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Original Article

Effects of Response Complexity and Limb Weight Variations on Premotor and Motor Components of Reaction Time

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Abstract

The advance in reaction time (RT) research through using electromyography (EMG) technique that has made it possible to divide the RT into the motor (MT) and premotor (PMT) has resulted in new findings. The present study was conducted to evaluate the effect of response complexity and limb weight changes on EMG records of simple and discriminative RT of young and elderly men. The participants included 14 young and 14 older adults. They performed arm flexion with or without added weight to a target at 60-cm distance away upon hearing simple or discriminative signals. The results of the repeated measures ANOVA indicated that there was a significant effect on PMT for three factors including the number of stimuli (p=0/001), limb weight (p=0/001) and response complexity (p=0/001). It was concluded that the variables affected RT had an effect on the PMT but might not affect MT. These delays in activating the involved muscles to prevent fall were due to the increased age and overweight in the elderly.

Keywords: Discriminative RT, Elderly, Electromyography, Simple RT

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Introduction

One of the most preferred strategies of studying human behavior is to study how an individual respond to the external stimuli. Through these types of research paradigms, the human information processing-system is explored. The reaction time (RT) constitutes significant components in the view of information-processing system. The RT is the interval between the unexpected emergence of a stimulus and beginning of response as well as is one of the important measures of human performance and valid criteria for determining the speed and efficiency of decision-making. The information-processing system in cognitive psychology includes three stages of stimulus identification, response selection and response planning [1]. Perception, decision-making and response planning are significantly contributed to the implementation of a motor (MT) program; however, whether the implementation of the RT task is limited to these stages or not is open to question. Despite the fact that the RT in the number of researches has been limited to these three stages, numerous research results show the effect of some variables, which are inconsistent with the view of limiting the RT to these stages.

Donders (1969) et al. studied on RT and identified three types of RT tasks including simple, discriminative and choice RT [2]. In a different view, the RT was proposed as a proof of the presence of an open-loop control [3]. The majority of the evidence that supports the prior programming to the action is based on the differences in RT as a function of response nature (e.g. the components of response). It seems that the RT differences depend on the demands of various response plans [4-9]. According to Henry's Memory drum theory, the RT is defined as a conversion of the stored plan in the memory into systematic movement commands to muscles [3]. Therefore, to produce more complex responses, a complete plan is required, and consequently, the neural messages entail more time for the direction and coordination of the plan along the MT neurons. Klapp (1981) has suggested that the simple RT might be affected by unrelated factors with response planning such as the speed-accuracy exchange and movement speed [10]. Klapp (1981) and Anson (1982, 1989) reported the effect of different inertia organs and variations on simple RT in muscle contraction [10-12]. During the recent decades, studying the RT by active muscle's electromyography (EMG) activity and dividing it into premotor (PMT) time and MT time components have resulted in new findings [7, 9, 13-15]. The EMG is an experimental technique in which the muscle's electrical signals are recorded and used to analyze its function. In the first study on EMG-RT, Weiss (1965) has defined PMT as the interval from presenting the stimulus to emergence of response potential, and time of beginning the muscle's potential until the observable motor response is considered as the MT [9]. Figure 1 shows the assumed EMG recorded from the involved muscles in the RT task [16]. In this figure, the RT is the time between the presentation of a stimulus signal and beginning of the movement in response to that signal. The RT is fractionated into PMT and MT components in the EMG records.

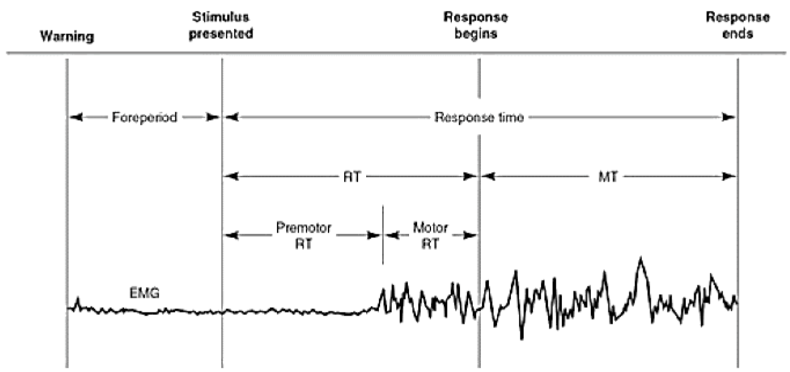

Figure 1- Critical events involved in the RT paradigm (According to Schmidt et al. 2018)

