Forest Workers and Steep Terrain Winching: the Impact of Environmental and Anthropometric Parameters on Performance

Giovanna Ottaviani Aalmo, Natascia Magagnotti, Raffaele Spinelli

Abstract

Winching is common in small-scale forest operations, especially on steep slopes, where tractors cannot reach the logs inside the forest. In this case, logs are dragged to the roadside with tractor-mounted winches, for later collection by transportation units. Winching is a heavy task, posing a high physiological stress on winching crew members. The aim of this study was to investigate the relationship between experienced workload, work conditions and operator fitness. The study confirmed the assumption that fit, young operators experience a lower workload than older ones. Workload depends on winching direction, and it is higher when winching downhill than when winching uphill. Results confirmed that gravity is the main factor, and it has a stronger effect than task type and tool weight. Walking uphill with no tools is heavier than walking downhill and carrying a steel cable. As a consequence, tool weight reduction can only palliate the problem, without solving it. Winching crews should be composed of fit, young workers. When the task is assigned to older workers, it is necessary to allow longer rest breaks, accepting a lower productivity.

Keywords: steep terrain, winching, workload, heart rate

1. Introduction

In many countries, small and fragmented forest-land ownership is quite common. Because of the land ownership pattern, small forest owners seek for solutions allowing profit increase with small investments. Farm tractors are a common solution for harvesting small-scale forests (Spinelli and Magagnotti 2012). They can be purchased at a fraction of the cost required for specialised forest machinery, and they are quite versatile, which allows their use in bunching, skidding, forwarding and loading tasks. Winch-equipped farm tractors can be used in steep terrain for the extraction of manually felled timber. In steep terrain, limited machine mobility and tight safety restrictions related to environmental concerns, prevent direct access to the loads. Therefore, the tractor stops on the road bank or skid trail and uses its winch to drag the logs to the roadside. This requires someone to pull the winch cable all the way to the logs, and connect them to the cable using choker chains. The work of pulling the cable up/downhill through the forest is physically demanding, and results in a high energy demand, which often exceeds the endurance limit (Stampfer 1998, Vik 1984). In addition, walking directly up the slope is one of the heaviest and most strenuous activities associated with forestry work.

Workload is a measure of the demand experienced by a subject across various means of mental and physical load, resulting from the effects of factors such as task requirements, effort, and performance. Determining the expected levels of overall workload can help evaluate the different tasks and eventually lead to a different system configurations (e.g. pre-determined rest breaks and task assignments) or identify the most efficient team compositions. The efficiency of each harvesting operation in forestry can be increased *inter alia* by assessing the workers critical workloads for each single task and for each of the task elements.

Overall workload gives a general understanding of the demands placed on the workers. Additional understanding regarding the specific types of strains is obtained by examining the individual overall workload channels, e.g., physical workload (Hart 1986).

The capacity of performing physical work depends on the ability of the muscle cells to transform food intake into mechanical energy output. This process is affected by parameters such as age (de Zwart et al. 1996), gender, body dimensions and fitness (Rodahl 2003). In motor manual cutting, Hagen et al. (1993) showed that there was no difference between heart rate of younger and older lumberjacks; Lilley et al. (2002) found no influence of age, while Rodgers (1997) found significant influence of age. Body dimensions (height and weight) were found significant in the development of back pain in several researches (Krause et al. 1997, Keyserling et al. 1988, Heuch 2010, Hagen et al. 2010). Afolabi and Akanbi (2013) found that they also significantly affected the aerobic power.

Heart rate has been and still is commonly used as the criterion for the evaluation of physical demands of work but also, for example, for determining rest allowances (Rodgers 1997). Because of the linear relationship between heart rate and oxygen uptake, heart rate can, therefore, be used for estimating the workload (Astrand et al. 2003).

Fitness of a subject can be evaluated via the maximal oxygen uptake (VO_2max), referring to the maximum amount of oxygen that an individual can utilize during intense or maximal exercise. It is measured as millilitres of oxygen used in one minute per kilogram of body weight. It is a factor that can determine the subject's capacity to perform sustained exercise and is linked to aerobic endurance. This index has been extensively used in forestry studies related to ergonomics (Afolabi and Akanbi 2013, Park et al. 2003, Parker and Kirk 1994, Staal Wästerlund 2001, Trites 1992).

The outdoor working environment also affects the physical performance of forest workers (Ovaskainen et al. 2004).

