Hip strength in Swedish soldiers

A correlation study between gluteus medius muscle strength and development of valgus during 2000 meter run with external load

Mathias Bergqvist

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**Abstract**

Background: A requirement for a soldier is to be able to move long distances under short time with heavy external load, creating high requirements on stability in the lower extremities. Weakness in gluteus medius muscle (Gmed) which is one of the main muscles for hip stability have been associated with several forms of injury in the lower extremities and particularly in the tibiofemoral joint. Since strength test protocols in the Swedish armed forces does not contain instructions to control hip stability, recruits with deficient Gmed strength may acquire a position in the military and due to lack of hip stability be in greater risk of injury.

Aim: The purpose of this study was to combine a two dimensional (2D) analysis of frontal plane gait kinematics with a Gmed strength test to determine if (1) there’s a correlation between subject’s Gmed strength and valgus during a 2000m self-paced run with external load (RWL) and (2) a 2000m run without external load (RNL) as well as (3) examine the difference in knee valgus between the run with and without load.

Method: 10 subjects participated in a correlational study. Gmed peak strength was measured by performing a concentric side lying hip abduction in a Quantum 1080 machine. Frontal plane knee alignment was recorded in the initial and final parts of the two 2000 meters running test on a treadmill, one without external load and one with a weight vest set to 20 kg.

Results: No significant correlation in terms of correlation coefficient (r) or coefficient of determination (r^2) was found between Gmed strength and RNL during initial recording (r = -0.04, r^2 = 0.08, p = 0.90) or second recording (r = -0.40, r^2 = 0.17 p = 0.25) The self-paced run with external load showed a no significant correlation in initial recording (r = -0.41, r^2 = 0.17, p = 0.27) but a strong negative correlation on second recording (r = -0.69 , r^2 = 0.44, p = 0.02) With the exception of trend towards significance (p = 0.07) in difference of knee valgus between the second recordings of both running tests, no significant difference was found within or between the tests.

Conclusion: The results showed a significant correlation between Gmed and valgus in the running test with external load and a significant change of valgus in comparison between late parts of both running test. Despite that the level of correlation in late part of running test with external load can create interest for larger studies, due to low number of subjects and no knee valgus value went beyond set boundaries, the connection to causation is in this study unclear.
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Background

Gluteus medius

In the bipedal system of human locomotion, walking and running is a repetitive motion where muscles around the three joints of the lower extremities (hip, knee and foot) works together to accelerate the centre of mass forward as well as stabilize the body to avoid a collapse due to gravity (Hamill & Knutzen, 2009; Brown, O'Donovan, Hasselquist, Corner & Schiffman, 2014). One of the contributors to hip and leg stability during gait is the gluteus medius muscle (Gmed) with its origin on the outer surface of the pelvis and insertion to the femur at the greater trochanter, making it one of the primary hip abductors for the lower extremities (Dauber & Feneis, 2006). During the unilateral stance of the support phase in walking and running, Gmed acts together with the muscle tensor fascia latae as a stabilizer to avoid lateral tilting of the pelvis (Hamill & Knutzen, 2009). It also works together with gluteus maximus, gastrocnemius, soleus and dorsiflexors to create vertical acceleration to counteract the effects of gravity on the body (Liu, Anderson, Pandy & Delp, 2005). Although gluteus maximus assists in support phase, its ability to do so ends during midstance phase. Gmed with its different segments (anterior, mid, and posterior) works throughout the entire phase. Activation occurs mainly in the posterior segment with assistance of mid- and anterior segment during second half of midstance (Liu et al., 2005). Weakness in Gmed may therefore be a cause to an increase in valgus.

Valgus

Valgus can be described as a medial displacement of the patellofemoral joint, caused by femoral adduction and internal rotation. A displacement that may increase with an increase of hip flexion (Hollman, Ginos, Kozuchowski, Vaughn, Krause & Youdas, 2009). Tibial adduction can be a result of excessive ankle pronation and may also be a contributor to adduction of the femur (Powers, 2003). A normal alignment of the lower extremities is a 180 degrees line from the femoral head, passing through the center of the knee and finish at the center of the ankle. This alignment is also known as the mechanical axis (Pickering & Armstrong, 2012). A position of the extremity that displaces this angle is considered a deformation, with a lateral displacement of the knee joint in relation to the load bearing axis is called varus deformation and a medial displacement is called valgus deformation (Cooke et al., 2007; Krackow, 2008).
While standing however the human body has a natural inclination which, depending on the research, is approximately 1-3 degrees (°) of valgus. Due to anatomical differences this can naturally vary between individuals (Cooke, Sled & Scudamore, 2007; Pickering & Armstrong, 2012). Differences have been seen during dynamic movements in regards of gender and movement characteristics, such as the range of valgus during initial ground impact (Russel, Palmieri, Zinder & Ingersoll, 2006). During bilateral (two feet on the ground) landing task these values can vary between 3° – 8° for men and 7° – 13° for women. When performing unilateral (one foot on the ground) tasks such as jump landing, values vary between 1° – 8° degrees among men and 5° – 12° for women (Herrington & Munro, 2009). These changes are not necessarily due to lack of strength in Gmed but more on anatomical aspects (Russel et al., 2006). Previous results pointed to a larger pelvis width while some more contemporary research points to a difference in length of femur between the genders (Ferber, Davis & Williams, 2003). Having fatigued Gmeds may also negatively change an individual’s ability to maintain neutral posture during unilateral static and dynamic balance tasks (Mcmullen, Cosby, Hertel & Ingersoll, 2011) as well as during bilateral tasks (Garcia, Eggen & Shultz, 2005).

