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Impact forces at improvised via ferrata
Doğaçlama Ferratada Darbe Kuvvetleri

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Öz

Dağlık arazilerde yapılan aktiviteler sadece turistlere veya sporculara ait bir ayrıcalık olmayıp birçok profesyonel için de bir iş çevresidir. Bunların içinde askeri personel için bu durum diğerlerinden farklıdır. Silahlı kuvvetlerin orada olması farklı amaçlar içerir (operasyonu tamamlamak gibi). Bu tip arazilerde kalmak ve hareket etmek farklı tekniklerin kullanımını gerektirir. Bu tekniklerden biri genelde askerler tarafından kullanılan ve doğaçlama bir tarzı olan ferrata rotalarıdır. Bu rotalar çoğunlukla tırmanışa uygun olmayanlar için kayalık arazilerdeki güvenliği sağlamak için yapılmıştır. Malzeme özelliği örneğin çelik yerine tekstil ve dinamik ipin kullanılması gibi birkaç farkla diğerlerinden ayrılır. Çelik kullanılan rotaların testlerle normalize edilmiş olması veya uygun kılavuzların bulunması veya açık sonuçların olmasına rağmen, doğaçlama ferrata ile benzer bir bilgi bulunmamaktadır. Bu çalışmada doğaçlama ferrata ile daha fazla darbe kuvvetine ulaşmak için 8 farklı koşulda 80 düşüş gerçekleştirilmiştir.

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Abstract

Movement in mountainous terrain is not only privilege of tourists or athletes but also the work environment for many professionals. One group of these, military personnel, differs from the others. The stay of armed forces has distinct purposes – to fulfil an operation. Moving and staying in remote exposed terrains requires the use of specific techniques. One of the unusual techniques utilised mostly by armies is the construction of improvised via ferrata routes. Those are mostly built for non-climbing units for their safety in rocky terrain. The construction itself differs from common saved routes in a few features whereas the most important one is the utilisation of textile, dynamic rope instead of the steel one. Whilst common steel saved routes are a matter of thorough examinations with normalised tests, proper construction manuals and precise results, there is no similar knowledge of improvised via ferratas. We performed 80 falls in 8 different conditions to find out more about impact forces at improvised via ferratas.

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Introduction

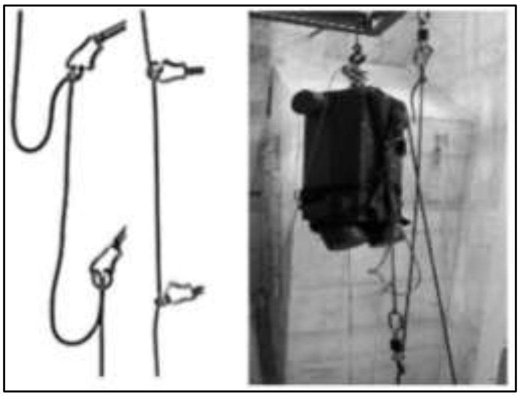
Save movement in mountainous terrain is possible by many ways yet not every of them is suitable for every condition or different climbing levels of mountaineers. Via ferratas originated as an easy way to reach inaccessible peaks for low-skilful climbers or enthusiastic tourists (Morgan et al., 2005). As the development was ongoing, the two main types of via ferratas emerged. The Eastern-Alps system and French-system (Semmel & Hellberg, 2008) with a few differences between each other.
The construction of both types works with the steel rope and steel/inox anchors (Semmel & Hellberg, 2008). As well as normalised via ferratas construction procedures, the utilisation of proper, normalised and checked equipment is required (EN 365). The common via ferrata user wears a helmet, sitting harness at least and via ferrata set with fall arrester (EN 958+A1). Many factors play a role in the risk management when moving via ferrata such as the falling rocks; condition, experience of climbers or weather yet the main purpose of all the precautions is to avoid as much as possible the repercussions of the user´s fall. The biggest harm might be caused by enormous size of impact force (Ströhle et al., 2020) which very often outreach the size of 2, in sport climbing the level where the complete safety chain must be excluded from successive usage (EN 365; Tendon, 2021).

