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The Effectiveness of Constant, Variable, Random, and Blocked Practice in Speech-Motor Learning

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In this experiment, we investigated the role of practice variability (constant versus variable practice) and practice schedule (random versus blocked practice) on spatial and temporal learning of a speech task as a function of aging. The participants were 80 healthy individuals (40–80 years) with no history of cognitive, sensory, or motor disorders. A median split was performed to divide the participants into older and younger groups. The median split was at 59 years of age, thus placing 40 participants in each age group. The participants were assigned to one of four practice groups and practiced a nonmeaningful phrase for two consecutive days. On the third day, the participants reproduced the speech phrase without practice. Data analysis revealed that older participants involved in constant practice demonstrated superior temporal learning of the speech task over participants on variable practice. Older participants on random practice demonstrated better spatial learning of the speech task than did participants on blocked practice. In contrast, there was no effect of practice conditions on spatial and temporal learning outcomes in the younger group. The findings indicate that practice variability and practice schedule influence different aspects of a complex speech-motor learning task among older adults but not among younger adults.

Keywords: aging, training, speech, motor learning, motor performance

Motor learning refers to processes that are associated with practice or experience resulting in relatively permanent changes in movement performance (Schmidt & Lee, 2011). Motor learning is an important psycho-physiological process that is essential to learn either novel motor skills (e.g., a golf swing) or to relearn lost motor skills (e.g., relearning to walk following a stroke) (Sul-

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livan, Kantak, & Burtner, 2008; Soderstrom & Bjork, 2015). In the context of motor learning, the individual performs certain motoric movements in a specific environment (Moreno-Briseño, Díaz, Campos-Romo, & Fernandez-Ruiz, 2010). The practice associated with performing these movements occurs during the acquisition phase of learning. An individual's performance during the acquisition phase is a precursor to the actual motor learning of a movement. Motor learning is determined during the retention phase. The usual way of assessing retention is to have an individual perform a practiced motor skill after a certain time interval of no practice. Principles of motor learning (PMLs) refer to a set of rules considered to facilitate the process of motor learning (Schmidt & Lee, 2011). 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 (Maas et al., 2008). The different practice conditions include practice variability (constant vs. variable), practice distribution (massed vs. distributed), practice schedule (random vs. blocked), attentional focus (external vs. internal), and target complexity (simple vs. complex). On the other hand, feedback condition include type, frequency, and timing of feedback (Maas et al., 2008).

The role of different practice conditions in the acquisition and retention of motor skills has been well investigated in studies related to non-speech-motor learning (Kantak & Winstein, 2012). The practice conditions that have received considerable attention in the motor learning literature are practice variability and practice schedule (Maas et al., 2008). Practice variability involves practicing different variations of a motor skill. A practice situation can either involve an individual practicing only one variant of a skill, referred to as the constant practice, or have the individual practicing more than one variation in the dimensions of a skill, referred to as variable practice (Breslin, Hodges, Steenson, & Williams, 2012). Most of the past studies investigating practice variability have found variable practice to favor motor learning over constant practice (e.g., Shea & Kohl, 1991; Shoenfelt, Synder, Maue, McDowell, & Woolard, 2002; Wulf & Schmidt, 1997). For example, Shoenfelt et al. compared the effects of constant and variable practice on shooting a basketball. The researchers found that 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.

Practice schedule refers to the order in which the practice stimulus is presented to the learner. Practice tasks can be scheduled either in a random manner (where the upcoming practice targets are unpredictable) or a blocked manner (where the learner practices the same set of motor movements before moving on to the next set; Schmidt & Lee, 2011). The majority of past studies comparing random versus blocked practice in motor learning have found random practice to be advantageous over blocked practice (Wright & Shea, 2001; Wrisberg & Liu, 1991; Sherwood, 1996). For example, Sherwood recruited 24 college students who were required to learn a rapid lever reversal movement so that the reversal point was 20 deg, 40 deg, 60 deg, or 80 deg. The participants were assigned to either random or blocked practice groups. All the participants practiced 90 trials of the task. Retention tests immediately after the acquisition phase and after 24 hr revealed that participants in the random practice group showed more spatial accuracy in comparison with the blocked practice group.

While the roles of practice variability (constant and variable practice) and practice schedule (random and blocked) have been clearly documented in non-speech-motor learning, surprisingly, there is limited evidence regarding the role of these practice conditions in speech-motor learning. There has been just one experiment that has investigated the effectiveness of practice variability in speech-motor learning. Adams and Page (2000) compared constant versus variable practice in a group of 40 healthy participants. One group of participants practiced 50 trials of the utterance “Buy Bobby a Poppy” with the target duration of 2.4 s (constant practice), and the other group practiced 50 trials of the same utterance with the target durations of 2.4 s and 3.6 s (variable practice). The participants underwent a retention test two days after the acquisition phase and produced the target utterance without further practice. 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 with the constant practice group.

As with practice variability, few studies have investigated the role of practice schedule in speech-motor learning. Scheiner, Sadagopan, and Sherwood (2014) compared the effects of random versus blocked on the learning of four novel speech utterances in 20 healthy individuals. The experiment lasted over two consecutive days. On the first day, participants in the blocked practice group produced each utterance 15 times in a row before producing the next utterance. Participants in the random practice group also produced each of the four utterances 15 times, but they produced the utterances in a random order. The second day served as the retention phase, during which the participants produced 10 trials of each of the four utterances without further practice or feedback. The researchers used behavioral as well as kinematic measures to measure the outcomes. The results revealed that, similarly to non-speech-motor learning, participants involved in random practice demonstrated significantly better retention of the novel utterances than participants involved in blocked practice.

With regard to clinical populations, more recently, Maas and Farinella (2012) compared random versus blocked practice in four children with childhood apraxia of speech (CAS) using alternating single-subject design with multiple baselines across behaviors. Participants were two males and females, aged 5.0–7.9 years. All four participants received the Dynamic Temporal and Tactile Cueing Approach to treat speech deficits associated with CAS. The speech targets that were selected for treatment were administered in a blocked as well as in a random fashion, so that each participant served as his/her own control. After the treatment, the researchers assessed the transfer effect of the treatment by asking participants to produce novel words. The findings were mixed, with two children benefitting from blocked practice, one child benefitting from random practice, and one child not benefitting from either practice condition.

