christchurch

Consent Form

Effect of principles of motor learning on speech and non-speech-motor learning

I have read and understood the description of the above-named project. On this basis, I agree to take part as a participant in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.

I understand also that I may at any time withdraw from the project, including withdrawal of any information I have provided.

NAME (please print): …………………………………………………………….

Signature:

Date:

Department of Communication Disorders

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Appendix 3

Edinburgh Handedness Inventory (Oldfield, 1971). The 10 activities used for the assessing the hand dominance and the scoring procedure are shown.

The Edinburgh Handedness Inventory requires answers to questions about the participants' practice in performing a number of habitual everyday activities in which the roles of right and left hands are clearly distinguished. The inventory consists of 10 different everyday activities and also a right and a left column for the participants to indicate their preference of handedness for the activities. The participants were provided with the following instructions to help them complete the inventory: "Please indicate your preference with regards to use of your hands in the following activities by putting a check in the appropriate column. Where the preference is so strong that you would never try to use the other hand, unless absolutely forced to, put two checks. If in any case you are really indifferent, put a check in both columns". The inventory is shown in Figure 1. Scoring involved the following steps:

- Calculating the total number of checks in the left and right columns and calculating the cumulative total of the right and left total.
- Calculating the difference between the right total and left total (Right total-Left total).
- Dividing the "difference" by the "cumulative total" cell and multiplying by 100.

Scores below -40 are indicative of left hand dominance, scores between -40 and +40 are indicative of ambidextrous, and scores above +40 are indicative of right hand dominance.

Task / Object	Left Hand	Right Hand
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking a Match (match)		
10. Opening a Box (lid)		
Total checks:	LH =	RH =
Cumulative Total	CT = LH + RH =	
Difference	D = RH – LH =	
Result	R = (D / CT) × 100 =	