Functional relevance of the small muscles crossing the ankle joint – the bottom-up approach

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REPORT

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ABSTRACT

It has been suggested that increasing muscle strength could help reducing the frequency of running injuries and that a top-down approach using an increase in hip muscle strength will result in a reduced range of movement and reduced external moments at the knee and ankle level. This paper suggests, that a bottom-up approach using an increase of strength of the small muscles crossing the ankle joint, should reduce movement and loading at the ankle, knee and hip. This bottom-up approach is discussed in detail in this paper from a conceptional point of view. The ankle joint has two relatively "large" extrinsic muscles and seven relatively small extrinsic muscles. The large muscles have large levers for plantar-dorsi flexion but small levers for pro-supination. In the absence of strong small muscles the large muscles are loaded substantially when providing balancing with respect to pro-supination. Specifically, the Achilles tendon will be loaded in this situation asymmetrically with high local stresses. Furthermore, a mechanical model with springs shows that (a) the amplitude of the displacement with the strong small springs is smaller and (b) that the loading in the joints of the springs is substantially smaller for the model with the strong small springs. Additionally, strong and active small muscles crossing the ankle joint provide stability for the ankle joint (base). If they are weak, forces in the ankle, knee and hip joint increase substantially due to multiple co-contractions at the joints. Finally, movement transfer between foot and tibia is high for movements induced from the bottom and small for movements induced from the top. Based on these considerations one should speculate that the bottom-up approach may be substantially more effective in preventing running injuries than the top down approach. Various possible strategies to strengthen the small muscles of the ankle joint are presented.

Keywords:
Ankle Joint – Small Muscles – Stability – Co-contraction – Running Injuries

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Introduction

Recreational running is used by many people who want to contribute to the health and well-being of their body (Paluska, 2005;van Mechelen, 1992). However, many of those runners experience running injuries. The reported injury frequencies depended very much on the severity of injuries considered in the study, e.g. 7.5% for one week or 58.0% for one day (Kluitenberg et al., 2016). However, it seems that over the last few decades there was no change in the injury frequency. Thus, running injuries seem to remain a constant problem for a large number of runners.

While it is quite known that "excessive" mileage, training frequency and/or previous running injuries play an important role in the development of running injuries (Bovens et al., 1989; Hespanhol, Pena Costa, & Lopes, 2013; Hreljac, 2005; Kluitenberg et al., 2015; Nielsen et al., 2014; Owens et al., 2013; Pollock et al., 1977; Rudzki, 1997; Saragiotto et al., 2014), it is suggested that specific changes of muscle strength could help to reduce the frequency of running injuries. There is ample discussion in the popular running literature about strengthening exercises and training programs that should help to reduce the frequency of running injuries, including decreased mileage, more rest, increased muscular strength, increased flexibility and change of running shoes (Aschwanden, 2011; Barios, 2014; Beverly, 2014; Hadfield, 2013; van Allen, 2014). Quite often, the stretching and strengthening programs which are proposed, focus on the hip and core areas. However, many of these suggestions are based on personal opinion/experience rather than on scientific facts.

One theory suggests that increased muscular strength around the hip and the core should help to reduce lower extremity joint movement and external joint moments at the lower extremities during running, and thus, reduce the frequency of running injuries (Hott, Liavaag, Juel, & Brox, 2015; Palmer, Hebron, & Williams, 2015; Powers, 2010). This approach could be called a *top-down* approach (Barton, Lack, Malliaras, & Morrissey, 2012, Brindle, Mattacola, & McCrory, 2003; Brumitt, 2009; Grelsamer & McConnell, 1998; Fredericson & Moore, 2005; Hollman, Kolbeck, Hitchcick, Koverman, & Krause, 2005; Hollman et al., 2006; Powers, 2010;). However, related experimental studies have shown no general support for the concept that strengthening the hip muscles affects the running mechanics such as range of motion and external moments during dynamic tasks (Herman et al., 2008; Willy & Davis, 2011; Palmer et al., 2015) suggesting that the top-down approach does not produce a change in the mechanics of the knee and ankle joint.

