DIFFERENCES IN MUSCULAR CONTROL AND GROUND REACTION FORCES IN SUBJECTS WITH STABLE AND UNSTABLE ANKLES

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The aim of this study was to investigate if there is a common behaviour distinguishing subjects with stable ankles from those with unstable ankles. Therefore the muscular response and the ground reaction forces (GRF) of 24 subjects performing horizontal jumps and also drop landings from a 40cm high box, on three different surfaces (a level one and two surfaces inclined 3° either laterally or medially) were measured. Eight parameters of the EMG signals from each of six muscles of the lower leg and several GRF parameters (eight for jumping and seven for landing) were analysed. EMG data reveal that stable subjects have higher mean power frequencies (MPF), whereas unstable subjects increase their amplitudes. The GRFs show significant differences ($p<0.05$) for the 2^{nd} vertical force maximum (Fz2) and its slope ($Fz2_{Slope}$), for the contact time (CT) and for the force maximum in medial direction (Fy_{min}). The one-legged horizontal jumping task, as well as the inclined ground conditions, seem to provide a better discrimination regarding ankle stability than the drop landing task and the level ground condition.

KEY WORDS: electromyography, ground reaction forces, ankle stability.

INTRODUCTION: Ankle stability is a major issue affecting sports performance and injury prevention. Joint stability is assured by the integrity of the ligamentous, capsular and bony structures (passive or mechanical stability (MS)) and by neuromuscular factors such as: sufficient force levels, intact proprioception and adequate neural steering (active or neuro-muscular stability). The outcome of the interaction between the former factors is usually called functional or neuromechanical stability (FS) (Freeman *et al.* 1965). There are concrete objective methods for quantifying MS. However, there is neither an accepted standardised method nor a general consensus about the interpretation or even the validity of such tests (Boruta *et al* 1990, Hintermann *et al.* 1990, Peters *et al.* 1991). Several studies indicate that there is no correlation between the results of these "static" radiological tests, or other tests assessing MS and the subjective feeling of functional stability of the ankle or the risk of injury (Freeman 1965, Peters *et al.* 1991, Tropp *et al.* 1985,). Finally, Tropp *et al.* (1985) concluded that MS is not a necessary condition for FS. The only plausible reason is that the neuro-muscular system were able to compensate for mechanical deficits. Neely (1988) stated that attempts to quantify objectively functional stability cope with the difficulty of this being multifactorial. In clinical practice, FS is usually defined by means of anamnestic data (subjective feeling of stability, frequency and kind of traumatisms, etc.). Many studies have used or studied factors that might correlate with instability such as peroneal reaction times (Ebig *et al.* 1997, Karlsson *et al.* 1997 and 1992, Konradsen and Ravn 1991, Löfvenberg *et al.* 1995, Rosenbaum *et al.* 1997), peroneal weakness (Bruns and Staerk 1992, Karlsson *et al.* 1997, Tropp *et al.* 1986), plantar flexor strength (Baumhauer *et al.* 1995) passive movement sense (Robbins and Waked 1998), postural sway, and the like. Although correlates have been found, there were also contradictory findings and no factor was strong enough to identify or account for instability on its own, probably because of its causes being manifold. Therefore, in clinical research FS is often defined as the concurrence of at least two or three from a list of factors related to joint instability. In the present study, we aim to examine whether there is a common behaviour pattern to distinguish subjects with stable ankle from those with unstable ankles. This would provide further knowledge about this complex phenomenon and help to develop prevention and intervention strategies.

METHODS: Twenty four male and female sport students, equally distributed in each group (14 stable: height: 1.77 ± 0.06 m, weight: 70.12 ± 9.23 kg; 10 unstable: height: 1.78 ± 0.06 m, weight: 71.34 ± 11.69 kg) had to perform one legged horizontal jumps and drop landings from a 40 cm high box, onto three different surfaces: a level one and two surfaces inclined 3° either laterally or medially. The analysed parameters and muscles can be seen in Table 1.

The subjects were assigned to one or another group according to their self-reported subjective feeling of stability and the results of a short anamnestic questionnaire. All subjects were still involved in sport activities, from a competitive to a recreational level. Only left lower legs were measured. After a brief instruction, the subjects had to complete the tasks. No training was allowed unless the subject felt uncomfortable at the first trial.

