FREEMOTION

INCLINE TRAINER
WHITE PAPER

ARMED FORCES

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EXPLORING THE SCIENTIFIC BENEFITS OF INCLINE TRAINING FOR THE ARMED FORCES

Marching long distances, running and crawling through rugged terrain, fighting effectively in areas of combat and other demanding activities require superb physical conditioning in the armed forces.

Incline and decline training is nothing new, but its benefits toward fitness and service readiness to optimize individual and unit performance often go unrecognized. Incline training offers a highly effective workout by mimicking the challenge of running or walking uphill outdoors on naturally varied terrains. Similarly, decline training teaches the body to develop eccentric strength to reduce the risk of injury.

This white paper examines the benefits of this powerful training method for the armed forces community, helping service members better understand why they should factor it into their routines, and equally important, how. Whether they're preparing for a physical fitness test or want to take charge of their health and well-being, their search for a dynamic workout ends with incline training on the Freemotion Incline Trainer.

Exploration of Benefits of Incline and Decline Training

According to the 2020 IHRSA Health Club Consumer Report[1], treadmills remain the most popular piece of equipment, with 28.3 million members (44%) reporting using a treadmill in 2019 (more than two out of five). Treadmills are also the most popular piece of equipment among all age groups, with an average of 42% reporting they do so for fitness.

While the rates among serving armed forces personnel are lower, obesity within the military is a well-recognized issue. According to the Department of Defense (DoD) Health of the Force report[1], the overall rate of obesity across the military continues a steady increase, with the Navy (23.2% of personnel) deemed most obese and the Marine Corps. (8.3%) the least. Overall, nearly 18% of military personnel were considered obese across the DoD, up from 16.3% in 2015. The findings align with earlier studies that have detected increases in obesity among the services since 2001.

To combat rising obesity numbers, we must meet exercisers where they are. If they most enjoy treadmill workouts[2], we should focus on maximizing their results using this training method and piece of equipment. Research shows that incline training provides beneficial opportunities for improved health that may be unreachable through other exercise modes. The benefits of adding incline training to walking or running workouts include increased heart rate and a boost in calorie burning, through the extra effort it requires from the user.

In addition, it's worth noting that while running is a traditional form of cardiovascular training for every military branch, there are occasions when running outdoors isn't possible (and/or limited to small, confined spaces) – such as high-security bases and ships. That is where incline training using a treadmill can really help.

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[1] Department of Defense (DoD) Health of the Force: report (2019) — *U.S. Department of Defense*
https://www.google.com/url?q=https://health.mil/Reference-Center/Reports/2020/11/24/DoD-Health-of-the-Force-2019&sa=D&source=editors&ust=1632760396324000&usg=AOvVaw1KyaE4LRdNZ_3tpOOdy4nwurl?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved-=2ahUKEwj87Laj45LzAhXB8uAKHZcFAagQFnoECBYQAw&url=https%3A%2F%2Fhealth.mil%2FReference-Center%2FReports%2F2020%2F11%2F24%2FDoD-Health-of-the-Force-2019&usg=AOvVaw3wTszU7F6hyod2doymiETX

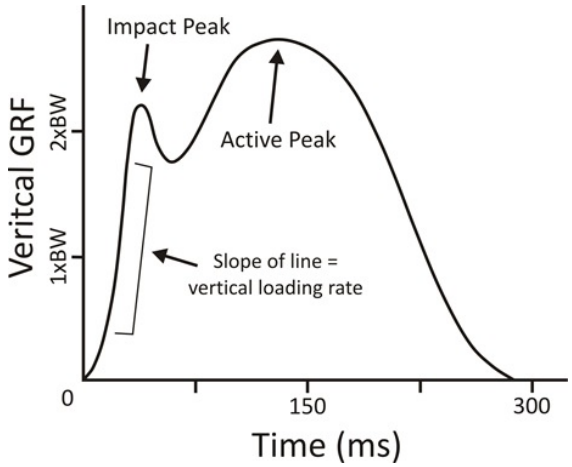
[2] 2018 Physical Activity Guidelines Advisory Committee Scientific Report — *U.S. Department of Health and Human Services*
https://health.gov/our-work/nutrition-physical-activity/physical-activity-guidelines/current-guidelines/scientific-report

Biomechanics of Incline and Decline Walking

Maintaining soldier readiness and avoiding injuries— while sustaining peak physical fitness— is essential to life in the armed forces. With this in mind, adding incline training to their mix of workouts can offer some significant benefits to those in the military.

