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Effect of Speed of Movement on Maximum Ground Reaction Force During the Sit-to-Stand Transfer

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국문요약

앉은 자세에서 일어서는 동안에 움직임의 속도가 최대 지면반발력에 미치는 영향

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연구의 배경 앉은 자세에서 일어서기는 일상생활동작중 흔한 동작중의 하나이다. 노인들을 포함한 많은 환자들은 앉은 자세에서 일어서기에 어려움이 있고 속도가 감소한다. 이 연구의 목적은 다른 두 속도로 앉은 자세에서 일어서는 동작을 실행할 때 최대 지면반발력의 세개의 요소를 비교하는 것이다. **대상자** 22명의 건강한 성인(20~36세)을 대상으로 하였다. **실험방법** 앉은 자세에서 일어서기동작 수행중 최대 지면반발력을 측정하기 위하여 힘판을 사용하였다. 대상자들은 메트로놈을 이용하여 각각 느린 속도(3초: 총 앉은 자세에서 일어서기동작 수행시간)와 빠른 속도(1.5초)에서 앉은 자세에서 일어서기를 수행하였다. 느린 속도와 빠른 속도중 최대 지면반발력을 비교하기 위해 짝비교 t-검정을 사용하였다. **결과** 빠른 속도시 최대 지면반발력의 수직($p<0.05$), 전-후($p<0.05$), 내-외($p<0.05$)요소에서 느린 속도시와 차이가 있었다. 최대 지면반발력의 모든 요소가 움직임의 속도의 증가에 비례하여 증가하였다. **토의 및 결론** 빠른 속도의 앉은 자세에서 일어서기를 수행하기 위해서는 최대 지면반발력의 수직, 전-후요소의 추진력이 요구된다. 최대 지면반발력의 내-외요소는 상전방으로 작용하는 모멘트의 증가에 대한 제동력으로 생각된다. 또한, 빠른 속도로 앉은 자세에서 일어서기 동작을 수행하기 위하여 추진력은 일어서는 순간의 모멘트에 대한 지면반발력의 내-외요소에 영향을 미친다. 이러한 결과들은 앉은 자세에서 일어서기 동작에 어려움을 갖는 노인이나 환자들의 노력을 덜기위해 느린 속도의 움직임이 필요함을 제안한다.

핵심단어: 최대 지면반발력(수직, 전-후, 내-외요소); 앉은 자세에서 일어서기 동작; 동작속도.

Introduction

One of the most common activities of daily living is the sit-to-stand movement. This transfer skill is a prerequisite to locomotion and requires not only the transfer of the body segments but also a controlled balance of the posture (Schenkman et al, 1990). Many patients, including the elderly, have difficulty and increased pain during the sit-to-stand transfer Munton and his associates (1981) reported that 42% to 43% of the elderly subjects surveyed had difficulty rising from a chair.

Many researchers have investigated the sit to-stand movement kinematically, kinetically, and muscularly through the use of motion analysis systems, force plates, and electromyography. The literature has documented that the sit-to-stand movement may be affected by several factors, such as seat height (Rodosky et al, 1989), initial position (Steven et al, 1989), knee flexion angles (Flenkenstein et al, 1988), patterns of the sit-to-stand movement (Nuzik et al, 1986), arm assistance (Seedholm and Terayama, 1976), age (Alexander et al, 1991, Bear and Ashburrn, 1995; Ikeda et al, 1991, Millington et al, 1992; Wheeler et al, 1991), type of chair (Burdett e. al, 1985; Ellis et al, 1979), and the speed of rising (Pai and Rogers, 1990; 1991; Schenkman et al, 1989) Because reduced speed of the movement is one of the common findings in patients and the elderly who have problems with sit-to-stand transfers and based upon previous findings of a few kinetic studies (Pai and Rogers, 1990; 1991), this study analyzed the maximum ground reaction forces at two different speeds during the sit-to-stand movement.