Another theory concentrates more on the ankle joint and suggests that an increase of strength, especially of the small muscles crossing the ankle joint, should affect movement and moments at the ankle, knee and hip joints (Feltner et al., 1994; Hollman et al., 2005; Tiberio, 1987;). This approach could be called a *bottom-up* approach and will be discussed in detail in this paper primarily from a conceptional point of view.

The importance of the small muscles crossing the ankle joint

The authors are of the opinion that the bottom-up approach is a very effective but not often considered approach as a strategy to reduce running injuries. In order to provide credence to a bottom-up approach, a number of considerations, where small muscles crossing the ankle joint play a considerable role in movements and balance are presented. Some of these considerations reference data, and others are more based on functional hypothesis.

Lever Arms and Asymmetrical Loading

The ankle joint has two relatively "large" extrinsic muscles (triceps surae and tibialis anterior) and 7 relatively small extrinsic muscles whose tendons cross the joint (flexor hallucis longus, flexor digitorum longus, tibialis posterior, extensor hallucis longus, extensor digitorum longus, peroneus longus, peroneus brevis). To understand the importance of the small extrinsic muscles crossing the ankle joint one should, as a thought experiment, consider the ankle joint without these small muscles (see Fig. 1 center). Let's assume for a moment that the only muscle groups acting are the tibialis anterior and the triceps surae. These two large muscle groups are well positioned to produce moments with respect to the ankle joint axis, allowing for dorsi- and plantar-flexion during movements like running.

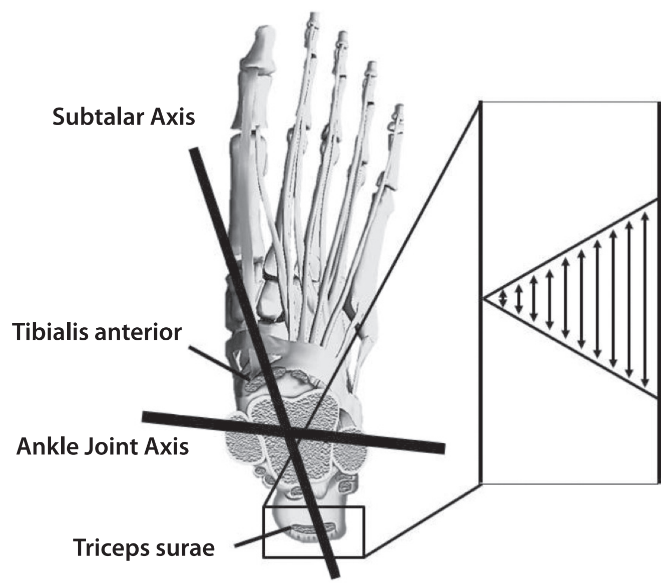

Figure 1: Illustration of the ankle joint complex assuming that only the tibialis anterior and the triceps surae are active. The triceps surae muscle group can only produce supination moments if activated asymmetrically, producing asymmetrical loads in the tendon.

However, these two muscles are not well positioned to produce moments (like pronation and supination) with respect to the subtalar joint axis. Specifically, the tibialis anterior runs medially with respect to the subtalar joint axis, and as a result, is only able to produce a supination moment with respect to the subtalar joint axis. The magnitude of this moment is relatively small due to the close proximity of the tibialis anterior line of action to the subtalar joint axis. The other major muscle group crossing the ankle joint, the triceps surae, is able to create a moment for both pronation and supination, but due to the fact that it crosses the subtalar joint axis, means that either pronation or supination moments can only be created through an asymmetric activation of this muscle group. If, for instance the triceps surae should be used to produce a pronation moment, then the lateral side of the muscle must be activated. Such asymmetrical activations have the side effect of producing asymmetrical loadings of the Achilles tendon, the insertion component of the triceps surae. Additionally, the lever of the part of the Achilles tendon that is on the lateral side of the subtalar joint axis is rather small. This means that the force in the Achilles tendon must be high to provide some meaningful balancing moment for movements about the subtalar joint axis. These thought experiments show that when the small muscles are absent (or weak) the stability must be provided by the large muscles and these muscles have only very small levers with respect to pro- and supination. Thus, in the absence of strong small muscles the large muscles are loaded substantially and, specifically, the Achilles tendon will be loaded asymmetrically with high local stresses.