The goals of this study are therefore to:

⇒ determine the workload experienced during log winching operations, in order to assess how taxing is this specific task, which is especially common in small-scale forest operations,

⇒ to investigate the effect of anthropometric and physical parameters such as age, fitness, weight and height in combination with external environmental parameters i.e. site conditions on the forest workers' heart rate while performing winching in a controlled operation.

No previous work has analysed the effect of these factors on the workload experienced specifically during log winching operations. The available evidence for other tasks is confusing, as some papers confirm the strong effect of these factors, while others find no effect at all. Therefore, it is possible that these effects are task-specific, which warrants specific studies for each given task.

Table 1 Description of test corridor

Test number	Direction of extraction	Slope, %	Length, m
1	Downhill	64	50
2	Uphill	53	48
3	Uphill	66	46
4	Downhill	60	50
5	Downhill	68	47
6	Downhill	64	55
7	Uphill	54	50
8	Uphill	62	47
9	Uphill	60	50
10	Uphill	60	50
11	Downhill	58	51
12	Downhill	53	50

Fig. 1 Farm tractor with Maxwald hydraulic single drum winch

Table 2 Details of the subject's anthropometric and physiological parameters

Subject	Age, years	Experience, years	Weight, kg	Height, cm	*BMI*	*HRr*, bpm	*Hr*max, bpm	VO_2max
1	45	26	85	170	29.4	68	175	38
2	43	24	104	182	31.4	60	177	41
3	52	34	75	165	27.5	61	168	32
4	22	3	73	176	23.6	63	198	60
5	42	13	77	170	26.6	68	178	36

2. Material and Methods

The study was undertaken within two different hauling operation sites in a region, where small forest owners use winches mounted on farm tractors for wood extraction. The tractor used in the test was equipped with a Maxwald single drum hydraulic winch (Fig. 1). This machine was equipped with a slack-puller, which eliminated the effect of drum resistance.

The test was performed over a total of twelve corridors. The corridors were chosen based on similar conditions in two different harvesting sites: eight on the first site and four on the second. Corridor length varied between 47 and 55 meters. All harvesting residues were removed so that no hindrance was present. At the end of each corridor, a sufficient number of 4 meter logs were prepared, ready to be extracted. The logs average diameter was 20 cm. Corridor slope varied between 53 and 68%.

Two settings were defined: (1) downhill extraction and (1) uphill extraction. Each subject was tested in each corridor. They pulled an 11 mm swaged steel cable, weighting 630 g/m to the logs location, set the choker around one log at the time, followed the log until the designed bunching area and released the log (Table 1).

The five subjects were selected among several steep terrain crews. They all had significant experience with this type of operations. They all agreed to participate in the test voluntarily. They were entitled to withdraw at any time, or decline to answer specific questions or complete specific tasks, if desired.

The performance of physical work is made possible by muscular activity. Muscles, during their movements, use oxygen to release energy. The energy, required for the performance of a given task, is proportional to the amount of oxygen absorbed; the more energy needed, the more oxygen is needed to compensate for the increased blood circulation. Consequently, a higher heart rate implies a close relationship between heart rate and oxygen consumption, with the rate increasing in proportion to work intensity (Astrand et al. 2003, Apud et al. 1989). Therefore, the physical workload can be evaluated comparing heart rates measured during resting and working. The task heaviness can be benchmarked by comparing the heart rate attained for each activity with the individual maximal oxygen uptake. The anaerobic threshold is assumed to be below 40% for an 8 hour working shift (Astrand et al. 2003).

Heart rate was measured to assess the level of physical stress of each task element, using a Polar RC3 GPS pulse monitor with continuous data logging and storage of the hart rate readings. Resting heart rate was measured and VO_2max was predicted through the Polar OwnIndex® upon arrival on the work-site, while lying down and resting in silence for 15 minutes. The OwnIndex® usually ranges between 20 and 95 and is comparable with the VO_2max commonly used to evaluate aerobic fitness (Table 2) (Polar 2015).

The task time elements measured in the time study are reported in Table 3. During the test, no delay was recorded. All technical and personal interruptions occurred while the workers were not under the test.