Definitions

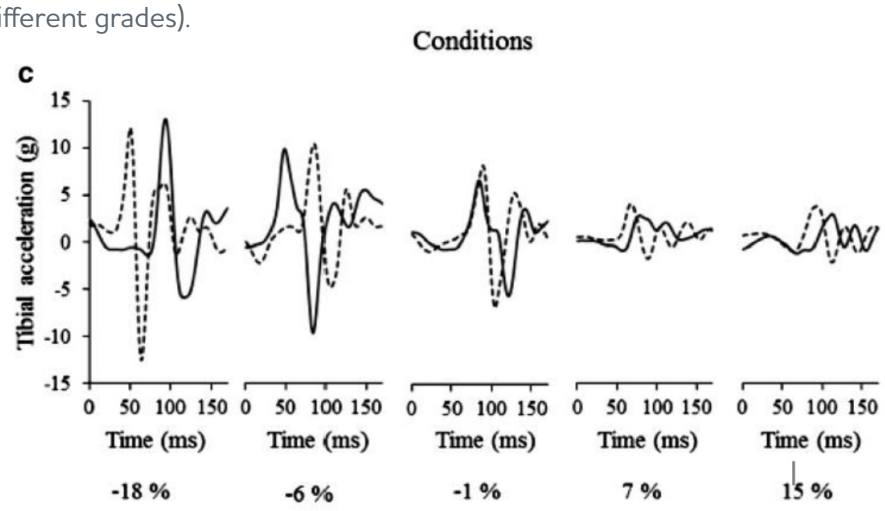
Impact force: Typically, this indicates peak impact force, as determined by a force plate or in-shoe sole sensor. It measures the initial impact with the ground. This is often determined by heel strike or the foot strike pattern. See figure below:



Tibial acceleration or tibial shock: This is the acceleration or shock measured in the tibia upon footstrike with the ground or treadmill. Sensors are placed on the tibia to determine this.

Impact forces

Most research has focused on grades of -15% to +15%. While individual variations in running style will result in different impact force levels, research has documented that normal impact forces and tibial acceleration (tibial shock) decrease as incline increases.[2] (see figure below adapted from Kram showing tibial acceleration at different grades).



Additionally, these normal impact forces continue to increase with downhill running. It should be noted that in the study by Kram, participants ran at the same speed, while only grade was adjusted.

A study by Hamill 3 used tibia-mounted accelerometers to measure leg shock (tibial shock). They found that leg shock increased by 30% during −5° downhill running and decreased by 24% during +3° uphill running. Gottschall and Kram2 reported that, compared to level running, at −9° the normal impact

peak increased by 54%, at −6° by 32%, and at −3° by 18%. At an incline of only 3° (~6% grade), the normal impact peak decreased by a non-significant 13%. However, for the seven subjects with a rear-foot strike pattern, at +6° (~10%), the normal impact peak decreased by 22%. Essentially, above an incline of 6% grade, impact peak becomes reduced significantly and leg shock is reduced in as little as 6% grade. A study by Swain4 looked at impact forces of participants that either walked at an 11% incline or ran on a level surface while matching calorie burn (intensity) between tests. Running on a level surface at a similar calorie burn resulted in increased peak vertical ground reaction force (peak impact) compared to incline walking. This study demonstrated that if a person wants to burn x number of calories, doing so at an incline will result in less impact (peak). Another interesting component of the study was that increasing walking speed from moderate to vigorous while at incline did not increase loading forces. A study by de Oliveira Silva[5] showed that the subject's perceptions of their knee pain were correlated to their impact loading. They suggest that strategies and treatments be sought to lower these impact forces as part of treatment and injury prevention. In other words, a participant feeling impact forces may correlate that with knee pain and incline walking, which is known to have less impact force than running.