As represented in figure 1, the muscle's EMG activity in a large segment of RT is inactive indicating that movement command has not reached to the muscle yet. Then, the muscle is activated, but still no movement is visible for 40 to 80 ms. The time interval between the response signal and onset of EMG activity is classically termed PMT while the time interval between the onset of EMG activity and onset of the required MT response is termed MT [1, 16, 17]. It is generally assumed that the PMT reflects the duration of central processes (including central motor processes) whereas the MT reflects the duration of peripheral motor execution. The literatures on EMG-RT are limited in scope; they have often assumed that various components of RT are distinct and independent concepts. Most studies have assessed the effect of one independent variable on components of PMT or/and MT. In fact, there is a lack of research showing that the PMT component indicates central cognitive processes involved in response production (processing and transferring information) whereas the MT component represents the processes related to the muscle's (MT) activity. The majorities of earlier researchers examined the effect of preparatory intervals (PI) on RT components [18]. Weiss (1965) has reported that the PI influence is limited to the PMT component and is likely associated with the central processes. Botwinic et al. (1966) examined the effect of PI (0.5, 3, 6, 15 seconds randomly and regularly) and concluded that this variable was associated with PMT component. In their study, no correlation was found between RT components. Although the correlation between PMT and MT was nearly zero, the RT and PMT variations in both blocked and random conditions were coordinated. Moreover, the PMT average in random blocks was significantly longer than the average of the blocked blocks. A higher mean PMT in the random blocks illustrated the individual's inability to anticipate the stimulus. Conversely, the fact that the PI had no significant effect on MT in means of blocked and random PI blocks were indication of MT independence from PI. Considering the fact that the PMT and MT components are independent of each other, the question is that what factors influence these variables and whether the hypothesis assuming PMT component as the central and MT component as the peripheral processes is valid or not?

A group of researchers evaluated the effect of submaximal exercise and warm-up on RT components and reported contradictory findings. In a number of submaximal exercise studies, shorter MT was found while in some others, shorter PMT was reported. Christina et al. (1985) manipulated the complexity of RT task based on Henry and Rogers's (1960) theory. When a part of movement of the upper organ was increased to two parts, the PMT increased for 19 ms while the MT enhanced for just 3 ms [5]. These findings display that the effect of movement complexity increase is related to the PMT and has slight effect on MT.

Various studies evaluated the effect of other variables including movement distance [6, 19], movement direction [20], number of limbs and involved parts [21], accuracy [4, 5], timing limitation as well as movement time duration [22, 23] on RT components. These variables are often associated with the part of PMT; however, there is a lack of comprehensive research that simultaneously investigates the peripheral and central components. Considering the effects of changes in contraction force as an important factor in RT changes, Nagazaki et al. (1983) have reported that the RT increases with the enhancement in the contraction force. Both of these changes occur in MT and PMT components. They have concluded that the movements with a larger force recruit more MT units, leading to an increase of electrical activity in these MT units. Therefore, it is expected that movements with higher force entail longer preparatory time [14]. Glencross (1973) reported no sign of force change on RT in dynamic movements [24]. The result of a study conducted by Kasai et al. (1990) has indicated that an increase in the muscle force results in a decrease in distance. In contrast to the results of EMG-RT studies which suggested longer PMT and considered the delay in the start of EMG due to longer processes needed to start a response, the result of Kasai et al. who indicated that this interval decreased as a result of an increase in contraction force [25]. These findings and their underlying hypotheses are in apparent contradictions. The reason behind some of these contradictions is the methodological issues that combine the force amount effect with other simultaneous parameters (e.g. speed, accuracy and complexity).

