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Original Article

The Role of Errors based on the Complexity in Learning a Motor Sequential Task in Elderly Women

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Introduction: One of the most important topics in the field of movement behavior is the acquisition of movement sequences, which is an important part of every person's life and the basis of many intelligent human behaviors. The aim of the study was to investigate the effectiveness of errorfull and errorless training based on complexity in the acquisition, retention and transfer of a motor sequential task in elderly women with emphasis on processing needs.

Methods: This semi-experimental study was conducted on 30 healthy elderly women over 60 years of age that were selected and randomly allocated into errorless and errorful groups. Then, they performed a sequence motor task assigned by the Serial Reaction Time Task software in the three phases of acquisition, retention, and transfer. In order to analyze the data, ANOVA with repeated measures, Wilcoxon test, Mann-Whitney U test and the independent samples t-test were conducted.

Results: A significant improvement was seen in the reaction time and the number of errors in both groups ($p < 0.05$). Also, the errorless group recorded a shorter reaction time than the errorful group in the acquisition, retention and transfer tests. However, the errorful group made fewer errors in the retention and transfer tests than the errorless group.

Conclusion: Errorfull and errorless training are effective on reaction time and amount of errors in the retention and transfer stages of a motor sequential task in elderly women. However, It is suggested that trainers use errorfull training methods in motor sequential tasks in order to reduce the error rate and provide a more optimal learning environment.

Keywords: Error, Complexity, Motor Sequential Task, Processing Load, Aged

Introduction

Scientists believe that human beings can perform tasks optimally until the end of the third decade of their lives, after which the process of neuronal destruction begins and cognitive and motor functions decline (1). In addition, with the development of medical, economic and social sciences nowadays, the world's population is aging (2). According to the World Health Organization, the age over sixty is considered old age, which is accompanied by changes in physiological, psychological and sociological dimensions (3). Given this, the elderly begins to suffer disorders in the sensorimotor system as well as cognitive and perceptual functions along with reduced ability and adaptability to sudden changes (4). Cognitive disorders occur in attention, memory, orientation, executive function, judgment, and problem-solving skills (5).

Research has shown that, although cognitive decline is an inevitable part of normal aging, it varies among the elderly. Of cognitive functions, executive control processes and the areas of the brain that support them

undergo the greatest decline of age-related functions (6). The aging process leads to a decrease in cerebellar function and the pre-motor cortex. Because the cerebellum regularly monitors and corrects sequential programming activities and given that learning a sequence is highly dependent on the integration of neural networks in the cerebellum, elderly people may have poor performance in motor sequences (7). According to Lin et al., (8), old people are slower at learning a sequence than the young.

One of the methods of measuring motor learning is motor sequence testing. Motor sequence is the process of movement in which discrete motions are grouped together so that they can be performed as a frequent and smooth sequence (9). In other words, the components of each movement are arranged in a specific order to achieve a desirable movement goal (10). Motor sequence forms the basis of many intelligent human behaviors, because the components of each movement appear in a specific order to achieve the desired movement goal (For example, dialing a phone number). Since the learning process is a motor skill, motor sequence learning can be examined as a representative of other types of motor learning (11). Indeed, motor sequence examination is a good way to become aware of age-related changes (12).

Some researchers such as Fraser et al., (13) have shown that the rate of sequence learning is similar among young people and the elderly, but older people show less progress during the practice process or it takes them longer to achieve similar performance compared to young people. In this regard, King et al., (9) found that the elderly could perform simple motor sequences like the young, but, as the task became more complex, the elderly made more errors than the young group. In other words, the more complex the sequence was, the slower the performance, and the more errors.

The storage and retention of information for future use is called memory (14). Any system that records and stores information is a kind of memory. Thus, as memory declines in the elderly, a decrease occurs in their ability to perform motor sequences (15). According to Schmidt (16), learning results from a series of relatively sustained changes that stem from experience and practice. There are various ways to organize practices for better learning (17). One way is to perform practices with or without errors, in which the number of errors is determined by the increase or decrease of the complexity of the practice.

There are views that assume errors beneficial for learning skills (18, 19), while there are other views suggesting that making errors can delay learning motor programs (20, 21). In errorless learning, the practice conditions in the acquisition phase are manipulated to minimize possible errors during the learner's performing of motor skills. Since it reduces the amount of attention paid to the explicit processing of rules, errorless learning is believed to arise from the lack of dependence on conscious processing to identify and eliminate errors (21).