Movement in mountainous terrain under military conditions are even more demanding and therefore more dangerous for military personnel. Climbing military personnel and regular soldiers often have to conduct their operations in high exposed terrain yet the utilisation of common civilian routes or mountain equipment is not plausible, therefore they use the special form of approaches from all the climbing disciplines, the military climbing (Kuhar et al., 2005; Federal Ministry of Defence and Sports, 2014, Michalička et al., 2019). Combining all the available techniques gives the military climbing the unique variety of different solutions applicable for every possible problem.
Via ferratas in military climbing result also from the combination of civilian approach, the military task, the limitation in gear, in amount and carried load and their purpose itself. The **military via ferrata** is firstly improvised which means it is not built up from steel and fixed anchors, it is made from **dynamic ropes** and **mobile anchors** such as cams (Samet, 2011), hitches and/or friction knots (Michalička et al., 2019) though. Friction knots themselves were proofed to be the weakest link (Michalička & Telvák, 2021) in safety chain. Secondly, the military via ferratas are temporary. These are only the means to get a military unit to the place of their operation and so it is not necessary to build them long-lasting. Thirdly, on the contrary to the civilian ones, the difficulty is not the goal. Military personnel gear often weight more than 40 kilograms per person (Knapik et al., 2012) so the route chosen must be easy and safe. Safety itself, though, is not the only priority. Military climbing has to cope with limited total weight carried and so the via ferrata sets with fall arresters are not part of the soldier´s gear.
The aim of this work is to extend a knowledge in military climbing risk management and find the precise threats proceeding at improvised via ferratas (IVFs) and improvised via ferrata sets utilisation.

Methodology

Safety of military personnel during movement via ferrata is provided by two main assets.
A] Utilisation of IVF set which should be solid enough to absorb the impact forces emerged during climber´s fall. The precise numbers of IF acting on IVF sets are not known though.
To find out the missing information needed for save mountainous military operations, we decided to conduct an experiment. **B]** Construction of IVF itself, where the dynamic rope strictly replaces the official steel rope designated to classical via ferrata and therefore should provide safer fall arrest with lower impact forces (IFs). The precise values of IFs acting on climbers are not known though.

IVFs in the military environment combines two basic types, as mentioned above, with the main difference in loops in the French-system and therefore looser fixed rope installation (Picture 1a).



Picture 1. a] French-system and Eastern-Alps system of IVFs **b]** Final laboratory experiment

We chose this type in our experiment not only because it is more common but also it is more universal. The construction was built from dynamic rope tied between two fixed points (Picture 1b). Laboratory conditions and steel anchors were chosen to provide a replicability of the experiment.

IVF set in military climbing is strictly constructed from a reep cord of 6 mm diameter without any fall arrest system. Utilisation of low cost, low time consumption and quite low knowledge for its construction is required. The IVF set is illustrated lower (Picture 2) out.

Picture 2. Improvised via ferrata set made from 6mm reep cord and its lab variant

All our measurements were conducted using only one IVF set strand to correlate with EU norms (EN 958+A1) for via ferrata set testing.

Textile material and experimental sample

The dynamic rope we used, had dynamic elongation of 34% and is used (Tendon, 2021) for beginners or for those who prefer a rope for a long life time. Its 10,5 mm diameter is common in the Czech military climbing for its great handling and durability. Usage of such rope is therefore a norm when constructing IVFs and other rope installations. During the experiment, we worked with common dynamic rope Ambition 10,5 (Tendon, Czech Republic) and 6 mm reep cord (Tendon, Czech Republic) where the thorough features are displayed in Table 1.

