©Journal of Sports Science and Medicine (2012) **11,** 8-15
http://www.jssm.org

Research article

Constraint-led changes in internal variability in running

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Abstract

We investigated the effect of a one-time application of elastic constraints on movement-inherent variability during treadmill running. Eleven males ran two 35-min intervals while surface EMG was measured. In one of two 35-min intervals, after 10 min of running without tubes, elastic tubes (between hip and heels) were attached, followed by another 5 min of running without tubes. To assess variability, stride-to-stride iEMG variability was calculated. Significant increases in variability (36 % to 74 %) were observed during tube running, whereas running without tubes after the tube running block showed no significant differences. Results show that elastic tubes affect variability on a muscular level despite the constant environmental conditions and underline the nervous system's adaptability to cope with somehow unpredictable constraints since stride duration was unaltered.

Key words: Electromyography, adaptation, performance.

Introduction

Variability in human (motor) behavior and performance is still a two-sided affair. Although the advantage of variability has already been mentioned as early as in the 1960's by Russian pioneer Nikolai Bernstein (1967), variability in the domain of sports (especially during movement production) has only recently been considered as an essential requirement. Traditional approaches saw variability or inconsistency in movement as noise or a problem to be reduced with training and practice (Bartlett et al., 2007; Davids et al., 2003). That neglected, however, its important functional role in motor behavior (i.e. variability that is beneficial to outcome performance) (Hamill et al., 1999; Hatze, 1986).

The development and successful integration of different perspectives (e.g. synergetics or dynamic system approaches, stochastic resonance, as well as natural and artificial neural networks) eventually contributed to a reconsideration of variability. The transfer of knowledge of, for example, information gained from networks within biological and computational science to sports highlights the importance of different experiential contents ensuring adaptation and flexibility (i.e. generalization) in task execution (Riley and Turvey, 2002; Schöllhorn et al., 2009). Research in other domains such as disease or aging (e.g. loss of variability in gait due to aging and Huntington's disease (Van Emmerik and Van Wegen, 2002)) further supports the positive characteristics of movement-production variability as being not only non-interfering, but rather fundamental to achieving a consistent movement outcome (Heiderscheit et al., 2002; Schöllhorn et al., 2009).

Given that most sport skills involve a large number of muscles and joints (i.e. many degrees of freedom), variability became an indicator reflecting readiness of these degrees of freedom to covary to achieve a required higher order macroscopic movement outcome (Handford et al., 1997). This dynamic variability is the consequence of variations from the underlying nonlinearities in the system and emerges due to shape new emergence of coordination and control (Davids et al., 2005; Hatze, 1986; Van Emmerik and Van Wegen, 2002). Due to this indeterminacy within sublevels in repetitive movements, the movement outcome as the result of a complex interplay of forces acting on the body (non-muscular forces or according to Bernstein (1967) reactive phenomena) and those forces actively produced by the person itself (i.e. internal or produced muscle forces) will always inhere a certain level of variability (Hatze, 1986).

In sports, analyses of even closed movements such as a free throw in basketball or treadmill running (e.g. Button et al., 2003; Verkerke et al., 1998; Wheat et al., 2005) illustrate that top athletes do, in fact, show variability in their execution levels (e.g. release angle in basketball (Button et al., 2003)). Despite this fact, they are still able to achieve the same movement outcome. This indicates that variability may be essential for producing skilled behavior (Bartlett et al., 2007; Wilson et al., 2007) and functionality for highly skilled athletes (pointing to an ability to co-vary) (Handford et al., 1997).

For training and development, this would further implement that adding variability by engaging athletes in complex and time-varying situations and settings may be adaptively advantageous in situations of environmental unpredictability (Fontanini and Katz, 2008). Several studies in various sports (e.g. volleyball (Spratte et al., 2007), soccer (Trockel and Schöllhorn, 2003), speed skating (Savelsbergh et al., 2010), indoor hockey (Beckmann et al., 2008; Birklbauer et al., 2006) or athletics (Schöllhorn et al., 2010)) support the positive effect of adding variability.

