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Effects of mental and muscular load on human equilibrium as measured by chaos analysis

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ABSTRACT

Postural sway is related to the function of different sensory systems - the vestibular system, the vision and the proprioception.Hitherto many of the ideas for the developing of posturography as a test method are based on disturbing the balance system input, or the coordination of the eyes and muscle reflexes (cerebellum and brainstem). The methods of disturbance could be to eliminate the natural sensory impressions or to present incorrect signals. Aim: The aim of this paper is to make the normal standing considerably more difficult in order to obtain more significant results. An alternative way to deepen the understanding of the regulating mechanism characteristics concerning postural sway is to study the micro mechanics of the sway. Material and Methods: To accomplish this, the movement direction of the body centre of gravity has been modelado as a random walk using chaos theory and then characteristic parameters have been computed. In this manner it is possible to see if the balance system has different strategies to handle varying types of instability. In this study we examine the effect of mental and muscular load on the micro mechanics of postural sway using th estabilogram diffusion method. Earlier studies on postural control has shown that there is often a principle of "posture first" in the neural control system. Tests were done both with eyes open and closed. Results: The results show that absent vision makes postural control less accurate, increasing sway areas and growth rates, impairing postural feedback mechanisms in the short time span but improving them in the longer time span. Regarding the muscular tension load, the mental counting load exercise and the control condition, only a small effect on long term feedback control was significantly affecting the results, and more prominently so when vision was absent. This effect showed that mental loading improved the feedback while muscular loading decreased this feedback. Conclusion: In conclusion, the study provides some support for the opinion that mental loading affects postural performance in a positive regulatory way. This could be due to improving mental alertness or dual task mechanisms.

Keywords: postural control, normal subjects, chaos theory, mental load, muscular load.

RESUMO

O balanço postural é relacionado à função de sistemas sensórios diferentes como o sistema vestibular, a visão e o propriocepção. Muitas das idéias usadas para desenvolver a posturografia como um método de teste são baseadas em perturbar a contribuição destes sistemas no equilíbrio, ou a coordenação dos olhos e reflexos musculares. Os métodos de perturbação poderiam eliminar as impressões sensórias naturais ou apresentar sinais incorretos. Objetivo: fazer a posição normal consideravelmente mais difícil de se obter e. estudar a micromecânica do balanço. Material e Métodos: a direção do movimento do centro de gravidade corporal foi modelado como um caminhar aleatório usando a teoria do caos e então foram computados parâmetros característicos. Desta maneira foi possível ver se o sistema de equilíbrio tem estratégias diferentes para controlar tipos variados de instabilidade. Neste estudo nós examinamos o efeito de carga mental e muscular nas mecânicas de microbalanço postural com o estabilograma de difusão. Resultados: a ausência de visão fez o controle das áreas de balanço postural menos precisas, prejudicando os mecanismos de avaliação postural no tempo curto, mas os melhorando no tempo mais longo. A carga de tensão muscular mostrou um pequeno efeito no controle de longo termo. Este efeito mostrou que a carga mental melhorou a avaliação enquanto carga muscular diminuu. Conclusão: o estudo provê apoio a opinião de que a carga mental afeta o desempenho postural de maneira positiva. Isto poderia ser devido a melhor agilidade mental ou a mecanismos de tarefa duais.

Descritores: controle postural, voluntários sãos, teoria do caos, carga mental, carga muscular.

INTRODUCTION

Human postural control involves several different sensory modalities, i.e., the visual, vestibular and somatosensory systems, as well as central integrative processes. Decreased function in all or some of these mechanisms results in an impaired postural control. It has been shown that performance of a silent mental arithmetic task (counting backwards in multiples of seven) is impaired when balance is perturbed (Andersson et al 2002). In this case the silent backward counting led to decreased sway instead of increased. There are various factors that may transmit the effects of a cognitive load on balance functioning. The first is attention towards balance. A second mediating factor is arousal that could be linked to the performance of the cognitive and postural tasks. A third factor is the difficulty of the balance task and to what extent different parameters of postural control analysis are capable of detecting differences (Andersson et al 1998a, 1998b).

The use of verbal cognitive tasks must be precluded since recent studies show that any task effect must consider the effect of respiration (Andersson et al 2002). However, considering this effect, there might still be an effect of silent mental activity on the amount of sway.

Dual-task studies (Shumway-Cook 1997) have shown impaired cognitive ability while at the same time challenging the balance system. Due to these findings a “posture first” principle has been suggested, i.e. the brain firstly pays attention to postural stability in a situation where demands are loaded on both the cognitive and the vestibular systems. Similar results have been found in a recent dual-task study on patients with vestibular disorders (Anderson et al 2003).