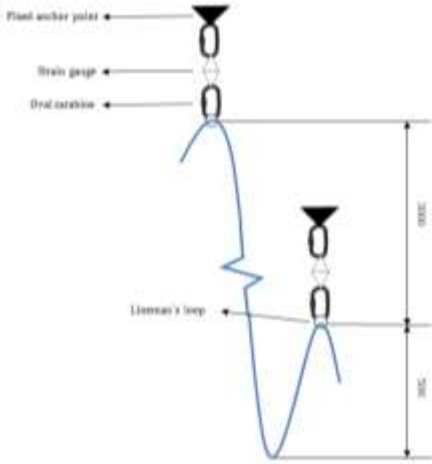
Table 1 Used material

Manufacturer	Tendon	Tendon
Rope trademark label	Tendon Ambition 10,5 mm	Tendon Reep 6 mm
EN standard Type	EN 892+A1: 2017	EN 564: 2015
Type	Single dynamic	N/A
Material	Polyamide (PA)	Polyamide (PA)
Year of manufacture	2020	2020
Diameter [mm]	10,5	6
Static breaking strength (Tenacity) [kN]	N/A	7,2
Static breaking strength [kN] from reference testing	N/A	10
Weight per meter [g/m]	69	23,2
Number of falls according to EN 1891 (f = 1)	9	N/A
Maximal Impact force [kN]	9,1	N/A
Sheath slippage [%]	0	N/A
Static elongation [%]	6	N/A
Dynamic elongation [%]	34	N/A
Knotability	0,8	N/A
Sheath mass [%]	39,2	N/A
Core mass [%]	60,8	N/A
Core structure	7S + 7Z	2S + 3Z

Due to the design of the experiment, both textile ropes were cut to 6 m fragments of dynamic rope and 5 m of reep cord respectively with a common fusible knife. The total length used was 240 m of rope and 200 m of reep cord respectively.

Design of the experiment had three phases conducted in the Climbing polygon of the Fire Rescue Service of the Czech Republic, Velké Poříčí. **A]** The goal was in defining the IFs values of IVF sets for different fall factors (FF). These were set on 0.5; 1.0; 1.5 and 2.0 which came out from praxis (the complete IVF set is designed from 5 m of cord and its strands are 1.0 ± 0.02 m (Michalička et al., 2019) length each) where climber cannot fall lower than ~ 2 m and therefore produce FF > 2. We conducted 10 measurements (Goh & Love, 2010; Pomares et al., 2020) for each FF value whereas the cord was brand new for each measurement. The fall itself was made at the fall tower using a 100 kg figurine in complete harness which was thrown to a single strand of IVF set (EN 958+A1). This strand ended with a clove hitch (ABoK #1177) and steel X carbine (EN 362) and was connected to a strain gauge LC1 Enforcer Load Cell (Rock Exotica, USA) and then to a fixed anchor point. **B]** The goal was to define the IFs values affecting a climber, his IVF set and anchor point of IVFs. We constructed a single section of IVF of 3m length with 1m loop in total rope length 4m. Connections were conducted via steel X carbines and LC1 Enforcer Load Cell (Rock Exotica, USA) at both high/low positions, see (Picture 3). The Lineman's loop (ABoK #331), Alpine butterfly, was used as the only connecting knot at every position. We simulated 0.5; 1.0;

1.5 and 2.0 FF fall of weight w/o IVF set or via ferrata set. We conducted 10 measurements (Goh & Love, 2010; Pomares et al., 2020) for each length value whereas the rope was brand new for each measurement.



Picture 3. Experimental laboratory section of via ferrata

C] Comparing the gain results from A], B] with the real praxis. We conducted a "control" measurement of IFs acting on complete system when the fall at IVF occurs. The design was to model the "real" fall under a "real" conditions, therefore IVF section using a dynamic rope A] and IVF set using 6 mm reep cord B] were put together. We simulated and examined the most extreme case – the fall from 4 m height into a single strand of IVF set. We hoped to find out more about the final impact forces which might act on a military personnel and therefore modify mountain training manuals, if needed.

A 100 kg weight was set for all three phases as a combination of "normalised" climber (EN 892+A1) and soldier who has to carry special gear as a ballistic helmet, plate carrier, ammunition. In experiment, the weight was always a body corpse figurine dressed up into a complete working harness (EN 361).