However, if, on the one hand, variability, induced by the set constraints or different executions or tasks, is too broad, the exercises may no longer be supportive for the actual task (i.e. no transfer of the exercises to the actual movement is possible); on the other hand, if there is no variability, the athlete is tightly constrained and it may be difficult to find the individual optimum (Schöllhorn et al., 2009). Hence, the magnitude of variability must be attuned to remain within a functional bandwidth of variability (Birklbauer et al., 2006; Handford et al., 1997). Combining the aforementioned

Received: 04 August 2011 / Accepted: 02 November 2011 / Published (online): 01 March 2012

variability aspects, it is assumed that the induced variability (at least at a certain skill level) should remain within the movement skill or at least within its immediate vicinity, to maintain the basic structure of the movement pattern.

Against this background, the application of elastic tubes to provide resistance to the lower extremities was assumed to meet the requirements to create variability within an optimal boundary. As the given elastic constraint (due to its property) may influence loading of lower extremities and the resulting alteration in the moment of inertia of the leg contribute to the movement outcome (Martin, 1985), the upcoming question is how elastic tubes influence a well-established behavior as for instance running.

It is obvious that running with different tube positions increases variability during movement production and perhaps results in a variable movement outcome. That is because the permanently changing environmental constraints may require adaptation in muscle synergies to achieve the desired movement outcome and perform the requested movement pattern; however, it would be of interest to identify whether one single application can increase variability and if so, the extent to which it is increased and how performance can be adjusted to changes through this constraint.

Up to now, the field of application of elastic tubes was resistance and conditioning training (e.g. athletics) (Corn and Knudson, 2003) but not as a technique (and coordination) training device as is the case in this study. The tubes (attached between the hip and heel) influence the freedom of movement of the lower extremities and alter the forces and, thus, lead to variation within the reactive phenomena. The imposed perturbation would result in supportive and counterproductive forces and for that reason muscle activations change accordingly with respect to an optimal pattern of coordination and performance. Consequently, it has been assumed that such a "variability" constraint increases variability on a muscular level. Running was chosen to be the investigated task because it is a routine and one of the most common types of locomotion (Abe et al., 2007).

Therefore, the aim of this study was to assess the acute effect of a one-time application of elastic constraints on variability of muscle activation variability during running. We wanted to determine whether it is possible to influence variability within the muscular components when running with elastic tubes. Specifically, it may be expected that there is a change and adaptation in variability over time during running with elastic tubes. Since participants were novices with the tubes, we expected to see an increase in muscle variability through the application of elastic tubes (and their sensitivity of initial condition) and also an after-effect, when switching back to running without tubes.

Methods

Participants

Eleven endurance-trained, male sports students (ø 24.6 yrs; who were not endurance athletes, but could run the requested intervals without total exertion) were recruited for this study. The original sample size was 13, but due to missing data only eleven participants were included in data analyses. All participants had previous experience in running on a treadmill. Nonetheless, all participants were novices with the training device (Tendybelt, Salzburg, Austria). All participants were provided with a running shoe (Adidas Supernova) to wear during testing. Participants were informed of the aims of this study, procedures, anonymity of all data, and their right to withdraw at any time. They had to give their written informed consent prior to testing. The approval from the local review broad was received prior to participant recruitment.

Design

Prior to the study, participants were stratified into two groups in respect to the initial condition as the order of presentation was counterbalanced across participants. Two intervals of 35 min each (including a standardized warm up of 5 min) had to be completed on a motorized treadmill (Marathon 2.0 V1, Sportgeräte GmbH, Austria) set with no incline (Figure 1). A 30-min rest period in-between trials provided a recovery period so as to minimize the effects of fatigue. Each 35-min interval consisted of three blocks and a standardized warm-up, all at 2.9 $m\cdot s^{-1}$. The three main blocks represented 5 min running, 20 min running with (intervention condition) or without (control condition) tubes and another 5-min block of running.