When discussing the factors that change RT, it would be interesting to include factors such as age since this factor is associated with cognitive and MT impairment in aged individuals who are particularly at risk of fall. The RT reaches its peak at the beginning of the third decade of life, decreases in middle age and declines rapidly in old age. The RT becomes slower as the individual becomes ≥70 years old [26, 27]. Lajoie et al. (2004) found that the elderly who faced more fall incidents had slower RT than their counterparts who fell less frequently [28]. According to Lord et al. (1991), poor balance is a common problem among the elderlies, and it is often blamed as the main cause of their falls [29]. Moreover, Brauer et al. (2000) and Brauer et al. (2002) have suggested that a poor lateral balance is the best predictor for fall incidents. This factor is frequently considered as the cause of falls when performing lower-body movements including gait and walking. In order to complete a gait, the postural muscles must be activated in right time with sufficient force; if this does not happen, then an incomplete gait is carried or a worse fall may follow [30, 31]. Cognitive decline in the elderly is attributed to the slower speed of information processing, but as important as this factor is, the role of MT and cognitive performance is not carefully examined simultaneously in the research literature. The hypothesis is that concurrent concentration on the MT and perceptual processes may result in deterioration of performance [32]. Hence, to test this hypothesis, this study was conducted to determine the effect of weight variation of the involved limb and the response complexity on the PMT and MT components of simple and discriminative RT. In addition, the age factor was included in the design to control the role of information processing speed in PMT and MT.

Methods

Subject and design

In this semi-experimental study, 28 healthy men were divided into two groups of 20- 30 years (n1=14, mean=25.5) and ≥50 years old (n2=14, mean=60.07). All participants filled out the written consent form had no previous history of taking part in professional sport or regular physical activity, were right-handed, did not use any medicine and had no MT impairment. They released this information on a self-report form.

Data Collection Instrument

Muscle’s electrical activity was recorded by the EMG device (Me6000 model, made in Finland). To determine the RT’s ending point, the goniometer (SG110 model made in England) was used. This instrument is synchronized with EMG device. The goniometer was calibrated before use and was installed on the skin with double-sided sticky fix them.

The participants sat on a chair and placed their right-hand elbow in a comfortable position on their thigh muscle in such a condition that the forearm could be positioned in external rotation, and the palm positioned upward. The participants in this position could perform the elbow flexion easily and quickly. The hair of brachial biceps muscle and elbow areas was shaved, and these areas were cleaned with alcohol to place the electrodes alongside the muscular fibers. The arms of goniometer were fixed on the both sides of the elbow by using double-sided tape. The RT task included arm flexion movement toward the target located 60-cm height distance in response to an audio signal. Since the high variations in PI have large effect on the components of RT, the interval for preparation between the warning signal and stimulus presentation was limited to 2-5 seconds, and these intervals were introduced randomly. In some trials, two other audio signals were added. The participant's task was to ignore these disturbing signals and continue performing the task after the main stimulus presentation. Therefore, the RT tasks were assigned into the simple and discriminative part. The MT response was performed in two simple conditions: one MT act and complex MT act including four components. By adding an extra weight of 1.2 kg to the performing limb; thus, a new variable was added to the design. Moreover, by increasing 1.2 kg limb weight in the mid of the study period, the test was performed in eight different conditions: 1. Simple, 2. Discriminative, 3. Simple with complex response, 4. Discriminative with complex response, 5. Simple with increase in limb weight, 6. Discriminative with increase in limb weight, and 8. Discriminative with increase in limb weight and complex response so that ultimately, an average of 16 trials was used in each condition. In order to decrease the effects of exercise, fatigue and repeating RT task conditions on each other, all trials were performed in one session and testing protocol. In addition, implementing all conditions were defined as one block, changing in contra balanced way in these 8 conditions, and it was attempted to keep repeating each condition at lowest possible (4 repetitions of each condition in a block of 32 trials). Eventually, to decline the precedence and regency effects of performing each condition, the participants repeated this block for 5 times in which the first block was omitted as the exercise, and the other 4 blocks were used in the analysis. Collecting data of each participant took almost 30-40 minutes.

The pretest instructions emphasized the speediness of implementation, and all participants were asked to place their elbows in the starting position, put their palms in supination position and stay ready for the next trial. The test was administered by a tester while EMG signals were being controlled on a monitor by another individual simultaneously. This approach was applied due to the methodological reasons of the present study. By employing this approach, the additional signals were prevented especially while relaxing and before presenting the stimulus. In the case of observing any additional signal, the participant was asked to change his muscles to a comforting position. Through such considerations, the EMG sudden onset or, in other words, the separating point of MT and PMT was identified more easily. Additionally, a human is superior to automatic devices in recognizing the occurred errors during the test procedure, and the tester is able to distinguish the errors more efficiently during test implementation. Muscle's EMG activity was recorded from the beginning of the procedure to the end, and the RT was divided into MT and PMT components after an accurate measurement and was utilized in analysis. In the present study, the PMT was defined as the interval between presentation of the audio stimulus and sudden onset of muscular activity while MT included the interval between the sudden onset of muscular activity and onset of elbow angle (3 degrees) alteration [13, 15, 16, 33]. Figure 2 represents a sample of RT task indicating the place of stimulus presentation. The amount of time point on the cursor values was 7.977 ms.