Although it could be hypothesized that findings of non-speech-motor learning with regard to practice variability and schedule can be generalized to speech-motor learning, there is very limited empirical evidence to demonstrate this, considering the neurophysiological and biomechanical differences between the speech and nonspeech systems. This warrants the need for well-designed experimental studies that investigate the role of practice variability and practice schedule in speech-motor learning.

In addition, past studies investigating practice variability and schedule in speech-motor learning suffered from two major limitations (Adams & Page, 2000; Wong, Whitehill, Ma, & Masters, 2013). The first limitation concerned the lack of consideration of both spatial and temporal components for motor execution (e.g., Wong, Ma, & Yiu, 2011). The process of motor learning involves executing the spatial as well as temporal aspects of a desired motor skill. Spatial learning refers to learning the general movement characteristics of the motor skill. For example, spatial learning of a non-speech-motor task might involve learning to shoot a basketball accurately (Breslin et al., 2012), while an example of spatial learning for a speech-motor task would be learning correct articulatory placement for individual phonemes of a word. Temporal learning refers to learning the duration and/or pacing requirements of the motor skill. An example of temporal learning of a non-speech-motor task would be to shoot a basketball within a specified pace. Temporal learning of a speech-motor task would be to articulate phrases of a word within a specified duration. Georgopoulos (2002) suggested that each movement is made up of corresponding spatial and temporal characteristics that can be dissociated and controlled separately, and motor learning involves learning both aspects. There is also evidence to demonstrate the importance of achieving spatial as well as temporal accuracy during motor learning in individuals affected with stroke (Boyd & Winstein, 2004). It is possible that overlooking either one of these aspects may not accurately reflect the nature of motor learning. Therefore, measuring both spatial and temporal aspects of performance captures the entirety of motor learning.

The second limitation is that speech-motor learning has not been systematically investigated as a function of the age of the learner. Previous studies investigating non-speech-motor learning have found that effects of practice conditions can vary based on the age of the learner (Jamieson & Rogers, 2000; Perrot & Bertsch, 2007; Pauwels, Vancleef, Swinnen, & Beets, 2015). A hallmark characteristic of aging is the decline in cognitive-motor performance (Gunning-Dixon & Raz, 2000; Cook, Brauer, & Woollacott, 2000). Old age is accompanied by changes in the speech-motor system such as deterioration in the physiological functioning of oral motor structures (e.g., tongue) (Calhoun, Gibson, Hartley, Minton, & Hokanson, 1992), fluency breakdowns (Searl, Gabel, & Fulks, 2002), and a decrease in articulation rate (Jacewicz, Fox, O'Neill, & Salmons, 2009). So it is likely that effects of practice condition on speech-motor learning can be influenced by the learner's age. However, this aspect has not been investigated, and it is essential to pursue this line of research to understand the aging effects on speech-motor learning.

The Present Experiment

The effectiveness of practice variability and practice schedule has been documented for a range of non-speech-motor learning tasks. However, considerably less evidence is available regarding the effectiveness of these PMLs for speech-motor learning, especially with respect to temporal and spatial learning. We considered it highly desirable to conduct a well-designed experiment to investigate the specific role of practice variability (constant versus variable) as well as practice schedule (random versus blocked) in speech-motor learning. Another aspect that can confound this line of research is the age of the learner, so we systematically investigated speech-motor learning as a function of the age of the learner in practice variability as well as practice schedule groups.

Method

Participants

Eighty healthy individuals (21 males and 59 females) in the age range of 40–80 years (*M* = 59, *SD* = 8.81) served as participants. Participants were recruited based on a nonprobability convenience sampling and were not matched according to sex. The inclusion criteria were (1) no reported history of sensory, motor, or cognitive abnormalities, (2) right-handedness, (3) being a native speaker of English, and (4) completion of a high school diploma. The 80 participants were randomly and equally assigned to two practice conditions representing practice variability (constant and variable practice) as well as to the two practice conditions that represented practice schedule (random and blocked). Thus, there were 20 participants in each of the four practice conditions. The mean age of the participants in each practice condition ranged from 58 years (variable group) to 61 years (constant group).

Participants were recruited by convenience sampling, and we did not have an a priori specific cutoff age for the older and younger groups. Following recruitment, we performed a median split to separate participants equally into older and younger age groups. 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 ages of the participants in the younger group ranged from 42 to 59 years (*M* = 52.2, *SD* = 4.9), and in the older group, they ranged from 60 to 78 years (*M* = 67.3, *SD* = 5.4). The distribution of age and sex for the older and younger participants in each of the four practice conditions are presented in Table 1. The appropriate regional ethics committee approved the current experiment and all participants provided written consent.

Speech Stimuli

The participants in each of the four practice conditions were trained on the target speech phrase "Thak glers wur vasing veen arad moovly." A nonmeaningful phrase was chosen as the stimulus for training based on the challenge point framework (CPF; Guadagnoli & Lee, 2004). According to CPF, a task or a skill is more likely to be learned if it is sufficiently challenging and difficult. The phrase was specifically designed to address both spatial and temporal aspects of motor learning. The spatial aspect of the phrase was addressed by requiring participants to execute a variety of speech sound articulations that do not represent known words. The phrase still adhered to English phonotactic constraints. The temporal domain of the phrase was designed to require participants to produce the phrase that was split into three segments based on temporal pauses, which served as boundaries.