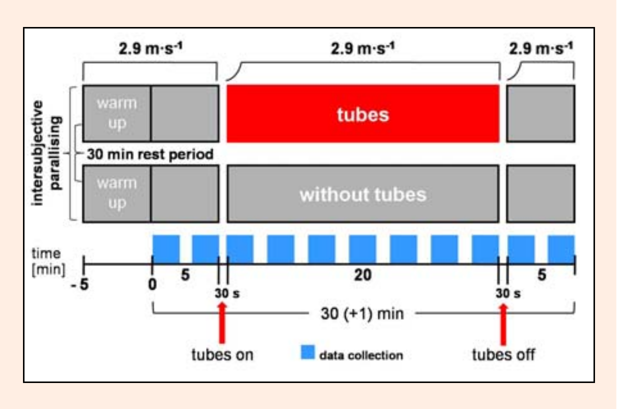

Figure 1. The running protocol showing the two running condition (the tube situation at the top with the tube block in red and running without tubes in the middle). The bottom line represents the time line with the blue squares representing the 2-min data acquisition blocks.

Training device

The tubes were attached by plastic karabiners on a specially designed chest belt made of nylon with a certain number of loops on which to fix the tubes (Figure 2). Tied around the waist was a belt with loops at the front and back and a hook-and-loop fastener at the front to fix the belt properly. The shoulder straps were heavily padded for better comfort. The tubes used in this study were black thera tubes (Thera-Band ® GmbH, Dornburg-Frickhofen, Germany), which were attached at the ilio-sacral joint and at the heel tab of the running shoes. Tube length was standardized at 40% of the individual leg length producing ~ 48 N at 100 % leg length.

Figure 2. An image of one subject wearing the training device and showing the tube positions.

Data collection

Following a 5 min warm-up, there was a direct transition to the 30-min interval and actual data collection (Figure 1). Data were captured in 2-min intervals (for data reduction) interspersed by 1-min breaks without measuring throughout the duration of the blocks, but starting at each transition from one block to another (i.e. data acquisition blocks started at min 0, 3, 5, 8, 11, 14, 17, 20, 23, 25 and 28). To attach and take off the elastic tubes, the treadmill was slowed down to 2.1 $m \cdot s^{-1}$ to make it easier for participants to step aside from and back on the treadmill belt once the tubes were attached and removed, respectively. After slowing down to 2.1 $m \cdot s^{-1}$, attaching or removing the tubes and speeding up to 2.9 $m \cdot s^{-1}$ again, data collection continued as soon as 2.9 $m \cdot s^{-1}$ were reached again to exclude possible influences of slower speed and restart of running on the calculated parameters, respectively.

To investigate motor behavioral variability muscle activity (EMG) was measured. EMG recordings were obtained from surface electrodes (Skintact, Leonhard Lang GmbH, Innsbruck, Austria). Skin preparation and electrode placement was performed as internationally recommended (Hermens et al., 1999; Merletti and Parker, 2004). EMG recordings were taken from the right leg and were obtained from three muscles that play a role in running (Novacheck, 1998) and were assumed to be primarily influenced by the tubes: tibialis anterior (TA), the lateral gastrocnemius (LG) and the rectus femoris (RF). A reference electrode was placed on the tibia. A biaxial accelerometer (Biovision, Werheim, Germany; bandwidth: DC - 500 Hz) was mounted on the right heel to trigger heel strikes to calculate stride data of the recorded EMG data. Additionally, heart rate was recorded using a Polar S810 monitor (Polar Electro Oy, Kempele, Finland) to estimate the actual exertion.

Data processing

EMG records were sampled with 2000 Hz. The raw signal was converted from analogue to digital (DAQ 6024 A/D card, National Instruments, Austin, Texas, U.S.) and stored on a computer. The signal was preamplified at source (bandwith 10-500 Hz, 3dB) with a single differential amplifier (Biovision, Werheim, Germany; individually adjusted for best resolution after a short test run). Data were bandpass-filtered (10-300 Hz; Butterworth second order) and full-wave rectified to calculate iEMG of each muscle.

