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Backward Sway 동안의 자세움직임 형태에 대한 근전도와 생체역학적 분석

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Electromyographic and Biomechanical Analysis of Postural Movement Patterns During the Backward Sway

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국문요약

이 논문의 주목적은 정상인을 대상으로 각기 다른 3가지의 (체중의 1.5 %, 3.0 %, 9.0 %) 부하를 통해서 자세의 불균형을 유발시켰을 때 나타나는 postural movement patterns을 기술하기 위한 연구이다. 연구대상의 허리중심에 체중부하를 주어 균형이 뒤로 이동하게 하여, surface EMG(표면 근전도)를 통하여 Tibialis anterior(Ta), Gastrocnemius(Gc), Quadriceps femoris(Qc), Hamstring(Ha), Rectus abdominalis(Ab)와 Paraspinalis(Pa) 근육들의 motor recruitment pattern(운동회집형태)를 측정하였다. 그리고 비디오 촬영은 고관절, 슬관절, 족관절의 움직임을 보기 위해 사용하였다. 특히 근전도(EMG)는 자세반응검사에 있어 첫 근반응(근수축) 경과시간(FR)과 분절간격간의 (ID)시간을 조사하는데 사용되었다. 이 연구의 결과는 4가지 중요한 사실을 전해주고 있다. 첫 번째로서, 연구대상자에게 체중의 1.5 %의 부하를 적용하였을 때 Ta가 가장 먼저 수축을 시작하였고 (FR:88 ± 19.4 ms) 발목과 대퇴사이의 분절 간격간(ID)의 평균은 +9.3 ms였다. 또한 족관절의 변화가 가장 뚜렷하여 Nashner(1985)의 족기전을 뒷받침하고 있다. 둘째로는 연구대상자에게 체중의 3.0 %의 부하를 주었을 때 Qc와 Ab근육이 원위부에서 근위부 순서로 수축하였고, 첫 번째 근육수축시간은 (82 ± 39.2 ms)였다. 그리고 이때 분절간격의 평균은 +8.3ms 이였고 Ta는 거의 반응하지 않았다. 족관절과 슬관절에 비해 고관절의 변화가 가장 현저하게 나타났고, 이 또한 Nashner의 고관절 기전과 같은 현상을 보였다. 셋째로 연구 대상자에게 체중의 9.0 % 부하를 허리에 적용하였을 때 근수축은 근위부에서 원위부 순서를 이루어졌다. 즉 Ab,Qc, Ta, Ps순으로 근수축 되었다. Ab가 처음으로 수축하여 첫 반응(FR)은 73±3.2 ms 이였고 슬관절과 고관절의 변화가 가장 뚜렷하였다. 넷째로 연구 대상자에게 체중의 9.0 %부하를 적용하였을 때, 균형을 잡기 위해 뒷걸음치는 것이 관찰되었고 이때 근수축 순서는 Ta,Ab.Ps,Qc,Hs 였다. 이 결과는 Nasher의 결과와 불일치하였다. 이상과 같은 결과에서 연구대상자의 자세운동형태(postural movement patterns)는 각기 다른 부하 정도와 시간에 따라 합성적으로 이루어지는 것으로 보여졌다. 특히, 자세운동형태는 부하의 적용위치와 연구대상자의 최근의 경험에 영향을 받은 것으로 밝혀졌다. 결론적으로 말하면 자세운동형태는 중앙신경계의 제한적(한정적) 명령 시스템에 의해서 움직임(movement)이 발생하기 전에 조직된다는 Nashner의 가설을 뒷받침하였다.

Introduction

Numerous studies have been performed to investigate the mechanism of postural control. Until recently, few investigators have been concerned with both the kinematic and electromyographic(EMG) changes(quantitative analysis and method) occurring during perturbation of standing. Specifically, the purpose of this basic scientific study is to better understand human postural controls with relation to the perturbation of standing during increasing loads at a subject's waist, employing the EMG and kinematic analysis. A descriptive comparative design and one-way analysis of variance (ANOVA) for repeated measures designs are used.

Statement of the Research Problems

What are the effects of perturbation of the center of gravity(COG) on the postural controls in human?

Definitions

Postural control is defined as abstractly the postural corrections to maintain equilibrium through neural and biomechanical responses relative to the perturbations induced by the three different loads at a subject's waist; operationally, EMG and Kinematic analysis will be used to answer the postural control.

Perturbation of center of gravity(COG) is defined as abstractly the displacement of COG from the base of support; operationally, the three different loads(light:1.5%, medium: 3.0 %, and heavy: 9.0 % of the subject's body weight) at a subject's waist destabilize the COG from the base of support.