Cognitive efforts rather consistently affect older subjects balance more than they affect younger subjects according to studies on balance performance when simultanously carrying out a cognitive task (Andersson et al 2002). Research on younger entrants with no balance suffering has been less consistent, and in some studies there has been an absence of an effect, or even less sway when performing a cognitive task. This observation would be in line with the “posture first” principle, and could even be interpreted as an overcompensation effect. Thus, when the young adult preferences balance and is concentrated on stabilisation, less sway is observed.

Decreased stability by spoken mental exercise has been shown in earlier studies, whereas a recent study (Andersson et al 2002), indicated the opposite, using silent backward counting. In another experiment (Yardley et al 1999), similar results were found though no certain statistical significance was reached. Yardley et al (2001, 2002) also found increased stability during the performance of mental tasks in a stable platform trial.

Usually postural control is appreciated as a total effect during a fairly long measurement period (i.e. 15-60 s), but as neural control presumably acts over much shorter time spans, a suggestive idea would be to estimate how the instantaneous sway growth develops over just a few seconds time span. A way to accomplish this is to model the movement of the body centre of gravity as a random walk using chaos theory and from this model compute characteristic parameters, as presented by Collins and de Luca (1993).

JJ Collins and CJ de Luca of Boston University, USA, developed the stabilogram-diffusion method, which is based on chaos theory (cf. Goldberger et al 1990, Hauge 1993), in the early 1990´s (Collins and de Luca 1993). The stabilogram is a diagram where a squared dispersion measure of the centre of pressure (COP) is plotted against a certain time. Collins and de Luca (1995) showed in their posturography studies of healthy subjects that the stabilogram-diffusion curves changed slope at a critical time (tc). The curve was for that reason divided into a short-term region (S, before tc) and long-term region (L, after tc). The results showed that the diffusion coefficient (i.e. sway growth) was larger in the short-term region than in the long-term region. In addition, the scaling exponents (HS and HL), i.e. a measure of sway feedback; show that sway increments in the short-term region are positively correlated, where increments in the sway measures tend to grow over time. On the other hand, sway increments in the long-term region are negatively correlated, thus counteracting sway growth. A major interest in this approach is to estimate how tightly the postural control feedback acts.

The stabilogram-diffusion method can thus be used to test hypotheses regarding the contributions of different sensory-motor systems and strategies used in control of the equilibrium, both in the short and long term aspects of sway regulation schemes, and also taking measures of feedback into account.

In our laboratory, a study by Grusell et al (1999, 2000) investigated how the vision affects the parameters of the stabilogram-diffusion method. Werner et al (2000) showed that there is no regulatory strategy change in the micro mechanics of the sway in young healthy subjects when the body is affected by an acute 20% extra load. The latter study adds further aspects to the results of a previous study (Ledin and Ödkvist 1993) which showed that increased inertial load deteriorates balance on a stable support surface, and similar results in a study where balance was disturbed by calf vibration (Ledin et al 2003). Lervik et al (2001) compared postural control in healthy elderly subjects with postural control in healthy young subjects as investigated earlier by Grusell et al (1999, 2000). Patients with neck lesions were compared to normal subjects in a study by Werner et al (2002).

The present study was conducted to investigate the effect of mental and muscular load on the micro mechanics of body sway by using the analysis model presented by Collins and de Luca (1993), in an attempt to broaden our view on factors affecting postural stability into the cognitive load area.

MATERIAL AND METHODS

MATERIAL

Included in the study were 23 subjects (14 males, 9 females) with a mean age of 29,2 years, mean length 174,7 cm and mean weight 75,7 kg. None of the trial persons had any anamnestic pathology concerning vertigo, vision, hearing or musculature. The subjects were also asked to be in normal status considering neurology and orthopaedic diseases. None of the subjects were using any medical treatment or drugs, contraceptives excluded. They were asked not to drink any alcoholic beverages within 24 hours before the tests were performed.

METHODS

The subjects were tested while positioned on a stable dual force plate (Equi Test Neurocom Int. Inc. Clackamas, Oregon, USA). They were asked to stand quietly during the measuring period of 30 sec. Every trial person was exposed to 3 different types of activities during the measuring periods. The activities were mental load (BO, BC), muscular load (MO, MC) and standing in a relaxed posture (CO, CC). (B=brain, M=muscle, C=control, O=open eyes, C=closed eyes). Each activity was measured 20 times (10 with open eyes, 10 with closed eyes respectively, after each open eyes test a closed eyes test followed). The sequence of the activities was randomised between subjects in a cyclic pattern. Sufficient time to rest between tests was given. Total test session duration was approximately 50 minutes. None of the subjects considered the test stressing or exhausting.