IEMG was calculated over each stride. To elicit variability in muscle activation, between stride standard deviation and the coefficient of variation (CV) of stride iEMG data were calculated. To normalize the iEMG values, each participant's individual average iEMG value during running without tubes was calculated using all strides during the 30-min running without tubes and the first 5-min running block in the tube running interval (Figure 1). This average value was taken as iEMG reference value (i.e. 100 %-baseline iEMG). The calculated, normalized data (expressed as a percentage of this baseline value) were then used for statistical analyses. For graphical representation of mean stride muscle activation patterns, linear envelopes were created (10 Hz low-pass filter using a fourth order zero-lag digital Butterworth filter).

Statistical analysis

Differences between the measurements collected during the intervals were performed using the statistical software package SPSS 16.1 (SPSS Inc., Chicago, IL., USA) and Office Excel 2007 (Microsoft Corporation, U.S.). OriginPro 8.0 (OriginLab Corporation, Northampton, USA) was used to graph the data. All significant differences reported are at $p < 0.05$. All data were checked for normality (Kolmogorov-Smirnov test) and sphericity, and means and standard deviations were calculated with conventional procedures. The differences in the two 20-min running blocks were compared using three 2 (situation) X 7 (data acquisition block) ANOVAs. Using 1 x 7 Repeated Measures ANOVAs, data were separately analyzed, particularly with respect to the change in variability within the 20 min of tube running and the change within the 20 min of running without tubes. To compare the last 2 min of tube running and the first 2 min of the final 5 min of normal running (i.e. de-adaptation), a 2 (situation) X 2 (data acquisition block) ANOVA was applied. Additionally, effect size partial eta squared (η_p^2).

Results

With respect to the variability data, standard deviation represents the main parameter. A summary of the standard deviation and CV data is presented in Table 1.

Overall comparisons: When comparing the two 20-min blocks, the 2 X 7 ANOVA for the stride-to-stride variability data showed significant effects for running condition as standard deviation was increased during tube running in all three measured muscles (Figure 3). The variability was significantly greater for RF with a 72.6 % -increase ($p < 0.01$; $\eta_p^2 = 0.75$) and LG with a 36.5%-increase ($p < 0.01$; $\eta_p^2 = 0.72$) through the tube application. Differences in variability for TA were not significant. Interactions to estimate the change in variability during running revealed significant results for all three muscles ($p < 0.05$; $\eta_p^2 > 0.20$) as running without tubes maintained the same level but tube running variability decreased ($p < 0.01$; $\eta_p^2 > 0.30$). Representative mean linear envelopes of each muscle are shown for one participant in Figure 4.

The increases in muscle activity ranged from 25 to 44 % for all three muscles for tube running. Mean iEMG was different in the two running conditions with

Table 1. Summary of the mean variability changes [%] with respect to the standard deviation (left) and coefficient of variation (right). RF stands for rectus femoris, TA for tibialis anterior and LG for lateral gastrocnemius.

Comparison	Muscle	Standard deviation Changes in variability [%]		p	η_p^2	Coefficient of variation Changes in variability [%]		p	η_p^2
Difference running without tubes vs. tube running	RF	72.6	$F_{1,8}$=23.8	< .01	.75	18.4	$F_{1,8}$=16.1	< .01	.67
	TA	74.2	$F_{1,8}$=2.5	= .06	.24	15.2	$F_{1,8}$=11.5	< .01	.59
	LG	36.5	$F_{1,9}$=22.7	< .01	.72	8.1	$F_{1,9}$=3.1	= .10	.26
Running without tubes by tube running interaction	RF		$F_{6,48}$=2.3	< .05	.22		$F_{6,54}$=0.9	> .50	.09
	TA		$F_{6,48}$=4.0	< .01	.33		$F_{6,48}$=2.8	< .05	.26
	LG		$F_{6,54}$=6.1	< .001	.40		$F_{6,54}$=5.7	< .001	.37
Separate analyses for tube running	RF		$F_{6,48}$=3.6	< .01	.31		$F_{1,8}$=1.7	> .10	.20
	TA		$F_{6,48}$=4.4	< .01	.36		$F_{1,8}$=4.4	< .01	.35
	LG		$F_{6,54}$=11.3	< .001	.56		$F_{1,9}$=10.6	< .001	.54
De-adaptation	RF	-31.9	$F_{6,48}$=11.7	< .01	.60	-8.8	$F_{1,8}$=1.0	> .30	.11
	TA	-2.9	$F_{6,48}$= 0.9	< .30	.10	15.3	$F_{1,8}$= 1.0	> .30	.11
	LG	-12.3	$F_{6,54}$= 0.4	< .40	.08	0.2	$F_{1,9}$= 1.0	> .30	.10