Table 1 Demographic Details of Older and Younger Participants in Each of the Four Practice Conditions

	Practice variability				Practice schedule			
	Constant		Variable		Random		Blocked	
Participants	Age	Sex	Age	Sex	Age	Sex	Age	Sex
1	46	F	42	F	44	M	44	M
2	46	M	44	F	46	F	45	F
3	48	F	49	F	49	M	48	F
4	51	F	51	F	50	F	52	F
5	53	F	52	F	52	F	57	F
6	56	F	54	M	52	F	57	F
7	56	F	55	F	52	M	57	F
8	57	F	55	F	55	F	58	F
9	57	F	56	F	55	F	58	F
10	60	M	57	F	57	M	59	M
11	61	F	59	F	62	F	61	M
12	62	F	60	F	62	F	62	F
13	64	F	61	F	63	F	63	F
14	64	F	62	M	65	F	64	F
15	67	F	63	F	65	M	64	M
16	71	F	64	M	70	M	64	M
17	71	F	65	M	71	F	71	M
18	71	F	70	M	72	M	72	F
19	73	F	71	F	73	F	72	F
20	78	F	72	F	73	M	75	F
M	59.6	—	57.3	—	58.6	—	59.3	—
SD	9.3	—	8.2	—	9.4	—	8.6	—

Two alternate speech tasks were created. The first alternate phrase consisted of the same nonwords as the target speech phrase but of different temporal duration. This phrase was used for the variable practice condition. The second alternate phrase was "Ang haky deebs reciled tofently roovly." This phrase was used for random and blocked practice conditions. In the current experiment, the phonemic composition as well as duration were varied between the target and second alternate phrases to alter the motor plan of the two phrases. The suitability of including the target and alternate phrases was determined through a pilot experiment. The findings of the pilot experiment indicated that the participants were able to learn the phrases but still found it challenging, thus ruling out floor and ceiling effects. Visual illustrations of the target and alternate speech phrases indicating their temporal boundaries are provided in the Figure 1. For task training, the target phrase and alternate phrases were prerecorded by a young-adult male speaker of New Zealand English.

Procedure

Participants in each of the four practice conditions were involved in a practice regimen of 50 trials per day on two consecutive days to learn the target task. A short prepractice session preceded the practice trials on both days of the

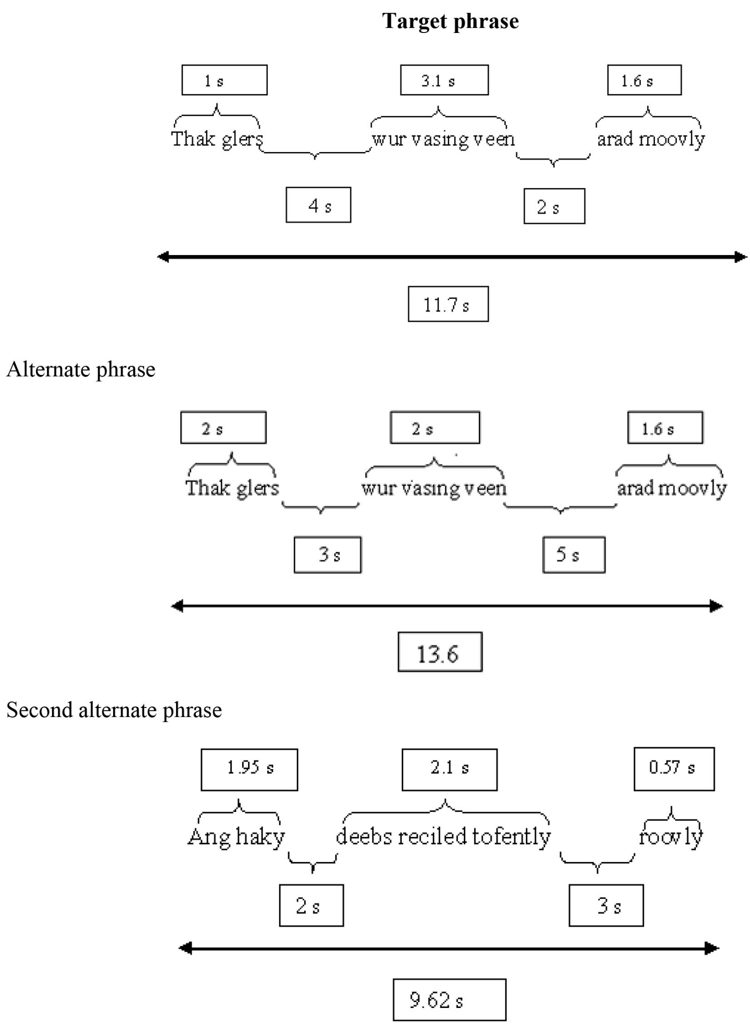

Figure 1 — Schematic representation of the target, alternate, and second alternate phrases.

acquisition phase. A prepractice session is important to prepare the learner for the actual practice session (Schmidt & Lee, 2011). During the prepractice session, participants were seated in front of a 19-inch computer screen, instructed on the goals of the practice and retention sessions, and motivated to learn the task. Specifically, the participants were instructed to match their production to the target as accurately as possible in terms of both spatial and temporal characteristics during the practice trials. The instructions were:

> In this experiment, you will be required to practice a non-meaningful phrase accurately as well as within a certain duration. The phrase is 12 s long, and is divided into three segments of words that are each separated by an interval of 4 s and 2 s, respectively. You will be shown the phrase on the computer screen accompanied by the audio recording of the phrase. Please make sure you articulate the words and pace them accordingly so that they exactly match the audio recording, as well as the visual example of this phrase on the computer screen.

Each prepractice session lasted 15 min. The practice regimen was carried out via a PowerPoint presentation. Each slide in the PowerPoint presentation provided visual representation of the required speech phrase on the computer monitor. This display was accompanied by an audio presentation of the phrase through computer loudspeakers. The volume of the loudspeakers was set at a comfortable loudness level for each participant. Fifty slides were used to complete 50 practice trials. The visual and auditory representations of the speech phrase contained words as well as the word and pause durations for the entire phrase as shown in Figure 1. The complete production following the provision of orthographic/visual and auditory representations comprised one practice trial. The screen remained constant during the speaker's entire production attempt.

At the conclusion of each 10th trial, participants were provided with summary feedback on their performance. There was a break of 5 min, during which time the researcher measured the spatial and temporal accuracy of the 10th trial. 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, the researcher also perceptually assessed the articulatory accuracy of the phonemes produced by the participants. This information was then shared with the participants. Confining feedback to every 10th production was based on earlier pilot work, which found that the 10th production seemed to reflect the cumulative performance of the previous nine trials in terms of spatial and temporal accuracy. Feedback was provided to the participants by displaying the target phrase on a sheet of A4 paper. 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 such as "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 analyzed the participants' productions and indicated whether the individual phonemes were articulated correctly in comparison with the target phrase. Thus, the nature of feedback was low frequency, knowledge of results, knowledge of performance, and delayed. Across the two consecutive days of practice, there were a total of 100 trials, and each participant received 10 instances of feedback on their production of the phrase. For participants in the variable, blocked, or random conditions, they received feedback on the nontarget phrase if it happened to occur on a 10th trial.