Tibial Shock

Higher rates of tibial shock have been associated with overuse injuries such as stress fractures and as shin splints. Research suggests the likelihood of the history of a tibial fatigue fracture has been shown to increase by a factor of 1.4 for every 1 g increase in tibial acceleration.[6,7] Milner et al.[7] showed that those with a history of a tibial stress fracture had greater tibial shock, as assessed by peak positive accelerations (PPA, AKA tibial shock) at initial contact with the ground. They assessed PPA in 20 women with a history of a tibial stress fracture compared to 20 healthy control women with no history of bone stress injuries. Peak positive acceleration was assessed by affixing accelerometers to the distal tibia of the injured limb. They found that peak positive acceleration was significantly higher in the tibial stress fracture group. In the stress fracture group, the peak positive acceleration was 30% higher. Waite et al.[8] asked runners to run at approximately -14%, level and +14% grade (4°) on grass, concrete, and asphalt. Results showed that with incline, tibial acceleration decreased regardless of the surface. See table below:

	Grass		Asphalt		Concrete	
Grade	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI
Incline	7.68 (1.35)**	6.86–8.50	6.99 (1.69)	5.97–8.02	7.26 (1.78)	6.19–8.34
Decline	8.08 (1.36)	7.25–8.90	8.12 (1.17)***	7.42–8.83	7.90 (1.66)	6.90–8.91
Level	8.22 (1.22)*	7.49–8.96	7.79 (1.44)#	6.92–8.66	7.47 (1.65)	6.47–8.47

These results parallel iFIT's internal research performed by Higginson[9], where ground running at incline resulted in reduced tibial shock. Interestingly, the cushioning system in the x11i minimized tibial shock at all inclines. See figure to the right:

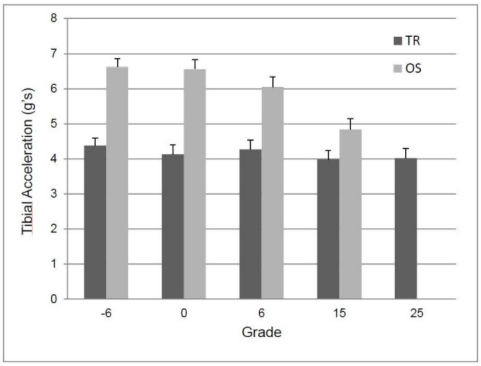


Figure 1. Comparison of treadmill (TR) and outdoor (OS) tibial acceleration (g's) across the five running grades (-6, 0, 6, 15, 25 %). All values expressed as Mean±SE.

Tibial shock levels have been associated with foot strike patterns, with heel strikers typically experiencing higher levels of tibial shock. Elite runners accustomed to downhill running have less heel strike and a more midfoot strike pattern compared to non-elite runners. Therefore it is safe to assume that training on downhill running may alter the extent of the tibial shock a person will experience during future downhill running.[10]

Uphill running shifts the foot strike to more of a midfoot or forefoot strike which is associated with a reduced tibial shock.[11] Another ground reaction force, parallel ground reaction force (think of the force of the foot pushing against the belt of the treadmill towards the rear), increases as incline goes up. This is not the same as peak ground reaction force. Peak ground reaction force can be thought of as the up and downforce, with parallel being thought of as the force to propel the body forward. This increase in parallel ground reaction forces may help explain the greater muscle activation rates seen with incline work performed on a treadmill.

Uphill walking has also been associated with reduced peak internal knee abduction. Peak internal knee abduction is not a good thing when considering knee problems. A study looked at internal knee abduction rates at 0, 5, 10 and 20% grade. There was an inverse relationship between grade and knee abduction rates. "The decrease in the internal knee-abduction moment during incline walking could have positive effects on knee joint health such as potentially reducing cartilage degeneration of the knee joint, reducing pain, and decreasing the rate of development of medial tibiofemoral osteoarthritis."[12] Another benefit of incline walking is that the knee joint is more flexed upon impact with the surface. The higher the incline, the more the knees are flexed upon impact. Having a bent knee upon impact reduces the blunt force on the knee and significantly reduces the risk of injury.[12]

While downhill running results in increased impact forces, the knee extensor muscles adapt with downhill training to assist with the power absorption necessary. However, research demonstrates that the negative grade must exceed -7% to observe these changes in the knee extensors.[13,14] If an individual is training for an event or work that included downhill exercise, it may be beneficial to train at grades beyond -7% decline.