Strong versus weak ankle joints

Evidence for the appropriateness of this theoretical consideration has been given in an experimental study published earlier (Enders, Lucas-Cuevas, Baltich, & Nigg, 2014). In this study, 18 test subjects were analyzed with respect to their muscle activation. Nine subjects were diagnosed with strong ankle joints and the other nine with weak ankle joints. In this study, the relative muscle activities was defined as the root mean square (RMS) of muscle activity during running divided by the RMS of the muscle activity during a maximum voluntary contraction (MVC). By using this approach, one can compare the relative muscle activity of different muscles during running for individuals with strong and weak ankle joints (Fig.2). The weak ankle joints show primarily gastrocnemius and soleus activity and only little peroneus activity. However, the strong ankle joints showed little gastrocnemius and soleus muscle activity. In this study, the peroneus activity represents only one of the small muscles crossing the ankle joint, and it is speculated

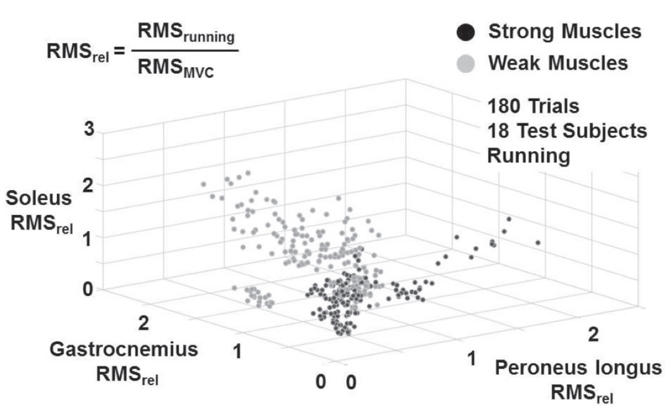

Figure 2: Illustration of the different use of muscles crossing the ankle joint for subjects with strong and weak ankle joints (from Enders & Nigg, 2014, with permission).

that for the strong ankle joint group, the other small muscles also contribute to the resultant forces. Based on these experimental results it seems acceptable to conclude that subjects with strong ankle joints tend to use their small muscles during running while subjects with weak ankle joints tend to use their large muscles (gastrocnemius and soleus) to stabilize the joint.

Spring Model

Further support for the importance of the strong small muscles has been provided in a model presented earlier (Nigg, 2005). A first model consists of a mast with four strong large springs (Fig 3, left) mimicking a leg with weak small muscles. A second model consists of the same four large springs combined with four strong small springs (Fig 3, right) mimicking a leg with strong small muscles.

Figure 3: Illustration of a model with for large springs (left) and another model with four large and four strong small springs. The model works with the assumption that the small springs can sense a change in movement faster than the large springs. (Form Nigg, 2005, with permission).

The model shows that when instability is introduced via a perturbation of the mast, (a) the amplitude of the displacement of the mast in the model with the strong small springs is smaller and (b) that the loading in the joints and in the insertions of the springs is substantially smaller for the model with the strong small springs. If we take the springs to represent the small and large muscles of the ankle joint, this would reflect smaller instabilities, and reduced loading of the Achilles tendon when the small muscles (small springs) are activated. This is further evidence for the importance of small strong muscles crossing the ankle joint.

Balance

Strong and active small muscles crossing the ankle joint have an additional importance for the loading of the lower extremities. If the small muscles are strong, they provide stability for the ankle joint (base). If the small muscles are weak, the balancing must be provided by the large muscles, especially by the triceps surae. Since part of the triceps surae is a two joint muscle (the two-headed gastrocnemius crossing the ankle and knee joint), co-contraction must be provided by the tibialis anterior as well as the quadriceps. Since part of the quadriceps (rectus femoris) spans the knee and the hip joint, co-contraction must be provided by the hamstrings to statically and/or dynamically balance the system. This means that the forces in the ankle, knee and hip joint increase substantially and due to these multiple co-contractions at the different joints, the loading in the joints and the insertions can be multiples of the original loading. In other words, when the muscles of the ankle joint are weak and don't participate in the stabilization of the locomotor system the joint and insertion forces can be multiples of normal joint and insertion forces.