Heart rate was recorded for each time element and for each task in accordance to the time study. Rest

Table 3 The time study element-break down

Work element	Description
Pull out	Pulling out the 630 g/m line until the logs location
Hook	Hooking the logs prepared on the slopes
Walk in	Follow the loads back to the landing
Unhook	Unhook the chokers from the logs

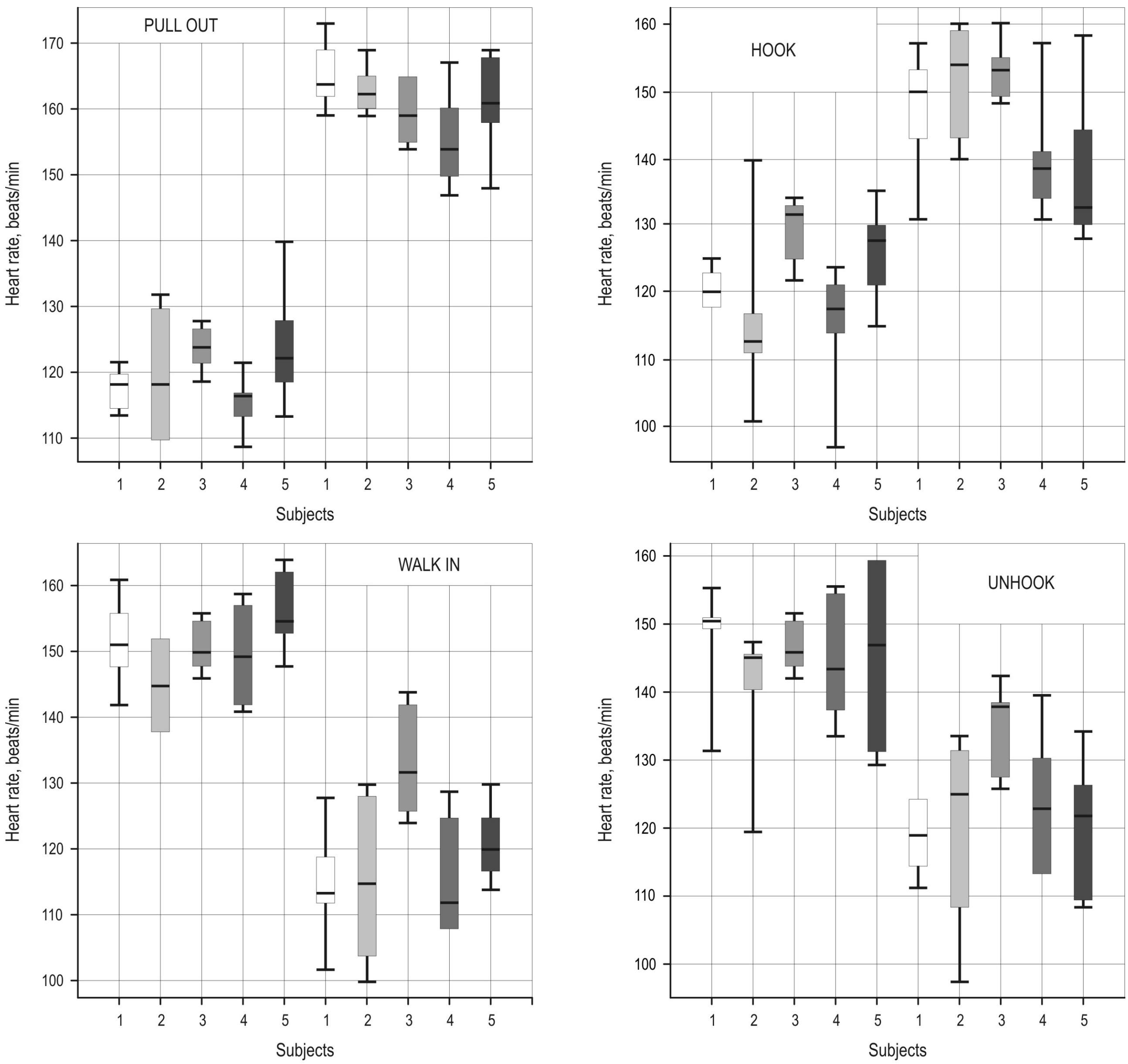

Fig. 2 Box plot showing the heart rate response for each time element, direction and subject

heart rate was obtained for each subject upon arrival at the work site. Subjects were asked to sit down and rest for 15 minutes. Between each test, the subjects rested for at least 45 minutes. The meteorological conditions for the 5 days of data collection were similar with a mean temperature of 18°C and a mean humidity of 51%.