> **In general, incline work on a treadmill results in a decrease in tibial shock, reduced impact forces, and reduced internal knee abduction. All of these point towards better knee health.**

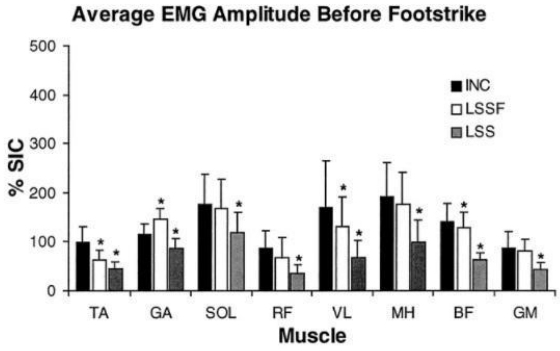
Treadmill vs level ground

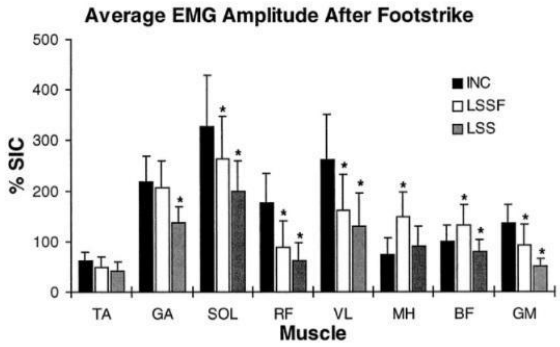
Treadmill running can influence both vertical and horizontal impact forces. iFIT's internal study by Higginson shows that running on the x11i treadmill reduces gravitational force impact at grades between -6 and +15% incline compared to running on a hard surface. A study by Bigelow[15.1] in 2003 demonstrated that the horizontal impact acceleration (but not the vertical impact acceleration) was reduced while running on a treadmill. This reduction in horizontal impact is likely due to having to push horizontally against the ground, whereas a treadmill motor assists in pushing the belt horizontally behind the runner. It appears then that the design of the treadmill will influence the magnitude of the impact forces. This is further demonstrated from an internal research study[15] that showed work on the Freemotion Reflex Treadmill had an average of 29% greater reduction in impact force compared to running on the other popular treadmills. The Freemotion Reflex Treadmill showed an average of 52% greater reduction in tibial shock compared to flat surface running. Additionally, the Freemotion Reflex Treadmill showed an average of 20.5% reduction in peak positive acceleration of the tibia (tibial shock) compared to leading competitor treadmills. In lay terms— when the foot strikes the belt, the tibia goes through less movement when using the Freemotion deck, compared to using the competitors' decks (Lifetime 95TS, Precor 835, Instrumented treadmill).

EMG of Incline and Decline Walking/Running

Many researchers argue against giving exact percentages when dealing with EMG and changes in muscle activation rates. This is due to the sensitivity of EMG to placement location on the muscle and large ranges in EMG activation between participants. Even a millimeter difference in sensor placement will result in different muscle activation levels. As such, all testing must be performed on the same day where sensors are not removed between tests. Additionally, most EMG results are indicated as a percent of MVC (essentially peak muscle activation rate) or SIC (standard isometric contraction) and do not take into consideration whether the muscle is acting in a concentric or eccentric fashion. Some studies look at total muscle activation, while others may look at peak muscle activation. This can be confusing when interpreting results. As such, a person need only look at the magnitude of changes in EMG muscle activation to see the story behind incline training.