•Basic position also used as control position.

Subjects standing without shoes on the platform. The head in neutral position. The feet positioned at an angle of approximately 10 degrees and heels approximately 5 cm apart. The arms folded on the chest. Straight legs and equal amount of weight is kept on both feet.

•Mental load

Subjects standing in basic position. The mental load was accomplished by silent backwards counting in steps of seven as fast and as precisely as possible. The subjects were given an arbitrary starting three-figure number, between 250-1000, settled beforehand. The subjects were naive to this number and numbers were not repeated for the same subject. After each trial the subjects reported their final achieved number, which was checked for exactitude and amount of steps of seven executed. No feedback was given during the tests.

•Muscular load

Subjects standing in basic position and instructed to moderately but firmly contract the muscles of their arms, still keeping them crossed over the chest. They were also told to moderately contract the gluteal, thigh and calf muscles simultaneously. Immediately after each measurement they were instructed to relax and then again tense their muscles just before the next test. No subject found the muscular effort stressing or exhausting in any way.

STATISTICAL METHODS

ANOVA and t-tests were used to compare groups and conditions. All statistical computations were conducted in Statistica (www.statsoft.com). P<=0,05 was considered significant.

RESULTS

The mean number of steps counted with open eyes was 8.18 spanning between 4.0-12.9. With closed eyes the mean number of steps was 8.11 ranging between 3.5-14.0. An overwhelming number of cases reported numbers that appeared to be correct ones. Thus, there was no significant effect of vision to be found on mental performance according to this experiment.

The following results presentation is based on the measures in the radial direction. All numeric values are given in the Table.

The critical times were not dependent upon visual inputs (p=0.41), and the dependence on the test type was not significant, but very close (p=0.052). Pairwise posthoc comparisons showed that muscular condition vs control had p=0.077, whereas muscular vs brain had p=0.10. The highest values in all test types were for closed eyes indicating earlier transition times when affected by lack of visual input, as shown in figure 1.

The critical areas at the transition time point were significantly larger with eyes closed as expected (p=0.004), but did not depend on test type (p=0.28). The variable interaction was significant, however only slightly (p=0.047). The highest scores was measured during muscular load in both visual conditions, first and foremost in the closed eyes state. This may indicate that muscular tension affects the proprioceptive feedback system and that vision and proprioception are dependent systems. Figure 2.

The diffusion coefficient in the short time range was not significantly dependent upon test condition (p=0.20), but showed a visual dependence (p=0.02) as could be expected from the critical areas analysis. In the longer time span, neither test condition (p=0.10) nor visual condition (p=0.07) was of importance. Similar to the results in critical areas, the diffusion coefficients in the short-time region were largest with muscular load and absent vision mostly appearing. In agreement with earlier results this interprets that vision influences postural control growth rates more in the short term span than in the long term span. Figure 3.

The scaling coefficients, reflecting the control systems feedback, in the short time range did not depend on test type, but was heavily significant (p=0.001) on the visual condition with absent vision indicating poorer feedback (larger scaling coefficient values). In the long run, however, both test type (p=0.044) and visual input (p=0.005) affected the test results. Post hoc analysis showed that muscular load was significantly different from mental load in this parameter, but the control condition did not differ from any of the two other test conditions. These findings may indicate better feedback control in the long-term region especially with no vision and during mental tension, on the contrary to short-term measurements, as shown in figure 4.

DISCUSSION

The critical times the present study reveals, in correspondence with Grusell et al (1999, 2000), Werner et al (2000, 2002) and Lervik et al (2001) a short-term zone up to approximately one second where postural feedback control is poor (HS>0.5). Later on, in the long-term region, feedback mechanisms are activated (HL<0.5) in order to increase stability. The critical time is essentially the same in the control and mental test types and has the lowest values during the muscular tension test. However, the dependence on test type did not achieve significance, but very close to (p=0.052). The critical time is, according to this experiment, not dependent on whether visual cues are available or not.

A significantly larger radial sway area at the transition point was, as expected and in concordance with the above- mentioned authors, found when the subjects were tested without sight. No dependence on test type could be be detected but a moderatly significant interaction was found during pairwise comparisons. This is probably due to that the values with muscular load and closed eyes are much higher that the other conditions. The critical area is measured at the point of critical time i.e. when the closed-loop control system comes into action and the long-term period starts.