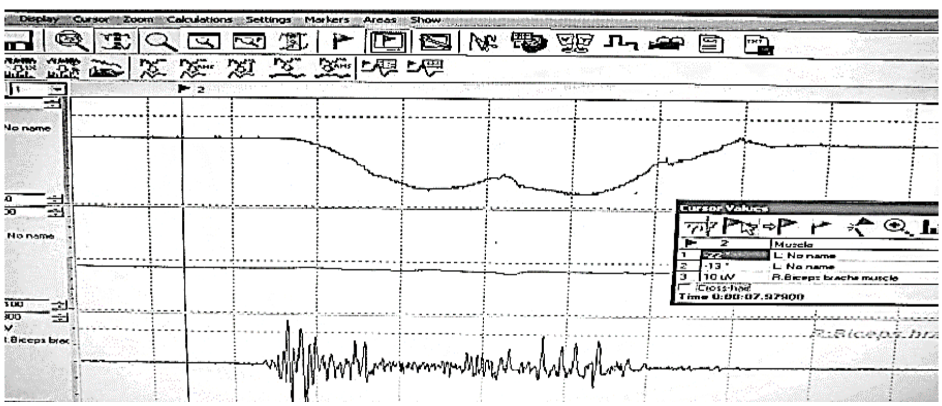

Figure 2- A sample of RT tasks (marked place of audio stimulus presentation)

According to the definition, in figure 2, the starting point of the muscular activity is the numerical point of 8.208 ms, and the starting point of the observable movement marked by goniometer variations is 8.285. The addition of RT, MT and PMT components was calculated by subtracting these numbers from each other.

Statistical Methods

Data analysis was performed using descriptive procedures including mean and standard deviation as well as inferential statistical tests such as Kolmogorov-Smirnov test, Levine test and factorial analysis of variance (ANOVA) test. The data were analyzed via SPSS 20, and 0.05 was considered as the least level of significance in inferential statistics ($p<0.05$).

Results

The result of the data analysis related to the simple and discrimination tasks on MT and PMT components for the two different conditions is presented in figure 3.

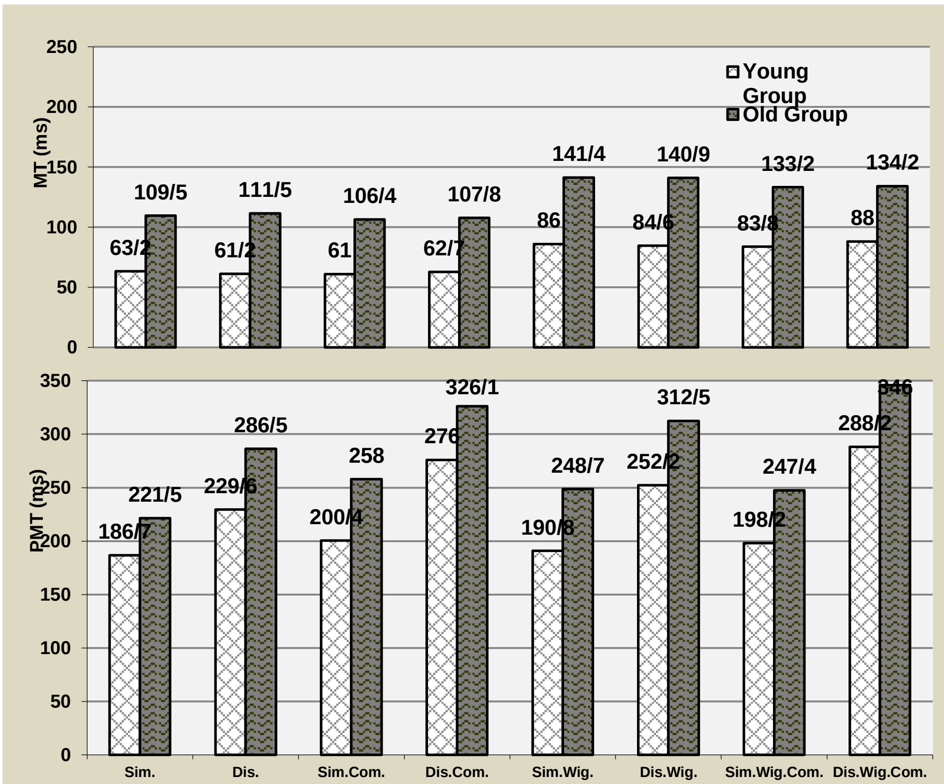

Figure 3- Performance of groups in MT and PMT components on eight different conditions of RT task

The results of Kolmogorov-Smirnov test confirmed normality of the distribution of scores in both groups, and the Levine test result indicated that their homogeneity variance existed for the variables. Table 1 presents the result of factorial ANOVA test at different time intervals.