All data were analysed using *R* statistical software (Team 2008). The heart rate was analysed using mixed effect modes with the nlme package (Pinheiro et al. 2012). The use of mixed effect models allows for modelling the dependent variable giving different intercepts and slopes for each subject participating in the experiment (Bates 2005).

Parametric statistics response variable is assumed to be linear in time.

The analysis was conducted in two phases. The first one aimed at building a mixed effect model for predicting the heart rate for each of the work elements, and the second phase in which the subject specific deviation from the intercept β_0 for each model (μ) was tested for each of the anthropometric parameters to visually check any trend explaining how the heart rate is influenced by individual characteristics. The most parsimonious model was selected out of the various models tested in the building process. The model was chosen on the basis of the Akaike Information Criterion (*AIC*).

The first model (mod. 1) predicted the heart rate of the subjects during the time elements requiring walking i.e. »pull out« and »walk in« (Table 3) the slope and the best fitting model was found to be:

$$Y_{ij} = \beta_0 + \beta_1 Slope + \beta_2 Speed \quad Uphill +$$
$$+ \beta_3 Speed \quad Downhill + \mu_i + \varepsilon_{ij} \qquad (Model\ 1)$$

Where:

Y_{ij} prediction of the heart rate at the end of the time element for each subject ($_i$) and replication ($_j$);

β_0 intercept;

β_1,β_2,β_3 unknown parameters to be determined;

Slope slope percentage of each test corridor, %;

Speed speed at which the subjects were moving on the slopes, m/s;

Uphill and downhill dummy variables indicating whether the extraction proceeds uphill or downhill, respectively;

μ_i random factor;

ε_{ij} individual specific error.

For the time elements not requiring walking i.e. hook and unhook the chokers (Table 3), the model selected was:

$$Z_{ij} = \beta_0 + \beta_1 Slope +$$
$$+ \beta_2 Time \quad Uphill + \beta_3 Time \quad Downhill + \mu_i + \varepsilon_{ij}$$
$$(Model\ 2)$$

Where:

Z_{ij} prediction of the heart rate at the end of the time element for each subject ($_i$) and replication ($_j$);

β_0 intercept;

β_1,β_2,β_3 are the unknown parameters to be determined;

Slope slope percentage of each test corridor, %;

Time time to perform the task, s;

Uphill and downhill dummy variables indicating whether the extraction proceeds uphill or downhill, respectively;

μ_i random factor;

ε_{ij} individual specific error.

In order to investigate whether the heart rate of each time element is affected by anthropometric parameters typical for each subject in the test, a visual inspection was performed of plots explaining the relationship between μ_i and different parameters.

The chosen anthropometric parameters are both directly measured or calculated and they indicate the physical size i.e. weight (kg), the degree of fitness i.e. VO_{2max} (mL/(kg×min)) calculated by means of the heart rate monitor and the age (years) of the subjects.

3. Results

A preliminary data analysis showed that there was a significant difference (p<0,05) in heart rate readings for time elements pull-out and unhook for different winching directions, uphill winching to the left, and downhill winching to the right of each plot. For the hook and walk-in elements the difference was less significant (p<0.1) (Fig. 2).

The summary statistics for the variables used in the test are presented in Table 4.

Table 4 Summary statistics of the data

Variable	Minimum	Maximum	Mean	*SD*	Count
Heart rate, pull out beats/min	109	173	140.60	21.40	–
Heart rate, hook beats/min	97	160	133.7	15.8	–
Heart rate, walk beats/min	100	164	135.50	17.95	–
Heart rate, unhook beats/min	97	159	134.43	15.36	–
Slope, %	53	68	60.13	4.72	–
Speed, m/s	0.11	1.09	0.50	0.29	–
Time, hook, s	28	313	85.73	49.91	–
Time, unhook, s	21	93	48.73	14.70	–
Uphill Downhill	–	–	–	–	30 30
BMI, kg/m^2	23.6	31.4	27.7	2.65	–
VO_2max mL/(kg×min)	32	60	41.6	9.41	–
Age, years	22	52	40.8	10.11	–
Variable	Minimum	Maximum	Mean	*SD*	Count

Table 5 Estimates and standard errors for the model including movement along the slope