**Ground reaction force**

During any gait, the surface walked on acts back on the individual with a ground reaction force (GRF) equal to the force placed upon it (Hamill & Knutzen, 2009). The amount of GRF set on the body increases linearly with an increase of speed (Keller, Weisberger, Ray, Hasan, Shiavi & Spengler, 1996) and the amount of force placed upon the body during running can be two to five times the person’s bodyweight (Keller et al, 1996; Hamill & Knutzen, 2009). Exceptions to this linear increase were found when running at 3 m/s or with a running style incorporating a high center of gravity, which increases downward velocity of the upper body. At these situations the GRF could exceed those of running with a higher speed (5 m/s) where the center of gravity is closer to the ground due to forward lean (Keller et al, 1996).

**External load**

Walking with significant body borne weight (~20kg), results in several kinematic changes. These changes include an anterior tilt of pelvis, increased knee flexion and ankle dorsiflexion (Silder, Delp & Besier, 2013). The degrees of these changes vary depending on the amount of external load and part of stand phase (Majumdar et al., 2010). Another change occurring is prolonged stance time, and increase in metabolic cost (Silder et al., 2013). In comparison to
running, walking has an advantage with a sequence of double support (both feet in contact with the ground) which makes it easier to evenly distribute the load. (Brown et al., 2014). When running with external load the stance leg receives no such support and must instead both stabilize the leg and generate enough force to develop the flight time (both leg of the ground) needed for the opposite leg to swing forward. This creates added stance time even in running, as well an increase of trunk flexion which might be an attempt to bring the load closer to the body’s centre of mass (CoM) (Brown et al., 2014). Carrying the external load closer to the body as (for example a gear vest) also increases the vertical GRF in comparison to carry it further away (backpack) (Birrel et al., 2006). A person with comparatively weaker Gmeds may be able to maintain a neutral alignment during dynamical tasks due to possible increase in neural activation (Hollman et al., 2009), although such research have been conducted where tasks have been performed during a short time span and without external load. The author of this study was unable to find studies investigating the development of valgus when running with external load.

Military load

Being a professional soldier is considered a physically demanding job. A major requirement for each individual soldier is to be able to move to a specific destination on foot, with various forms of gear and over various forms of terrain, on a strict time (Knapik, Harman & Reynolds, 1996). Due to technological advancements, the weight of standardized gear has also increased over the history of warfare (Knapik et al., 1996). Even if these loads are often only carried during marches, US soldiers in Afghanistan were reporting carrying a “fighting load” of approximately 29 kg. This makes it an average of 36 percent of the soldier’s bodyweight (Orr, 2010).

Injuries

Dysfunctional alignments like abnormally large valgus angles have been associated with injuries such as patellofemoral pain syndrome (PFPS), and general knee pain (Powers, 2003; Hewett et al., 2005; Herrington, 2014). PFPS is one of the most common knee disorders and affects athletes, recreational runners and soldiers due to extended amount of running (Mascal, Landel & Powers, 2003). One possible injury mechanism presented is lateral maltracking of the patella due to valgus, which is then exposed to overload due to physical activity (Petersen, Ellerman, Gösele-Koppenburg, Best, Rembitzki, Brüggemann & Liebau, 2014). When
investigating hip musculature in patients with PFPS, suggestions are made regarding weakness in patient’s hip abductors and external rotators (Barton et al., 2012).

**Military related injuries**

In the US military, training related injuries are considered to be the leading cause of hospitalization and a major threat to readiness for their armed forces (Bullock, Jones, Gilchrist & Marshall, 2010). The most prominent risk group is individuals with low fitness level, who are 2-3 times more likely to be injured (Bullock et al., 2010; Jones & Knapik, 1999). When investigating injury incidence, sites of injury and activities associated with them in several different units of US military personnel, almost all groups reported joint pain as one of the greatest complains and largest amount of injuries were located in the knee joints (20 – 27 %). Area of activity most associated with injury was physical training and road marching, however most individuals were unable to point out a single event that caused the injury. Instead they experienced the injury as a gradual-onset. (Knapik, Graham, Rieger & Steelman 2013). A hypothesis from these reports could be that micro traumas could occur in lower extremity tissues due to increased valgus and by continuous running, marching and other weight bearing activities, this condition is aggravated (Knapik et al., 2013; Orr, Pope, Johnston & Coyle, 2014) beyond the body’s own ability to repair and tissue disruptions as a possible result (Cowan et al., 1996; Bullock et al., 2010). This may be a critical factor when running with external load, although the researchers are not in complete consensus that valgus increases with walking with external load (Swain, Ringleb, Naik & Butowicz, 2011). During treatment and rehabilitation of PFPS, lack of strength in the hip abductors and dysfunction in quadriceps is often discovered. After implementation of strength exercises aimed to target hip musculature, subjects have shown both an increase in strength and decrease in valgus during unilateral dynamic movements. Subjects that have undergone these exercises, have reported less experience of knee pain (Tyler, Nicholas, Mullaney & McHugh, 2005; Boling, Bolgla, Mattacola, Uhl & Hosey, 2006; Mascal et al., 2003). With these findings in mind, it’s possible that the lack of strength in Gmed could have been a contributor to the occurrence of malalignments causing such injury.
Swedish Armed Forces

As a requirement for service within the Swedish armed forces (SAF), recruits must undergo an examination of physical strength. This is done using SAF:s own “multitest”, a standardised set of 6 tests designed to examine the recruits overall strength in the major muscle groups (Berg, 2008). The multitest may have some requirements of hip stability strength during exercises like push ups and vertical jump test in order to keep the body in proper stance. However instructions given to test examiners contain no information regarding examination of hip, knee or foot angles for proper execution of the tests. An endurance test (beep test) is also performed but no instructions are mentioned to control recruits for poor running kinetics (Berg, Danielsson, Ekblom, Olsson & Salén, 2008). Therefore there could be a possibility that individuals with inadequate muscle strength in the hip abductors pass the tests, receive a position within SAF but are unable to maintain a running gait that has minimal risk of overuse injuries in the knees. Another way of measuring a soldier’s endurance within SAF is to perform a running test called “Fälttest” (appendix 2). The soldier is instructed to run 2000 meter on a flat surface as fast as possible, carrying personal military gear. The total weight of the gear is set to 22 kg (Berg et al., 2008).