It is well demonstrated that incline work results in greater muscle activation in the lower extremities compared to flat surface walking and running. This was further demonstrated by analyzing muscle glycogen levels after performing equal calorie burn from either running on level ground or at an incline, again while burning the same total calories per test. Glycogen depletion was greater in the incline work even though the total calories burned were the same between tests. Swanson[16] asked participants to run normally on a level surface (LSS), at 30% grade (INC), and then again on a level surface using the same stride frequency as the incline run (LSSF). The authors didn't disclose the exact % change in EMG activity. The EMG was separated to include muscle activation before footstrike and muscle activation during the footstrike phase of the run. The majority of muscles examined demonstrated increased muscle activation during incline work. The results are in the table below:





A recent review article looked at EMG of several different studies. The table below is a general summary of changes in muscle activation while running at different inclines.[17]

Table 3 Summary of studies examining the effects of uphill and downhill running on the electromyography (EMG) activity of different lower limb muscles

Study	*n*	Running speed ($km \cdot h^{-1}$)	Slope (%)	ILP	GMed	GMax	HA	RF	MH	BF	VL	VM	TA	MG	SOL
Abe et al. [45]	8	11.9	0 vs. +5								→				
			0 vs. −5								→				
			−5 vs. +5								↗				
Padulo et al. [22]	18	15	0 vs. 2			↗		↘		→		↘	↘	→	
			0 vs. 7			↗		↘		→		↘	↘	→	
Swanson et al. [23]	12	16.2	0 vs. 30			↗		↗	→	→	↗		→	↗	↗
Wall-Scheffler et al. [47]	34	6.5, 9.7 and 13	0 vs. 10		↗	↗	↗	↗	↗	↗	↗			↗	
			0 vs. 15		↗	↗	↗	↗	↗	↗	↗			↗	
			0 vs. 20		↗	↗	↗	↗	↗	↗	↗			↗	
Yokozawa et al. [36][a]	6	18	0 vs. 9.1	↗		↗	↗	↗		→		↗	→	→	→

