ORIGINAL RESEARCH PAPER

EMG AND JOINT ANGULAR DISPLACEMENT DURING RUNNING AT DIFFERENT TERRAIN AND GROUND SURFACE CONDITIONS

Johnny Nilsson[1], Asbjörn Gjerset[2], Egil Johansen[2] and Mikkel Lund[2]

[1] The Swedish School of Sport and Health Sciences, Stockholm Sweden
[2]The Norwegian School of Sport Sciences, Oslo, Norway
Address: Johnny Nilsson
The Swedish School of Sport and Health Sciences (GIH)
Box 5626, S-114 86 Stockholm, Sweden
Phone: +46 8 12053739
E-mail: johnny.nilsson@gih.se

Abstract

The purpose was to study joint angular displacement and myoelectric activity (EMG) of the hip, knee and ankle extensor muscles during running in different terrain-surface-gradient (TSG) settings at competition speed. In total six male regional to national level elite orienteers participated in the study. Mean (range), height and weight were 25 (19-32) years, 180 (1.74-1.88) m and 71 (67-75)kg. Joint angular displacement was determined by electrogoniometers taped over the hip, knee and ankle joints of the right leg. Surface electrodes were used to record the EMG activity in m. gluteus maximus, m. vastus lateralis and m. soleus. The data was recorded by means of a data logger at 1000Hz and stored for later computer analysis. The participating orienteers performed runs in six different TSG settings: forest, forest uphill, forest downhill, timber felling, wet moss and gravel road. The time in each TSG setting was recorded by means of an ultra-sound based timing unit and the mean speed was calculated. The results showed a mean perceived competition speed in all test conditions of approximately 5 $m \cdot s^{-1}$ with the exception of wet moss and forest uphill which showed a competition speed of about 3 $m \cdot s^{-1}$. Despite of this the cycle duration in the different TSG settings was not significantly different. The basic angular displacement pattern was consistent in most TSG settings with exception of forest uphill and wet moss. The mean EMG activation level differed between the TSG settings. It can be concluded from the results in this study that different TSG settings put specific demands on joint angle amplitude and muscle action as well as activation, which has to be taken under consideration in the training design.

Key words: *angular displacement, electromyography, running, terrain.*

Introduction

Surprisingly few scientific studies have been conducted on orienteering. Among the research performed on this sport the aerobic energy demands has gained the largest interest (Creagh & Reilly 1997). This research on aerobic processes cover for example energy cost during running on different surfaces. The increase in energy cost during running on sand compared to treadmill running increase the energy cost by 15 to 40% as reported by Zamparo et al. (1992). A similar comparison concerning forest terrain showed an increase in energy cost from 26 to 72% depending on surface undergrowth density and gradient (Jensen et al. 1994, Creagh & Reilly 1996, Sloniger et al. 1997).

The relative aerobic demand in orienteering competition among female orienteers has been estimated on the basis of a maximum oxygen uptake of 52ml O_2/kg/min to be 80%, which was approximately at the anaerobic threshold level (Creagh 1996). Thus, orienteering competition cause a large energy demand. The reported data do not exclude that even higher relative work intensities can be reached during an orienteering competition. This is plausible during e.g. sprint distances in orienteering competitions.

Also anaerobic energy processes, as indicated by blood lactate accumulation, among male elite orienteers varied between 4.4 and 6.7mmol/L on different stages of an orienteering competition as shown by Dresel (1985). As a result of severe ascent the lactate concentration increased to 7.3mmol/L (Dresel 1985). Average blood lactate concentration levels of 3.4mmol/L have been recorded on female orienteers in the Norwegian national team (Gjerset et al. 1997).

Muscle strength is another area that has been sparsely described in the orienteering literature. Only a few studies on muscle fiber composition and knee joint torque production have been presented (Thorstensson et al. 1977, Johansson et al. 1988). These data are important pieces of information but not extensive enough to allow any conclusions about the strength demands in orienteering.

