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Original Article

The Effect of Jogging on Dual-Task Performance of Nervous System, Equilibrium Control, and Cognitive Reaction

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Keywords
Biomechanics; Reaction time; Exercise; Neural system

Abstract
Background: The effects of exercise and physical activity on dual-task performance have attracted many researchers' attention in the last decade due to the vulnerable nature of the industrialized life style. The aim of this work was to study the effect of physical exercise on dual-task performance of young healthy individuals in which the dual-task scenario is defined as balance control and reaction to external stimulation.
Methods: To do this, experimental tests were performed on one hundred people using a simultaneous measurement of the equilibrium and reaction time. Participants in this study were men with an average age of 24 ± 5 years and an average weight of 73 ± 5 kg. The performed tests included a single-task balance control test, a single-task response test, and a dual-task balance and reaction time test before and after five minutes of jogging.
Results: In this research, indicators were introduced for assessing the function of the nervous system in the single- and dual-task conditions. Comparison of the performance of motor control of the brain in single and dual activity showed that the performance of motor control in dual task balance was reduced by an average of 19%. On the other hand, the reaction time of the nervous system in dual-task mode increased by about 15% relative to the single mode.
Conclusion: By comparing the results before and after exercise, we conclude that for most of the test subjects, the impact of an action changes the performance of dual activity to the extent that exercise can improve balance and at the same time increase reaction time. But despite this improvement, the accuracy of people is often reduced.

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Introduction

Maintaining balance (static or dynamic) along with performing a cognitive task is a very important issue that everyone faces in performing many daily activities. The

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enormous importance of this issue on the one hand and the aging problem of many societies on the other hand has led to the study of dual-task performance mainly in the elderly. Due to the risk of falls and its consequences, maintaining balance and performing a cognitive task in the elderly is important.[1-3] However, in many industrialized communities, younger people are also at risk of related injuries. This is much more pronounced in people with sensitive jobs such as surgeons, athletes, the military personnel, and so on. During daily activities, as people engage in more complex tasks with higher levels of brain and muscle involvement, factors such as focusing on multitasking and allocating attention to different tasks in progress, high response speed, and spatial focus will also be involved.[4,5]

In many activities, we require quick thinking, high decision speed, and well-defined actions, along with other tasks such as balancing. Thereby, two factors of reaction speed together with a balance of positioning are greatly enhanced in activities ranging from simple and basic levels such as ball catching and balance to advanced levels such as balancing on bicycles and showing appropriate and timely reaction to when dealing with obstacles.[6] Maintaining balance is an important issue in a variety of movements or maintaining the body in a particular situation. Balance maintenance is an important sensory-motor function and requires the ability to collect inputs from various sensory devices (visual, somatic, and atrial) and to use a combination of sensory signals to coordinate motor activity in order to maintain balance. Given the matters mentioned and given the importance of the subject, up to now, many studies have been performed to understand the effective factors as well as to suggest strategies for improving the neuromuscular performance in bifunctional activities.[7]

One of the most basic and commonly-used scenarios for studying the function of the nervous system is in the dual task of measuring one's ability to maintain balance as well as one's precision and speed in response to an external stimulus. It is worth noting that the reaction rate to external stimulation is usually known as simple reaction time. Simple reaction time is the entire time interval between the stimulation and the reaction in the individual. In fact, this time consists of several parts. After the stimulation is applied, there is a delay, which initially occurs when the receiving processor begins to move to its maximum. The second time will be spent on centrally transmitting sensory pulses to the motor fibers and eventually there will be a time delay for muscle contraction and movement initiation for the responding organs. Any factor affecting any of these processes will clearly affect the reaction time. Since most studies on reaction time deal with the overall time of the process, time studies have been investigated.[8]