The entire experiment took place over three consecutive days. The first two days served as the acquisition phase, lasting 60–90 min each day. The third day was the retention phase, during which the participants returned to the laboratory and were required to produce the target phrase without practice or feedback. All task attempts during the retention phase were audio-recorded using a desktop condenser microphone (DSE-PC). The mouth-to-microphone distance was kept constant at about 14 cm. The output acoustic signal from the microphone was fed into a laptop computer (Lenovo IdeaPadS10e) running an acoustic analysis software program (Audacity 1.3). These recordings were later used for acoustic analyses. The retention phase lasted 10–15 min.

The procedures of practice for each of the practice conditions representing practice variability as well as practice schedule are detailed below. A depiction of the acquisition and retention phases for the four practice conditions is given in Figure 2.

Practice Variability

Constant Practice. During the acquisition phase, the participants practiced 50 trials of the target task in a repeated manner each day, and received feedback after

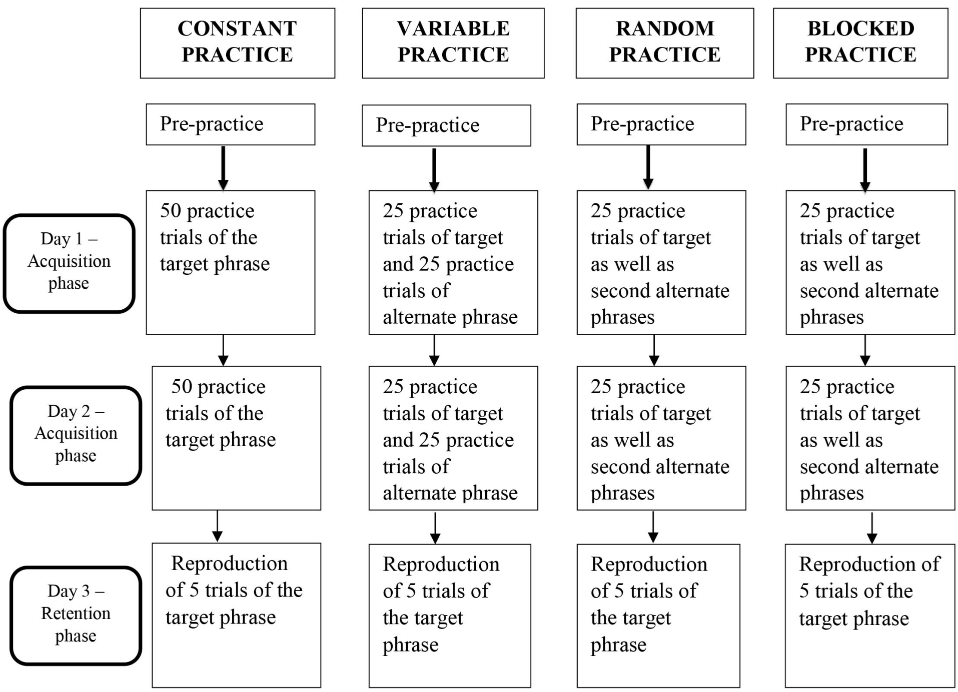

Figure 2 — Schematic depiction of the acquisition and retention phases for the four practice conditions.

each set of 10 trials. During the retention phase, participants produced five trials of the target phrase without practice or feedback.

Variable Practice. To satisfy the criteria of variable practice, participants practiced 25 trials of the target phrase and 25 trials of the alternate phrase (50 trials in total) during each day of the acquisition phase. This arrangement resulted in participants receiving three instances of feedback on the target phrase and two instances of feedback on the alternate phrase at the end of 50 trials on the first day. This was reversed on the second day, so that by the end of acquisition phase each participant had received five instances of feedback trials for both the target and alternate phrases. The practice sequence and the order of receiving feedback of the target and alternate phrases were randomized across 100 trials as well as among the participants. During the retention phase, the participants produced five trials of the target phrase.

Practice Schedule

Random Practice. Participants practiced 25 trials of the second alternate speech phrase in addition to 25 trials of the target speech phrase. An equal number of target and alternate phrases were randomized across 100 trials. The manner of practice, feedback provision, and retention phase were similar to those of the variable practice condition.

Blocked Practice. Participants practiced the target speech phrase in trials 1–25 and the alternate phrase in trials 26–50. The order was reversed on the second day. Feedback at the end of the 30th trial was based on the task that was practiced in trials 25–30. The procedure of feedback provision was similar to that of the other practice conditions. This resulted in each participant receiving five instances of feedback on the target phrase and five instances of feedback on the second alternate phrase at the end of the acquisition phase. The retention phase on the third day followed a similar procedure to that of the random practice condition.

Data Analysis

The five trials of the target speech phrase obtained from each participant during the retention phase only were analyzed. A previous experiment used a similar analysis approach to estimate speech-motor learning in healthy participants (Adams & Page, 2000). The data were analyzed according to spatial and temporal features of production accuracy as a function of the learner's age.

Spatial Analysis. Spatial analysis of the speech task involved evaluation of production accuracy of the target speech phrase by calculating the percentage of phonemes correct (PPC; Shriberg, Austin, Lewis, McSweeny, & Wilson, 1997). This measure has been shown to be effective as an outcome measure in studies related to nonword repetition (Dollaghan & Campbell, 1998). During the retention phase, each of the five production trials of the target phrase for all participants was transcribed verbatim using the International Phonetic Alphabet. The PPC was calculated by dividing the number of correct phonemes by the total number of phonemes, and multiplying it by 100. Correct production of a phoneme required it to be within normal perceptible limits. Instances of phoneme distortion, substitution, addition (including epenthesis), and omission were considered to be incorrect productions. Differences in production as a result of dialectal variations were not penalized. A mean PPC was obtained from the final five retention trials of each participant, as well as a group mean for the 20 participants in each practice group.