statistically significant results for RF ($p < 0.01$; $\eta_p^2 = 0.70$) and LG ($p < 0.01$; $\eta_p^2 = 0.66$). Interactions for muscle activity revealed significant results only for RF ($p < 0.05$; $\eta_p^2 = 0.27$). Separate post hoc analyses within the main 20-min blocks unveiled significant decreases for RF ($p < 0.05$; $\eta_p^2 = 0.24$) and LG ($p < 0.05$; $\eta_p^2 = 0.30$) in the tube running condition.

De-adaptation: With respect to variability, during de-adaptation (i.e. from tube running to running without tubes), a statistically relevant interaction was found only for RF ($p<.01$; $\eta_p^2=.80$; Figure 3). Significant decreases ranging from -10.9 % to -24.1 % were found for iEMG ($p<.05$; $\eta_p^2\geq.30$).

Comparing the five minutes following return to running without elastic tubes to the five minutes before the tube running interval, no significant differences were

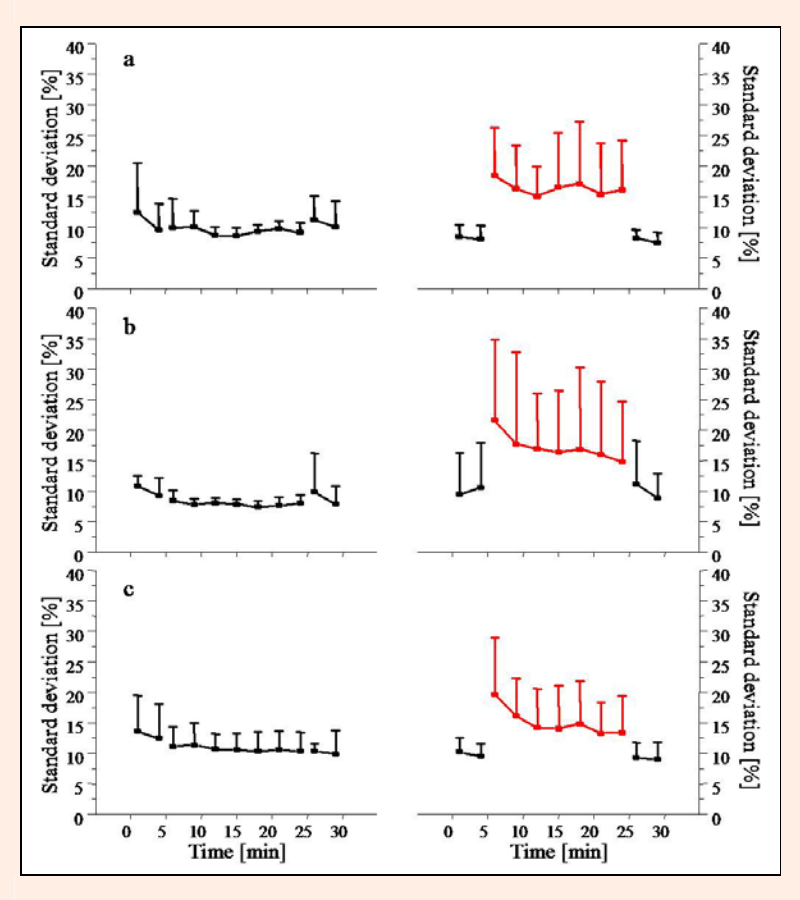

Figure 3. Shown are the average values for variability (i.e. standard deviation) of the RF (a), TA (b), LG (c). Error bars represent confidence intervals. The left diagrams represent the interval when running without tubes, the right diagrams the tube running interval with the actual tube running blocks being represented in red. In both diagrams, the first two blocks represent the two data acquisition blocks of the 5min, the middle 7 blocks the data acquisition blocks of the 20min intervals and the last two blocks the final 5min of running without tubes.