Significance/Need

In clinical setting, clinicians tend to assess grossly, or qualitatively client' postural control disorders. Consequently, these qualitative assessment have limited value in delineating the postural control problems that underlie the observed deficits. this basic scientific research utilizing quantitative method will refine theoretical postulates of the mechanism of neurobiomechanical regulation of the posture during the perturbation of standing.

Hypotheses

1. If the light load (1.5 %) is applied, the subject may use ankle strategy, defined as follows: In EMG analysis, the latency of ankle muscles is 11 msec or more prior to that of trunk and thigh muscles: the amplitude of ankle muscles is greater than testing muscles; the sequence of muscle firing is from distal (ankle muscles) to proximal(trunk muscles); lastly, in kinematic analysis the angular velocity of ankle joint is greater than other testing joints.

2. If the medium load (3.0 %) is applied, the subject may use hip strategy, defined as follows: In EMG analysis, the latency of trunk, or thigh muscles is 11 msec or

more prior to that of ankle muscles: the amplitude of trunk, or thigh muscles is greater than that of ankle muscles; the sequence of muscle firing is from proximal to distal; lastly, in kinematic analysis the angular velocity of hip joint is greater than other testing joints.

3. If the heavy load (9.0) is applied, the subject may use mixed ankle-hip strategy, defined as follow: In EMG analysis, the intersegmental latency is less than 11msec among the testing muscles; the amplitude of the testing muscles is relatively similar; the sequence of muscle firing is simultaneous among the testing muscles; lastly, in kinematic analysis the angular velocity of the knee joint is greater than that of testing joints.

Rationale for Hypotheses

The effects of mechanical and sensory perturbation depend on their physical (magnitude and location), temporal(speed, duration, and frequency), and cognitive (predictability) qualities (Lee, 1988). Specifically, the different magnitudes of perturbation will determine how strongly it will disturb postural output. Low magnitude of perturbation may be detected and corrected before their effects are too great, whereas very great magnitude of the perturbation may occur too quickly to be corrected.

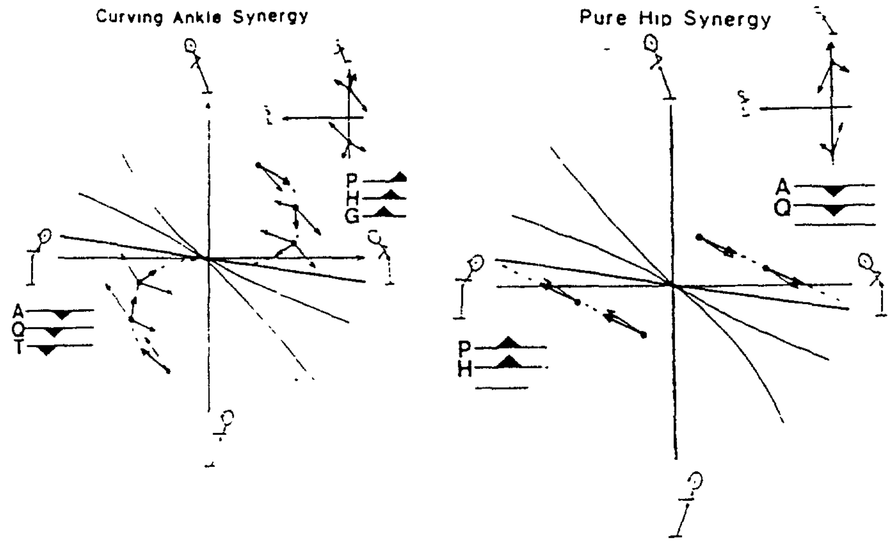
The number of leg and trunk muscles available to perform postural movements about the ankle, knee, and hip joints are considerable. At all three joints there is functional overlap among muscles exerting force across two adjacent joints. However, the minimal number of muscles, working in push-pull fashion, required to independently control the motions of three joints are six. Therefore, for the purposes of developing a general scheme of muscular coordination we selected an antagonist muscle pair for each joint: (1) ankle plantar flexion, anterior tibialis; ankle dorsiflexion, gastrocnemius; (2) knee flexion, gastrocnemius and hamstrings; knee extension, quadriceps(rectus femoris head: (3) hip flexion, quadriceps and abdominalis; hip extension, hamstrings and paraspinals.

Review of Literature

The task of staying upright usually begins with muscular actions at the support base. First the ankle joints are adjusted, after which the body moves like an inverted pendulum that is hinged at the ankles. This concept(Gurfinkle & Shik, 1973) has led to fruitful analysis by combining biomechanical and muscular response to perturbations of individuals who are standing on a platform with built-in force sensors.