The speed of rising as an independent variable has been investigated kinematically and kinetically Two kinematic analysis studies investigated the sit-to-stand movement using motion analysis. Pai and Rogers (1991) investigated and observed the sit-to-stand movement under three different self-selected speeds (slow, natural, and fast). They found no changes in the hip and knee, but did change plantar flexion of the ankle. Furthermore, the resultant joint torques of peak hip flexion, knee extension, and ankle dorsiflexion were increased when the speed of the sit-to-stand movement increased progressively. Schenkman and her coworkers (1989) studied the effect of a variety of controlled conditions including the speed of movement kinemetically They reported: "Doubling the rising time increased the rate of the maximum torque development at the hip and knee but did not alter magnitude and increased the upper body velocity and decreased its fluctuation." In another study, Pai and Rogers (1990) focused on the vertical and anterior-posterior component of the ground reaction forces. They studied the control of body mass transfer as a function of the speed of rising by using a self-selected speed (slow, natural, and fast). According to their results, the peak linear momentum component was progressively increased in the vertical direction. Nevertheless, in the horizontal direction, the peak linear momentum component did not increase from the natural to the fast speeds, though it increased from the slow to the natural speeds. As a result, they suggested that the sit-to-stand movement may have necessitated different requirements for the horizontal and vertical directions, which were related to "the control of balance" in one direction, and "the increase of gravitational potential energy" in the other. In other words, the effect of "the control of balance" may

Table 1. Characteristics of the subjects

	Height (cm)	Weight (kg)	Age (yr)
Mean and SD	166.14±7.04	63.34±11.19	28.45±3.33

identify as a breaking force, which breaks the momenta of the horizontal and vertical directions, and the effect of "the increase of gravitational potential energy" can be shown as an impulsive force, which generates the momentum of each direction.

Therefore, the generation of the momentum and postural stability should be considered simultaneously in different speeds of sit-to-stand movement studies. In fact, a few studies (Engardt and Olsson, 1992) reported the medial-lateral component of the ground reaction force and the effect of speed of rising at the medial-lateral component of the ground reaction force to be relatively unclear. Thus, this study focused on the role of three components of the maximum ground reaction forces for "the control of balance" and "gravitational potential energy" at two different speeds in the sit-to-stand movement.

This study hypothesized the following: (1) The vertical and anterior-posterior components of the ground reaction force would be increased as the speed of the sit-to-stand movement was increased because increased muscle pulling forces and "gravitational potential energy" were required at the fast speed movements; and (2) The medial-lateral component of the ground reaction force would be decreased as the speed of the sit-to-stand movement was increased due to the increased need of postural stability at the slow speed of the sit-to-stand movement.

Methods

Subjects

The sample consisted of twenty-two healthy young subjects. None of the subjects had a history of neuromuscular or cardiopulmonary disorders. Fourteen men and eight women, aged 20 to 36 years, were recruited. The subjects' characteristics are presented in Table 1.

The study was approved by the Human Subjects Committee of New York University. Before data collection, all subjects gave their informed written consent to participate in this study.

Equipment

The Kistler force plate,[1] which was connected to an amplifier,[2] a BNC Board, and an A/D board, was used in this study. A force plate was used to collect the data of the ground reaction force in three dimensions by computer analysis,[3] Fx, Fy, and Fz represented the anterior-posterior, medial-lateral, and vertical components, respectively. In order to get the digital data, the force-time curves were converted to the digitalized data through the A/D board. The period of recording time was

1) Kistler Instrument, AG Winterthur CH-8480, Winterthur, Schweiland. Telex. 896-296.
2) Pre Amplifier (type 9865).
3) Analog Module (C) CBA Inc. (1986-1994).

set at 5 and 3 seconds for the slow and fast speed trials, respectively. A 10% pretrigger was used to prevent any lapse in data collection at the very start of the sit-to-stand movement.

Procedure

A modification of the test procedures described by Engardt and Olsson (1992) and Hanke and his coworkers (1995) was used. The subjects were asked to stand from a sitting position at two different speeds after practicing the sit-to-stand movement in a controlled amount of time. The test consisted of two sit-to-stand tasks, one at a slow speed, the other at a fast speed.