According to Adams (22), during practice, errors weaken the correct perceptual trace, while errorless practices reinforce the perceptual trace and create effective learning. Masters and Maxwell's reinvestment theory (23, 24) states that the reduction of errors in practice leads to the learning of the corresponding skill under latent conditions such that, under stress or a dual task, performing motor skills will not be disturbed by external factors. The existence of many errors in practice leads to the use of conscious mechanisms so as to acquire the intended skill. In times of stress or dual tasks, it causes investment or the repeated recall of those mechanisms, and the performing of the task tangibly deteriorates (20).

Some studies have shown that reducing errors is critical, especially in the early stages of learning. This is because it eliminates the use of working memory to consciously identify and correct errors and leads to better learning (25). On the other hand, some scientists introduce errorful motor learning as an appropriate practicing method for learning.

Errorful practice conditions provide the learner with opportunities to choose the correct movement pattern, which is carried out through gaining different experiences and derived from practice and overcoming errors (26, 27). According to the schema theory proposed by Schmidt (16), there are two memories, including recognition memory to produce action and recognition memory to evaluate movement. In this theory, the errors made during movement lead to better motor schema formation. So, practice with error leads to better schema formation and, hence, better learning. In other words, the schema theory considers errors effective in motor learning. Schmidt sees all successful and unsuccessful trials in practice as building blocks, which gradually build up strength and ultimately create a set of rules that play a positive role in motor learning.

The challenge point hypothesis made by Guadagnoli (28) also holds that, as the challenge of a task or the conditions under which a task is performed increase, so does learning.

Considering that one of the important goals of research on human motor learning is to identify the type of practice that maximizes the learning of motor skills, researchers have recently addressed this issue by manipulating various variables. Also, due to the importance and novelty of learning motor sequence (18, 29, 30), the contradictory results, and the lack of the precise knowledge of researchers about the appropriate level of complexity in the task, there is a need for more research in this regard. So far, little research has been done in this area despite the awareness of the decline in the cognitive function of the elderly and the difficulty of these individuals to perform motor learning sequences (31). Given the points above, the present study seeks to investigate whether or not the error rate has a different effect on learning a sequence task for the elderly.

Method

Study design and participants

This was a semi-experimental study with pre and post-test design including two experimental groups. The statistical population of the study included elderly women in the age range from 60 to 70 years. In this study, the convenience sampling method was used, and 30 elderly women were selected as the participants. The

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inclusion criteria comprised right-handedness, literacy, ability to follow simple instructions, general health, no history of cognitive-behavioral problems, no previous experience of the given task or sequence tasks, normal or normally-modified vision, and no use of drugs affecting cognitive and motor status.

Data collection instrument

The instrument used in the research included the personal information form, General Health Questionnaire, Edinburgh Handedness Inventory, Short Mini-Mental State Examination, and Wechsler Digit Span Test.

1. Personal Information Form: This form included questions about age, sex, level of education, dominant hand, use of special medicine and presence of vision problems, etc.
2. General Health Questionnaire (GHQ): The 28-question general health questionnaire was presented by Goldberg and Hiller (1979) and has four subscales of physical symptoms, symptoms of anxiety and sleep disorder, social functioning, and symptoms of depression. In the present study, if a person scored higher than 23 (cutoff point), she was not allowed to participate in this test. The validity and reliability of this questionnaire in Iran has been confirmed by Malekooti et al., (32).
3. Short Mini-Mental State Examination (MMSE): This test was used to check the cognitive status of the subjects and ensure that they do not suffer from senile dementia. This 17-question test has been standardized in the age groups of different societies. If a person scored less than 22 (cutoff point) in this test, she is suspected of dementia and cannot participate in the test. This test has been validated in Iran by Seyedian et al. (33).
4. Wechsler Digit Span Test: The test was presented in two stages of forward digits (direct) and backward digit (reverse) span. The forward numbers were started with a series of four-digit numbers and the reverse numbers with a series of three-digit numbers. If the subject succeeded in repeating the first series of digits, the next series of digits continued, and if the subject failed in two related attempts, the test was stopped. In this test, the subject's score is equal to the number of the last series of digits that the person can repeat successfully (34).
5. Edinburgh Handedness Inventory (EHI): EHI is a 10-question questionnaire that includes questions about the use of the preferred hand while doing homework. In fact, this questionnaire is used to determine the superior hand. The validity and reliability of this questionnaire was reported by Alipour and Agah Harris (35).
6. Serial Reaction Time Task (SRTT) software:

Using this software, first proposed by Nissen and Bullemer (36), is an important common method to evaluate implicit memory. It is based on multiple target stimuli that appear in multiple space locations, and the participants must respond as quickly as possible by pressing the key associated with the proposed stimulus location. Such types of motor tasks have two motor and cognitive components, and the participants need to provide a motor response to a cognitive stimulus. Numerous versions have been designed based on SRTT (37). The problem with this software is that the assigned tasks are not configurable. However, the software designed in the present study meets all the requirements of these assignments and is able to set goals, stimuli and stimulus intervals, select the type of sequences, sequence the stimuli within a block, and determine the rest interval between blocks, the size of the stimuli on the plane, and their distance from each other. The method is presented in Visual Studio version 2015 and implemented in C language. Also, Structured Query Language version 2016 is used to store the task data (37).