Variables		Coefficient	Standard error	t	P-val
Model »pull out« (1a)					
Constant	β_0	128.07	20.24	6.32	<0.001
Slope	β_1	0.28	0.28	1.01	0.31
Speed×uphill	β_2	–30.97	7.18	–4.31	<0.001
Speed×downhill	β_3	55.27	20.61	2.68	<0.001
Subject variance		2.01	1.42	–	–
Model »walk in« (1b)					
Constant	β_0	125.66	19.49	6.45	<0.001
Slope	β_1	0.32	0.26	1.23	0.22
Speed×uphill	β_2	6.77	7.47	0.96	0.36
Speed×downhill	β_3	–100.19	21.43	–4.67	<0.001
Subject variance		14.90	3.86	–	–

Table 6 Estimates and standard errors for the model including the »static« time elements

Variables		Coefficient	Standard error	t	P-val
Model »hook« (2a)					
Constant	β_0	150.77	21.73	6.93	<0.001
Slope	β_1	–0.19	0.35	–0.53	0.59
Time×uphill	β_2	–0.19	0.04	–3.94	<0.001
Time×downhill	β_3	0.03	0.03	0.97	0.33
Subject variance		13.16	3.62	–	–
Model »unhook« (2b)					
Constant	β_0	73.13	15.58	4.69	<0.001
Slope	β_1	0.87	0.25	3.49	<0.001
Time×uphill	β_2	0.37	0.07	4.76	<0.001
Time×downhill	β_3	–0.06	0.09	–0.69	0.49
Subject variance		23.78	4.86	–	–

The parameters of the mixed effect models for the heart rate in the »pull out« element and the »walk in« element (Model 1) are reported in Table 5.

As expected, the slope is positive in both models; in the first model (1a) the interaction between speed and direction is negative with the uphill extraction (i.e. pulling the cable downhill), while it is positive correlated to the heart rate when the extraction is downhill (i.e. pulling the cable uphill); the opposite occurs in the model 1b, where the subjects are walking without any loads.

Model 1b shows a higher variance in the subjects, meaning that when the subject is not undergoing very heavy workload i.e. pulling the cable uphill, the anthropometric parameters are different in terms of the heart rate.

The parameters of the mixed effect models for the heart rate in the elements of »hooking« and »unhooking« (Model 2) are reported in Table 6.

In the model 2a, the intercept is quite high and this is in line with the fact that when the subjects perform the hooking task they are under a severe strain in the pull out phase. The time to perform the hooking is not sufficient for recovering (avg=86 sec). The predicted heart rate is lower when the subjects move downhill. The model 2b shows that the *HR* prediction is lower and this follows the rules of the physiology of recovery. During the walk-in phase, the effort for moving uphill corresponds to the strain to move the body mass uphill when performing uphill extraction, while in downhill extraction, walking is down-hill. In this way the body has the time to recover and to take the *HR* back closer to normal activity values.

The specific intercept of the *HR* for each time element and each subject has been extracted from the fitted model and plotted against the anthropometric parameters, age, *BMI* and VO_2max (Fig. 3).

The visual inspection of the plots shows a potential relationship between the *HR* for each time element and both the degree of fitness (VO_2max) and the age, while there was no evidence for the effect of *BMI*. The subject with a higher VO_2max i.e. with the best fitness status is the one showing a lower intercept of the model. The same subject is also the youngest giving a lower intercept also in the plots checking the age influence. Also, in this case there is a potential trend in the phases requiring a higher physical effort i.e. pull out and walk in while the trend is not evident in the other time elements.

4. Discussion and Conclusions

This study demonstrated that, when implemented on steep terrain, winching is a very heavy task, which becomes increasingly harder as the slope increases.