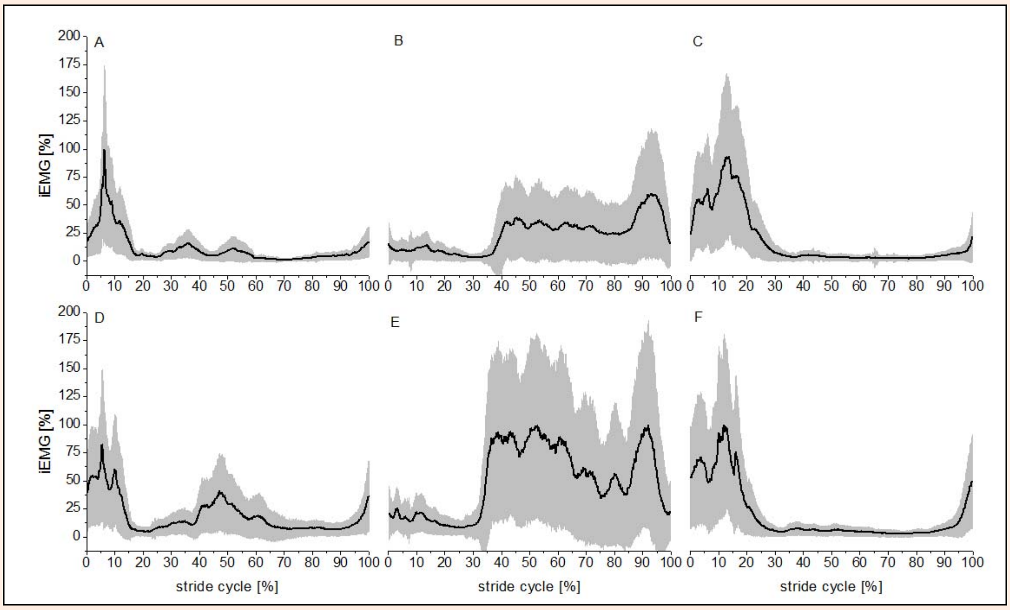

Figure 4. **Mean (±standard deviation) of the EMGs of each muscle graphed as a function of a standardized stride cycle (0-100 % from right heel strike to the next right heel strike) of one participant. For illustrative purposes linear envelopes were calculated (10 Hz low-pass filter using a fourth order zero-lag digital Butterworth filter) and subsequently normalized to the mean muscle activation of running without elastic tubes at each time instant. That is, the percentage of muscle activation displayed on the y-axis is in relation to the mean muscle activation during running without tubes. Graphs A-C show muscles when running without tubes, in graphs D-F the tube running condition is displayed (rectus fem: graphs A and D; tibialis anterior: B and E; gastrocnemius lat.: C and F). Black lines show mean muscle activation with the gray area expressing standard deviation.**

found for both variability and iEMG; however, iEMG variability after a 20-min tube interval increased with effects ranging from $\eta_p^2 = 0.11$ to $\eta_p^2 = 0.22$ compared to running without tubes before tube running.

Heart rate data used to measure exertion demonstrated significant differences neither between the two situations nor for de-adaptation ($p > 0.20$; $\eta_p^2 < 0.21$).