Nashner and colleagues (1976, 1977, 1979, 1981 & 1985) have used support-surface perturbations and EMG analysis of muscle responses to study strategies used to maintain postural control. They have reported that most common postural responses of standing subjects to subtle support-surface perturbations involve an ankle strategy. The ankle strategy rotates the body primarily around the ankle joint and subsequently moves the center of gravity within the base of support(figure 1). This strategy is characterized by synergistically organized muscle responses. For example, in response to an induced backward sway, the tibialis anterior and quadriceps femoris muscles contact in a distal-to-proximal sequence. When the support surface is narrow or the perturbations are large, postural control maintained by a hip strategy(figure 1). During a hip strategy, the center of gravity is maintained within the base of support by flexing or extending the hips. The hip strategy is also synergistically organized. The thigh and trunk muscles antagonistic to those used in the ankle strategy contract in a proximal-to-distal sequence. For example, in response to induced backward sway, the paraspinals and hamstring muscles contract. If the platform perturbations are large or fast, the ankle and hip strategies may not be effective in restoring the center of gravity within the base of the support. In this case, a mixed ankle-hip strategy or stepping strategy is employed to maintain the balance(figure 2). From their study, Nashner and McCollum (1985) have proposed that the postural control is maintained by a few strategies (ankle, hip, mixed ankle-hip strategy) derived from a very limited set of distinct contractile patterns.

In contrast to support perturbations, I observed that many clinicians have applied the destabilizing force of different magnitude, delivered at the waist rather than at the feet to evaluate and treat the clients with balance disorder. Therefore, I decide to investigate the postural control during the perturbation of standing at the waist with healthy individuals utilizing EMG and Kinematic analysis.



2A 2B

Figure 1. Sway trajectories in the ankle- hip plane produced by ankle and hip strategy movement are characterized. EMG patterns are shown in a "musical score" format. Lines represent ankle, thigh, and trunk segment muscle pairs. Extensors of each segment point upward, flexors downward. 2A: Muscles on the same aspect of the leg and trunk contracting in distal-to-proximal sequence move the body toward the origin in a clockwise-curved trajectory while maintaining stability in the vertical axis . 2B: Thigh and trunk muscle contractions on the same aspect of the leg and trunk move the body to hip-flexed and hip-extended positions along the locus of nonerect balanced positions, while also maintaining stability in the vertical axis (From L.M.Nashner & McCollum,1985, The Behavioral and Brain Sciences)

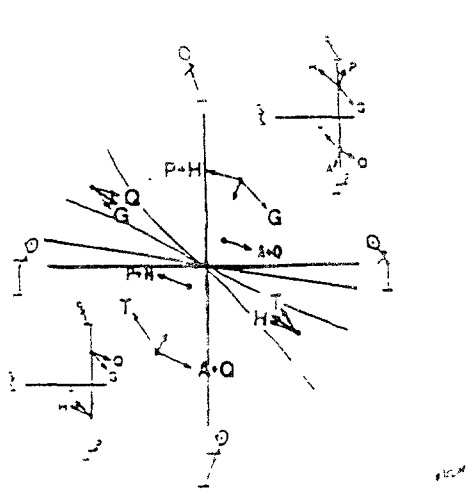


Figure 2. Division of the ankle-hip position space into four regions characterized by different minimal combinations of muscles which when contracting together accelerate the body toward the origin. In the upper right and lower left regions. the ankle,thigh and trunk muscles on the same dorsal or ventral aspect of the body move the body move the body toward the origin without first crossing a region boundary. The insert in the upper right corner shows how these muscle accelerations combine to maintain metastable equilibrium in the vertical axis. In the two lateral regions, ankle and thigh muscles on opposite aspects of yhe leg accelerate the body not only toward the origin but also upward or downward.(From L.M.Nashner & G.McCollum. 1985. The Behavioral and Brain Sciences)

Method

<Subjects> The participants are 10 healthy individuals (5 men and 5 women), aged from 20 to 50. Because the perturbations may be uncomfortable and disturb the subjects' balance and there is a risk of falling backward, the subjects (20 to 50) may have less risk of falling backward, the subjects have any history of any diseases or surgery of the testing joints. All subjects had physical examinations to exclude significant orthopedic or neurological impairment. They understand that researchers will keep, use and dispose of the findings with provision that their names will not associate with any of the results by using the numbers. Prior to participation, each subject signs an informed consent from in accordance with the regulations of human subject research review committee at New York University and Universal Institute. The proposal will be submitted to New York University and Universal Institute.