Drop landings: The subjects were standing on a 40 cm high box positioned in front of the force plate. They were told to step forward, land on only their left leg and stand stable as soon as possible. *Horizontal jumps*: The subjects started at a horizontal distance of 1.5 times their body height to the centre of the force plate. They had to perform two left-legged jumps, the second ground contact being on the plate and the next one at 1 time their body height distance away from the plate. The horizontal jumps and the drop landings were performed in no specific order on a level surface and on a surface inclined 3° either medially or laterally. The subjects had to carry out three valid trials for each condition. The force (40 cm x 60 cm Kistler; 1000 Hz) and EMG (Biovision) measuring systems were synchronised by starting both with the same trigger. Pre-amplified (Bandwith 10-500 Hz) bipolar surface electrodes, with a 2 cm inter-electrode distance, were placed on the muscle bellies of 6 muscles (Table 1) of the lower leg in order to measure the EMG signal (1000 Hz). EMG-data was rectified and smoothed using a second-order Butterworth lowpass filter with a cut-off frequency of 10 Hz. The filtered EMG data were normalised to the first valid trial (horizontal jumping and drop landing) on the level surface as follows:

$$EMG_{Nk} = \frac{EMG_{Fk}}{EMG_{\max,k}} \cdot 100$$

Equation 1.

EMG_{Nk} : normalised EMG-Data from k-Muscle
EMG_{Fk} : linear envelope EMG-Data from k-Muscle
$EMG_{max,k}$: maximum linear envelope EMG-Data from k-Muscle of each athlete during the first valid trial on the level surface.

All force parameters were normalised to body weight.

Table 1. Parameters and muscles studied.

EMG		**GRF**		**Muscles**
$TIME_{PA}$:	Pre-activation time	$Fz1_{max}$:	First force maximum (jump) or absolute maximum (land).	PL: Peroneus longus
EMG_{max}:	Highest amplitude			PB: Peroneus brevis
$IEMG_{PA}$:	Integral during pre-activation	$Fz1_{Slope}$:	Gradient from touch-down to Fz1max	SOL: Soleus
				GL: Gastroc. lat.
$IEMG_{CP}$:	Integral during contact phase	$Fz2_{max}$:	Second force maximum (only for jumping)	GM: Gastroc med.
				TA: Tibialis anterior
RMS_{PA}:	Root mean square during pre-activation.	Duration of ground contact (only for jumping)		
RMS_{CP}:	Root mean square during ground contact	Fx_{min}:	Backward force maximum	
		Fx_{max}	Forward force maximum	
RMS_{TOT}:	Root mean square from pre-activation to take-off.	Fy_{min}:	Force maximum in medial direction	
MPF:	Mean power frequency from pre-activation to take-off	Fy_{max}:	Force maximum in lateral direction	
		DVz:	Change in vertical velocity of the centre of mass.	

All EMG parameters, except mean power frequency (MPF) and root mean squares (RMS) which were calculated from the raw signal, were calculated from normalised EMG data. The onset for pre-activation time of every muscle was considered to be at the point when the normalised EMG value exceeded 7.5% of the maximal amplitude of the normalised signal. The instant of ground contact was determined from the force data.

Statistical analysis: All three trials from each athlete and for each condition entered the statistics. A non-parametric test for two independent samples (Mann-Whitney U test) was applied. Two-tailed asymptotical significances were used to assess significant differences among groups at $p<0.05$ and $p<0.001$.

RESULTS AND DISCUSSION: Thirty five percent of all studied EMG parameters show differences ($p<0.05$) between the stable and unstable subjects (42% jumping, 28% landing). SOL and GL provide most of the differences during the jumping, whereas PB does the same during the drop landing. All amplitude-related EMG parameters for jumping displaying significant differences show higher values for the unstable subjects. However the mean power frequency (MPF) which is frequency related is higher for the stable ones. For the drop landings some amplitude related parameters display higher values for stable subjects. This apparent incongruity could be due to methodological issues (task specificity) and needs further analysis. During the jumping, GRF parameters describing vertical propulsion (2nd vertical force maximum (Fz2) as well as at its slope ($Fz2_{Slope}$)) are significantly higher for stable subjects, whereas contact time (CT) and force maximum in medial direction (Fy_{min}) are higher for unstable subjects. For the drop landing, only the medial inclined condition provides differences and only for horizontal force parameters (Fx_{min}, Fx_{max}, Fy_{min}). These are, in all cases, higher for the unstable subjects and may in turn lead to higher shear forces in the ankle joint.