Discussion

The purpose of the study was to examine the variability of muscle activity during treadmill running with and without elastic tubes. Up to now, elastic tube systems generally have been used in the training process with respect to strength and conditioning only, their primary field of use being the application as a resistance constraint (e.g. athletics) (Corn and Knudson, 2003). In this instance, the tube system was not applied as a conditioning training tool but as a technique (and coordination) training device that could be implemented in various sports and directly within their skills and movements. It was hypothesized that running with tubes may lead to an increase in EMG variability by the altering reactive phenomena. By creating enhanced variability within the movement skill, experiences may be conceived of as emergent and self-organizing higher-order patterns due to interaction of neuro-musculoskeletal subcomponents (Davids, et al., 2005). This should permit more flexibility to achieve a desired movement outcome and therefore enable a stable movement outcome regardless of the given perturbations (Handford, et al., 1997).

Our analyses showed a significant increase in iEMG variability in all three measured lower extremity muscles during the elastic constraint application. Analyses also revealed increases for the average iEMG values during tube running compared to running without tubes; however, the changes in variability were higher (also evident in an increased coefficient of variation; see Table 1).

The measured changes in EMG variability (i.e. comparing EMG variability when running without tubes to tube running) may on the one hand seem surprising given that treadmill running is known to constrain the behavior and is less variable than overground running (Dingwell et al., 2001; Jordan et al., 2007). And the increase in EMG variability may be even more surprising as stride duration was similar in both situations (running without tubes: 0.75 sec ± 0.03; running with tubes: 0.76 sec ± 0.03).

Then again, such EMG variability increase in the tube running condition was expected since a rescaling of the parameters to adjust to this new unfamiliar constraint was required (Sanders et al., 2009).

During tube running, the system's variability (i.e. variability in muscle activity) increased as a consequence of permanent adaptation (Bernstein, 1967). Since movements such as running are affected not only by the input of the nervous system but also by the segments' biomechanical properties (the loading and inertial characteristics) all these factors also contribute to the movement outcome (Martin, 1985). And as the tubes' influences alternately increase or decrease due to the changing initial conditions, the alteration in the variability of reactive phenomena results in an increased variability of muscle activity (i.e. due to enhanced co-variation). So, the increased variability signifies the ability of a compensatory mechanism between active muscle forces and reactive phenomena (Bernstein, 1967). This provides a dynamic system that properly adapts to changing environmental and behavioral constraints. The decrease in muscle activity variability indicates adaptation to the tubes (Wilson et al., 2008).

On the contrary, the increased variability may also be due to the participants' inability to use the occurring and impinging reactive phenomena. The constraints (i.e. the combination of induced and natural interacting constraints) then resulted in an intervention-induced variability that was no longer supportive, but rather asked too much of the runners. Because of the tubes' properties and their application, participants were not able to co-vary by assembling other and more functional coordination patterns and, thus, control the altered forces (Müller and Sternad, 2009). The set boundaries in the form of the tubes overstrained the runners being not able to either handle or use the tubes (and their forces) complicated by their sensitivity. The prevailing variability in muscle activity may, therefore, be more unstructured and random.

However, different forms and especially the structuredness of the assessed variability should be considered (Riley and Turvey, 2002). Our analyses did not allow an estimation of this issue, which is the aim of subsequent evaluations.

Analyzing the change in variability within the unfamiliar tube running situation, we found a decrease of variability over the 30 min. According to Bertenthal (1999) and his learning-related U-shaped variability function (i.e. variability is high, decreases and increases again to a high(er) level), this suggests that runners were at least at the beginning not able to cope with the situation since they were novices with the tubes. At that time, runners explored different running patterns to find possibilities to deal with this unfamiliar constraint. The decrease in variability indicates that appropriate rescaling of the parameters of the muscle synergies during practice occurred. We postulate that an increase in functional variability (Bertenthal, 1999; Wilson et al., 2008) may occur at a later stage of tube running, for which the 30 min of running were not sufficient. Stable and flexible patterns of coordination due to the advanced ability to co-vary can then emerge (e.g. Bernstein, 1967) so as to fine tune the performance. In addition, the decrease in variability and therefore adaptation would be in line with the runners' feedback and hints towards a "normalization" of the tube running situation.