Table 1- Factorial ANOVA- Repeated measure results

Interpersonal Comparison								
	PMT				MT			
Source	Sum of squares	DF	F	Sig.	Sum of squares	DF	F	Sig.
St.	279604/44	1	565/881	*0/001	36/16	1	1/665	0/208
Wig.	8600/64	1	14/048	*0/001	38168/64	1	242/29	*0/001
Com.	39220/07	1	74/785	*0/001	391/14	1	8/798	*0/006
St. × Wig	3394/57	1	9/072	*0/006	1/82	1	0/001	1/000
St. × Com.	8600/64	1	17/822	*0/001	87/50	1	4/190	0/051
× Com. Wig.	3225/44	1	6/698	*0/016	33/01	1	0/780	*0/385
St. × Wig. × Com.	665/16	1	2/160	0/154	15/01	1	0/001	0/978
Between-Groups Effects								
Age	157728/28	1	138/38	*0/001	136127/12	1	174/20	*0/001

* The significant differences at a=0/05

The results of the analysis showed that there was a significant main effect on PMT components for all three factors including the number of stimuli (P=0.001), weight limb (P=0.001) and response complexity (P=0.001). In the MT component, the effect of adding more stimuli from simple to discriminative condition was not significant (P=0.208). However, the effect of limb weight addition (P=0.001) and response complexity (P=0.006) was significant. The between-group factor of age in both PMT (P=0.001) and MT (P=0.001) components was significant. Besides, the results indicated that the interaction between these variables in PMT components was considerably more.

Discussion

The ongoing study was conducted to evaluate the effect of limb weight change and response complexity on EMG recording of simple and discriminative RT of elbow flexion movement in young and elderly men. The result of PMT component demonstrated that there was a significant main effect of adding stimuli (St.), limb weight (Wig.) and response complexity (Com.). The effect of task type from simple to discriminative MT component was not significant (P=0.208). Considering the effects of two variables related to the performer, that is, limb weight and stimuli increase, it seemed that these findings supported the hypothesis of MT dependence on movement factors (e.g. weight increases) since the difference in RT task changing from simple to discriminative had no significant effect on this component whereas the increased limb weight resulted in significant change.

The pairwise contrasts demonstrated that the MT components had no dependence on the increased number of stimuli whereas the limb weight change resulted in significant change. In spite of this, the effect of weight increase in the limb on PMT was not in agreement with the prediction of the hypothesis because in the hypothesis, it was assumed that movement factors had no effect on PMT. The results of post-hoc comparison in PMT component displayed that the effect of the change in the involved limb weight was less than that of the change in the number of stimuli. As well, limb weight increase and contraction force change had some effects on PMT component.

The result of the current study regarding the effect of limb weight increase was the same as that of Nagazaki et al. (1983) who reported that contraction force increase had a significant effect on both PMT and MT components of RT [14]. On the contrary, the result of a study conducted by Glencross (1973) revealed no effect of force change on PMT and MT components [6]. It was likely that the discrepancy of the findings was related to the methodology. For instance, the use of dynamic movements applied by Glencross was different from that employed in the present study. Kasai et al. (1990) presented contrary findings to the results of other studies through representing that there was a decrease in PMT component as the contraction force increased. They attributed their findings to speed-accuracy trade matter and concluded that forcing the participants to exert specific force resulted in the complexity of time regulation of muscles in charge of acceleration-deceleration and caused longer PMT [25]. Baba et al. (1983) stated that different timings needed in RT tasks led to a change of the time required doing the central processes; hence, it seemed that the timing of contraction force was a parameter in an organized movement regulated prior to the movement onset [34].