All the measures in the short-term zone: critical times (tc), critical transition areas (r2c), diffusion coefficients (DS) and scaling exponents (HS) increase in the trial subjects when no vision is obtainable, i.e. the body in this circumstance displays a more free-floating behavior, with escalating postural sway as a consequence. This is true for all of the three test modalities.

The diffusion coefficients mirror the growth of sway. In the short-term region no significant effect was recorded on diffusion coefficients (DS) due to test type but showed dependence on optical impressions. In the longer time span, diffusion coefficients (DL) were basically unaltered by visual input, neither did the test type influence the results in any means of importance. This is in agreement with our previous studies in the laboratory (Grusell et al (1999, 2000), Werner et al (2000, 2002) and Lervik et al (2001).

Regarding the scaling exponents these reflect the feedback of the control system. In the short time zone scaling exponents did not depend on test type, but was profoundly worse with absent vision indicating subordinate feedback (larger scaling coefficient values). In the long run, however, both test type and visual input exaggerated the test results in a significant manner. Muscular load was significantly different from mental load in this parameter, but the control condition did not differ from any of the two other test conditions. These findings may indicate better feedback control in the long-term region especially with no vision and during mental tension, on the contrary to short-term measurements, as shown in figure 4.

In conclusion, the study provides some support for the opinion that mental loading affects postural performance in a positive regulatory way. This could be due to improving mental alertness or dual task mechanisms.

Figure 1: Critical times for control, mental and muscular tension with and without vision. The critical times(tc) were not significantly affected neither by visual input nor test type. The three leftmost bars refer to open eyes tests.

The two last letters under each bar refer to the test condition used during the measures:
co=control open eyes, bo=brain open eyes, mo=muscular open eyes, cc=control closed eyes,
bc=brain closed eyes, mc=muscular closed eyes

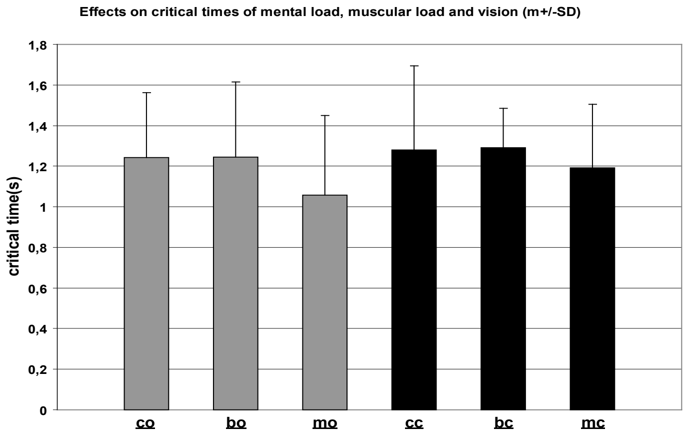

table 1: Critical areas for control, mental and muscular tension with and without vision.

Variables	CONTROL			MENTAL LOAD			MUSCULAR LOAD					
	No vision	Vision		No vision	Vision		No vision	Vision				
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Critical time, trc (s)	1,28	0,37	1,24	0,32	1,29	0,42	1,25	0,39	1,19	0,31	1,06	0,19
Critical area, r2c (mm2)	127,63	103,77	96,11	143,59	107,02	95,7	90,29	154,27	325,66	212,9	104,57	162,01
Diffusion coefficient, short-term, drs (mm/s2)	65,29	49,1	56,17	92,55	54,38	43,54	38,43	54,58	130,19	248,1	69,24	118,19
Diffusion coefficient, long-term, drl (mm/s2)	5,29	6,14	3,34	2,69	3,43	4,84	3,67	5,51	8,45	12,92	7,04	12,56
Scaling exponent, short-term, hrs, -	0,86	0,04	0,82	0,05	0,85	0,04	0,82	0,04	0,86	0,04	0,84	0,03
Scaling exponent, long-term, hrl, -	0,14	0,07	0,16	0,08	0,11	0,08	0,18	0,08	0,14	0,07	0,19	0,07

The critical areas were significantly larger with obstructed vision but were not

affected by test type. The three leftmost bars refer to open eyes tests.