Statistical analysis

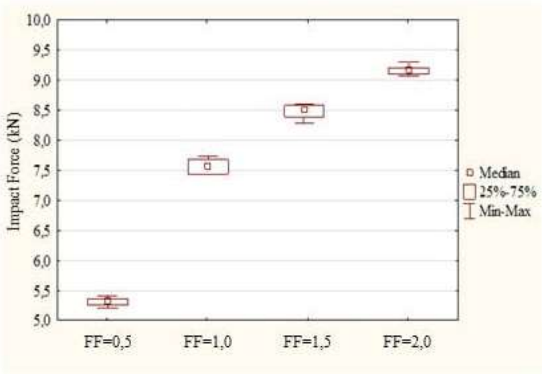
Statistical analysis was performed using The Jamovi project, ver. 2.2.4. (Computer Software, Sydney, Australia), and Microsoft Excel 2016 (Microsoft Corporation, Redmont, Washington, USA), with the alpha level for significance set at ≤ .05. Descriptive statistics (min, max, SD, average) was used for each set of values. The normal data distribution was tested by Shapiro-Wilk test. Paired samples t-test was then used to compare values of IFs gained during fall set at FF 0,5; 1,0;1,5 and 2,0 with IVF set to fixed anchor point and IFs values from a fall into a laboratory section of IVF.

Results and Discussion

It is often necessary to build up an improvised via ferratas and improvised via ferrata sets in military mountainous operations. The textile material used has different features in contrast to the steel via ferrata constructions yet its behaviour is not known during the possible fall of military personnel. In order to gain proper results, the experimental model was designed divided into three phases. Each phase examined specific conditions of IVF techniques used in the Czech military climbing system.

The air temperatures detected with the thermometer during the tests ranged from a minimum of 17,9 °C to a maximum of 22,9 °C, while humidity varied from 44 to 52%.

A] Improvised via ferrata set strength
According to EN 564, the static breaking strength is set at 7,2 kN for 6 mm reep cord, whereas 10 kN was the static breaking strength, tenacity, of 6 mm reep cord we measured (Michalička & Telvák, 2021). We conducted 40 dynamic measurements using 0.5; 1.0; 1.5 and 2.0 values of FF (Picture 4) using a single strand of IVF set which was 1.0 ± 0.02 m length. The strand ended with a clove hitch (ABoK #1177) and steel X carbine (EN 362) and was connected to a strain gauge. For each of 40 experimental sessions, the brand new textile material was used.



Picture 4 IVF set strength in different FF values

Table 2 Descriptive statistics for IVF set IFs values

n=10	FF=0,5	FF=1,0	FF=1,5	FF=2,0
Maximal IF (kN)	5,37	7,74	8,60	9,35
Minimal IF (kN)	5,17	7,44	8,37	9,13
Average IF (kN)	5,28	7,57	8,49	9,22
SD Ø (kN)	0,064	0,117	0,110	0,063

As we predicted, the IFs values grow exponentially yet the biggest gap is between FF=0,5 and FF=1 where the final average IF grew from 5,28 kN up to 7,57 kN. Also, the IFs values generally for FF=1,0; 1,5 and 2,0 are always higher than guaranteed maximal tenacity (EN 564) of used reep cord.
FF=2 always led to **malfunction** of the system. Its average IFs values were always above 9kN and the experiment always ended with the connecting claw hitch (ABoK #1177) breakage – the claw hitch itself was the weakest point in the IVF set.
We can assume that IVF set at fixed anchor point is strong and therefore **safe** for the climber only **when FF<1,0** (Kuhar et al., 2005). Even when the strand itself is constructed from two ropes and end with claw hitch (Michalička et al., 2019)., the weakest point is the hitch itself. It must be taken under the consideration that normalised tenacity is set to 7,2kN (EN 564) and weakening the rope by the knot might be as high as 56 % (Frank & Kublák, 2007; Evans, 2016, Šimon et al., 2020). When FF>1,0, the risk for the climber is unacceptable, it will lead into breakage of the system. Utilisation of both IVF set strand is crucial.

B] Impact forces at improvised via ferrata section
A single section of IVF was built up in a total rope length of 4m (Picture 3). We simulated 0.5; 1.0; 1.5 and 2.0 FF fall of weight w/o IVF set or via ferrata set. We conducted 10 measurements while the section ended with a Lineman's loops (ABoK #331) and steel X carbines (CE EN 362) and was connected to a strain gauges. For each of 40 experimental sessions, the brand new textile material was used.