With the heavy conditions of an active solider and the changes in body posture, resulted from an increase in external load, it should be considered that hip strength and stability is of high importance to maintain leg alignment. Yet no such requirements for mandatory screening of hip to knee or knee to foot angles, in order to detect any malalignments during physical activity has been found. There could therefore be a risk that several of the reported overuse injuries occurring in the knee- and foot joints are a symptom of weakness in soldier’s hip abductors. These injuries could therefore preventable with an adequate and correct strength training program for the hip abductors.
**Aim**

The purpose of this study was to combine a two dimensional (2D) analysis of frontal plane gait kinematics in correlation with a Gmed strength test to determine:

(i) Is there’s a correlation between a participant’s Gmed strength and valgus during a 2000m self-paced run without external load?

(ii) Is there’s a correlation between a participant’s Gmed strength and valgus during a 2000m self-paced run with external load?

(iii) Are there differences in valgus between previous mentioned runs with and without external load?

**Method**

**Subjects**

13 male subjects volunteered for this study. Nine from the local military regiment “Luftvärnsregemente 6” (LV6) and four from Halmstad fire department. Subjects recruited from LV6 were chosen based on following inclusion criteria:

(i) A minimum of one year of continuous service in the military/fire department

(ii) Have the experience of at least 1 completed 2000m test according to SAF:s requirements for position group B (Appendix 2).

(iii) The external weight must not go passed 20 – 30 % of the individual’s bodyweight (BW).

(iv) No recorded injury in the lower extremities for the past year and symptom free of injury in the lower extremities within the last 6 months.

With the exception of experience of military service and the previous experience of the 2000 meter running test, the individuals from Halmstad fire department were recruited based on same criteria. The subjects were asked to refrain from strenuous physical training 24 hours before and a heavy meal 2 hours before a test. No further changes to subject’s daily activities were made.
Testprocedures

Strength test

All measurements were done on subject’s dominant leg, described as the preferred leg to kick a ball (McMullen et al., 2011). The one-repetition maximum isokinetic strength test of Gmed was conducted in a 1080 Quantum machine (1080Motion AB, Stockholm, Sweden) at Högskolan i Halmstad. To target Gmed as effective as possible and minimize the number of synergists, exercise chosen was a concentric side lying hip abduction (Distefano, Blackburn, Marshall & Padua, 2009) (Figure 1). Settings chosen on the 1080 Quantum machine were the preinstalled hip abductor exercise as a concentric movement, the resistance was set to 1 kg and the speed of the cable was set to 0,1 m/s. Prior to the strength test, the subject performed a 5 min warm up on a Monark Ergometer 828E stationary bicycle (Medema, Solna, Sweden)(Costa, de Oliviera, Watanabe, Jones & Natour, 2010), resistance was self-selected after given the instruction not to pass level 10 on Borgs RPE scale (made to measure perceived rate of exertion with 6 as no exertion and 20 as maximum)(Borg & Kaijser, 2006). After warm up, the subject was instructed to lie sideways with the trunk on a padded bench and both feet resting on a chair with the dominant leg upwards and fully extended. A strap was attached to the dominant leg, with centre of the strap 3 cm superior to the upper ridge of the patella (Laheru, Kerr & McGregor, 2007; Nakagawa et al., 2008; Mcmullen et al., 2011;) and connected to the lever arm of the Quantum machine. To avoid frontal plane tilting of the pelvis, a towel was folded and placed underneath the participant that was also fixed to the bench with a strap, located at the waist. The test leader was stationed behind the subject with the test leader’s thigh in contact with the subject’s posterior part of pelvis (in line with sacrum) to avoid tilting in the transverse plane. Instructions were given to perform one lateral raise of the dominant leg with maximum force to maximum range of motion and thereafter return the leg to its original position. Several practice trials (maximum 5) with different resistances in term of speed of the cable (1.8 – 0.1 m/s) was given in order to familiarize with the procedure. The participant was given 3 minutes rest before proceeding with the actual test. Time of rest was also set to 3 minutes and controlled using a stopwatch. The procedure was repeated until the participant had performed 3 sets of 1 repetition. Verbal encouragement was given in an attempt make subjects attempt maximum performance. Minimum time between the strength test and running tests was set to 24 hours in order to avoid any possible interference from the previously performed test.
2000 meter running without load

The running test was conducted on a Woodway 4Front treadmill (Woodway, Waukesha, United States) in the conditioning facility at LV6. For the frontal plane analysis, a Panasonic SDR-S26 digital camera (Panasonic, Osaka, Japan) was placed at the height of the participant’s knees and aligned perpendicular to the frontal plane (Herrington, 2014). After initial testing, the distance was set to 2.5 meters using measuring tape from the participant’s knee to the camera. In order to get the proper distance to the camera on all the recordings, the participant was instructed to stay in the same area of the treadmill during the recording times. This was achieved by verbal instructions to keep the participants hip in line with test leader’s hand, directed by coloured markings on the treadmills handrail. When running without external load (RNL), the equipment worn was training shorts and the participants own military/working boots. In preparation for these tests, red tape was attached on the subject’s anterior superior iliac spine (ASIS), patella and the subject’s boot, which was attached in relation the subject’s midpoint of the ankle (Herrington & Munro, 2010). All sites were palpated to find the correct centre point, and application of tape was done by the test leader. To avoid risks of clothes obscuring the view of the video camera, training shorts was not allowed to reach the knees and the participant was given the option to either have the t-shirt folded up to above the umbilicus and was taped to avoid falling down during the run, or remove the t-shirt completely. The participants were instructed to bring their own boots used during work. Prior to the test, the participant conducted a 10 min warm up on the treadmill with a standardize starting speed of 9 km/h, the participant was thereafter free to change the speed to achieve a self-selected “comfortable pace”, with the instruction to not surpass level 10 on Borg RPE scale. During the warm up, the adjustment for distance to the camera was rehearsed. The running test was conducted on the same treadmill as
the warm up. The starting speed of the test was standardized to 10 km/h and thereafter self-selected for the remaining part of the run. Subjects was free to ask for an increase or decrease in speed by using the word “faster” or “slower” at any time during the test. A spoken wish of change in speed resulted either in a change on 1 km/h or a specific amount (2, 3 or 4 km/h) for increase/decrease. Video recordings was done of the subjects lower extremities during 2 periods of the run, set to first 5 seconds after 90 seconds of running and the first 5 seconds in the last 100 meters of the race (Damsted, Nielsen & Larsen, 2015). After each video recording, the subject was asked to inform perceived exertion according to a given Borg scale. Time taken to finish the run was noted.