Movement coupling

The coupling or movement transfer between foot and tibia has been determined in cadaver experiments for movements induced from the top corresponding to the tibia and movements induced from the bottom corresponding to the calcaneus (Hintermann, Nigg, Sommer, & Cole, 1994; Nigg & Herzog, 1998). These results showed very low coupling for movements originating from the top and very high coupling for movements induced from the bottom. This would suggest that we should expect more movement transfer when initiating movement and movement changes from the bottom (i.e. calcaneus) and less movement transfer when initiating the movement from the top (i.e. tibia). Thus, bottom-up approach should have substantially more movement transfer than the top-down approach.
Based on those considerations one could speculate that the bottom-up approach may be more effective in preventing certain running injuries than the top down approach. However, the evidence for such a statement is still missing since no prospective injury studies have been published, comparing these two approaches.

Experimental evidence for training forms for strengthening the small muscles of the ankle joint

There are many different possibilities to strengthen the small muscles crossing the ankle joint. Some selected possibilities will be discussed shortly here.

(a) Unstable shoes
Unstable shoes such as the MBT have been shown to have a positive effect on the muscle activation of the small muscles crossing the ankle joint. An array of EMG sensors arranged around the ankle joint (Coza, von Tscharner, & Nigg, 2009; Nigg, Federolf, von Scharner, & Nigg, 2012) showed that the muscle activity when using unstable shoes increased substantially for certain small muscles (Fig. 4).

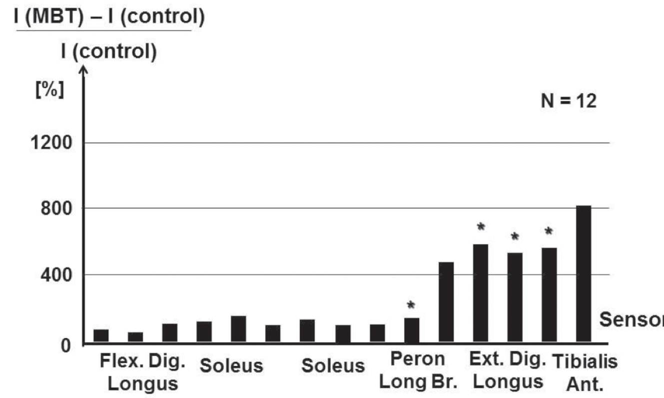

Figure 4: Differences in EMG activity for selected small muscles crossing the ankle joint when using an unstable MBT shoe compared to a stable normal running shoe using an EMG sensor array with 15 sensors (from Nigg et al., 2012, with permission).

In addition, a prospective study with 37 male golfers who experienced low back pain after golfing who trained using unstable MBT sandals (Nigg, Davis, Lindsay, & Emery, 2009) showed a significant 44 % reduction of low back pain after golfing while the control group did not show any significant changes with respect to back pain. In this study, unstable shoes increased the muscle activity of the small muscles crossing the ankle joint and provided a substantial and significant reduction of low back pain after golfing. It was assumed that the increased stability contribution from the ankle joint reduced the need for activation of selected low back muscles.

(a) Isometric training during daily activities
There are many situations during our daily activities where training of the small muscles crossing the ankle joint is possible. For instance, while sitting in a chair, one can press the feet towards the legs of the chair isometrically for a short period of time (15 seconds). Important for such a "training" is that the isometric exercises are done in all directions, multiple times within a session, and on a regular basis (every few days).

(a) Functional training
Functional training, like doing lunges onto a "bosu" ball, also provide a way to strengthen the small ankle joint muscles. Initial research has been published comparing the effects of resistance (isometric) training compared to functional training (Baltich, Emery, Stefanyshyn, & Nigg., 2014). The results of this initial study with 75 subjects can be summarized as follows (Baltich et al., 2014): The resistance training had the highest increase in ankle joint strength. The functional training had the highest number of running injuries (prospective). However, all results were not significant. One of the most practical conclusion of this study was that such training programs must be closely supervised.

Limitations

Despite the fact that running injuries continue to be common among a large group of runners, it is surprizing that no prospective studies have been published that quantify the effect of the top-down versus the bottom-up approach with respect to running and running injuries. Thus, the final evidence is still missing and it is suggested that such a study would be a logical next step. Furthermore, there are many different running injuries and a next step should include to distinguish between specific running injuries.

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Competing Interests

The authors have declared that no competing interests exist.

Data Availability Statement

All relevant data are within the paper.

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