The two letters under each bar refer to the test condition used during the measures:

co=control open eyes, bo=brain open eyes, mo=muscular open eyes, cc=control closed eyes,

bc=brain closed eyes, mc=muscular closed eyes

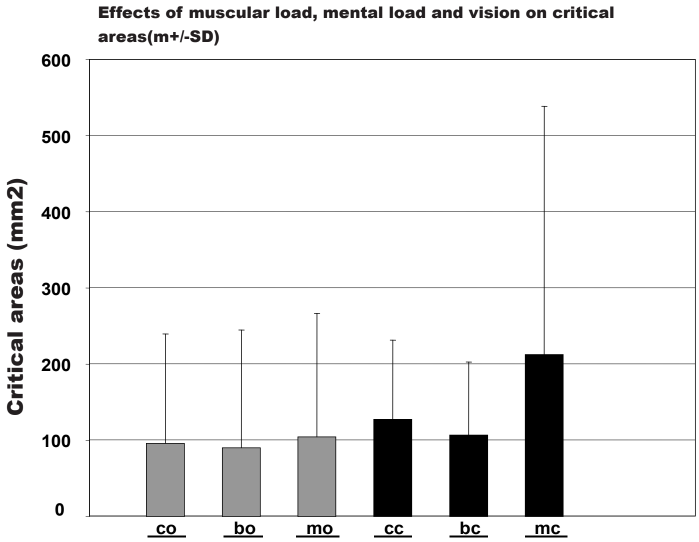

Figure 2: Diffusion coefficients for control, mental and muscular tension in the short and

long-term with and without vision. Diffusion coefficients reflect sway growth. In

the short-time region no significant effect was recorded due to test condition

but dependence on visual input was shown. In the long-term region neither test

type nor visual condition was of importance. The six leftmost bars refer to short term tests.

The first letter under each bar refers to long-term, l, and short term tests, s. The two last letters under each bar refer to the test condition used during the measures: co=control open eyes, bo=brain open eyes, mo=muscular open eyes, cc=control closed eyes, bc=brain closed eyes, mc=muscular closed eyeslong term, with and without vision.

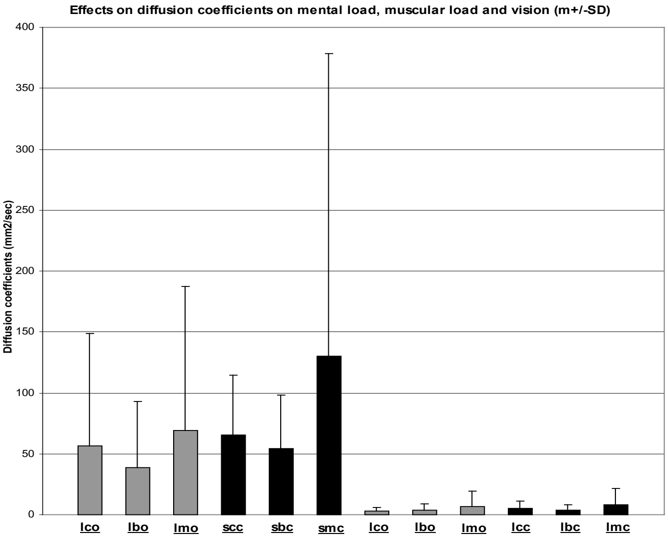

Figure 3: Scaling coefficients for control, mental and muscular tension in the short and

The scaling coefficients reflect the feedback of the control systems. In the short time region no dependence on test condition was found whereas a strong significance with absent vision was recorded. In the long time span both test condition and vision influences the results. The six leftmost bars refer to short term tests.

The first letter under each bar refers to long-term, l, and short term tests, s.The two last letters under each bar refer to the test condition used during the measures: co=control open eyes, bo=brain open eyes, mo=muscular open eyes, cc=control closed eyes,

bc=brain closed eyes, mc=muscular closed eyes

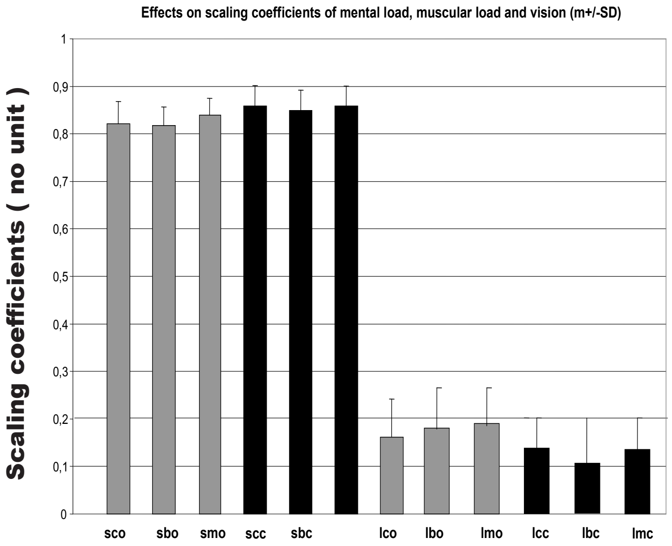

Figure 4: feedback control in the long-term region

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