In 1999, an experiment was performed on three different tasks, namely, the sitting task, the task of pursuing motor vision, and the dual task of pursuing motor vision while maintaining balance on six adult faces.[9] Both experiments were performed with and without disturbance of equilibrium. The purpose of this study was to find a significant relationship between the time required to pay attention to the task and the time needed to restore balance. In this experiment, people had to stand on pedals that were rotatable and in the dual task, they had to try to maintain balance while pursuing a moving target on the computer screen. The second root mean error was recorded in the experiment. In 86% of the experiments, there was a delay in pursuing the moving target when the balance was disturbed (small and sudden movement of the pedals). Researchers in this study believe that when disturbance in equilibrium occurs, attention is removed from the visual target and focuses on maintaining balance and, ultimately, by measuring the interruptions created in the various phases of equilibrium, they examined the amount of attention required to maintain balance in its various phases.[9]

The purpose of the title of this study was to draw the conclusion that visual stimuli involved part of the attention, but in sensitive conditions, namely disturbance of balance, attention was removed from the second task in accordance with the "first balance" strategy. It focuses on balance to achieve stable conditions. These results are also found in other articles.[10] Numerous studies have been conducted to investigate the balance. Since balancing is done automatically in the body, checking it needs to provide conditions that either disengage it or make it easy to access. To this end, many studies have examined equilibrium along with one or more other tasks that play a challenging role in equilibrium. Studies have also addressed the simple balance task of people with various brain or limb injuries, older people, or people with certain types of illness.[11,12]

These studies, which may not be fully focused on equilibrium, have sought to study the performance of this spectrum of individuals, and this has been the focus of much attention in the field of rehabilitation. In another set of studies, various influencing factors such as age, gender, level of brain or physical injury, types of disease, and multiple tasks have been implicated.[12]

In addition to research investigating the mechanism of performance and the interplay of tasks on performance, extensive studies have been performed to improve the ability to maintain static and dynamic equilibrium as well as to enhance the performance of the second task.[13-15] Physical activity is one of the fundamental approaches that have been suggested to enhance the ability to perform a dual task, especially in the elderly.[16] Indeed, exercise or physical activity is considered as the simplest way to improve the dual-task performance such that the physical activity ameliorates the impact of the cognitive task on postural sway.[17] It has therefore been suggested to be incorporated in fall prevention programs.[12,18]

Other studies show that some exercise types are gently effective, but most of the reported research often have large amounts of missing data, insufficient methods, and small sample sizes that indicate a lack of evidence on the effectiveness of exercises such as walking and cycling to improve clinical balance.[19,20]

The aim of the current effort is to investigate the effect of short-time jogging on the dual-task performance of young and healthy individuals. In order to obtain informative results, the performance of static balance, cognitive task, as well as dual task was measured before and after short-time jogging paradigm.

Methods

Experiment protocol: In order to investigate the effect of jogging on neuromuscular performance in dual-task conditions, tests were performed on 100 healthy men with a mean age of 24 ± 5 years and mean weight of 73 ± 5 kg. All subjects were considered in exactly the same conditions and to avoid repetitive learning effects, the experiments were performed after only one training session. The test process was such that the person was positioned on the balance plate and, while maintaining balance which was equivalent to keeping the balance plate in a horizontal position, was asked to respond quickly to light stimuli and show them correctly. This process was repeated for five minutes before and after the jogging. The description of the experimental apparatus is presented in the next subsection.

Experimental setup: An apparatus designed and built at the AJA University of Medical Sciences, Tehran, Iran, was used to perform dual-task experiments.[21] To better explain the components and functions of the apparatus, some related concepts are reviewed first.

When an external force enters the body, or when a person moves in a particular manner so that the center of gravity of his body is removed from the support space (such as when running or standing on a bullet), the only way one can prevent his/her body from falling is to create appropriate internal torque opposing external torques created by weight.

In all mentioned conditions, whether the internal forces disrupt the equilibrium or the external forces affect the balance, the mechanism for maintaining the equilibrium is the same. The body reports to the brain through sensory nerve cells. If the balance is disturbed, the brain detects the amount of deviation created and provides the muscles with proper commands to neutralize the momentum created through the motor nerves. By executing the command of the brain, the muscles try to keep the center of gravity in the space of support. If any of the organs mentioned in this mechanism are damaged, the balancing act would be a problem and this is a kind of pathological condition in many diseases. The device used in this study works, considering the above-mentioned paradigm to assess the balance performance.