Temporal Analysis. Temporal analysis focused on calculating the synchrony of productions of the speech phrase during the retention trials in comparison with the original example of the target phrase. Productions during the retention trials, as well as the original example of the target phrase, were digitized at 44 KHz and simultaneously displayed on a computer monitor as amplitude-by-time waveforms. Each production trial was horizontally aligned with the target phrase based on the onset points of the two waveforms. The onset point was the same for the production and original waveforms. The offset point of the production waveforms was based on the offset of the original target waveform. If the participant's productions extended beyond the duration of the target waveform, the extra portion of the waveform was truncated and excluded from the analysis. After the alignment, a pair of vertical cursors was placed at the onset and offset points. The portion of the two waveforms between the vertical cursors was converted into binary values. The process of converting the waveforms into binary plots was carried out by a MATLAB-based program, with the steps as follows:

1. The digitized waveforms of the target phrase yielded 514,800 samples. The number of samples for the participant productions during the retention trials ranged from 264,000 to 500,000.
2. The next step involved rectifying and smoothing the target waveforms as well as the waveforms of the participant productions.
3. Following the rectification and smoothing, a threshold was set at 10% of the waveform's amplitude to arrive at the binary values. The portion of the waveform that was above the threshold was converted to 1s and part of the waveform below the threshold value was converted to 0s. Setting a cutoff threshold of 10% limited the inclusion of the extraneous noises (such as breathing) in the signal.
4. The binary values were used to calculate the phi correlation between the participant productions and the target phrase to determine the temporal synchrony, and also to yield a binary plot. A mean phi correlation was obtained from each of the final five trials for each participant. A grand mean phi correlation value was calculated for the 20 participants in each of the four practice conditions. An example of the temporal synchrony between the waveform of a participant's production during the retention trial and the target waveform is given in Figure 3.

Statistical Analysis

Two different statistical analyses were conducted. The first set of analysis compared the spatial as well as temporal learning between participants involved in constant and variable practice as a function of the age of the learner. For spatial learning, the PPC values of the older and younger participants were subjected to a two-way analysis of variance (ANOVA; 2 age groups * 2 practice conditions). Similarly,

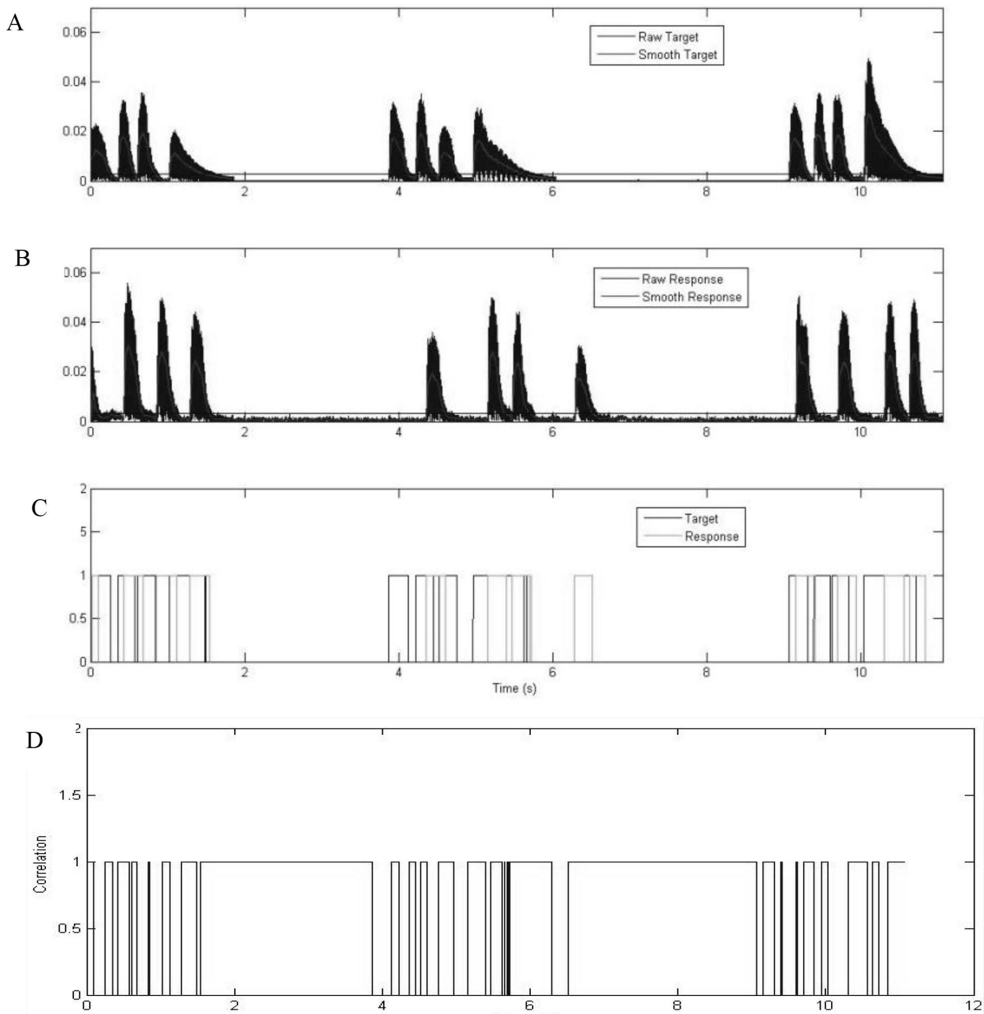

Figure 3 — An illustration of temporal synchrony between the waveform of a participant's production during the retention trial and the target waveform. Panel A depicts the target waveform after rectification and low-pass filtering. The lighter trace indicates the smoothed version of the waveform, and the horizontal line depicts the 10% threshold. Panel B depicts the waveform of the participant's production after rectification and low-pass filtering. The lighter trace indicates the smoothed version of the waveform, and the horizontal line depicts the 10% threshold. Panel C depicts the binary plots of the waveforms of the target task and the participant's 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.

for temporal learning, the phi correlation values of older and younger participants were subjected to a two-way ANOVA (2 age groups * 2 practice conditions). The second set of analyses analyzed the outcomes of participants involved in random versus blocked practice as a function of the age of the learner. The spatial analysis involved subjecting the PPC values of the younger and older participants to a two-way ANOVA (2 age groups * 2 practice conditions), and the temporal analysis subjected the phi correlation values to a two-way ANOVA as well (2 age groups * 2 practice conditions). This allowed investigation of main effect of practice, main effect of age, and possible interaction between age and practice condition.