The increase in the number of stimuli had an effect on the PMT component while the enhancement in the involved limb weight caused longer time in both components of RT. It seems that the increase in limb weight causes an increase in muscle's inertia in addition to an increase in complexity of response, and processes needed to recruit more units probably result in calling for synergic muscles. All these factors need to be taken into consideration when discussing PMT component and processes including afferent pathways, peripheral neural organs, efferent pathways, central processes and even functioning of neuromuscular junctions. Therefore, there are considerable differences between the information processing system (central processes including stimulus identification, response selection and response planning) and processes known as premotoric processes in EMG studies. When discussing information-processing system, the central nervous system (CNS), specifically the brain, is normally considered as the controlling center of these processes whereas premotoric processes include central processes, peripheral sensory organs, afferent pathways and efferent pathways to muscles [10].

With such a difference, it can be realized that information-processing stages are not the only comprising components of RT, but they are stages of premotoric processes that comprise only one component of RT in the EMG-RT studies. Making this distinction, it is clear that the information process stage is not the only part of RT, but these processes are part of PMT processes that only make up a part of RT in the EMG-RT studies. Considering the extension of the processes in the PMT processes, it is obvious how an increase in the limb weight and contraction force has an effect on not only the inertia and prolongs MT but also the PMT component.

The results of the analysis represented that the older age group was 40-50 ms slower than the young group in the total RT. In addition, there was a significant difference between two age groups of RT variations. The older people were more prone to variables that occurred on RT. The findings of the present study are similar to those of Brauer et al. (2002) who assessed the effect of high, normal and low readiness (signal awareness) of participants on rapid stepping of RT task of young and older adults. In their study, the participants were given 80, 50 or 20% chance to know what stimuli signal was presented to move one of the legs. The results represented that in both conditions of normal and low readiness, the EMG muscle activity was longer than the high readiness condition regardless of the age groups. Nevertheless, the mean performance of the young group was faster than that in the old group. They concluded that the differences between these age groups might be attributed to the time dealt with the uncertainty in decision-making [31]. Therefore, it should be pointed that the delay in activating the muscles, response selection and response to the loss of balance in the older age group compared with the young individuals might be so long that any efforts to prevent falling became ineffective. McLean et al. (2010) reported that an increase in PMT time in the older adults led to a delay in the activation of the stabilizing muscles and increased the likelihood of muscle injury. If the delay caused by the lack of pre-awareness of balance loss and mental readiness to make a rapid response is added to the old age delay, it probably results in a more prolonged delay to prevent fall [13].

According to these explanations and more details presented by Brauer et al. (2002) and McLean et al. (2010), when the delay caused by the lack of advance awareness of balance loss and mental readiness for rapid and appropriate response is summed up with the old age delay, it will result in prolonged delay leading to fall. In fact, in any fall case that is a commonly unexpected incident, the individual has no warning signal in advance to anticipate the loss of balance and make postural adjustments; thus, activating the involved muscles to prevent fall is made with a delay [28]. In addition to this condition, the old-age group tends to show a longer delay in activating the postural muscles compared to the younger group even for voluntary movements or those with advance warnings like this research [29]. Hence, once such delay related to the age is added to the delay associated with the activating muscles because of the absence of advance signals or lack of readiness, the result might be executing a movement that is not quick enough to maintain the balance.

Conclusions

In summary, factors such as obesity and muscular weakness that cause changes in the muscle's inertia and MT factors, in general, may have a significant effect on the older adult's MT performance via the involvement of PMT and MT components simultaneously. Thus, decreasing the fat mass weight and strengthening muscular strength may be an appropriate strategy for the elderly people to compensate for the slow information-processing procedures. In this way, decreasing movement inertia and omitting the additional processes related to the contraction force can partly reduce the delay for compensating the balance and consequently fall.

The results of the ongoing study as well as those stated in the literature indicated that the variables affected RT had also effect on the PMT but might not affect MT. Some of them may influence on MT component, but it is unusual to find a variable affected on MT without having any effect on PMT component. It means that the variables which significantly alter the RT MT components also change the PMT processes. Accordingly, considering the hypothesis proposed that the PMT and MT components were related to central processes and muscle's MT activities was not a holistic view to consider the details as follows: Firstly, the PMT processes include a wider range of information-processing system and central neural processes. In addition, the factors that have significant effect on muscles' inertia have a simultaneous effect on several premotoric processes such as the number of muscles, motor units, number of synapses in neuromuscular junctions and EMG activity of the muscle. Change in the planning of this processes and increase of complexity of the efferent lead to change in PMT component.

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Author Contributions

The authors state that they are responsible for the research that they have designed and carried out.

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