The apparatus used in this study consists of two modules of equilibrium evaluation and reaction time measurement. The balance module consists of a circular plate called a balance plate, located on a ball-and-socket joint, which is schematically shown in figure 1a.

To use the device, the test targeted individual is positioned on the balance plate. As the center of gravity changes, the center of pressure of the legs changes as well, and accordingly the balance plate deviates from horizontal position. In fact, the plate deviation represents the center of gravity deviation. The position of the center of gravity line is measured using four force sensors (load cells) located below the balance plate. In addition, the sensitivity of the device for the center of gravity is adjustable by software through a computer screen (Figure 1b). The better the individual's balance, the less the deviation from the center of gravity force or the center of pressure of the legs from the center of the plate coordinate axis. The reaction time module of the device consists of an ergonomic handle which includes reaction buttons and light-emitting diode (LED) lights to stimulate. This module includes simple time and diagnostic tests. In the simple temporal test, we present a simple optical driver to the user and she/he can show a suitable response with pressing a button. In this kind of reaction, there is just a single driver and a single response. In the diagnostic test, there are multiple drivers but there is only a single related response.

Performance evaluation indices: Based on the explanations provided for the neuromuscular mechanism of balance and the structure and function of the device, a variety of quantitative indicators can be used to measure the readiness or ability of individuals to maintain balance under normal and dual-task conditions. To do this, it is simply necessary to calculate the indices of equilibrium in both normal and dual-task situations separately (the parameter measurement section explains how to measure it).

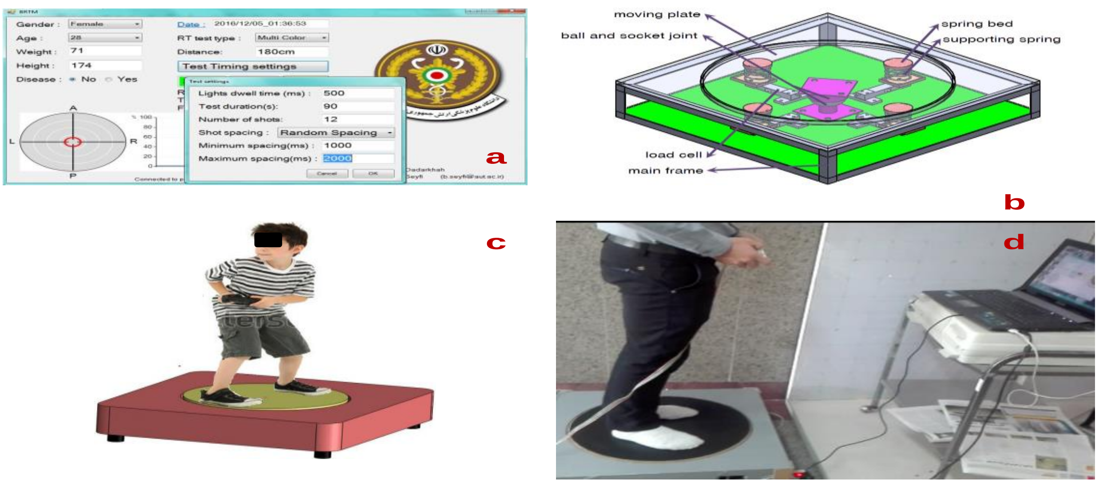

Figure 1. Experimental setup: a) an overview of the software user interface; b) schematic view of balance system mechanism; c) schematic view of testing procedure; d) real experiment environment

Then, a single index can be used to evaluate the bilateral effectiveness of either motor control (equilibrium) or cognitive (reaction time) activities. The index is presented in the following equation:[22]

$$DTE_{\text{balance}}(\%) = \frac{I_b^{(D)} - I_b^{(S)}}{I_b^{(S)}} \times 100 \quad (1)$$