Practice protocol

After the participants were selected, they were given a personal information form and a consent form to complete. The objectives, needs and characteristics of the research were also explained to assure them that the test would not cause them any physical or psychological problems and their information would be kept confidential. The studied groups were matched in terms of the scores obtained on their mental status and general health as well as on Wechsler digit span tests. For the practice protocol, the elderly participants were divided into two 15-member groups, errorless and errorful.

Based on the results obtained from the pilot study (to ensure the occurrence of high and low errors in two training groups), a practice protocol was provided for the elderly. For both errorless and errorful groups, five fixed targets appeared on the screen in the acquisition test, and they were all turned on and off by the software at the researcher's request. The timing of the stimuli was immediately after pressing each key on the keyboard. The target keys (f-g-h-j-k) were labeled on the keyboard for the easy identification of the correct key. For the errorless group, 10 blocks of 40 trials with an 8-component sequence (3-2-1-1-2-3-3-4-5) were set to turn the stimuli on and off. In the errorful group, 10 blocks of 40 trials were arranged in an 8-component sequence (1-5-4-2-4-1-3-4) to turn the stimuli on and off. Presenting the stimuli in three out of ten blocks in both groups was carried out randomly by the software, and there was no specific sequence in these blocks. The rest interval between the two groups was 20 seconds per block. It should be noted that due to the nature of errorless learning based on the elimination or reduction of errors during the learning process in order to reduce the amount of attention to the explicit processing of the rules and reduce the load on the working memory, a simple sequence of movements was chosen for the learners. While in errorfull learning, the initial learning environment was presented with complex sequences in such a way that a person would make a large number of errors in his practice and try to solve the challenges.

The retention test was completely similar to the acquisition test, and it was taken by both groups in 24 hours. After completing the retention test, the participants were exposed to a new sequence to be evaluated for their performance in a transfer test. In this test, four fixed targets appeared on the screen, and they were turned on and off by the software at the request of the examiner. The timing of the stimuli was immediately after a key was pressed on the keyboard. The target keys (v-b-n-m)

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were labeled on the keyboard so as to be readily identified. For both errorless and errorful groups, one block of 20 trials with a sequence of five components (4-2-1-4-3) was set to turn off the stimuli.

Statistical analysis

As a part of data analysis, the Shapiro-Wilk test was used to examine the normality of the data distribution, and ANOVA with repeated measures along with the Wilcoxon test served to examine the changes over time, and Mann-Whitney U test for comparing the groups. The significance level was considered to be $p < 0.05$ in all the tests. The research data was analyzed by SPSS software version 20.

Ethical considerations

After the initial evaluations, the plan has been approved by Yazd University Ethics Committee with the code : IR.YAZD.REC.1401.021.

In addition, before the implementation of the research, the consent form was given to the subjects and the objectives of the research were explained. Also, they were assured that the information would remain confidential and this experiment would not cause physical or mental problems for them and they can refuse to cooperate at any stage of research.

Results

Table 1 shows the demographic information of the participants.

Figure 1 shows the changes in the reaction time, and figure 2 refers to the changes in the number of errors in the different blocks of the acquisition sessions as well as retention and transfer tests. There was a decrease in the reaction time and the number of errors over time in both groups. In terms of the reaction time, the errorless group outperformed in all the stages. Similarly, in terms of the number of errors, the errorless group performed better than the errorful group in the acquisition sessions. However, in the retention and transfer tests, the errorful group had fewer errors than the errorless group.

The results of the ANOVA with repeated measures statistical test to investigate for the changes of reaction time over time are presented in Table 2.

The results of the independent samples t-test to examine the differences between errorless and errorful practices on the reaction time in each of the different stages of the test showed that in the acquisition stage, the comparison of the average reaction time scores in the acquisition blocks showed no significant difference between the two groups ($t\ 28.82 = 1.68$, $p = 0.11$). However, there was a significant difference between them in the retention test ($t\ 28 = 2.63$, $p = 0.01$) and transfer ($t\ 28 = 2.13$, $p = 0.04$).