The total time taken for the slow rise of the subjects was 3 seconds. The fast speed trial was performed within 1.5 seconds. In each task, the subjects practiced the sit-to-stand movement five times to familiarize themselves with the metronome. Then, three trials of the sit-to-stand movement were recorded. In order to avoid cumulative fatigue, 30 seconds of rest was given in between the trials and the order of two tasks was randomly chosen.

The chair was placed 1 inch from the board of the force plate. The subjects were barefooted, and sat on the chair with a seat height of .44 m, which was chosen as representative of a standard-chai- (Jeng et al, 1990, Wheerler et al, 1991). The subjects were asked to place their feet on the board of the force plate. The starting position for the subjects was as follows: arms were folded on the chest; eyes were straight ahead; the feet were placed parallel and 15 ㎝ apart; the knee joints were flexed (American Academy of Orthopaedic Surgeons, 1965) 100° ~105° ; and the feet were evenly placed on the floor. In order to check whether the subjects pressed their feet evenly, an oscilloscope of the force plate was employed.

During the tests, verbal commands were given: "ready", "set", "one", "two", "three", "four", and "relax" according to beating sounds of the metronome. The subjects were asked to initiate their movement at "one" and to complete it at "four". During the sit-to-stand movement, the subjects did not use their arms and looked straight forward. During the data collection, the investigator indicated the starting and ending of the sit-to-stand movement through the graph of the vertical component of the ground reaction forces because two baselines (before and after the movement) were easily identified. (Fig. 1). For instance, the starting and ending base lines occurred at .08 and 1.58 seconds, respectively in Fig. 1.

Data Analyses

Three components (vertical, anterior-posterior, and medial-lateral) of the maximum ground reaction forces were obtained from the mean of three repeated trials of the slow and fast speeds of the sit-to-stand movement. A paired t-test was used and a p-value of .05 was set for significance of the results

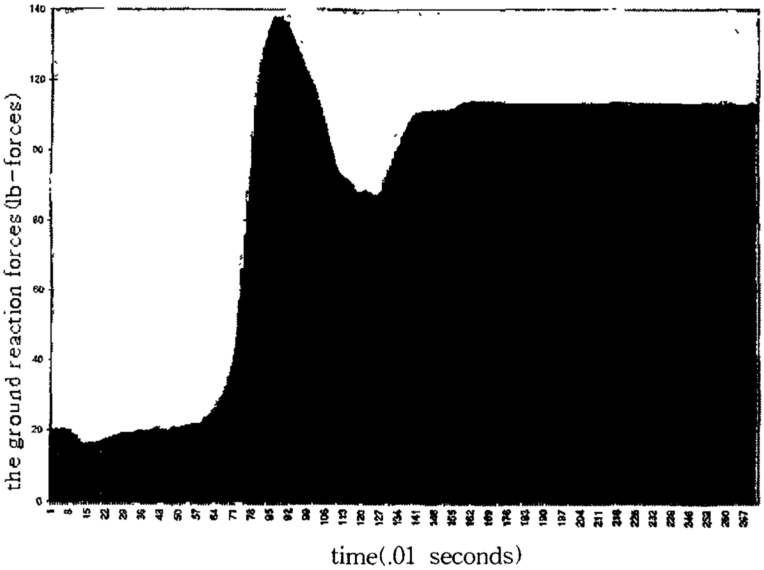

Fig. 1. The vertical component of the ground reaction forces

Results

The results showed significant differences ($p<.05$) between the slow speed trials of the three components of the maximum ground reaction forces and those of the fast speed trials (Table 2).

The vertical component of the maximum ground reaction forces

The means of the maximum ground reaction forces at the slow and fast speed trials were 673.72 N and 748.26 N, respectively. The vertical components of the maximum ground reaction forces at the

Table 2. The means of three components of the maximum ground reaction forces and the means and standard deviations of D (D: the slow speed trials - the fast speed trials). Unit: N (kg · m /s^2)

	The vertical component	The anterior-posterior component	The medial-lateral component
The slow speed trials	673.72	37.63	9.06
The fast speed trials	748.26	58.88	10.21
The mean of D	-74.55	-21.26	-1.16
The SD of D	48.84	13.21	3.96

slow speed trials were significantly different from those at the fast speed trials ($p<.05$).