Table 2. Significant differences ($p<0.05$) in EMG parameters during drop landing.

	Land. level surface	**Land. lat. Inclined surface**	**Land. med. inclined surface**
PA_{time}	PL^{u}, TA^{u*}	PL^{u*}, SOL^{u}, TA^{u}	PL^{u}, SOL^{u}, TA^{u}
EMG_{max}		TA^{u}	
$IEMG_{PA}$	SOL^{u}, TA^{u}	SOL^{u}	PL^{u}, SOL^{u}
$IEMG_{CP}$	PB^{s}, GL^{s}	PB^{s}, GL^{s}	
RMS_{PA}	PB^{s}	PB^{s}	PB^{s}
RMS_{CP}		PB^{s}, GL^{s}	
RMS_{tot}	PB^{s}, GL^{s}	PB^{s}, GL^{s}	
MPF	PB^{s*}, GL^{s}, GM^{s}, TA^{s}	PL^{s}, PB^{s}, SOL^{s},GL^{s}, GM^{s}	PL^{s}, PB^{s}, SOL^{s}, GL^{s}, GM^{s}

^{s} : Values are higher for stable than for unstable subjects
^{u} : Values are higher for unstable than for stable subjects
* : $p<0.001$

Table 3. EMG parameters for jumping: Significant differences ($p<0.05$)

	Jump level surface	**Jump lat. Inclined surface**	**Jump med. inclined surface**
PA_{time}		PL^{u}, PB^{u} SOL^{u*}	PL^{u}, PB^{u}, SOL^{u}
EMG_{max}	SOL^{u*}	SOL^{u*}, GL^{u}	SOL^{u}, GL^{u}
$IEMG_{PA}$	PL^{u}, SOL^{u*}, GL^{u*}, GM^{u}	PL^{u}, SOL^{u*}, GL^{u*}, GM^{u}, TA^{u}	PL^{u}, SOL^{u*}, GL^{u*}, GM^{u}
$IEMG_{CP}$	PL^{u}, PB^{u}, SOL^{u*}, GL^{u*}	PB^{u}, SOL^{u*}, GL^{u*}, GM^{u}	SOL^{u*}, GL^{u*}, GM^{u}
RMS_{PA}	SOL^{u*}, GL^{u}	SOL^{u*}, GL^{u*}, GM^{u}	SOL^{u*}, GL^{u*}
RMS_{CP}	SOL^{u*}	SOL^{u*}, GL^{u}	SOL^{u}, GL^{u}
RMS_{tot}	SOL^{u*}, GL^{u}	SOL^{u*}, GL^{u}	SOL^{u}, GL^{u}
MPF		PB^{s}, SOL^{s}	PB^{s*}, SOL^{s}, GL^{s}, GM^{s}, TA^{s}

^{s} : Values are higher for stable than for unstable subjects
^{u} : Values are higher for unstable than for stable subjects
* : $p<0.001$

CONCLUSION: Regarding EMG, unstable subjects demonstrate that lower MPF could reflect lower firing frequencies. They also show higher values for amplitude related parameters. Stability is possibly linked to the ability to reach high firing frequencies. If so, increasing the amplitude of muscle activity may be a strategy to compensate this deficit. It was concluded that a common pattern to distinguish subjects with stable ankles from those with unstable ankles could be identified. However, the fact that some parameters deliver opposite results for drop landing and one legged horizontal jumping points towards a task specificity of stability (i.e. subjects use different strategies for different tasks). In this way, when stability has to be assessed, it would be advisable to study a variety of tasks. Jumping and also inclined surface conditions lead to more parameters showing significant differences between the two subject groups. Therefore, it is concluded that one-legged horizontal jumping activities are better when attempting to discriminate stable and unstable subjects, than in drop landing tasks. The same happens in true for the inclined surfaces compared to the level ground.

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