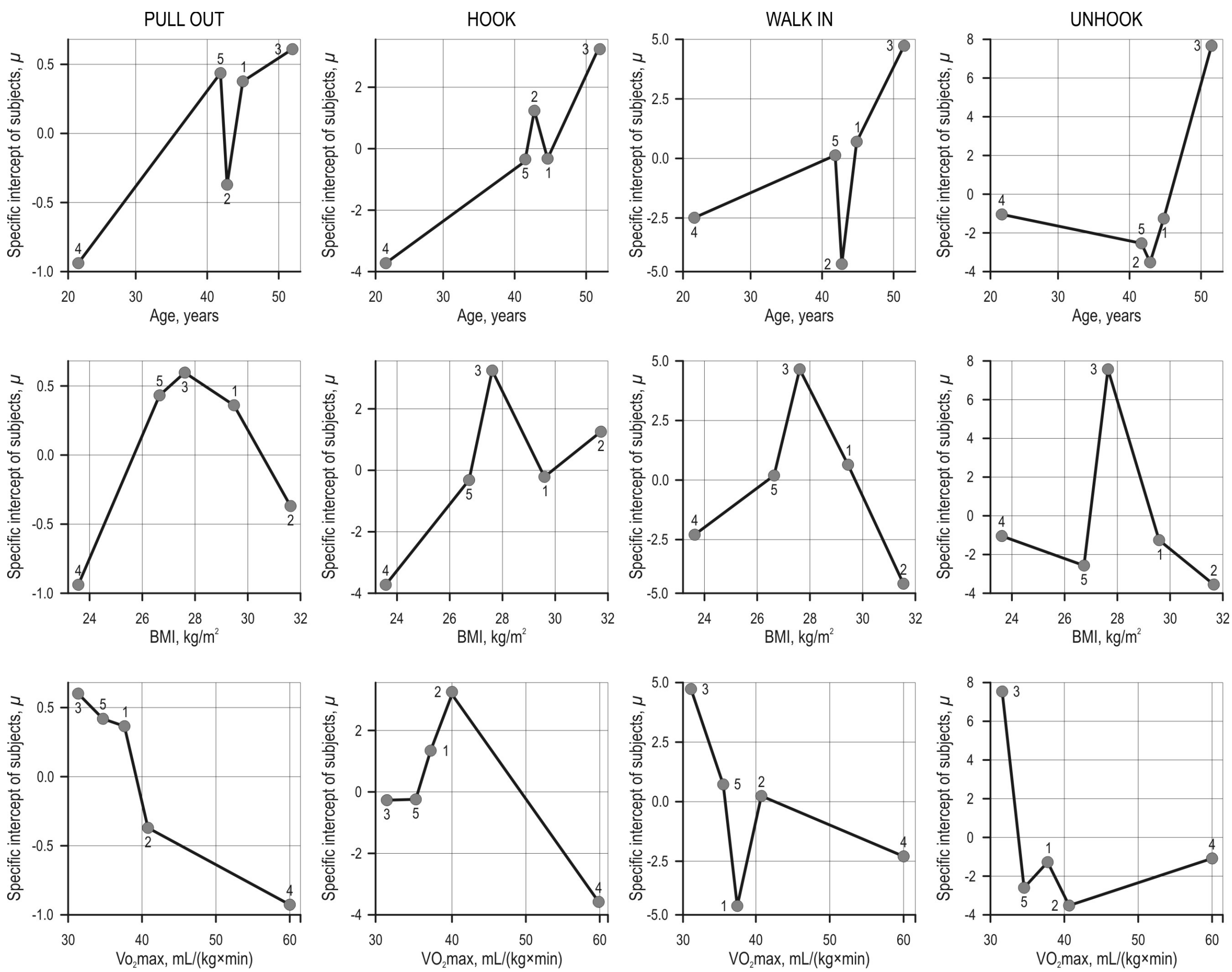

Fig. 3 Plotting the specific intercept for each subject (μ) against the subjects' physical parameters

Task demand can be classified according to the severity of workload. Generally, as workload increases, heart rate increases (Miller 2001). The results of our research showed that winching tasks fall in the heavy, very-heavy ranges. Depending on winching direction, the highest effort would occur during cable pull out (if winching downhill), or during walk in (if winching uphill).

The effect of cable weight during the pull-out phase is visible in both cases, but it is obviously much stronger when winching downhill (i.e. pulling the cable uphill). Our results show that winching downhill is a much harder task than winching uphill, because the operators have to pull out the cable in an uphill direction in order to reach the logs. Furthermore, downhill winching is heavy on the cable itself, because the load can slide during the drag, causing cable tension to drop and favouring cable nesting into the drum. Therefore, winching operations should be planned in such a way to avoid downhill winching whenever possible for ergonomic and safety reasons.