Also, the results of the Wilcoxon statistical test to investigate the effect of errorless and errorful practices on the number of errors showed a significant difference between the two stages in both errorful ($p = 0.02$, $z = -2.85$) and errorless ($p = 0.03$, $z = -1.89$) groups.

The Mann-Whitney U test was also conducted to compare the effects of errorless and errorful practices on the number of errors in different stages of the test due to the non-normal data distribution. The results are presented in Table 3.

Table 1. Demographic information of the participants in two groups

Group	N	Mean ± SD (age)	GHQ score	MMSE score
Erroefull	15	66.07 ± 3.12	19.93 ± 1.81	25.13 ± 0.69
Errorless	15	64.20 ± 3.44	19.46 ± 1.14	24.93 ± 0.85

Table 2. Results of the ANOVA with repeated measures for the changes of reaction time over time

Indices test	Group	Value	df	Error df	F	p	Partial Eta Squared
Willks lambda	Errorful	0.70	1	14	32.82	0.0005*	0.70
	Errorless	0.70	1	14	178	0.0005*	0.93

*Significant at $P < 0.01$

Table 3. Comparison of the two groups in terms of the number of errors in different stages of the Mann-Whitney U test

Indices variable	Group	Test	Mean rank	Sum of means	Mann Whitney U	Z	p
Number of errors	Errorful	Acquisition	18.86	14	51	-1.69	0.02*
	Errorless		11.40	15			
	Errorful	Retention	12.33	15	65	-2.02	0.04*
	Errorless		17.86	14			
	Errorful	Transfer	11.80	15	57	-2.49	0.013*
	Errorless		18.43	14			

*Significant at $P < 0.05$

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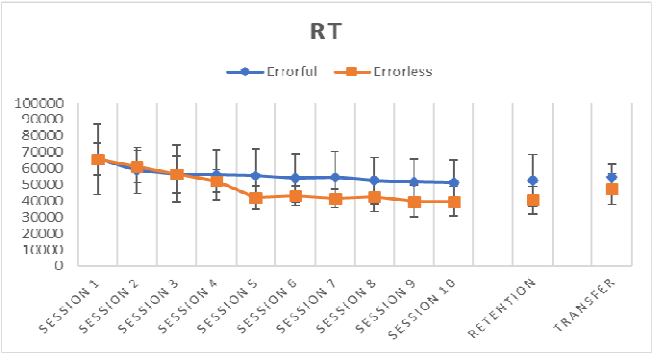

Figure 1. Changes in the reaction time of the study groups at different stages

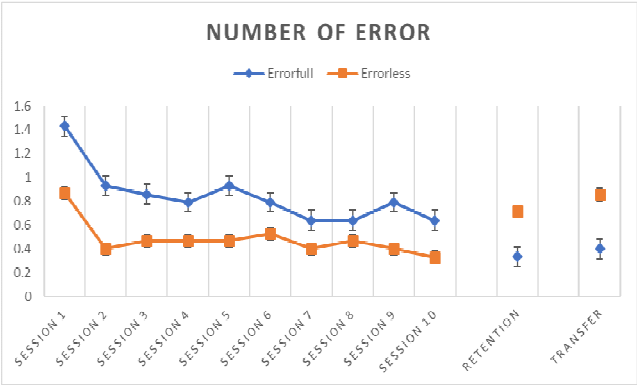

Figure 2. Changes in the number of errors at different time stages

Discussion

The aim of this study was to investigate the complexity-induced errors made by the elderly in the acquisition, retention and transfer of sequence motor tasks. The results showed a significant difference between the groups in the acquisition, retention and transfer stages. The errorful group also had more reaction time than the errorless group, which was consistent with the studies by Levac (38), Niermeyer et al. (31), Scheper (39), and Beik (18).

According to the results of Niermeyer experiments (31), the reaction time of the elderly was longer in difficult sequences, which may have been due to fatigue or the inability of the elderly's brain system to do rapid processing. Also, in Levac's research (38), the students performed better in errorless practices than in errorful tasks. Accordingly, the central nervous system acts better in errorless conditions, and the ability to process information and ultimately respond to a stimulus is greater in simple conditions than in situations where a person makes more errors during practice. These results are consistent with Adams's closed-loop theory (22).

Adams believed that all movements during motor practice were learned by comparing the feedbacks from the limbs with the perceptual trace and corrective reference stored in the memory. Thus, the fewer errors during practice, the faster people enjoy (22).