**2000 meter running with load**

The running with external load test (RWL) was conducted one week ± 2 days after the first test (Damsted et al., 2015). Due to current restrictions regarding lending of military gear, the load carried consisted of a Ziva ZTF-0304 weighted vest (Ziva, Shanghai, China) to compensate combat gear, helmet and rifle (Figure 2). The total weight of the vest was set to 20 kg (Figure 3). No other changes were made in comparison to the previously conducted test.

![Figure 2. Subject running with a weight vest during Running with load-test](image)

![Figure 3. Vest used during Running with load-test. White dots indicates loaded pockets, posterior side loaded identical.](image)
Valgus measurement

Video recordings of the lower extremities was imported to Dartfish Classroom 5.5 (Dartfish, Fribourg, Switzerland) (Eltoukhy, Asfour, Thompson & Latta, 2012) were lines from midpoint of the patella marker, to midpoint of the boot marker and finally midpoint of the hip marker were drawn. Value in degrees (°) was compared to normal alignment of 180°. Any value lower than 180° was considered an increased (positive) value of valgus and any value higher than 180 was considered a decreased (negative) value, therefore a varus. The mean valgus angle was measured from the initial 5 steps in mid-stance phase from both recordings of the run. Fixed time frame when the body was at its lowest centre of mass, thus reaching maximum compression, was chosen for analysis (Damsted et al., 2015). A value of normal valgus alignment was set to 3° (Pickering & Armstrong, 2012). All data were collected in Windows Excel and later transferred to IBM SPSS Statistics v.20 (IBM, Armonk, United States) for statistical analysis.

Ethical considerations

Even though most of the subjects had previous experience in the test, it’s could still be a considerable increase in risk if a subject have a malalignment in the knee joint. Subjects received therefore information regarding the tests and possible risk factors via email beforehand along with the informed consent. The informed consent was gathered in paper form at each subject’s initial test and the subjects were informed that they could at any time stop the test without questions. To maintain confidentiality during data analysis, each person was given an identification number used instead of names during recordings. Given the fact that only men volunteered to this study, the group can be considered more homogeneous and results will be more reliable for that group. The results will however not be applicable to all personnel in those fields of work as both sexes are not represented.

Social considerations

Increased valgus during activities similar to that conducted during this study could indicate that current training regiments conducted by individuals employed are insufficient in regards to maintain safe leg alignments. The results of this study could therefore be useful to make reconsiderations regarding the aim of current programs regarding strength and endurance training within SAF, Halmstad fire department and other similar organisations where physical...
activity with external weight is common. Increased information about the importance of hip strength in order to avoid lower extremity injuries may also be of interest to individuals of the general population.

**Statistical analysis**

The mean value of Gmed peak force from 3 repetitions of 1RM was measured in Newton (N). All data were initially analysed in regards of their statistical distribution using Shapiro-Wilks normality test, all data used for further analysis were normally distributed. Descriptive statistics for peak strength in Gmed included mean and standard deviation (±) and speed in meters per second (m/s) was calculated from mean value of subjects run time. All results are presented as mean and standard deviation (SD). Pearson’s correlation coefficient (r) was used to correlate between Gmed peak strength and valgus in all four recordings, with an r-value of: < 0.4 as weak, 0.4 – 0.6 as moderate and > 0.6 as strong (Thomas, Nelson & Silverman, 2011). Differences of mean valgus angles within and between the running tests, was examined using a paired sampled t-test (Thomas et al., 2011). P-value for significance was set to < 0.05.

**Results**

Of 13 initial subjects, two subjects dropped out due to scheduling conflicts and one reported a knee injury sustained during training unrelated to this study. This subject was therefore no longer being eligible in regards to inclusion criteria. In total ten subjects completed all three tests. At one instance after the running without load test, the subject turned off the treadmill before the running time was acquired and thus not a part of the data. Due to corruption of video file, one subject’s initial recording of the running with load test was lost and could not be analysed. Subject characteristics are presented in table 1.

**Strength test**

The side lying hip abductor strength test showed a peak strength of gluteus medius muscle at 377 ± 53.1 N.
**2000 meter running with no load**

The subjects completed the RNL test with a mean speed of 3.7 ± 0.4 m/s. No significant difference of knee valgus angles was found between the recordings of RNL (table 3). Pearson’s correlation showed no correlation between Gmed peak strength and knee valgus at the initial recording of RNL, however a moderate negative correlation was found between Gmed peak strength and knee valgus in the second recording of RNL (table 4). During the running tests, one subject was found to run with a slight varus, giving a negative (-) value in the data shown (Figure 4 & 5).

**2000 meter running with load**

The subjects completed the RWL test with a mean speed of 3.0 ± 0.4 m/s. No significant difference of knee valgus angles was found between the recordings of RWL (table 3). RWL test showed moderate negative correlation between Gmed peak strength and knee valgus on the initial recording. A strong negative correlation between Gmed peak strength and knee valgus in the last RWL recording, significance was also found in the last recording of RWL (table 4). Calculations of speed to m/s showed subjects to run in a pace more susceptible to higher GRF forces during RWL than RNL (Keller et al., 1996).
In comparison between RNL and RWL, valgus angles proved to be very similar with a lower value at the second recording. Both the minimum and maximum values of valgus were higher in RWL in comparison to RNL (table 2).