This study indicates that the effect of slope dominates over the effect of cable weight when the average HR readings for pulling the cable uphill and moving uphill with no load are very close in range, 160.8 and 150.6, respectively. This was confirmed by previous work conducted by Ottaviani et al. (2011) for cable yarder operations, and by Magagnotti and Spinelli (2012) for winches equipped with synthetic cable. Even the effect of speed is mediated by slope, as shown by the fact that increasing pull-out time (i.e. lower speed) will decrease work load when pulling the cable uphill, whereas it will increase work load when pulling the cable downhill. That means that the operator can make gravity work to his own benefit, and use it for faster downhill movements, which will allow reducing the time under effort without increasing effort level. Of course, we are not suggesting that workers should rush their downhill walk, as that may involve an increased risk of tripping and may be hazardous. We are just observing a fact and using it to support our conclusion that the slope is the most important factor contributing to the workload experienced by steep terrain workers. Reducing tool weight is not enough, since the operator's own bodyweight is already difficult to move uphill, on a steep slope. Tool weight reduction may make possible an otherwise impossible task, but it will not turn a heavy job into a light one.

As the heart rate is an important indicator for stress levels, adoption of lighter cables can palliate the problem, but not solve it. Other measures aimed at relieving the operators workload could be found in the use of special harness for increasing walking efficiency and decreasing walking effort (i.e exo-skeleton) or dedicated cable recovery devices for pulling out the cable all the way to the hooking site, without an operator walking back and forth all the time. This latter solution is offered by mini-yarders (Spinelli et al. 2010), tong-throwers (Bruce 2009) or the newer cable recovery equipment recently developed in Central Italy.

Considering the results of the relationship between the anthropometric parameters and the heart rate predictions for each subject, the study did disclose a significant effect, but it could not solve all the doubts caused by conflicting evidence in the available literature. It was found that the workload was inversely proportional to fitness and directly proportional to age. That could be expected, but had not yet been specifically demonstrated for the case of log winching. Winching is less taxing for younger, fit workers than for older workers, especially if their fitness level (as expressed by the Polar OwnIndex®) is low.

A typical winching cycle is constituted by relatively short phases (i.e. time elements): this pattern has great influence on the physiology of recovery which should take place during the less effort-intensive phases. As recovery time is directly proportional to age (Darr et al. 1988), employing crews with older members might impose the need for frequent rest, which will affect productivity.

Since winching is a strenuous and intense job, any winching operation would be more efficient and safer if implemented by crews composed mainly by fit young workers, while assigning older or less fit workers to other tasks requiring a lighter workload. In fact, this is common practice in commercial operations, where choker tenders are generally selected among the youngest and fittest subjects. In general, operator selection and careful work planning (i.e. job rotation, crew composition) can palliate the strain placed on the workforce by winching. Further progress in that direction requires adopting radical innovation, going beyond the simple reduction of cable weight and drum friction. Additional research in this field would be necessary, since this study was carried out on a limited number of subjects.

Acknowledgments

The authors wish to thank Mr. Sergio Poli and ERSAF Lombardia for making available the locations and the team to perform the study, Maxwald for lending the equipment, and the team members for their patience.

5. References

Afolabi, B.O., Akanbi, O.G., 2013: Effects of body mass index on aerobic power (VO_2max) and energy expenditure (EE): A case of manual load lifting in agro-processing. IJSER 4(5): 1718–1721.

Apud, E., Bostrand, L., Mobbs, I.D., Strehlke, B., 1989: Guidelines on ergonomic study in forestry. ILO, Geneva.

Astrand, P.O., Rodahl, K., Dahl, H., Strømme, S.B., 2003: Textbook of work physiology: physiological bases of exercise. New York, McGraw-Hill, 656 p.

Bates, D., 2005: Fitting linear mixed models in R. R news 5(1): 27–30.

Darr, K.C., Bassett, D.R., Morgan, B.J., Thomas, D.P., 1988: Effects of age and training status on heart rate recovery after peak exercise. Am J Physiol Heart Circ Physiol 254(2): H340–H343.

de Zwart, B.C., Frings-Dresen, M.H., van Dijk, F.J., 1996: Physical workload and the ageing worker: a review of the literature. Int Arch Occup Environ Health 68(1): 1–12.

Hagen, K., Vik, T., Myhr, N., Opsahl, P., Harms-Ringdahl, K., 1993: Physical workload, perceived exertion, and output of cut wood as related to age in motor-manual cutting. Ergonomics 36(5): 479–488.

Hart, S.G., 1986: Theory and measurement of human workload. Praeger, New York. Human Productivity Enhancement Vol 1: Training and Human Factors in Systems Design: 396–456.

Heuch, I., Hagen, K., Heuch, I., Nygaard, Ø., Zwart J.A., 2010: The impact of body mass index on the prevalence of low back pain: the HUNT study. Spine 35(7): 764–768.