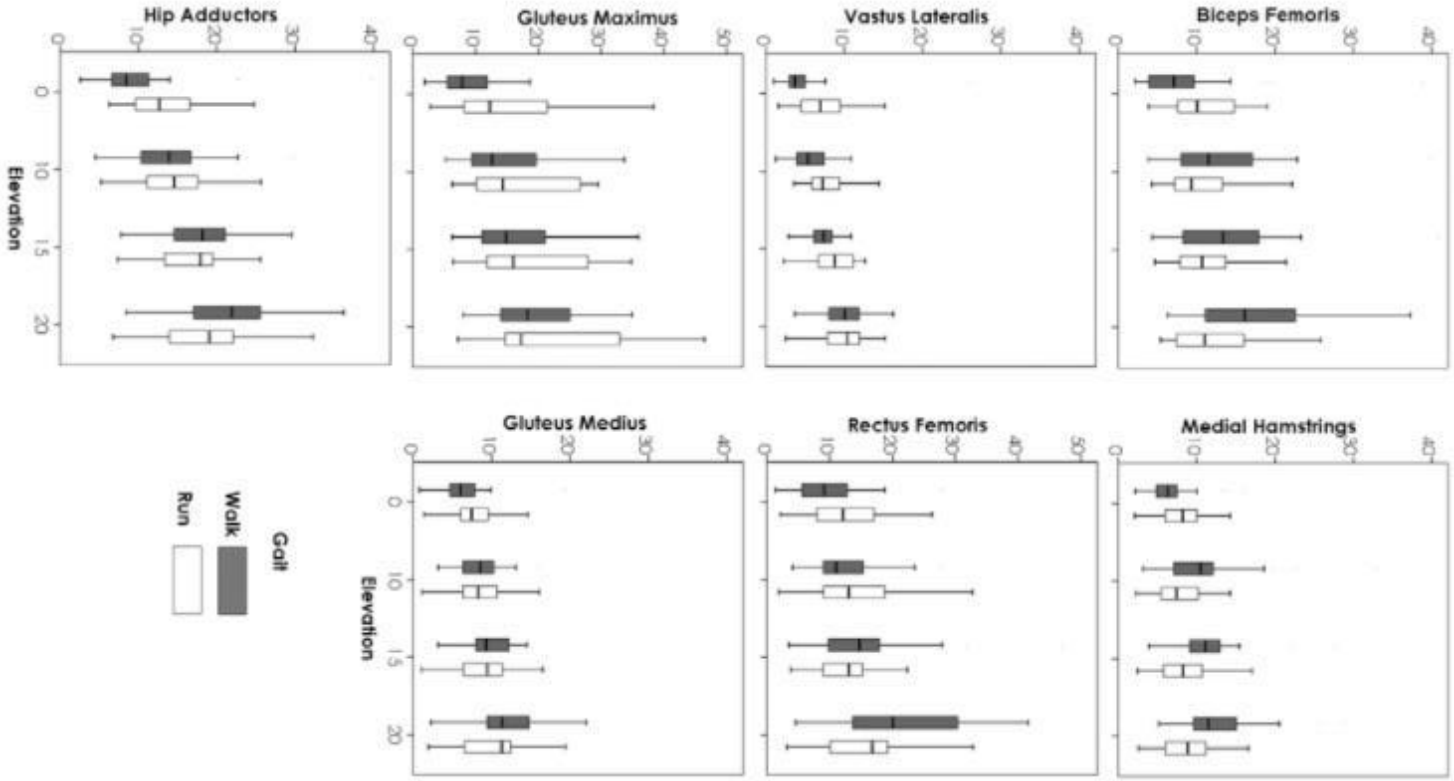
n indicates the number of subjects

↗, ↘, → indicate increase, decrease, no change in EMG activity, respectively, as a function of the slope change

ILP iliopsoas, *GMed* gluteus medius, *GMax* gluteus maximus, *HA* hip adductors, *RF* rectus femoris, *MH* medial hamstring, *BF* biceps femoris, *VL* vastus lateralis, *VM* vastus medialis, *TA* tibialis anterior, *MG* medial gastrocnemius, *SOL* soleus

[a] Indicates that muscle activities of the lower limbs were assessed by using a musculoskeletal model

An encompassing study by Wall-Scheffler looking at average EMG activation (integrated muscle activity - "how active the muscle is over time") at different inclines and different speeds. The authors didn't give exact percentage changes, rather just graphed the averages and identified where significant changes occurred. The figure below contains the results.[18]



In all scenarios, incline resulted in increased muscle activation! Interestingly, increased gluteus maximus activity was not significantly associated with increased speed alone on the treadmill. Rather, incline was the significant factor in activating the gluteus maximus compared to baseline values. An additional finding of the study was that pelvic shape and width play a role in how much the different muscles are activated. This should be considered when trying to compare the results of one study to another; that different people will experience different percent of muscle activation. However, it is safe to say the general trends will be similar.

iFIT's own internal research also supports the increased muscle activation rates observed during incline training.9 These results compare peak muscle activation levels at incline to 0% grade (with 0% grade being the baseline as opposed to compared as a percent of MVC). See table below:

Table 2. Changes (mean±SE) in muscle activation, expressed as a percentage of muscle activation associated with level running, across all five running grades (-6, 0, 6, 15, and 25 %) for treadmill and outdoor running.

	Condition	Incline				
		-6%	0%	6%	15%	25%
Tibialis Anterior	Treadmill	1.05±0.04	1.00±0.00	1.03±0.03	1.18±0.06	1.46±0.07
	Outside	0.89±0.04	1.00±0.00	0.97±0.04	1.02±0.06	
Soleus	Treadmill	0.86±0.02	1.00±0.00	1.16±0.03	1.52±0.05	2.06±0.12
	Outside	0.92±0.04	1.00±0.00	1.13±0.05	1.33±0.06	
Gastrocnemius	Treadmill	0.75±0.03	1.00±0.00	1.22±0.04	1.66±0.09	2.34±0.18
	Outside	0.86±0.05	1.00±0.00	1.22±0.05	1.57±0.08	
Vastus Lateralis	Treadmill	0.99±0.03	1.00±0.00	1.11±0.03	1.64±0.07	2.22±0.12
	Outside	0.93±0.05	1.00±0.00	1.06±0.06	1.39±0.07	
Rectus Femoris	Treadmill	1.00±0.03	1.00±0.00	1.07±0.03	1.51±0.09	2.17±0.16
	Outside	0.94±0.04	1.00±0.00	1.03±0.04	1.29±0.07	
Biceps Femoris	Treadmill	0.94±0.03	1.00±0.00	1.16±0.03	1.61±0.08	1.96±0.13
	Outside	0.89±0.05	1.00±0.00	1.16±0.07	1.41±0.11	
Gluteus Maximus	Treadmill	1.03±0.07	1.00±0.00	0.94±0.06	1.09±0.14	1.27±0.16
	Outside	1.06±0.12	1.00±0.00	1.19±0.14	1.45±0.26	