Biomechanical knowledge about the running performance in orienteering is very sparse (Creagh & Reilly 1997). Temporal and kinematical characteristics of running in rough terrain through high grass were described by McArdle and co-workers (1991). The effects of running speed and surface on EMG activation level was described by Havas & Kärkkäinen (1995). Still there is a great lack of information on biomechanical aspects of running in different terrain, on different surfaces and with different gradient (TSG). In order to specifically adapt to movement demands for different types of terrain, surface and gradient we need detailed information about joint angular displacement and muscle activity (EMG) pattern under these conditions. This may clarify the specific movement demands in different situations and the adaptation in running technique and muscle strength etcetera that are needed to better cope with the different external demands.

Thus, the purpose was to investigate joint angular displacement and EMG activity of "prime movers", i.e. musculature that are prominent in the propulsion of the body, during running in different TSG (terrain-surface-gradient) settings at competition speed.

Material and methods

Participants. In total six male regional to national level elite orienteers participated in the study. Mean (range), height and weight were 25 (19-32) years, 180 (1.74-1.88) m and 71 (67-75)kg. The study was approved by the Regional Ethic Committee. The participants wore traditional orienteering shoes and light clothes during the tests.

Electrogoniometry. Joint angular displacement was determined by electrogoniometers that were attached by elastic tape and adhesive straps over the hip (*trochanter major*), knee (*articulatio genu*) and ankle (*lateral malleolus*) joints of the right leg (Fig. 1A). The left and right leg symmetry was assumed. Angular displacement in the sagittal plane was recorded. Cycle duration or stride rate was calculated from consecutive cycles of the knee angular displacement.

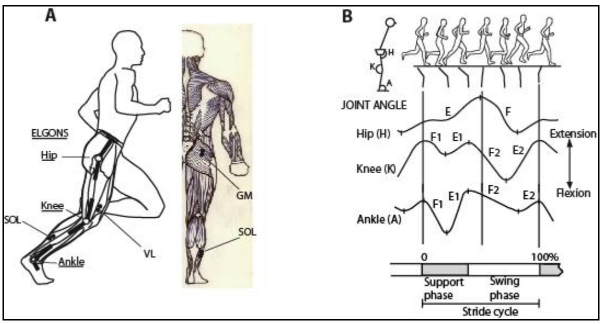

Figure 1. (A) Hip, knee and ankle joint electrogoniometers (elgons) and locations of surface electrodes above gluteus maximus (GM), vastus lateralis (VL) and soleus (SOL). (B) Angular displacement of the hip, knee and ankle joint cycle normalized to the stride cycle (100 percents). The hip joint cycle contain one extension phase (E) and one flexion phase (F). The knee and ankle joint angle cycle contains two Flexion phases (F1 and F2) and two extension phases (E1 and E2).

Electromyography (EMG). The electrical activity in *m. gluteus maximus* (GM), *m. vastus lateralis* (VL) and *m. soleus* (SOL) of the right leg was recorded with bipolar surface electrodes taped over the belly of the muscles (see Figure 1A for placements of the electrodes). The site of the electrode placements was carefully shaved and cleaned with alcohol before application of the surface electrodes.

Data logging. Electrogoniometric and EMG data were recorded by means of a portable data logger (ME3000P, Mega Electronics, Finland). The data was sampled at 1000Hz and temporarily stored in the data logger and subsequently transferred to the hard disc of a personal computer for further analysis.

Test settings and test speed. The participating orienteers performed, after a warming up period, runs at perceived competition speed in six different TSG settings: forest (horizontal level, low density undergrowth), forest uphill (seven degrees elevation, low density undergrowth), forest downhill (seven degrees descent, low density undergrowth), timber felling (horizontal level, medium roughness), wet moss and gravel road (horizontal level). The test intervals were marked in the terrain and the time between markers in the test intervals was recorded by means of an ultra sound based timing system (Time-it, Eleiko AB, Sweden). The mean speed (Fig. 2A) was calculated by dividing the length between time markers by the time spent in this interval. The duration of each run at preferred competition speed was shorter than 15 seconds. The participants were allowed repeated runs in the test intervals if the preferred competition speed was not reached and rest periods were allowed between runs to avoid fatigue. The rest periods were about 90 seconds or longer.