### Table 1. Subject characteristics

<table>
<thead>
<tr>
<th></th>
<th>Number of individuals</th>
<th>Mean values ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>10</td>
<td>28 ± 6.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>10</td>
<td>179 ± 5.0</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>10</td>
<td>80 ± 8.0</td>
</tr>
<tr>
<td>Dominant lower extremity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right (n)</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Left (n)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Gmed peak strength (N)</td>
<td>10</td>
<td>377 ± 53</td>
</tr>
<tr>
<td>Run time RNL (min)</td>
<td>9</td>
<td>8.8 ± 1.0</td>
</tr>
<tr>
<td>Speed RNL (m/s)</td>
<td>9</td>
<td>3.7 ± 0.4</td>
</tr>
<tr>
<td>Run time RWL (min)</td>
<td>10</td>
<td>10.7 ± 0.8</td>
</tr>
<tr>
<td>Speed RWL (m/s)</td>
<td>10</td>
<td>3.0 ± 0.4</td>
</tr>
</tbody>
</table>

Explanation of abbreviations: cm = centimeters, kg = kilogram, n = number of subjects, Gmed = Gluteus Medius N = newton, min = minutes, m/s = meters per second. RNL start = Running with no load at 90 sec. RNL End = Running with no load at last 100 m. RWL Start = Running with load at 90 sec. RWL End = Running with load at last 100 m.

In comparison between RNL and RWL, valgus angles proved to be very similar with a lower value at the second recording. Both the minimum and maximum values of valgus were higher in RWL in comparison to RNL (table 2).

### Table 2. Mean value of knee valgus during recordings of running test

<table>
<thead>
<tr>
<th></th>
<th>Degree ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valgus angle RNL Start</td>
<td>3.0 ± 2.1</td>
</tr>
<tr>
<td>Valgus angle RNL End</td>
<td>2.1 ± 1.4</td>
</tr>
<tr>
<td>Valgus angle RWL Start</td>
<td>3.0 ± 1.9</td>
</tr>
<tr>
<td>Valgus angle RWL End</td>
<td>2.8 ± 1.8</td>
</tr>
</tbody>
</table>

Values of valgus during all four recordings, displayed in degrees (°). N = Individuals. RNL start = Running with no load at 90 sec. RNL End = Running with no load at last 100 m. RWL Start = Running with load at 90 sec. RWL End = Running with load at last 100 m.
Statistics showed no significant difference of valgus between the recordings of RNL (p = 0.10) or RWL (p = 0.64) as well in comparison of the initial recordings of both running tests (p = 0.85). However a comparison of the second recordings of both tests showed a considerable trend towards significance (p = 0.07) (table 3).

| Table 3. Difference in degree of valgus between recordings of both running tests. |
|---------------------------------|-----------------|--------|
| Valgus angle RNL Start – RNL End | Degree of difference ± SD | p - value |
|                                 | 0.85 ± 1.46     | 0.10   |
| Valgus angle RWL Start – RWL End | 0.31 ± 1.94     | 0.64   |
| Valgus angle RNL Start – RWL Start | 0.11 ± 1.74     | 0.85   |
| Valgus angle RNL End – RWL End  | 0.70 ± 1.11     | 0.07   |

Explanation of abbreviations: RNL Start = Initial recording in running with no test, RNL End = Second recording in running no load test, RWL Start = Initial recording in running with load test, RWL End = Second recording in running with load test, r = Correlation Coefficient, r^2 Coefficient of determination *= Significance.

The correlation strength found between Gmed peak strength and knee valgus in initial recording of RWL showed to be similar to the correlation strength found in the second recording of RNL (table 4).

| Table 4. Pearson correlation between Gmed peak strength and valgus angle in all four stages of running tests. |
|-------------------------------------------------|-----------------|--------|
| RNL Start vs. Gmed                              | R               | R^2    | P - Value |
|                                                 | -0.04           | 0.05   | 0.90      |
| RWL End vs. Gmed                                | -0.40           | 0.17   | 0.25      |
| RWL Start vs. Gmed                              | -0.41           | 0.17   | 0.27      |
| RWL End vs. Gmed                                | -0.69           | 0.44   | 0.02*     |

Explanation of abbreviations: RNL Start = Initial recording in running with no test, RNL End = Second recording in running no load test, RWL Start = Initial recording in running with load test, RWL End = Second recording in running with load test, Gmed = Gluteus Medius, r = Correlation Coefficient, r^2 = Coefficient of determination *= Significance.
Figure 4. Correlation between Gluteus medius peak strength (N) and degree of valgus (°) during initial (A, $r^2 = 0.05$) and second (B, $r^2 = 0.17$) recording respectively of the running test with no external load (RNL). Negative values indicate varus.

Explanations of abbreviations: RNL Start = Initial recording during running without load test, RNL End = Second recording during running without load.

Figure 5. Correlation between Gluteus medius peak strength (N) and degree of valgus (°) during initial and second recording respectively of the running test with external load (RWL). Negative values (-) indicate varus.

Discussion

Results discussion

Gluteus medius strength

The isometric, Gmed peak strength test used in this study gave a mean value of 377 N. An issue with comparing values from previous studies regarding Gmed strength was the fact that all previous studies found used isokinetic tests for hip abductor strength and using newton meter (Nm) for measurement of torque. Since the distance of the lever arm (leg) was not measured during testing in the present study, this conversion of units was not able to be conducted. Studies where newton was used was found to be scare and solely testing isometric strength. Thorborg, Bandholm & Hölmich (2012) received a highest mean value of 164 N during their isometric test of hip abductors. Even though their study group was heterogeneous the difference is notable. Values similar to this study were found by Wollin, Purdam & Drew (in press) which found isometric strength in hamstrings up to 450 N. However due to the size of hamstrings the differences should hypothetically be larger, one possible reason for these differences in values could be a lack of validity of the Quantum machine.