Table 3a Descriptive statistics for IVF section IFs values

n=10	FF=0,5 (High/Low/Final)			FF=1,0 (High/Low/Final)		
Maximal IF (kN)	1,11	2,21	3,44	1,32	3,44	4,62
Minimal IF (kN)	1,02	1,96	3,21	1,16	3,21	4,31
Average IF (kN)	1,07	2,11	3,34	1,24	3,34	4,48
SD Ø (kN)	0,030	0,094	0,070	0,0544	0,066	0,090

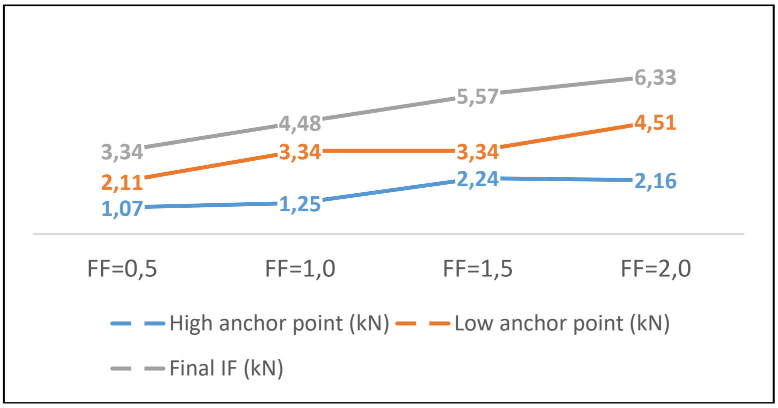
* High/Low/Final are values valid for anchors and final IFs

Table 3b Descriptive statistics for IVF section IFs values

n=10	FF=1,5 (High/Low/Final)			FF=2,0 (High/Low/Final)		
Maximal IF (kN)	2,32	3,49	5,69	2,24	4,61	6,48
Minimal IF (kN)	2,18	3,21	5,42	2,05	4,35	6,19
Average IF (kN)	2,24	3,33	5,57	2,15	4,51	6,33
SD Ø (kN)	0,042	0,082	0,081	0,054	0,086	0,094

* High/Low/Final are values valid for anchors and final IFs

We gathered three IF values from each of the experimental sessions for each of the FF values, see Table 3a,b. What is obvious, max IF < 6,48 kN at every measured point and therefore much lower than guaranteed tenacity of reep cord (EN 564) or tenacity we measured – see Table 1, or rope respectively (EN 892). The average IF gathered as the Final, the climber, numbers are also positive when they got to IF = 6,33 kN. This number, valid for the "hardest" level, FF = 2, is quite promising while the guaranteed maximal impact force of the rope is 9,1 kN (Tendon, 2021). It can be said, that utilisation of the dynamic rope in unusual way, the IVF, is **possible and save** in a matter of material.