Analysis. The stored data was analyzed by means of a custom made program script in the Matlab® software (Matlab Inc., USA). The stride cycle for the hip angular displacement was divided into two phases; the extension phase (E) and the flexion phase (F) (see Figure 1B). The knee and ankle angular displacement in the stride cycle was divided into four phases; the first flexion phase (F1), first extension phase (E1), second flexion phase (F2) and second extension phase (E2) (see Figure 1 B).

The cycle duration was measured between onset F1 knees in consecutive cycles. The absolute mean cycle duration were calculated and are presented in graphical form (Figure 2B). Also the onset and termination of the angular phases and the EMG bursts were normalized with respect to cycle duration and presented in graphical form (Figure 3). Each EMG burst was rectified and filtered and the mean EMG amplitude was calculated by dividing the area under the EMG curve by burst duration.

Statistics. Standard descriptive statistics including means, standard deviations (sd) and ranges were employed in the data analysis. Differences between mean data were tested using repeated measures ANOVA and the alpha level was set to 0.05 to assume statistical significance. Post hoc comparisons were made using the Tukey procedure.

Results

In the result section the speed in the different TSG settings will be presented together with the absolute stride cycle duration (Figure 2 A and B). From the stride cycle duration the angular phase duration has been normalized together with the EMG burst duration (Figure 3). Finally, the mean EMG amplitude for the different TSG settings will be presented (Figure 4).

Speed and stride cycle duration. There was no significant difference between the perceived competition speeds in forest terrain, forest downhill and horizontally on a gravel road with an average speed of approximately 5 m•s^{-1}. However, the speed during uphill running and running in wet moss was approximately 3 m•s^{-1} and significantly lower than the other TSG settings. Despite the difference in competition speed presented above there were only small differences (n.s.) between Tc in all TSG conditions the exception being wet moss. Most surfaces showed a Tc of approximately 0.65 s, which corresponds to a stride frequency of approximately 1.54 Hz.

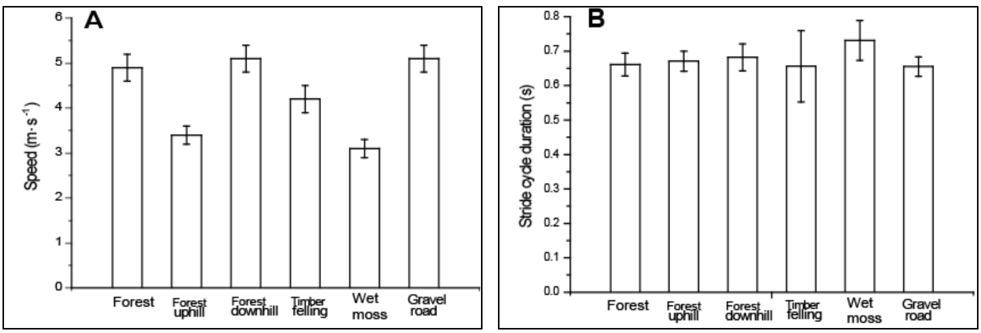

Figure 2. (A) Mean speed (±sd) in different TSG. (B) Mean (±sd) stride cycle duration during running in different TSG settings.