The anterior-posterior component of the *maximum ground reaction forces*

The anterior-posterior component of the maximum ground reaction forces were significantly different at each of the two trials ($p<.05$), and the means of the maximum ground reaction forces at the slow and fast speed trials were 37.63 N and 58.88 N, respectively.

The medial-lateral component of the maximum ground reaction forces

A statistically significant difference ($p<.05$) was found in the medial-lateral component of the maximum ground reaction forces at the slow and fast speed trials. The means of the maximum ground reaction forces at the slow and fast speed trials were 9.06 N and 10.21 N, respectively.

Discussion

The results indicated that three components of the maximum ground reaction forces at the fast speed trials increased in magnitude. These findings somewhat confirmed those of Pai and Rogers's (1990), who compared the maximum momentum of the body segments in the vertical and horizontal directions at each of three self-selected speeds instead of two in this study. Table 3 shows the magnitudes of three components of the maximum ground reaction forces as the percentage of the body weight.

The vertical component of the maximum ground reaction force

To perform the sit-to-stand movement at a faster speed, more impulsive forces were required. Thus, "the increase of gravitational potential energy" elicited increased the vertical component of the maximum ground reaction forces. The maximum ground reaction forces were found at the moment of lift-off from the chair as several previous studies (Pai and Rogers, 1990; 1991) reported.

The anterior-posterior component of the maximum ground reaction forces

The maximum ground reaction forces were checked just prior to lift-off and the

Table 3. The maximum ground reaction forces at the slow and fast speed of the sit-to-stand movement. The means of the maximum ground reaction forces were divided by the mean of the subjects' body weight and then multiplied by 100. (BW: body weight)

	The vertical component	The anterior-posterior component	The medial-lateral component
The slow speed trials	108.46% of the BW	6.06% of the BW	1.46% of the BW
The fast speed trials	120.46% of the BW	9.48% of the BW	1.64% of the BW

direction was forward. At first, backward ground reaction forces were increased, then the magnitude increased sharply forward. In this study, all of the maximum ground reaction forces were recorded in the forward direction (Fig. 2). This finding was the same of that of Schenkman and her coworkers (1990).

Medial-lateral component of the maximum ground reaction forces

This finding did not support the hypothesis and the findings of Shenkman and coworkers (1989). In slow speed sit-to-stand movements, more postural stability was required and Shenkman's kinematic study showed a doubling of the rising time without change of magnitude of the maximum torque, with increased upper body velocity, and with decreased fluctuation. Thus, medial-lateral weight shift was decreased as the speed of rising increased. However, the results of this study found the maximum ground reaction forces in the medial-lateral directions increased as the speed of the movement increased.

This finding confirmed that of Pai and Rogers (1988) who compared the body center of gravity at fast and neutral speeds. They studied sit-to-stand transfer at self-selected fast and natural speeds in eight healthy subjects (30~38 years), and suggested there was greater instability for the fast movement in sit-to-stand transfer. Even though, the procedures and outcome of measurements were different from this study, basically, greater instability was noted at the fast speed of the movement.

The maximum ground reaction forces were identified as both "propulsive impulse" and "breaking impulse" (Pai and Rogers, 1990), which played a role to break the