On the other hand, the results obtained for the reaction time were inconsistent with Sanli and Lee (26), which may be due to the presence of young subjects in this study. The difference in the processing speed between the elderly and the young may be one of the reasons for the differences of the present study from Lee and Sanli's research. In Sanli and lee's study (26), the subjects performed the practices in two methods, errorless (easy to hard) and errorful (hard to easy). Also, the results were inconsistent with Schmidt's theory (16).

Also, a likely reason for the inconsistency of the present study with the research by Lee (19) can be the existence of five different experiments as well as different subjects with heterogeneous age and sex. Based on Schmidt's theory, performing right or wrong movements has positive results in learning.

Since schema is based on the relationships among all the components stored in the memory, it has effects on correct movements as much as it affects incorrect movements, thus reducing the individuals' speed of action in practices (16).

The results showed that the number of errors in the retention test during the retention and transfer stages was significant, and the errorless group had more errors in the retention and transfer tests than the errorful group. In other words, the errorful group performed better in terms of the number of errors.

These results were similar to those of Sanli and Lee (26), Lee (19), Beik et al., (18), and Schmidt's schema

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theory (16). Rodriger and Karpicke (40) suggest that the effect of errorful practices is greater due to the retrieval of information from the memory, which leads to better retention and comprehension over time. In other words, learning in difficult situations develops explicit processes which depend on working memory capacity and information manipulation.

According to the schema theory, performing correct or incorrect movements has positive results in learning. Because schema is based on the relationships among all the components of the memory, it affects incorrect movements as it does correct movements. Nonetheless, as Guadagnoli (28) argues in his theory, information-dependent learning is available and interpretable through motor functions. In other words, the amount of information is a challenge for the performer, and the existence of this information is a factor for his or her learning. Thus, the presence of errors in practices leads to faster and more stable learning (28).

On the other hand, the results of this research obtained from the retention and transfer tests are not consistent with the findings of Adams (22), Masters and Maxwell (23) in their reinvestment theory, Niermeyer et al., (31), Levac et al., (38), and Schaper et al., (39). This discrepancy is due to the age and sex of the subjects and the type of software used. Based on their reinvestment theory, Masters and Maxwell (23) believe that error in practice leads to the use of conscious mechanisms to acquire the desired motor skills. In the case of dual tasks, error leads to the investment or repeated recall of those mechanisms, and performing the tasks will be significantly diminished. The difference between the results of the present study and the views of Masters and Maxwell may be due to the psychological traits of the elderly subjects, such as having confidence in performing sequence tasks, which distresses them reduces their psychological pressure. Perhaps, individuals can easily participate in difficult practices and learn effectively if have a desired level of psychological traits. In general, it can be said that the errorless group had a better time performance than the errorful one, but the latter had fewer errors in the retention and transfer tests. This indicates the accuracy-speed trade-off among the elderly.

The speed-accuracy trade-off, as a common feature in the practice of motor skills, is described by the Fits mathematical rule. Fits (1954) emphasized the negative correlation between the difficulty of a movement and the speed of its execution (41). Therefore, the harder a task, the slower it is, but the easier the task, the faster it is done. Barnhoorn et al. (42) showed that tasks with fast or accurate instructions are useful for developing a skill. As they observed, single sequences were performed faster by the speed group. Instead, the accuracy group seemed to be more accurate than the speed group when responding to random stimuli as well as in repetitive situations. In other words, the speed group, despite spending less time on the task, learned the sequence pattern, but the accuracy group performed more accurately and errorlessly in new and random conditions.

Conclusion

Errorfull and errorless practice are effective on reaction time and amount of errors in the retention and transfer stages of a motor sequential task in elderly women. However, it seems that errorfull practice is more appropriate to reduce the error rate of the elderly women. It is suggested that trainers and occupational therapists use errorfull training methods in order to reduce the error rate and provide a more optimal and stable learning environment when designing exercises and training programs for motor sequential tasks of the elderly women. Moreover, it is suggested that in the future studies, the research should be conducted on other groups and the results should be compared with each other. Also, conducting research under pressure condition and dual tasks is one of the things that researchers may consider.

Study limitations

Despite its strengths, the current study had limitations. The experiment was conducted only on elderly women, and the generalization of the results to other groups should be done with caution. The lack of accurate control of the subjects' motivation and interest while participating in the test, as well as the difference in mental states, could affect their effort levels. The impossibility of testing the subjects simultaneously and at the same time of the day was another limitation of the research.

Conflict of interest

The authors declared no conflict of interest.

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Authors' contribution

Faeghe Askarinejad: Implementation of test and setting introduction, Hossein Samadi: Setting introduction and discussion and endorsed the final manuscript for submission to the journal, Farahnaz Ayatizadeh Tafti: Statistical analyses and setting discussion.

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