<Equipment> External static loads (1.5, 3.0, and 9.0 % of BW) consist of free weight attached to each subject's waist (Figure 2). A multichannel surface EMG with an accuracy of 99.8 % is used to record the testing muscle activities (medial gastrocnemius, tibialis anterior, vastus medialis, medial hamstrings, paraspinals, and rectus abdominalis) of the subject's right

side. Signals are band pass limited to 3-db/decade from 75-Hz to 4-KHz and processed with a total differential gap 175,000. ARIEL movement analysis system, expected to be highly reliable, is used to measure the joint angular velocity of the testing joints (ankle, knee, and hip joint). A video- camera, stop-action recorder, markers, and reference frame are used.

<Procedure> Subjects stand barefoot and maintain their arms at sides, looking straightforward. Subjects are asked to wear short running shirt and swim short because 2.5 cm surface electrodes are placed on the surface of the testing muscles; spaced 2.5 cm apart. The markers are attached on lateral condyle of humerus, lateral styloid process of radius, great tuberosity of femur, lateral condyle of tibia, lateral malleolus of fibular, and the lateral head of fifth metatarsal bone. The reference frame is established parallel to the subject with 3 m distance from the left lateral malleolus to coordinate sagittal plane. The video-camera is set up 7m from the sagittal reference frame at a height to maximize the subject within its field of view. A pilot study has revealed that 5 % of BW(originally planned maximum load) was not enough to produce maximum perturbation. Revised weights(1.5, 3.0 and 9.0 % of BW) are applied and removed at a slow, constant speed by a experimenter. Backward perturbation is only performed for this experiment. To reduce the subject's adaptation or expectancy to the external perturbations due to repeated trials, the counter balancing procedure is employed with no cues. The subjects are tested a minimum of 30 min session. The subjects can take 5 min seated rest upon their request to reduce muscle fatigue. The subject is guarded by two assistants who stand behind the subject.

<Data Analysis> One- way Analysis of Variance(ANOVA) for repeated measures design for within-subject effect is performed to determine the marginal contribution of critical factor(increasing magnitudes) to the overall variability in latency, angle, and amplitude. Individual trial data rather than trials means are used for data analysis.

Results

As predicted, analysis of the EMG response and the changes in the joint angles revealed that a limited repertoire of the distinct movement strategies were produced and the magnitudes of the loads greatly influenced the postural movement patterns. It was found that when the heavy load was applied, complicated or stepping movement patterns were employed, which was not consistent with distinct movement strategies that were introduced by Nashner. In comparison, application of the light or medium load evoked an ankle or hip strategy to maintain standing balance, consistent with Nashner's observations.

Three measures of the postural responses were examined: 1) latency to the first muscle responses(FR) and intersegmental delays (ID) in the EMG responses; 2) the changes of the ankle, knee, hip joint angles; and 3) the muscle response patterns. The findings were fourfold. Firstly, exposing standing subject to a backward sway perturbation induced by a light load (1.5 %) elicited sterotyped patterns of Ta and subsequently Qc muscle activations with the FR latency (88+19.4 ms) and ID mean (+9.3 ms between the ankle-thigh segment). The change in the ankle joint angle was the greatest among the other joints. This corresponds as to Nashner's ankle strategy. Secondly, the successful maintenance of balance during stand with the backward sway induced by the medium load (3.0 %), the Qc and muscles were activated in the distal-to-proximal sequence with FR latency (82+39.2 ms) and ID mean (+8.3 ms), whereas the was seldom responsive. The changes in the hip joint angle were significantly larger than the other joints. This corresponds to Nashner's hip strategy. Thirdly, a more complex postural movement strategy was elicited by exposing subjects to the heavy load (9.0 %). During this condition, the sequence of the muscles activation between the ankle-trunk segments was usually in the proximal-to-distal order, showing Ab, Qc, Ta, followed by Hs and Ps with the FR latency (73+3.2 ms) and ID mean (=3.6 ms). The changes in the knee and hip joint angle were large. Finally, an additional pattern was observed during the initial trial of the heavy load, when subjects stepped backward to regain their balance. The sequence of the muscle activation was Ta, Ab,Ps and Qc, followed by Hs with no other muscle activations. No corresponding strategy was described by any researcher.

Discussion

The results may imply that subjects can synthesize postural movement patterns in different magnitudes and temporal relation (times) of three different loads. The combination of the strategies used in a particular instance is influenced not only by the localization and magnitudes of the loads(force), but also by a subject's recent experience. These observations are consistent with Nashner's hypothesis that postural movement patterns may be organized by a limited repertoire of central programs selected in advance of the movement.

Future research that measures torque and quantifies the amplitude in the EMG responses may give a better picture of the postural movement patterns. The clinical implications of these results suggest that different methods of balance perturbations require different response times and alter the postural movement patterns. It is also suggested that the standing balance responses are specific to the location and forces. Therefore, when clinically assessing or treating balance dysfunction, the clinician should be cognizant of the effects of varying points or magnitudes of perturbation on the observed responses.

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