2000 meter running tests

In the present study, very poor correlation between Gmed peak strength and increased valgus was found, both at the start and end of RNL test. The poor correlations between RNL and valgus found in the present study could hypothetically give an indication that subject’s strength and endurance in Gmed is good enough to sustain their natural knee alignment during running. Subjects with stronger hip abductors would therefore have no advantage during this test. These results are not unexpected as the hypothesis is that an increase of valgus appears during activities while carrying external load.

The low correlation between Gmed strength and knee valgus in the initial part of the RWL test may, similar to RNL test, be contributed to their ability to sustain their knee alignment, however both minimum and maximum mean values of valgus increased slightly in comparison to RNL. This increase of valgus may indicate that changes in knee alignment did occur to some subjects when external load was added, and a trend towards significance (p = 0.07) in change could be seen in comparison between the second recordings on both running test. This trend towards
significance may be the result of a lack of strength in Gmed in the second recording of RWL, however it may also be the result of changes in running kinetics due to change in center of mass from the added weight (Brown et al., 2014). Since the running speed in RWL decreased, in comparison to RNL, to 3.0 ± 0.4 m/s it also increases the possibility of increased GRF placed upon the body as mentioned by Keller et al. (1996), making the risk of injury larger when running with external load.

Noticeable was the strong correlation, in regards to coefficient of determination, in the late part of the RWL test. This thesis coefficient of determination showed that 44% of the values of valgus were explainable by variability in Gmed strength. Since the ability to maintain leg posture during stance phase of running is highly related to the work of Gmed, particularly during work with external load due to increased gravity, an $r^2$-value off 0.44 is of interest even in a smaller group. In a larger group of subjects, 0.44 would be reasonable for causation. The low number of subjects does however creates difficulties in assuming causation, as the coefficient of determination values were considerably lower in previous recordings and minor changes of knee valgus in a few subjects could’ve drastically changed the results during late part of RWL. A larger study group is therefore needed to confirm causation.

In present study the mean values of knee valgus angle for RNL were 3.0⁰ during initial recording of RNL and 2.1⁰ for the last recording during RNL. Initial recording of RWL showed a mean value of 3.0⁰ and 2.8⁰ in the last recording. Since previous studies using a similar 2D running tests could not be found, a direct comparison with previous work to determine if the changes of valgus in this study are somewhat common was proved difficult. Research on other dynamical tasks have measured valgus between 4.9⁰ – 10.9⁰ (Schmitz, Schultz & Nguyen, 2009; Herrington & Munro, 2010). Research made by Whatman, Hing & Hume (2009) showed values of hip adduction in ranges of 2.0⁰ – 13.0⁰, with the lowest value for a single leg task were a single leg hop (9⁰). All research points to higher values than found in this research. Main reason could be the different dynamical task, which could have different kinematic properties. Both Herrington & Munro (2010) and Whatman et al. (2009) conducted research on movements where the end of the movement was stationary which could give differences in valgus due to the need to decelerate the body to a still and with a larger knee flexion. Schmitz et al. (2009) performed tests on younger individuals that required propulsion, and reached knee valgus angles between 9.0⁰ ± 6.2⁰ and 13.1⁰ ± 8.7⁰. A difference was however, that these tests were performed on solid ground and therefore creating higher demands on the body in comparison
to running on a treadmill (Caekenbergh et al., 2013). The values from both running tests do however come close to the natural alignment of the lower extremities and small differences may be explained by naturally occurring differences (Pickering & Armstrong, 2012). Despite the increase in valgus in the subjects during RWL, those values do not exceed the boundaries set according to Herrington & Munro (2009). As none of previous mentioned studies showed as small knee valgus angle as this study, one can reasonably assume that running does not create high knee valgus and the subjects stayed in a variance of degrees of angle that’s without increased risk of injury. Some caution is however needed since the normative values presented are primarily aimed for a short and explosive movement, how these correlate with a larger difference in angles between normal alignment during stance and prolonged running is unclear. Considering that only men with experience of working with heavy external load participated in this study, further studies should focus on investigating how similar conditions affect women soldiers or firefighters as well as individuals with less experience of activities involving external load.

One aspect to be considered in regards to the running tests is the participant’s natural knee alignment. In the present study, this was not controlled prior to the test and is therefore unknown. It could be that subjects with higher value of strength in Gmed could have higher natural degree of valgus. Other variables could be as previously mentioned difference in alignment but also strength differences in muscles not measured, such as vastus medialis. Speed differences between the running tests (table 1) could indicate a difference in running gait which may give a difference in valgus regardless of Gmed strength.

**Methods discussion**

**Participants**

The initial purpose of the present study was to conduct the tests solely on military personnel. As the number of soldiers from LV6 acquired proved to be small, fire fighters were recruited based on their similar working conditions. Despite this addition, very low number of subjects were available, which creates a statistical type I error due to insufficient data. As all soldiers asked to join for this study had previous experience of a completed field test running test in, those participating might have been those comfortable enough in their strength to complete the test when assigning to the study. This could’ve resulted in only receiving soldiers that were in
such good psychical condition they could finish the running test without issues regarding Gmed strength.

**Strength test**

Scientific literature on validation, reliability and usage of the Quantum machine were unavailable to the author. Although the Quantum machine can’t be considered validated, in terms of reliability the Quantum machine was the best option available to the author for the particular movement. Studies read that conducted a variance of methods to determine Gmed strength (Downing, Clark, Hutchinson, Colclough & Howard, 2001; Nakagawa et al., 2007), however Chang et al. (2005) supports that a concentric test can be correlated to the dynamic task of posture stability during gait. The exercise was changed in comparison to Chang et al. (2005) to side lying hip abduction (Distefano et al., 2009) with the test procedures of Nakagawa et al. (2007) as they were more applicable for that exercise.

**Running test**

The “field test” according to SAF:s standard was chosen as it was a test military personnel are familiar with and is widely used. In order to have the participant run in as a natural gait as possible, it was decided to have a self- selected pace.