Measurement Reliability

Intrarater measurement reliability for calculation of the spatial and temporal measures was based on randomly choosing and remeasuring 20% of the data (i.e., 16 of 80 participants) and performing a Pearson correlation. The intrarater reliability of the spatial analysis between the original and remeasured data ranged from $r = .91$ to $r = .99$, ($p < .01$). The correlation between the original and remeasured data for the temporal analysis ranged from $r = .99$ to $r = 1.00$ ($p < .01$).

Results

The results are presented based on the outcomes of participants involved in practice conditions that represented practice variability and practice schedule.

Practice Variability

Spatial Learning. The PPC values for the younger and older age groups in constant as well as variable practice conditions are shown in Table 2. The marginal PPC means of the participants in constant and variable practice conditions as well as the two age groups are presented in Figure 4. The results of two-way ANOVA showed that there was no significant main effect for practice condition, $F(1, 36) = 1.45$, $p = .23$, or age, $F(1, 36) = 10.29$, $p = .58$. There was also no significant interaction effect.

Temporal Learning. The mean phi correlation values for the younger and older age groups in constant as well as variable practice conditions are shown in Table 3. The marginal phi correlation means of the constant and variable practice conditions as well as the two age groups are presented in Figure 4. The results of two-way ANOVA revealed a main effect of practice condition, $F(1, 36) = 5.22$, $p = .02$, with the constant group ($M = 0.33$, $SD = 0.17$) demonstrating better learning outcome than the variable group ($M = 0.21$, $SD = 0.21$), but there was no main effect of age, $F(1, 36) = 0.42$, $p = .51$. The main effect was qualified by an interaction between age and practice condition, $F(1, 36) = 11.06$, $p = .002$. This interaction was followed up with Tukey HSD test, and the results revealed that older participants in the constant practice condition demonstrated superior learning of the temporal task than did participants involved in variable practice, $p < .001$. But there was no significant difference between the practice conditions among the younger participants.

Table 2 Distribution of Percentage of Phoneme Correct Values (%) in the Younger and Older Age Groups for the Speech Task Across Four Practice Conditions Representing Practice Variability and Practice Schedule[1]

	Practice variability				Practice schedule			
	Constant		Variable		Random		Blocked	
Participants	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

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

Practice Schedule

Spatial Learning. The PPC values for the younger and older age groups in random and blocked practice conditions are presented in Table 2. The marginal PPC means of the participants in random and blocked practice conditions as well as the two age groups are presented in Figure 5. The results of two-way ANOVA indicated a main effect of practice condition, $F(1, 36) = 6.48$, $p = .01$, with participants in the random practice condition ($M = 91.14$, $SD = 10.39$) demonstrating superior learning over participants involved in blocked practice ($M = 77.58$, $SD = 25.19$). There was also a main effect of age, $F(1, 36) = 9.17$, $p = .05$, wherein younger participants ($M = 92.43$, $SD = 10.75$) demonstrated better learning than older participants ($M = 76.29$, $SD = 24.22$). These main effects were qualified by a significant interaction effect between practice condition and age, $F(1, 36) = 6.48$, $p = .01$. The results of follow-up Tukey HSD test revealed that older participants in random practice condition demonstrated superior spatial learning than did participants in the blocked practice condition, $p < .01$. However, there was no significant difference between random and blocked practice conditions among the younger group participants.

A

B

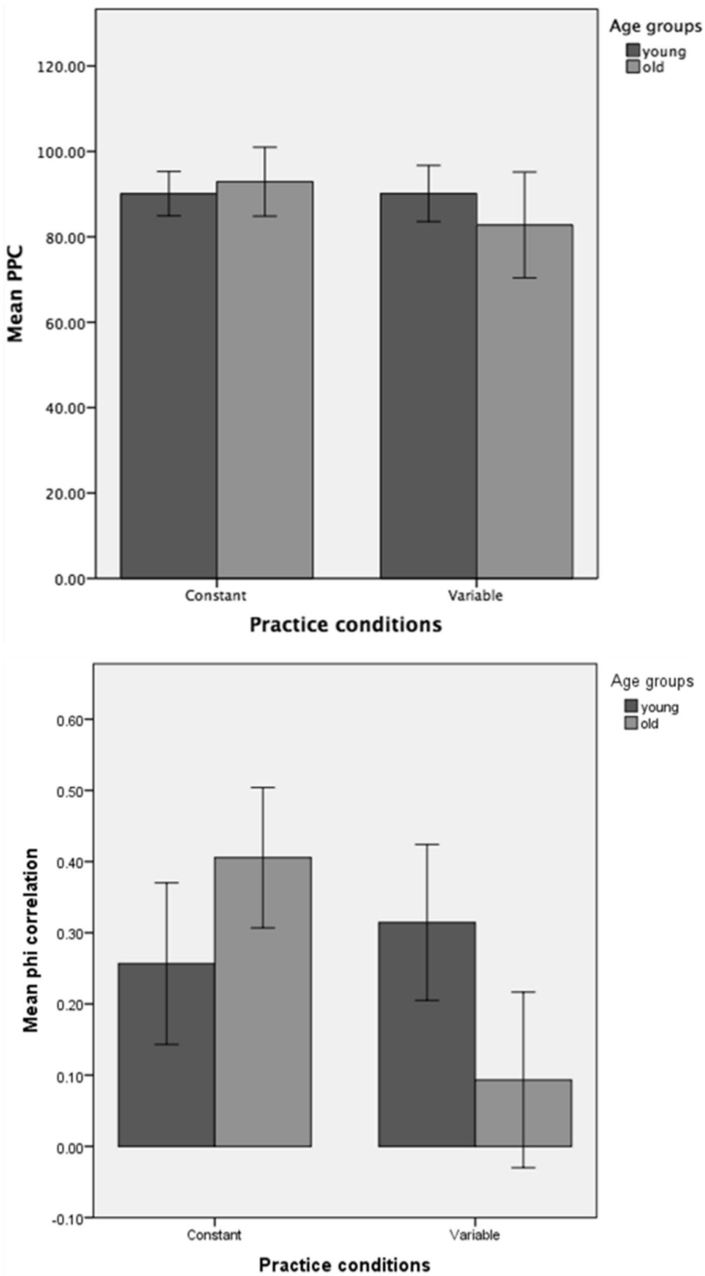

Figure 4 — The marginal means of the participants in constant and variable practice conditions as well as the two age groups. Panel A depicts the marginal PPC means, and Panel B depicts marginal means of phi correlation values. Errors bars represent two standard errors of variability.