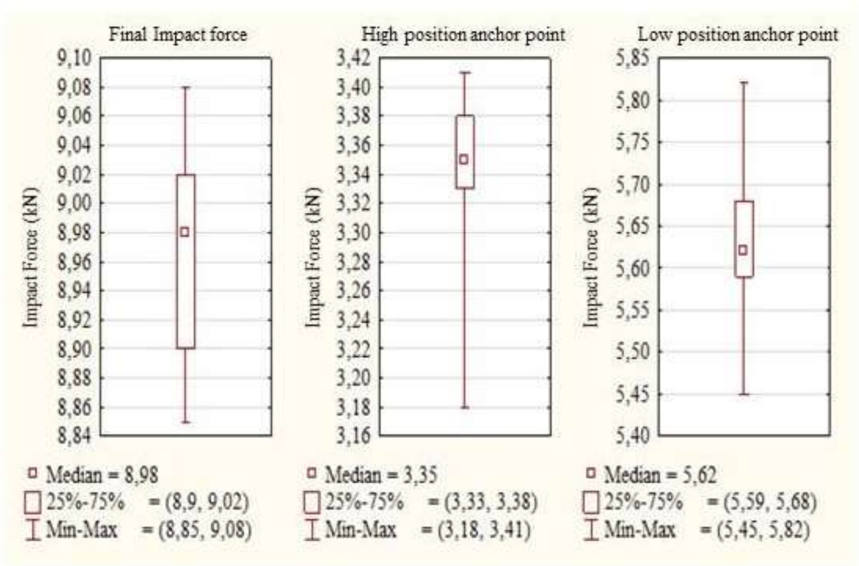


Picture 5 Average IFs values at measured points

The most obvious is the difference between IFs values acting on high/low anchor point. At all FF levels, the Low anchor point IF values were almost always 2x higher than High anchor point IF values. We assume that it might be explained through the construction of French-system itself (Semmel & Hellberg, 2008). The length of the whole IVF section was 4 m, the loop at the low anchor point measured 1 m, the half of it – leading to the low anchor point 0,5 m. The differing lengths of the available rope which absorbs the final IF led to the difference between IFs values at the points (Seifert et al., 2016). What must be mentioned, is the limitation of the real anchor points in praxis, the cams (Samet, 2011; Michalička et al., 2019) their real tenacity is often less than measured 5,51 kN for FF = 2,0 (Vogwell & Minguez, 2007).

Exponential growth of Final IFs at different FF levels does not correspond with values from both anchor points at the ends of the IVF section. Not even a simple sum of these values corresponds with the values at final point. The more thorough experiments aimed at this problem should be conducted as well as the experiment working with Eastern-Alps system of IVF.

C] As mentioned above, we put together both variants A], B] together to model the most dangerous case in IVF section – the 4 m fall into an IVF set. 4 metres was chosen as a maximal length used in the Czech military climbing system of vertical section (Michalička et al., 2019) and also due to the limitation at the fall tower. From the combined conditions, the values we gathered are displayed lower (Picture 6) and therefore we can conclude the fall under these extreme conditions as the very high risk for the climber. Final IFs average was almost as high as the limitation of IF max of the rope itself, both anchor points were also extremely loaded. These facts will almost certainly lead in to malfunction of the IVF section. **We strictly recommend** the shortage of the IVF section under all circumstances as well as usage of both IVF set strands.



Picture 6 Average IFs values at measured points in extreme fall

Table 4 Descriptive statistics for extreme fall IFs values

n=10	FF=4 (High/Low/Final)		
Maximal IF (kN)	3,41	5,82	9,02
Minimal IF (kN)	3,18	5,49	8,85
Average IF (kN)	3,33	5,62	8,97
SD Ø (kN)	0,067	0,106	0,073

* High/Low/Final are values valid for anchors and final IFs

D] Paired sample t-test showed that the differences between IVF section and IVF set for each FF condition were statistically significant ($p < .001$). This fact was predicted yet the proper values were unclear. We can postulate that it is significantly safer to to use a dynamic rope for French-system IVF constructions. We can also support this fact, the effect size, thanks to Cohen's d (Table 5).

n=10	t-test	*p*-value	Cohen's d
FF=0,5 (IVF set/IVF section)	-66,4	<.001	-21,0
FF=1,0 (IVF set/IVF section)	-55,2	<.001	-17,5
FF=1,5 (IVF set/IVF section)	-82,9	<.001	-26,2
FF=2,0 (IVF set/IVF section)	-103,4	<.001	-32,7

Table 5 Comparing the IVF section and IVF set

Conclusion

The utilisation of improvised via ferrata in military praxis constructed and used unusual ways, has some limits. Single usage of improvised via ferrata set is highly risky and might be considered save only when Fall factor < 1,0. Utilisation of dynamic climbing rope for improvised via ferratas in the French-system is save and plausible. This fact was also supported by statistical analysis. Combination of these two technical solutions is save only under the condition of the improvised via ferrata section shorter than 4 vertical metres. Usage of both strands of improvised via ferrata set is highly recommended. Other measurements must be conducted for the precise values of acting impact forces in Eastern–Alps system.

Disclosure and Conflicts of interest

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References

Ashley, C. W. (1944). *The Ashley book of knots* (Vol. 13). Doubleday Books.