Where $DTE_{balance}$ is the effect of dual-task activity on the preserving balance and I_b is the index of preserving balance in which superscripts *(S)* and *(D)* denote single task and dual-task conditions, respectively. We used a similar formulation to measure the reaction time index under normal conditions and performing the dual-task activity. The difference is that in calculating the reaction time index, since its low value indicates better performance, a negative sign is added to the equation:

$$DTE_{RT}(\%) = \frac{I_{RT}^{(S)} - I_{RT}^{(D)}}{I_{RT}^{(S)}} \times 100 \quad (2)$$

Where DTE_{RT} is the value of susceptibility to dual-task activity, $I^{(s)}_{RT}$ is the index of preserving balance in the single activity, and $I^{(D)}_{RT}$ is the index of preserving balance in dual-task activities. Interactivity of two tasks is the crucial factor in the evaluation process of the nervous system in performing dual-task activities. For defining a parameter as a single index for the ability of individuals to perform dual tasks, *DTPI* has been defined as below:

$$DTPI(\%) = \left[1 - \frac{DTE_{RT} + DTE_{\text{balance}}}{2}\right] \times 100 \quad (3)$$

Where $DTE_{balance}$ and DTE_{RT} are the indexes of the susceptibility of the motor control activities and cognitive activities to dual-task, respectively.

Parameters measurement: As shown in figure 2, the balance plate is divided into four circular sections and four quadrants. According to the device settings, the central zone, represented by the letter A, is known as the normal zone, and zones A to D indicate the individual's weakness in balance, respectively. Therefore, depending on what percentage of the test time the person's center of mass is mapped to the area, one's ability to maintain balance is measured. In other words, the more successful individuals in maintaining balance are, the lower the center of mass of the oscillation will be and thus the percentage of time it is out of zone A. Accordingly, the performance evaluation index of the brain motor control and the nervous system as a whole is preserved in the biomechanical equilibrium equal to the percentage of time the body's center of gravity is present in zone A. For example, the number 100 for this indicator indicates that the person has performed perfectly well and has been able to maintain biomechanical balance throughout the test.

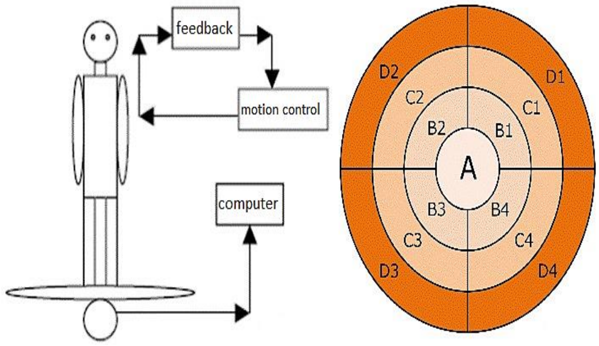

Figure 2. Four circumferential zones in order to show the gravity line; left: A schematic view of system operation

As mentioned earlier, the cognitive task includes correct and quick reaction to external color light stimulation. Given the multiple steps involved in the formation of the reaction process to external stimulation and the origin of the different effects of each of the reaction time subgroups, the analysis of the results requires a presentation of some of the data obtained to illustrate brain and overall musculoskeletal system function in different parts of the system that are responsible for each of the subgroups mentioned. In other words, the analysis of the results had to elucidate the extent to which each of the different parts of the nervous system played a role in generating the overall reaction time. To quantify this process, the reactions shown over a time span of more than eight tenths of a second or the wrong color selection are regarded as inaccurate responses, and conversely, the correct response is the correct reaction by selecting and pressing the relevant button in less than eighteen seconds. According to the device capabilities, the reaction time test results can be divided into three categories: correct answers, incorrect answers due to wrong color selection, and incorrect answers due to delayed reaction.