With their previous endurance training, a minimum of 120 hours (5 days) between the running tests was considered sufficient time without a notable decrease in muscle performance. However due to military exercises and the need for retests, the time gap between the tests varied for certain subjects up to 11 and 19 days. Without an account of for activities between the tests, this might have created variations of performance level within the subject group and therefore influenced the results. The amount of variance is however unclear.

Literature on 2D- analysis in the frontal plane of valgus during running proved to be few and unable to be acquired, due to lack of access to databases. This running test was therefore based on validated examinations of valgus during single leg tests in frontal plane (Munro, Herrington & Comfort, 2012; Herrington, 2014) and recorded treadmill running analysis in sagittal plane (Damstead, Nielsen & Larsen 2015). Differences made from Damstead et al. (2015) were an increase of number of recordings to two and an individually set height of the camera.
The method of recording was in accordance with Herrington (2014) with the exception of recording distance which was reduced from 3 to 2.5 meters, after difficulty to achieve acceptable video quality. Video analysis still showed to be difficult due to moderate lighting of the room and subject’s different body shapes which placed the marking tape in different angles. Careful observation frame by frame in Dartfish was therefore necessary and slight errors in measurements of valgus may have occurred. These errors would however been small in scale (0.1 – 0.3 degrees).

Time set for initial of recording (90 seconds after start of treadmill), was chosen to give the participant time to achieve a rhythmic running pace. The second sequence was chosen to avoid a change in gait, caused by the participant by an attempt to initiate a sprint in order to complete the test as soon as possible. However a few subjects chose to increase the speed in the end of the test, which may have affected their running kinetics.

As subjects ran in their own boots of varying models and certain subjects were inexperienced in running with boots, changes in normal running gait could have occurred. This was however considered necessary to implement as running shoes are never used during SAF:s test or during military exercises.

The running test can’t be considered to give a complete view of the participant’s gait when running on solid ground. As Caekenberghe et al (2013) mentioned the body inertia become absent on a treadmill, due to the lack of increased propulsion (Hong et al., 2012). A three dimensional test on solid ground would have been preferable, however was deemed impractical due to camera work and resources needed unavailable. Further studies with mentioned modifications may give a clearer view on running with external weight in a more military oriented situation.

**Conclusion**

In physically trained military personnel and firefighters, Gmed strength was not a significant factor in regards to development of valgus during the unilateral stance phases in running 2000 meters. A strong negative correlation was found between Gmed strength and valgus in the second part of a 2000 meter run with an external load of 20 kg. A higher degree of valgus
occurred during RWL in comparison to RNL, however non-significant in a comparison between the initial and second part of the run. The second part of RWL had a significant change of valgus in comparison to second part of RNL. These findings indicate that running with external load may increase the demands of Gmed and insufficient strength may create an increase of femoral adduction and increase of valgus. However due to low number of subjects, the coefficient of determination value is not high enough to confirm causation. No values of valgus reached a point outside set standards of natural alignment. To give a more clear relationship between Gmed and valgus during military activity, further studies should investigate the development of valgus with a larger study group, when running on solid ground and include both sexes.
References


Appendix 1 – Informed consent

Informerat deltagande
Kandidatuppsats
Mathias Bergqvist

Syfte:
Syftet med studien är att i kombination utav ett styrketest undersöka aktiveringen av hovtmuskulaturen i korrelation med position utav knäled under Försvarsmaktens fälttest.

Testgenomgång:

Styrketest – Halmstad Högskola
Inledningsvis kommer en genomgång av testet samt Quantum-maskinen att ske. Därefter görs en kortare uppvärmning enligt instruktioner samt ett provtest av maskinen. Testet kommer utföras på personens ”dominanta” ben.
Test utförs genom att deltagaren ligger på sida på en bänk, en rem kopplad till Quantum-maskinen fästes runt deltagarens ben och ska därefter lyfta benet med maximal kraft. Testdeltagaren får därefter vila mellan 3 – 4 minuter och upprepar därefter proceduren. Benlyftet utförs totalt 3 gånger.

Utrustning – Träningskläder

Löptest – LV6
Som förarbete kommer referenspunkter till 2D analysen, i form av färgad tejp appliceras på höften, knä, samt känga i höjd med vristerna. Deltagarens dominanta ben kommer väljas och testet kommer att filmas framifrån med vit bakgrund vid 2 tillfällen under testet.
Genomgång av testet ges och därefter görs en 10 min uppvärmning på löpband.
Deltagaren kommer utföra ett springtest på löpband, med hastigheten justerbar utav testledaren utefter deltagarens önskemål, i syfte att så fort som möjligt klara av 2000 m. Kontroll av deltagarens ansträngningsnivå kommer kontrolleras under testets gång.

Utrustning – Träningskläder (shorts, ej långbyxor) + kängor.

Fälttest – LV6
Fälttestet utförs en vecka efter löptestet med exakt samma utförande, med ändringen att testet utförs med extra utrustning i form av viktväst, standardiserad efter Försvarsmaktens instruktioner till 22 kg.

Utrustning – Träningskläder (shorts, ej långbyxor) + kängor

Samligt arbete kommer utföras av testledaren samt alternativt assisterande testledare under förstnämndas översikt.
Hantering av persondata:

Risker:
Då fältestet är ansträngande kan obehag upplevas. Friktion axlar och bål kan uppstå p.g.a. viktvästen.
Med tanke på att den externa vikten sätter extra press på kroppens leder och muskulatur kan överansträngning ske. Testdeltagaren måste därför vara skadefri och inte uppvisat symptom på skada inom de senaste 6 månaderna. Testdeltagaren har därmed ansvaret att i förväg ha informerat om tidigare skadehistorik och tidigare upplevd smärta. Om smärta uppstår uppmanas testdeltagaren att meddela detta till testledaren, både deltagare och ledare har rätt att oberoende av varandra avbryta testet om så anses nödvändigt. Testdeltagaren behöver inte ange en orsak till avbrott av testet.