Evans, T. (2016). "*A Review of Knot Strength Testing*", in: Int. Techn. Rescue Symp

EN 361 (832620). (2003). *Personal protective equipment against falls from a height - Full body harnesses.* European Committee for Standardization. Brussel.

EN 362 (832623). (2005). *Personal protective equipment against falls from a height - Connectors.* European Committee for Standardization. Brussel.

EN 365 (832601). (2005). *Personal protective equipment against falls from a height - General requirements for instructions for use, maintenance, periodic examination, repair, marking and packaging.* European Committee for Standardization. Brussel.

EN 564 (942001). (2015). *Mountaineering equipment– Accessory cord– Safety requirements and test methods.* European Committee for Standardization. Brussel.

EN 892+A1 (942007). (2017). *Mountaineering equipment– Dynamic mountaineering ropes– Safety requirements and test methods.* European Committee for Standardization. Brussel.

EN 958+A1 (942008). (2017). *Mountaineering equipment – Energy absorbing systems for use in klettersteig (via ferrata) climbing – Safety requirements and test methods.* European Committee for Standardization. Brussel.

Goh, Y.M.; Love, P.E.D. (2010). Adequacy of personal fall arrest energy absorbers in relation to heavy workers. *Safety Science 48*, pp 747–754.

Federal Ministry of Defence and Sports. (2014). *Austrian Armed forces field manual: Military mountain training.* Supply number 7610-10133-0808 Vienna. 685 p.

Frank, T., & Kublák, T. a kolektiv. (2007). Horolezecká abeceda. Praha: Epocha, 663 p.

Knapik, J. J., Harman, E. A., Steelman, R. A., & Graham, B. S. (2012). A systematic review of the effects of physical training on load carriage performance. *The Journal of Strength & Conditioning Research*, *26*(2), 585-597.

Kuhar, M., Dobovšek, M., Primožič, B., Davis, M., Lipič, L., & Pograjc, B. (2005). *Military mountaineering skills*. Defensor.

Michalička, V. et al. (2019). *Pub-71-84-06 Speciální tělesná příprava Vojenské lezení.* Praha. Vojenský obor FTVS UK, Armáda České republiky.

Michalička, V., & Telvák, R. (2021). Friction knots—Their strength under static load. *J. Outdoor Act*, *14*, 7-16.

Morgan, D., Moore, K., & Mansell, R. (2005). Adventure tourists on water: Linking expectations, affect, achievement and enjoyment to the sports tourism adventure. *Journal of sport tourism*, *10*(1), 73-88.

Pomares, J. C., Carrión, E. Á., González, A., & Saez, P. I. (2020). Optimization on personal fall arrest systems. Experimental dynamic studies on lanyard prototypes. *International journal of environmental research and public health*, *17*(3), 1107.

Samet, M. (2011). *The Climbing Dictionary: Mountaineering Slang, Terms, Neologisms & Lingo: An Illustrated Reference*. The Mountaineers Books. ISBN 978-1-594-85503-0.

Seifert, L., Wolf, P., & Schweizer, A. (2016). *The Science of Climbing and Mountaineering*. Routledge.

Semmel, Ch., Hellberg, F. (2008). *Recommendation for the construction of klettersteigs (also known as via ferrate) and wire cable belay systems.* German Alpine Club Safety Analysis Unit. Munich, Germany.

Ströhle, M., Haselbacher, M., Rugg, C., Walpoth, A., Konetschny, R., Paal, P., & Mair, P. (2020). Mortality in via ferrata emergencies in Austria from 2008 to 2018. *International journal of environmental research and public health*, *17*(1), 103.

Šimon, J., Dekýš, V. & Palček, P. (2020). Revision of Commonly Used Loop Knots Efficiencies, *Acta physica polonica A*, 3 (138). 404- 420.

Tedon (2021). *Catalogue 2021/Eng.* Lanex a.s., Bolatice.

Vogwell, J., & Minguez, J. M. (2007). The safety of rock climbing protection devices under falling loads. *Engineering failure analysis*, *14*(6), 1114-1123.