Table 3 Distribution of Phi Correlation Values in the Younger and Older Age Groups for the Speech Task Across Four Practice Conditions Representing Practice Variability and Practice Schedule

	Practice variability				Practice schedule			
	Constant		Variable		Random		Blocked	
Participants	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

Temporal Learning. The mean phi correlation values for the younger and older age groups in random as well as blocked practice conditions are shown in Table 3. The marginal phi correlation means of the participants in random and blocked practice conditions as well as the two age groups are presented in Figure 5. The results of two-way ANOVA revealed a main effect of age, $F(1, 36) = 5.48$, $p = .02$, with the younger participants ($M = 0.27$, $SD = 0.15$) having learned the temporal task better than the older participants ($M = 0.15$, $SD = 0.17$). There was no significant main effect for practice condition, $F(1, 36) = 0.02$, $p = .86$, and no significant interaction effect.

Discussion

The research presented is novel in a few different ways. First, this is the first experiment to investigate the role of practice variability as well as practice schedule in learning a novel speech task. Second, the current experiment also measured the spatial and temporal aspects of speech-motor learning, which has not been examined thus far. Finally, an important aspect the current experiment considered was the age of the learner with regard to speech-motor learning. The results of spatial and temporal learning are discussed within the context of nature of practice as well as age effects.

A

B

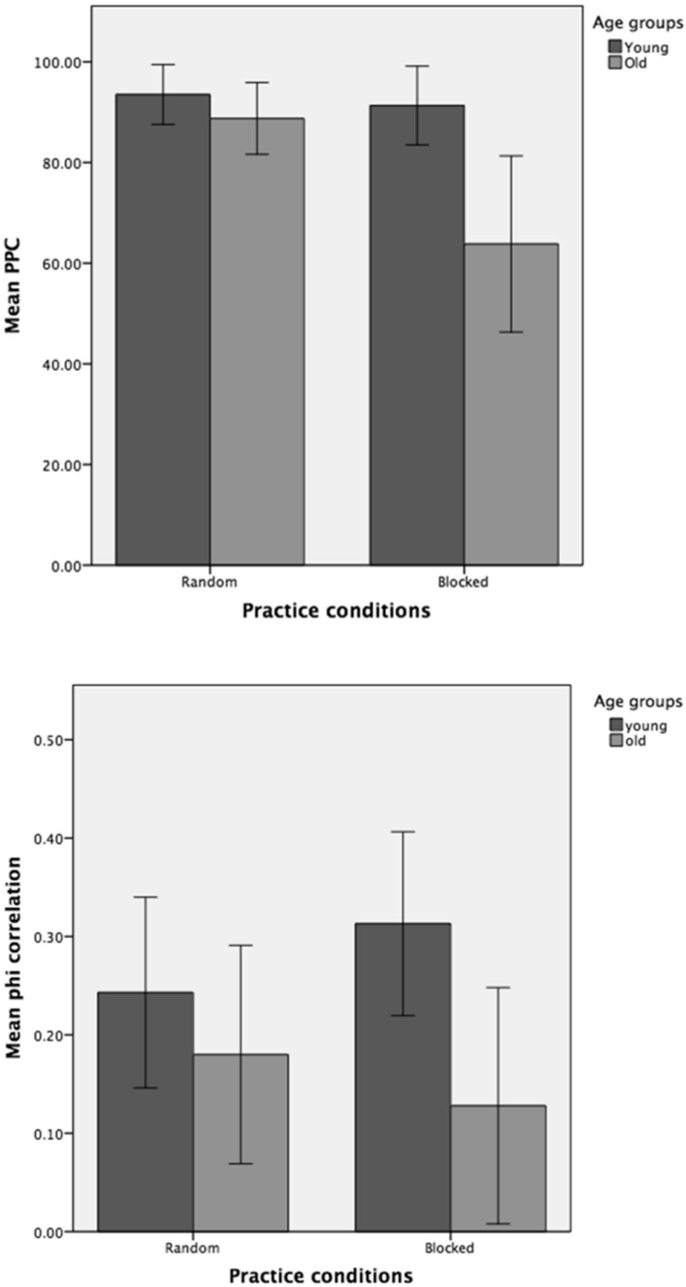

Figure 5 — The marginal means of the participants in random and blocked practice conditions as well as the two age groups. Panel A depicts the marginal PPC means, and Panel B depicts marginal means of phi correlation values. Errors bars represent two standard errors of variability.

Practice Variability

Overall, we found that, irrespective of age, there was no superiority for either constant or variable practice in spatial learning of novel speech utterances. On the other hand, older participants benefitted more from constant practice than from variable practice in temporal learning of the target speech phrase, as opposed to the younger participants, for whom there was no difference. As a part of a larger experiment, Adams and Page (2000) investigated the role of constant versus variable practice in temporal learning of a meaningful phrase among a group of 20 young healthy individuals aged 21–40 years. The participants were randomly assigned to either the constant or variable practice condition. The participants in both practice groups were asked to learn the production of a 2.4 s utterance (“Buy Bobby a Poppy”). The constant practice group practiced the utterance in a block of 50 trials. In contrast, participants in the variable practice group practiced production of a 2.4 s utterance as well as a 3.6 s utterance in blocks of 25 practice trials each. The retention results after two days of practice revealed that participants in the variable practice group learned the temporal task better than did participants in the constant practice group.