Nevertheless, it is rather surprising that despite muscle activity and its variability were influenced by the tubes, stride duration remained almost unaltered. It could be assumed that the runners tried to maintain a preferred running pattern (Nigg, 2001). The increase in variability on muscular level is therefore the consequence of restructuring the sublevels to maintain this pattern. This indicates that the unfamiliar constraint did not demand a complete change in the fundamental movement pattern but rather requires some practice to appropriately rescale the parameters of the muscle synergies (Sanders et al., 2009).

Due to the fact that we analyzed the stride, no conclusions can be made on the within-stride behavior and variability. Consequently, within-stride parameters may demonstrate a different behavior than the superior stride level (e.g. a shift in stance-swing time (Martin, 1985) or increased / decreased muscle activity during stance or swing).

Another observation in our analyses was a small shift in switch on and switch off times of muscle activity on a descriptive level. All runners appeared to activate all three measured muscles slightly earlier in the tube running condition (Figure 4). This shift was also obtained in other studies where participants initiated their movements earlier when they knew that their movements were perturbed (Button et al., 2002). Since our runners could not anticipate the tubes' influence due to their properties, they could not anticipate the kind of perturbation applied to their behavior (i.e. supportive or restrictive).

Participants probably initiated their movements earlier to react to possible perturbations and coordinate their behavior under the given constraints within their neurobiological systems (Glazier and Davids, 2009). Especially for TA and LG an increase in activity was measured. This antagonistic co-contraction may be a strategy for the runners to make the motor system more controllable (Hossner and Ehrlenspiel, 2010) and to prestabilize prior to heel strike because of possible tube perturbations (Novacheck, 1998).

Another explanation for the increased muscle activity may be a shift of attention to an internal focus. Since running was no more the routine behavior, an attention shift to the lower extremities could also be the reason for the increased EMG activity. Several studies reported an increase in EMG activity under internal focus conditions when performing biceps curls (Zachry et al., 2005), during basketball shooting (Hossner and Ehrlenspiel, 2010; Vance et al., 2004) or dart throwing (Lohse et al., 2010). More so, the applied constraint disrupted the acquired automaticity of implicit motor control during running and resulted in the observed increased muscle activity and variability to regain the impaired motor control (Hossner and Ehrlenspiel, 2010).

As our study only investigated performance, no conclusions for learning can be made. However, that elastic tubes do provide a stimulus for learning and motor behavior was shown in a study on the volleyball smash, wherein variable practice with elastic tubes according to the differential learning approach was superior in variable, competition-like situations compared to traditional learning (Haudum et al., 2011). Another study was done in the ski touring (Haudum et al., 2012). Here the application of tubes and the increase of variability were found to have positive effects on performance as less energy was required during walking with
tubes compared to walking without tubes.

Nevertheless, limitations of the current study were that only muscle activity was measured and no additional information (e.g. lower extremity kinematics, kinetics or physiological parameters) is available. The combination of those would allow better demonstration of the actual influences. With respect to the type I error, there is also a small chance of its inflation beyond the $p < 0.05$ standard given that five statistical tests were performed on the same EMG data.

Conclusion

Concerning the current study, a one-time application of this constraint was analyzed and longitudinal studies should be conducted to confirm these results and to unveil changes in coordination variability after familiarization with the tubes. Although further work is required, it can be concluded that the tubes provide an increase in variability that may induce some kind of exploratory behavior for the athlete (Newell and Ranganathan, 2009; Schöllhorn et al., 2009). However, an intervention like this could certainly enable a search process in areas outside the natural variability that would otherwise not have occurred (Corbetta and Vereijken, 1999). Therefore, an intervention study to analyze the process of adaptation or differences after having adjusted to tube running may be of interest.

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Key points

- The elastic constraints led to an increase in iEMG variability but left stride duration variability unaltered.
- Runners adapted to the elastic cords, evident in an iEMG variability decrease over time towards normal running.
- Hardly any aftermaths were observed in the iEMG analyses when comparing normal running after the constrained running block to normal running.

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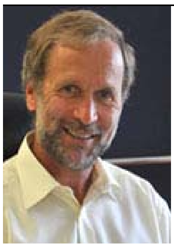

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