Research by Lankford[19] demonstrates that incline walking above approximately 15% grade results in a leg swing pattern more similar to a walking lunge than level surface walking. In other words, the leg doesn't swing like a pendulum with high incline walking, rather it is a straightforward walking lunge style movement. With the increased muscle activation patterns observed during incline walking and the studies showing incline walking can elicit maximal cardiovascular responses (elevated HR, VO2max testing etc), it is a logical assumption that incline walking may result in improvements in lower body strength adaptations similar to forms of resistance training of similar movement patterns, while also serving as a form of cardiovascular exercise.

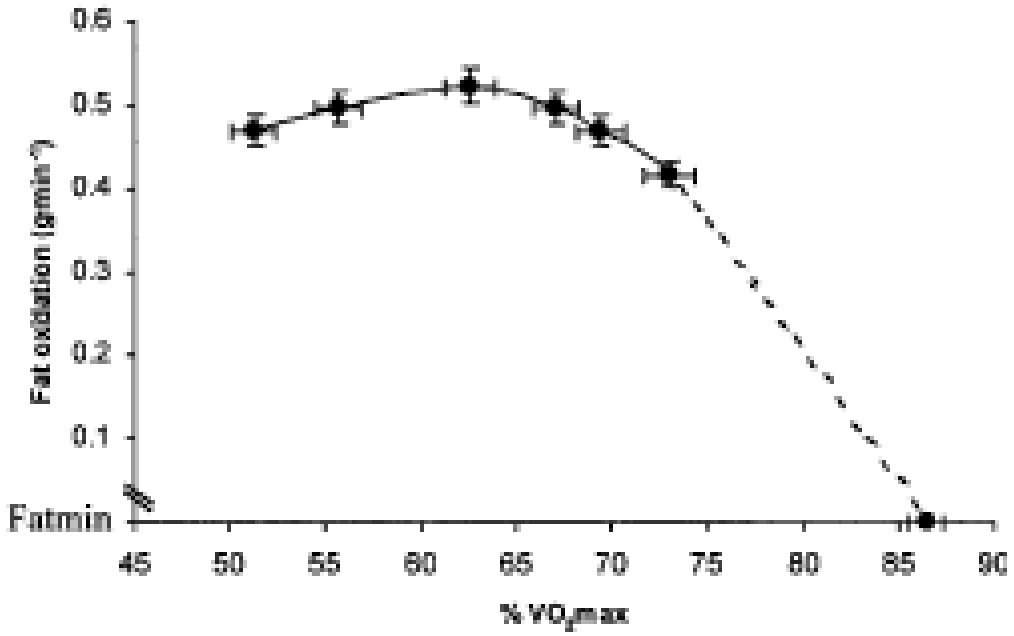
> In conclusion, walking and running at an incline results in dramatically higher muscle activation levels

In conclusion, walking and running at an incline results in dramatically higher muscle activation levels of the Iliopsoas, gluteus medius, gluteus maximus, hip adductors, rectus femoris, medial hamstring, biceps femoris, vastus lateralis, medial gastrocnemius, soleus muscles. While strength in these areas is important for everyone to help with their mobility, for military personnel it's absolutely essential. Carrying heavy armour and weaponry in the field, moving across demanding environments and terrains and transporting equipment (or wounded colleagues) are all very real scenarios faced by personnel on a regular basis.

The tibialis anterior and vastus medialis show mixed results as to whether their activation rates stay the same or decrease. Walking often produces even greater muscle activation levels compared to running at the same incline!