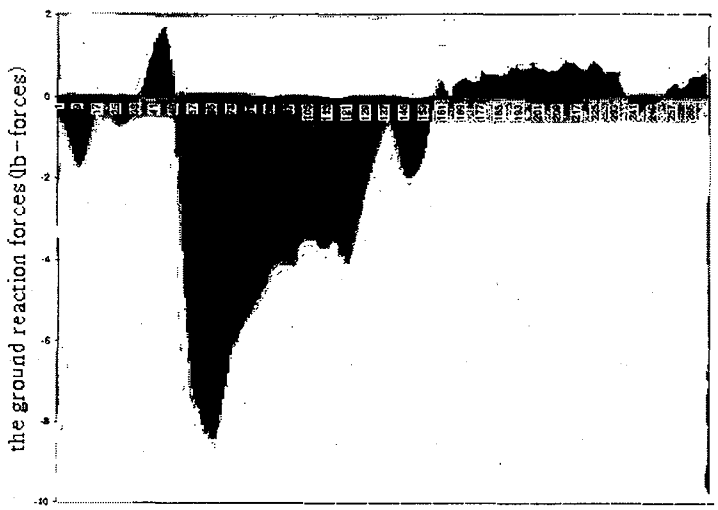

Fig. 2. The anterior-posterior component of the ground reaction forces

momentum in each direction during the sit-to-stand movement, and these forces were found either at the moment of lift-off or at the moment of a stabilization. In other words, "propulsive impulse" and "breaking impulse" indicated the lift-off and the stabilization phases, respectively. At the slow speed trials, most of the medial-lateral component of the maximum ground reaction forces were found during the stabilization phase. On the other hand, the maximum ground reaction forces at the fast speed trials were found mostly during the lift-off phase. Therefore, to generate a faster speed of the movement, strong impulsive forces were required, and these values were larger than the magnitude of the "breaking impulse," which played a role as the balance control of the increased momentum in the medial-lateral direction. At the slow speed trials, however, the magnitude of the "breaking impulse" was larger that those of "propulsive impulse" because relatively severe instability occurred in the medial-lateral direction. In this study, the results showed that the magnitude of the "propulsive impulse" at the fast speed trials was larger than those of the "breaking impulsive" at the slow speed trials. So, for patients with balance disorders, the fast speed of sit-to-stand may not be appropriate despite the fact that the magnitudes of the medial-lateral component of the maximum ground reaction forces were 1.64% of the body weight. Therefore, physical therapists when training patients with balance impairment in the sit-to-stand movement should consider focusing on correcting instability at the lift-off and stabilization phases because the propulsive impulse and breaking impulse are maximal at those phases.

Limitations

This study assumed that the subjects' performance of the sit-to-stand movement would be consistent and symmetrical. In the procedure, however, a controlled speed may not be appropriate for performing the sit-to-stand movement consistently, even though the subjects practiced five times at the pretrial to familiarize themselves with the task. The symmetry or asymmetry of the sit-to-stand movement at a self-selected speed and controlled speeds warrants further study. Additionally, Lundin and his associates (1995) pointed out there was some differentiation of right and left among the healthy subjects. In their study, peak joint moments at the ankles, knees, and hips were compared, and they found asymmetric ground reaction force data, which suggested that the assumption of bilateral symmetry of lower extremity joint moments was not valid. These results indicated that the medial-lateral component of the maximum ground reaction force may have been affected especially if the subjects' sit-to-stand movement was not symmetric.

In terms of clinical implications, the findings may not provide a valid standard for judging the clinical impairment of patients because only young healthy subjects were tested. However, the controlled times used in the trials were closer to the real times used by patients and the elderly. One study (Engardt and Olsson, 1992) reported the total time taken for the sit-to-stand movement of 42 patients who had sustained a stroke was 3.7 seconds, and in 23 normal elderly subjects, the average time for the sit-to-stand movement was 1.56 seconds (Alexander et al, 1991). Based on these clinical facts, a more realistic speed of the sit-to-stand movement was investigated in this study.

Considering these results, physical therapists should possibly consider guiding the patients and the elderly to perform the sit-to-stand movement by means of appropriate slow speed movement because a relatively less magnitude of ground reaction forces is required. Further study should focus on the establishment of normative data on the maximum ground reaction forces during the sit-to-stand movement.

Conclusion

Reduced speed of the sit-to-stand movement is one of the common findings in patients and the elderly. Thus this study focused on the effect of the speed of movement on maximum ground reaction forces during the sit-to-stand transfer. The results of this study found greater impulsive forces at three components of the ground reaction forces required during the faster sit-to-stand movement. At the slow speed sit-to-stand movement, the medial-lateral component of the ground reaction forces tended to play a role in balance control.

Because this study used young healthy subjects, the same results cannot be expected among patients and the elderly, but these findings may serve as a foundation for the evaluation of the performance of therapeutic procedures and transfer skills taught in a physical therapy program.

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