Jag som testdeltagare är med helt på fri vilja samt:
• Är fri att avbryta testet när jag vill utan att svara på varför
• Har blivit informerad om testets utförande och fått möjligheten att ställa frågor.
• Är medveten om potentiella risker med utförandet av testet

<table>
<thead>
<tr>
<th>Deltagarens signatur</th>
<th>Datum</th>
</tr>
</thead>
</table>

Testledare: Mathias Bergqvist
Biomedicin – Inriktning fysisk träning
Högskolan i Halmstad
mathias.bergqvist@hotmail.com
Appendix 2 - Fälttest
Instruktioner Försvarsmaktens Fälttest 200m (red).

1. Inledning
Fälttest 2000 meter syftar till att mäta att personalen har en tillräcklig förmåga att omsätta energi (syreupptagning/förbränning, spjäckning) för att med aktuell utrustning kunna lösa tänkta uppgifter avseende markstrid. För att minimera felkällor genomförs testet i stridsutrustning.

Testet ska ledas av FMIF certifierad testledare.
Observera att beroende på låg syreupptagningsförmåga hos den testade (TP) kan Fälttestet bli ett max.test.
En förutsättning för TP att få genomföra fälttest är att FM FysS grundnivå, regelbunden träning genomförts.

2. Personal som berörs av Fälttest 2000 meter samt kravnivåer
Markstrid - personal som är placerad i markstridsbefattning i förband/enhet ingående i insatsorganisationen och med en anbefalld beredskapstid om högst 360 dagar (krav), samt personal placerad i markstridsbefattning i förband/enhet ingående i insatsorganisationen och med en anbefalld beredskapstid över 360 dagar (utbildningskontroll).

2.1 Indelning av markstridspersonal/enheter

<table>
<thead>
<tr>
<th>Grupp</th>
<th>Personal/enheter</th>
</tr>
</thead>
</table>
| A     | Personal i stabsbefattning för att leda markstrid.  
 | Ex: batstab, stridsgruppstab |
| B     | Personal och markstridsenhet med annan huvudtjänst än strid till fots. 
 | Ex: stab och trossplut, lvto, ledningsplut, ingplut |
| C     | Personal och markstridsenhet med huvudtjänst strid till fots. 
 | Ex: pskplut, amfskplut, skplut, närskyddsto, fbassäkplut |
| D     | Personal och enhet med jägartjänst (motsv). 
 | Ex: splut, kjplut, jplut, fbasjplut |
2.2 Kravtabell

<table>
<thead>
<tr>
<th>Grupp</th>
<th>Officer individuellt krav</th>
<th>Soldat individuellt krav</th>
<th>Godkänd medeltid/enhet</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>13 min 30 sek</td>
<td>13 min 30 sek</td>
<td>-----</td>
</tr>
<tr>
<td>B</td>
<td>12 min 30 sek</td>
<td>13 min 30 sek</td>
<td>12 min 30 sek</td>
</tr>
<tr>
<td>C</td>
<td>11 min 30 sek</td>
<td>12 min 30 sek</td>
<td>11 min 30 sek</td>
</tr>
<tr>
<td>D</td>
<td>10 min 15 sek</td>
<td>11 min 30 sek</td>
<td>10 min 15 sek</td>
</tr>
</tbody>
</table>

3. Utrustning

TP ska ha:

Stridsutrustning, enligt SoldR Mtrl 2003
Fältuniform 90 eller annan i FM godkänd fält- eller sjöstridsuniform. FM overall grön eller blå kan användas.
Marschkängor 90, alternativt kängor enligt förbandschefs (motsv.) bestämmande.
- AK 5, alternativt attrapp (4,5 kg).
- Hjälm 90 med hjälmduk.
- Kroppsskydd 90, 94 eller 04 utan förstärkningsplattor
- Stridsväst, eller annan av FM godkänd bäranordning för stridsutrustning, med:
  * 4 st magasin (tomma)
  * Fylld, dricksflaska 90 1L eller vätskebehållare 02
  * TBH Ak 5 /s (påse, kontrolldon, läsklina m fodral, etui, borstviskare, läskända och universalverktyg)

TL ska ha:
- Gällande regler för FM FysS
- Tidtagarur (motsv.)
- ( Borgskala för skattning av ansträngning)
4. Standardisering
- Bansträckningen ska vara flack och **kontrollmått till 2000 meter**.
- Underlaget bör vara hårdpackat grus (motsv.).
- Väderleksförhållanden ska vara gynnsamma.
- TP ska ha har rätt utrustning.
- TP ska vara fysiskt och fysiologiskt utvilad vid start av test.
- Vapnet ska bäras i grundställning eller som vapen i slinga med axelstöd utfält.
- Vapnet ska vara laddat med tomt magasin.
- Hjälmen ska bäras på huvudet.
- TP ska vara uppvärmd innan start av testet.

5. Säkerhet
- Kontrollera hälsostatusen hos TP. Test genomförs ej om TP har feber, någon infektion, förkylning eller liknande.
- Kontrollera att TP genomfört regelbunden träning.
- Kontrollera att utrustningen är tillpassad och bärs på rätt sätt.
- Gör under testet, där möjlighet finns, en okulär bedömning av TP status eller/och låt TP skatta sig mot Borgskalan.

6. Genomförande
- Intervjuar TP om hälsostatus, regelbunden träning mm.
- Genomgång av syfte, utförande, kravtider, säkerhet mm.
  - **Kontrollera utrustningen.**
  - **Låt deltagarna värma upp minst 15 min.**
- Justera utrustningen och starta inom 5 min.
- Ta tid (mellantider om möjligt).
- Låt deltagarna varva ner.
- Utvärdera.
Mathias Bergqvist is born in Uppsala and currently resides in Halmstad where he attained a bachelor degree in Exercise Biomedicine and a NSCA Personal Trainer certificate. He is currently working as an instructor and studying for a masters degree.