Although the current experiment was similar to Adam and Page’s experiment in terms of temporal learning task, practice conditions employed, and the practice amount involved in both the practice conditions, the findings of the current experiment conflict with those of Adam and Page’s. It is essential to examine the experimental variables that could have contributed to these differences in learning outcomes between the two studies. The effects of skill difficulty and skill characteristics on motor learning have been well established (Bortoli, Robazza, Durigon, & Carra, 1992). The participants in Adam and Page’s experiment were required to learn to produce a simple meaningful phrase, whereas participants in the current experiment were asked to focus on both spatial and temporal performance of learning of a complex nonmeaningful utterance. It is possible that as the complexity of the task increases, a practice regimen such as constant practice, which allows participants to practice the same task without any other interference, could be beneficial over variable practice, which requires participants to practice two or more variations of the task. Given the problems with dual task performance among older adults (Voelcker-Rehage & Alberts, 2007), it is not surprising that older participants in the current experiment benefitted from the constant practice regimen, compared with younger participants. Notwithstanding, both the younger and older participants had similar spatial learning outcomes on constant and variable practice. Although participants involved in the variable practice condition practiced two temporal variants of the target phrase, they practiced just one spatial variant of the target phrase. So participants in constant as well as variable practice were involved in similar practice styles and amounts with regard to spatial learning. This would seem to account for lack of differences between constant and variable practice for both older and younger participants.

Practice Schedule

The results of the practice schedule with regard to spatial learning indicated that older participants involved in random practice demonstrated superior learning over participants involved in blocked practice. However, there was no difference in learning outcomes among younger participants involved in random and blocked practice. In the case of temporal learning, both older and younger participants in blocked and random practice demonstrated similar learning outcomes.

Scheiner et al. (2014) compared the effects of blocked versus random practice on learning novel nonword utterances. In that experiment, participants in blocked as well as random practice conditions practiced a comparable amount of four novel nonword utterances. The retention test after one day revealed that participants involved in random practice had better learning outcomes than participants in blocked practice. The findings of the current experiment with regard to older participants are in close agreement with the findings of Scheiner et al. The role of contextual interference (CI) in motor learning was first demonstrated by Battig (1972) in a verbal learning task. CI is a learning phenomenon wherein the interference caused due to practicing different tasks within the same practice session proves to be beneficial (Magill & Hall, 1990). It is well known that older adults present with cognitive-motor deficits (Jamieson & Rogers, 2000), so it is likely that the older participants in the current experiment needed to be cognitively engaged through the end of the practice and benefitted from the greater CI effect intrinsic in random practice. However, the CI effect offered by random practice did not benefit younger participants.

In the case of temporal learning, both the younger and older participants benefitted similarly from random and blocked practice. Although the reason for a lack of superiority of random practice in spatial learning among younger adults and in temporal learning for both age groups is unclear, it is possible that the cognitive advantages offered by random practice may not be generalizable across all age groups and learning tasks.

It is interesting that only the older participants were influenced by practice conditions, and not the younger participants. Research pertaining to speech-motor learning is still at its infancy and is marred by several variables. An important variable that is likely to influence the speech-motor learning outcomes is the speech stimuli used for training purposes. So it is important to interpret the findings of the current experiment based on the stimuli that were used for training purposes. The notion of speed-accuracy trade-off (SAT) among older adults is commonly implicated in motor learning research (Forstmann, Tittgemeyer, Wagenmakers, Derrfuss, Imperati, & Brown, 2011). In a typical SAT situation, the speed of the motor skill is reduced when focus is on accuracy and vice versa (Schmidt & Lee, 2011). The older participants in the current experiment demonstrated a spatial-temporal trade-off, in an analogy to the notion of SAT. It appears that if older participants are confronted with a learning task that is too complex, as might well be the case in the current experiment, they might focus either on the temporal or spatial aspect of the task, but not on both. So, perhaps, it is not surprising that the older participants in constant practice focused on temporal learning, whereas the older participants in random practice focused on spatial learning. However, future studies need to confirm if temporal and spatial learning of similar complex speech-motor tasks are consistently facilitated by constant and random practice, respectively, among older adults. A possible reason for this trend not being seen in the younger group is that they may have been (as was asked) correctly aiming to achieve both spatial and temporal accuracy, in which case, no practice condition was more beneficial than another for achieving both spatial and temporal accuracy. Another caveat is that the results of the current experiment need to be interpreted in the context of the age ranges of the two groups. While the age range of the older participants in the current experiment (60–78 years) resembles those in most of the previous studies investigating speech and non-speech-motor learning, the age range of the younger participants (42–59 years) was higher than those in some of the previous research (e.g., Perrot & Bertsch, 2007, in which the age range of the younger group age was 20–30 years, whereas the age range of the older group was 61–75 years).

Limitations

The current experiment is not without its limitations. There were substantially more female participants (n = 59) than male participants (n = 21). Traditionally, manual tasks (e.g., finger tapping) have found a male advantage, but in tasks requiring complex motor planning (e.g., as in the current experiment), there can be a female advantage (Dorfberger, Adi-Japha, & Karni, 2009; Kennedy & Raz, 2005). Although sex differences in learning novel utterances have not been systematically analyzed, it is possible that the higher proportion of female participants influenced the current results.

A novel method of temporal performance estimation was developed for the present experiment by evaluating temporal synchrony. This method is a departure from previous studies measuring relative or absolute durations. The low correlations found using the temporal synchrony measure would suggest that it might not be sensitive to the subtle aspects of temporal learning that may have otherwise been measured.

Finally, it is important to recognize that the acquisition phase was based on a 2-day training period and that retention was assessed on the following day. Past studies investigating speech-motor learning have assessed retention following an acquisition phase ranging from 2 days to 1 week (Adams & Page, 2000; Pendt, Reuter, & Müller, 2011; Rostami & Ashayeri, 2009). In the present experiment, additional training of the participants may have resulted in improved/increased temporal learning of the speech task. Similarly, assessing retention after an interval of more than 24 hr may also have influenced the results.

Conclusion

Despite some limitations, the current experiment has important scientific as well as clinical implications for age-related changes in speech-motor learning. The findings of this experiment suggest that practice variability and practice schedule facilitate different aspects of a complex speech-motor learning task among older adults. Constant practice is superior to variable practice in learning the temporal aspect of a speech task, whereas random practice is more beneficial than blocked practice in learning the spatial aspect of a speech task. Collectively, our findings suggest that some of the PMLs traditionally considered to facilitate non-speech-motor learning cannot be generalized to speech-motor learning tasks. It is important for clinicians to be cognizant that factors such as task complexity and the amount of practice associated with that task need to be accounted for when designing speech therapy protocols incorporating different practice variables.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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