Relative phase duration, timing and displacement. Despite the difference in TSG the basic pattern of the two angular phases of the hip joint and four phases for knee and ankle joint were present. Only in the ankle joint angular displacement uphill the E2 phase was not present i.e. the F2 phase continued directly into F1 in the subsequent cycle (see Figure 3: ankle joint, forest uphill). The F1 and E1 knee and ankle angular phase duration of the normalized cycle represent approximately the support phase in the running stride (Nilsson et al. 1985). The relative duration of this phase was about 30 % of Tc in most TSG conditions with exception of forest uphill and wet moss where it reached about 40 %, thus, a longer relative duration. Also note the longer relative duration of the E1 phase of the knee and ankle in these situations. The net angular amplitude over the whole cycle is similar in all TSG conditions except in forest downhill, which shows smaller net amplitude for the hip and ankle joint. The reduction in F1 phase amplitude for the knee joint during running forest uphill and wet moss is also prominent. A similar basic timing pattern of the recorded muscles was seen in all TSG settings. This pattern shows a pre-activation of the muscles prior to the F1 phase in the knee and ankle joint and mainly activation during the F1 and in some cases also during the E1 phase (Figure 3).

Mean EMG activation level. The inter-muscular amplitude pattern is similar in the recorded muscles in all situations except running in forest terrain (horizontal) (Figure 3). There are amplitude differences between TSG:s, e.g. a larger mean activation of the musculature is needed uphill compared to downhill despite lower mean velocity (Figure 2 and 4).

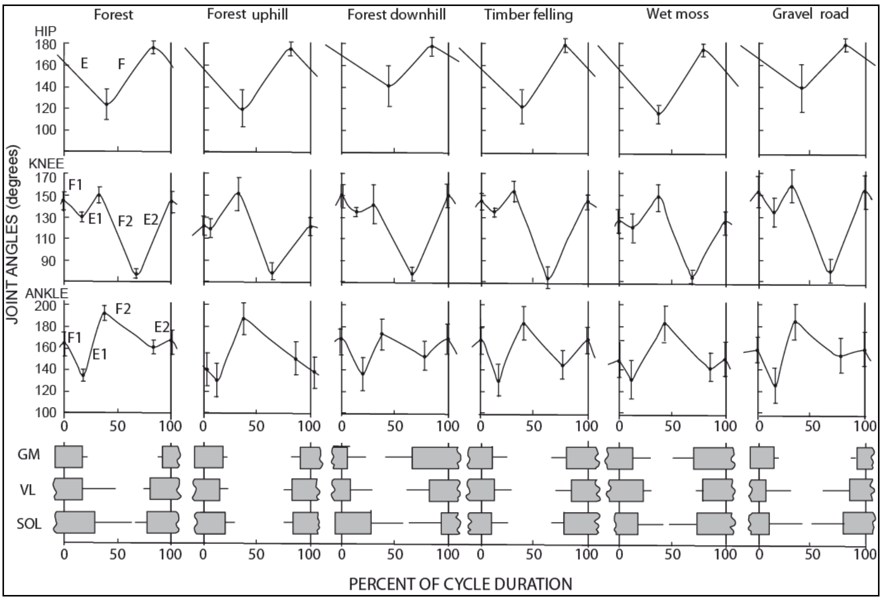

Figure 3. Mean (±sd) angular displacement and EMG burst duration in different TSG:s during running at perceived competition speed.

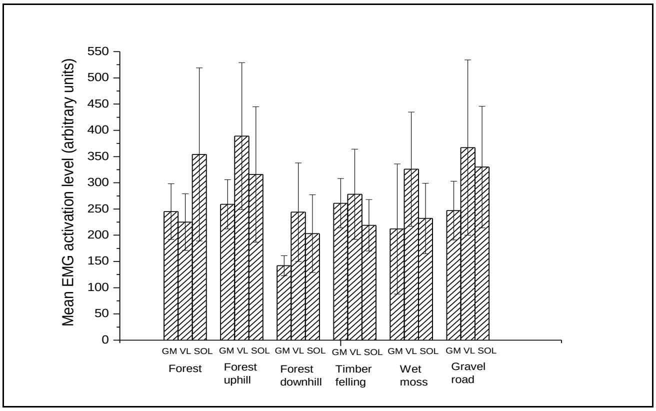

Figure 4. Mean (±sd) EMG activation level in different TSG settings during running at perceived competition speed.