Metabolic Responses to Incline Walking/Running

There is a misnomer that low-intensity exercise is best for fat burning. It is true that during low-intensity exercise, a higher percentage of the calories burned come from fats. However, the total calories burned either in total or from fat are minimal compared to higher intensity exercise. As the exercise intensity increases, so does fat burning (fat oxidation). This occurs up until approximately 50% of maximal cardiovascular effort (VO2max), and 60% of maximal heart rate.[20] (see figure below from a study by Achten[21]).



This maximal fat-burning intensity often correlates with the intensity of exercise where an accumulation of lactate in the blood occurs (lactate threshold).[22] Above this intensity, the muscle appears to limit fat uptake from the blood and subsequent fat burning.[23] Based on internal research, walking at an incline can be utilized to maximize fat burning. This typically occurs around 18% grade when using a walking speed of approximately 2 mph. Walking at grades steeper than this could also constitute High Intensity Interval Training (HIIT) even though the participant is only walking. Sprint interval training (SIT) is often a bout of exercise that can only be held for seconds. For many people, exercising at 30-40% grade and 1-2 mph may constitute HIIT training, all while reducing impact compared to level ground running. This demonstrates the versatility of incline walking as a form of exercise.

Other factors are known to influence metabolic rate such as the mode of exercise, and enjoyment (i.e., stress) of the activity. New exercise tests have been developed that show maximal cardiovascular exercise effort (VO2max) testing can be performed on high incline treadmills that require walking only (as opposed to jogging/running).[24] This form of testing may be more applicable for populations that have daily activities

of walking and or strenuous walking – such as those working in the armed forces.) Participants in the study by Lankford et al.[24] were asked to exercise to maximal exertion using either a high incline walking protocol, or a standard walk/jog protocol. More participants preferred the high incline walking protocol over standardized walking and jogging even though both styles resulted in maximal oxygen uptake. Additionally, evidence suggests that training should consist of the mode of activity most similar to what is expected to be performed. Therefore, individuals expected to walk at steep grades as part of their occupation or hobby may benefit from specificity training using high incline treadmill walking or running.

Individuals have been known to exercise at higher intensities without realizing the extra effort as long as the exercise is enjoyable.[25] This may result in a reduced perception of effort (RPE) even though the participant is working harder. Participants may be capable of performing exercise for longer durations without feeling fatigue if they feel the exercise is more enjoyable. If incline walking is more enjoyable than level grade running, it may promote increased activity levels and improved fitness levels.

Balance

Certain individuals may feel less comfortable running on a treadmill as opposed to walking on a treadmill. It has been demonstrated that running on a treadmill requires a familiarization and transition phase. This exact time for this familiarization is undetermined.[18] Being uncomfortable running on a treadmill may lead to balance issues during the adjustment phase and possible injury. {Updating} It seems probable that incline walking may be safer than running if a participant is uncomfortable with exercise on a treadmill.

Additionally, individuals with balance issues may see benefits from high incline walking. Improved strength and power are associated with a reduced risk of falling.{Updating} The increased muscle activation patterns observed during high incline walking may result in an improved balance.

Claims

- Incline walking is a versatile form of exercise that can be tailored to result in peak fat burning.
- Incline training can be utilized for HIIT training.
- Incline training is an effective part of cardio training.
- Incline training causes increased muscle activation rates of the lower extremity. (This has been documented up to 30% grade).
- Incline walking results in increased concentric muscle activation compared to level ground.
- Decline running results in increased eccentric muscle activation compared to level ground.
- When working at the same intensity (calorie burn), walking at an incline results in lower peak impact force than running on a level surface. (this has been documented up to 11% grade).
- Incline training results in greater muscle activation while decreasing impact forces that commonly lead to injury.
- Downhill running increases impact forces. However, training at a decline can result in a modified foot strike which lessens the impact forces. In other words, if you are expected to perform downhill work, it might be a good idea to train for it.
- Running at an incline reduces tibial shock. Tibial shock has been associated with shin splints and other knee problems.
- Walking at an incline reduces internal knee abduction. This reduction is associated with better knee joint health.

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