Results

The results of the experiments performed here are presented in different forms for better analysis and interpretation. As described in the description of the experiments, this study examines the performance of the neuromuscular system of young healthy people in different conditions such as a single task of balance control, single task of reaction time, and dual-task activity including balance control and cognitive reaction. All experiments were repeated after about 5 minutes of jogging to investigate the effect of physical activity on dual-task performance. It is worth noting that in the simultaneous dual task of maintaining biomechanical balance and responding quickly and correctly to an optical stimulation was considered. The experiment was performed on 100 healthy young men. According to the aforementioned points, the evaluation index of the performance of the brain motor control and generally nervous system during preserving biomechanical equilibrium is equal to the duration of presence of the center of gravity of the body inside region A. To compare the function of brain motor control in dual-task condition with a single task and in other words, the amount of susceptibility of motor control function for performing a cognitive task, the index of single and dual-task has been calculated. The values of this index and the index of susceptibility $DTE_{balance}$ before and after jogging are presented in table 1.

As noted earlier, the dual-tasking process must take into account the interplay of both motor control and cognitive reaction. To this end, according to the results presented in table 1, which relate to the balance controlling ability's effect on dual-task conditions, similar parameters or indices for cognitive activity, namely a quick and correct response to stimulation, are calculated and presented in table 2.

As mentioned earlier, the incorrect response in the reaction time test is defined in two categories: late reaction and incorrect color selection. Table 3 shows each of these responses separately. Also, in this table, results of the reaction time test before and after the morning exercise of candidates are visible. To evaluate the hypothesis about the effect of the time of the test on the results, distinct results for studies in the morning and afternoon have been presented.

Discussion

Diversity of motion tasks and environmental conditions have significant influence on the equilibrium mechanism during standing and walking phases. For example, development of coordination of equilibrium during walking into dark rooms or passing streets is difficult. During walking on sand, ice, or moving surfaces, the need for equilibrium increases. Vision has a great role in gathering required data about the surroundings, their variations, and anticipated required adjustments.

Table 1. Balance performance index and the effect of dual-task before and after exercise

After jogging			Before jogging		
$DTE_{balance}$	Percentage of zone A (dual task)	Percentage of zone A (single task of balance control)	$DTE_{balance}$	Percentage of zone A (dual task)	Percentage of zone A (single task of balance control)
39 ± 5	50 ± 11	82 ± 5	43 ± 3	39 ± 8	69 ± 6

Data are presented as mean ± standard deviation (SD)
DTE: Dual task effect

Table 2. Cognitive task performance index and effect of dual-task before and after jogging

After jogging			Before jogging		
DTE_{RT}(%)	Percentage of correct response (dual task)	Percentage of correct response (single cognitive task)	DTE_{RT}(%)	Percentage of correct response (dual task)	Percentage of correct response (single cognitive task)
5 ± 3	71 ± 5	75 ± 11	5 ± 2	78 ± 4	81 ± 9

Data are presented as mean ± standard deviation (SD)
DTE: Dual task effect

Maintaining equilibrium during walking and standing is different. During standing, the aim is to maintain the center of gravity in a level of reliance. While in walking, the main aim is to control instability. Also, the performance of the nervous system in doing cognitive tasks is under the influence of maintaining equilibrium and motor control activities. The rate of reaction depends on different factors. As a result, we can conclude that maybe there is not a general value for the reaction time. Various factors are effective in the responses and the time of reaction. Momentum times are different in various organs and depend on the persistence of body, age, exercise, and gender.[23]

The data obtained from the various tests performed in this study yield meaningful results. Based on the results obtained, by comparing the presence of the center of gravity in different zones of the balance plate including zone A, which is called the normal zone, it is revealed that the percentage of time in which the center of gravity was in zone A is considerably different before and after an exercise activity. As shown in figure 3, under dual-task condition, exercising improves the brain performance in maintaining balance. Since the musculoskeletal system plays a key role in maintaining balance and since the lower limb muscles are significantly active in jogging, there is a significant effect of leg muscle involvement and activation in terms of exercise results on better maintaining biomechanical balance in dual-task activity. Also, comparison of brain motor control performance in single and dual-task activity (before jogging) showed that balance control performance in dual-task condition decreased by 19% on average.