Keyserling, W.M., Punnett, L., Fine, L.J., 1988: Trunk posture and back pain: identification and control of occupational risk factors. Applied Industrial Hygiene 3(3): 87–92.

Krause, N., Ragland, D.R., Greiner, B.A., Fisher, J.M., Holman, B.L., Selvin, S., 1997: Physical workload and ergonomic factors associated with prevalence of back and neck pain in urban transit operators. Spine 22(18): 2117–2126.

Lilley, R., Feyer, A.M., Kirk, P., Gander, P., 2002: A survey of forest workers in New Zealand: Do hours of work, rest, and recovery play a role in accidents and injury? J Safety Res 33(1): 53–71.

Magagnotti, N., Spinelli, R., 2012: Replacing Steel Cable with Synthetic Rope to Reduce Operator Workload During Log Winching Operations. Small-scale Forestry 11(2): 223–236.

Miller, S., 2001: Workload Measures Document id: N01-006, National Advanced driving Simulator, The University of IOWA, 65 p.

Ottaviani, G., Talbot, B., Nitteberg, M., Stampfer, K., 2011: Workload benefits of using a synthetic rope strawline in cable yarder rigging in Norway. Croatian Journal of Forest Engineering 32(2): 561–569.

Ovaskainen, H., Uusitalo, J., Väätäinen, K., 2004: Characteristics and significance of a harvester operators' working technique in thinnings. IJFE 15(2): 67–77.

Park, H., Lee, J., Choi, Y., Kim, M., 2003: Evaluation of work intensity by moving work in forest. J Korean For Soc, 92, http://agris.fao.org/agris-search/search.do?recordID= KR2004005048.

Parker, R., Kirk, P., 1994: Physiological workload of forest work. LIRO Report (New Zealand Logging Industry Research Organisation) 19(4): 1–49.

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., Team, R.C., 2012: Linear and nonlinear mixed effects models *R* package version 3.1–104.

Polar, 2015: Retrieved 06/03/2015, from http://www.polar.com/en/ support/polar_fitness_test_and_ownindex

Rodahl, K., 2003: Physiology of Work. Taylor and Francis, Inc., Bristol, PA, USA, 266 p.

Rodgers, S., 1997: Work physiology–fatigue and recovery. Handbook of human factors and ergonomics. 2nd ed. John Wiley and Sons, New York, 268–298.

Spinelli, R., Magagnotti, N., 2012: Wood extraction with farm tractor and sulky: estimating productivity, cost and energy consumption. Small-scale Forestry 11(1): 73–85.

Staal Wästerlund, D., 2001: Heat stress in forestry work. Acta Universitatis Agriculturae Sueciae, Silvestria 213: 1401–6230.

Stampfer, K., 1998: Stress and strain effects of forest work in steep terrain. Proceedings of the IUFRO/FAO Seminar on Forest Operations in Himalayan Forests with Special Consideration of Ergonomic and Socio-Economic Problems in Thimphu/Bhutan. (Heinimann, H.R. and Sessions, J. editors). http://www.upress.de/abstracts/3-933146-12-7.html. Kassel University Press, Kassel: 113–119.

Team, R.D.C., 2008: R: A Language and Environment for Statistical Computing. Austria, Vienna, ISBN 3-900051-07-0. Available at http://www. R-project. org, 2008.

Trites, D.G., 1992: Ergonomics of tree planting work among British Columbia forest workers. Theses (School of Kinesiology)/Simon Fraser University, 96 p.

Vik, T., 1984: Impact of terrain on human effort in forest operations. Paper presented at the Human Resources in Logging. Proceedings of a seminar, Rotorua, New Zealand, 150–155.

Received: January 1, 2015
Accepted: June 16, 2015

Authors' address:

Giovanna Ottaviani Aalmo, PhD.*
e-mail: giovanna.ottaviani.aalmo@nibio.no
Norwegian Institute of Bioeconomy Research
Pb 115, NO-1431 Ås
NORWAY

Natascia Magagnotti, PhD.
e-mail: magagnotti@ivalsa.cnr.it
Raffaele Spinelli, PhD.
e-mail: spinelli@ivalsa.cnr.it
CNR Timber and Tree Institute
Via Madonna del Piano, Pal. F
50019 Sesto Fiorentino, Firenze
ITALY

* Corresponding author