Discussion

It is obvious from Figure 2A and B that the stride cycle duration is not significantly different i.e. similar stride frequency despite significantly lower speed during running uphill and in wet moss. As indicated by the equation: $v= s \bullet f$, v (mean speed) is equal to mean stride length (s) times mean stride frequency (f). If f is constant and speed changes the stride length must be the parameter that changes the speed. Thus, the stride length seems to be the parameter that is most affected by the different TSG settings. In this context it is interesting to compare the speed, stride length and frequency parameters with the EMG output during running in TSG settings. Here forest downhill running show about 30% lower EMG output compared to forest and gravel road running despite similar speed, which presumably is related to the difference in performed work per unit of time. Despite the lower speed during running in timber felling and wet moss (horizontal run) the mean EMG output is approximately equal to forest running on the horizontal level. Thus, different terrain and surfaces demand different muscle activation, which may explain the differences in energy cost (Jensen et al. 1994, Creagh & Reilly 1996).

The difference in EMG output between GM, VL and SOL is not possible to compare due to factors such as difference in electrical impedance between electrodes and muscles due to skin resistance, interfacing tissue between muscle fibers and electrodes etcetera. Therefore, the analysis is focused on specific muscles in different TSG settings. Cross-talk between muscles is another factor that has to be taken into consideration. Due to the size and thickness of GM and VL it is less likely that the EMG signals in these muscles are subjected to cross-talk. The electrodes over SOL are very close to m. gastrocnemius, which cause a risk of cross-talk. Moritani and co-workers (1989) reported an average overall cross talk of 6 percent between soleus and medial gastrocnemius peak to peak EMGs. However, the soleus and gastrocnemius muscles have a similar role in the displacement in the ankle joint which makes the problem of possible cross talk less disturbing.

Running in the different TSG settings showed a rather consistent basic phase structure but still there are interesting deviating details. One such detail is the rudimental F1 phase in the knee joint during uphill and wet moss running. This implies that the stretch-shortening contraction for VL may be strongly reduced and that VL in these situations (uphill and wet moss) is mainly utilizing concentric contractions. Further, the smaller knee angle at onset F1 indicates that the VL muscle has to work with another muscle length, which in turn can affect performance.

The longer relative duration of the E1 phase of the knee and ankle joint indicate that the speed of contraction of e.g. VL and SOL may be lower in these phases. Muscle length (joint angle amplitude), type of muscle action and speed of contraction are important aspects of specific strength training (Sale & McDougal 1981, Jones et al. 1989). The results indicate that the orienteer has to adapt to a large range of joint amplitudes, speed of contraction and also type of muscle action. The specificity in muscle strength adaptation (Sale & McDougal 1981, Jones et al. 1989) thus demand that the training among orienteers has to meet a variety of TSG settings in order to optimally adapt to the demands in running technique, strength and muscle endurance. If these demands are not adapted for it is possible that the orienteer will suffer from local fatigue and fail to produce large enough muscle force in critical joint angle phases which may cause a less optimal running technique and an impairment in running economy.

At this point we have only addressed different TSG settings at perceived competition speed. The fact that also the perceived competition and absolute speed may fluctuate considerably during an orienteering race makes the adaptation demand even greater. Thus, the training design of the orienteers should indicate that the physical training contain specific elements i.e. training in different TSG settings and should also be performed at different speeds. The use of specific strength might benefit from “overload” of the musculature in a running like pattern which may be performed in different TSG settings (Nilsson et al. 2013b). The optimal combined or separated generic and specific designs of training need to be further discussed by athletes, coaches and sport scientists.

Conclusions

It can be concluded from the results in this study that different TSG settings put specific demands on joint angle amplitude and muscle action as well as activation, which has to be taken under consideration in the training design.

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