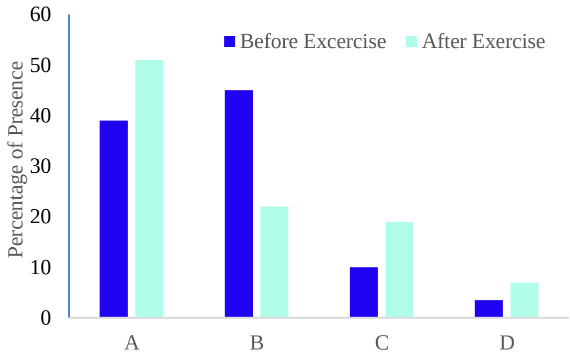

Figure 3. Presence of the center of mass in four cercumfrential zones, before and after the exercise

Based on data obtained from cognitive brain activity, the percentage of the quick and true responses in dual-task conditions is reduced. In other words, the reaction time of the nervous system in dual-task mode increases by about 15%.

Table 3. A comparison between cognitive function of brain in correct and fast reaction to optical stimulation in dual-task paradigm

Before jogging								
All cases			Afternoon			Morning		
False		True	False		True	False		True
Delayed	Incorrect		Delayed	Incorrect		Delayed	Incorrect	
19 ± 3	10 ± 2	71 ± 6	6 ± 2	9 ± 3	85 ± 7	17 ± 4	12 ± 3	71 ± 8
Before jogging								
All cases			Afternoon			Morning		
False		True	False		True	False		True
Delayed	Incorrect		Delayed	Incorrect		Delayed	Incorrect	
9 ± 3	13 ± 4	78 ± 9	11 ± 2	15 ± 4	74 ± 7	18 ± 5	13 ± 3	69 ± 9

Data are presented as mean ± standard deviation (SD)

By comparing cognitive function before and after exercise, we conclude that exercise, or in other words fatigue, increases reaction time. This result was observed for both groups of test subjects in the morning and afternoon. Another point to note is the definition of correct and incorrect answers that was mentioned earlier. Incorrect answer means wrong or delayed answer. The effects of dual-task activity on the cognitive function of the brain were greater in tests performed in the morning than in the afternoon tests. Similarly, analysis of the results before and after exercise showed that incorrect answers in pre-exercise tests mainly consisted of wrong answers; but post-exercise tests mainly consisted of delayed responses. Examination of the values obtained for the various impact indicators presented in table 3 yields significant results.

For better interpretation of these results, the conceptual diagram in figure 4 can be used.

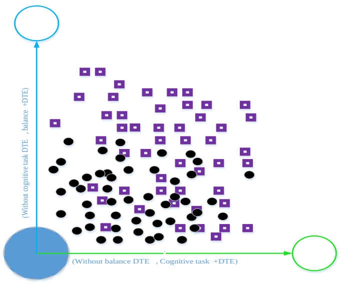

Figure 4. The effect of cognitive and motor control activities on each other

In this diagram, the effect of cognitive activity on dual activity and vertical axis shows the effectiveness of motor control activity or maintaining balance on dual activity. Accordingly, the closer the point to the center is, the better the performance of the brain and the nervous system in performing dual tasks in general will be. According to this diagram, the circular and square points represent the pre- and post-exercise tests, respectively.

Conclusion

The exercise and physical activity have been considered as an important issue in research literature due to the vulnerable nature of industrialized life style. In this work, the effect of physical exercise on dual-task performance of youth healthy individuals has been explored. A dual-task experiment was defined as a balance controlling and fast/correct reaction to external stimulation. Several quantitative and meaningful results were obtained and interpreted as presented in previous sections. These results show that for most testers, the effect of one activity on the dual activity is that the exercise improves balance and reduces reaction time. But despite this improvement, people's accuracy often declines.

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Conflict of Interest

Authors have no conflict of interest.

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