Assessment of Physical Workload of Choker Setter in Tree-length Extraction Operation by Cable Yarder

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Cable yarding operations on steep terrain have always been a challenge with respect to safety as they are mostly undertaken by manual laborers, particularly in South Korea. Steep slopes are associated with a high workload for choker setters. Therefore, the main goals of this study were to determine the heart rate and oxygen consumption of choker setters and evaluate their workload during clear-cut operations on a *Larix kaempferi* stand using a Polar M400, H7 heart rate sensor. Three choker setters were continuously evaluated during one working day. Overall, the mean working heart rate (HR_w) during choking operations ranged from 87 to 104 bpm at a maximum oxygen consumption rate of 0.9 to 1.4 L/min. The choker setters recorded most of the effective work time on the "wait" (68.5%) and "walk-in" (7.8%) work elements. In addition, the physiological workload differed among the various elements of the cable yarding operation, with a higher HR_w associated with a higher workload. Our findings may provide useful information for managing the health and safety of forestry crews during cable extraction activities.

1. Introduction

Various forest operations have relatively high safety risks as they are completed outside in all weathers, and operators are required to cover long distances during a workday in isolated locations.[1,2] Although there are differences in mechanized forestry and timber-harvesting equipment, all of these tools require human intervention; such human intervention has economic, social, and environmental advantages.[3] In addition, intermediate logging technology, which is defined as motor-manual felling and processing exclusively teamed with extraction machines (e.g., skidders and cable yarders), is widely used to reduce operating expenses, particularly in Europe and South Korea.[4–6] Thus, motor-manual harvesting has been associated with a high risk of occupational health and safety problems.

The incidence of fatal accidents is considerably higher in forestry than in other industries, such as agriculture, fishing, and construction. For example, Garland[7] reported that the rate of

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fatal injuries (FIR) among logging workers [136 fatalities per 100000 full-time equivalent workers (FTEs)] in the United States during 2016 was 34 times higher than the all-worker FIR (4 fatalities per 100000 FTEs). Moreover, fatal accident rates in the forestry sector were seven times higher than the annual average FIR in New Zealand during the period 2006 to 2012. In Korean forestry, the FIR during 2020 (1016 fatalities per 100000 FTEs) was 1.3 times greater than the annual average FIR (810 fatalities per 100000 FTEs).[8] Fatal accidents are related to intensive work associated with task demands, piecework, face-moving, and inadequate training.[3,9] Furthermore, fellers and choker setters perform more strenuous work than chasers and machine operators.[7,10] Hence, it is necessary to investigate physical and mental fatigue to determine the energy expenditure and provide a suitable work–rest regimen in this industry.

Heart rate (HR) and oxygen consumption increment have been widely used to evaluate physiological workload.[3,11] Heart rate monitoring (HRM) methods have been broadly applied to understand physical and mental workload changes in real time,[12–14] as well as to determine the heart strain, as an accessible predictor of cardiovascular activities to monitor forest worker health and safety.[11] Although real-time signal monitoring can detect changes immediately, it also has challenges, including the natural variation in signal and the change in point detection (CPD).[13] However, it may be justifiable to assume HR variability since CPD is widely used in the investigation of biomedical problems.[13] Additionally, several previous studies have assessed workload using the maximum oxygen consumption capacity (VO_{2max}), but this is difficult to record under field conditions.[3,5] An alternative method is to perform a maximal incremental running test on a treadmill.[15] Indeed, previous studies, which are mainly case reports on forest operations, provided a physical workload evaluation of forest crews by HRM.

Most Korean forests are located in steep mountainous areas (approximately 54%) with complex terrains.[16] In Korea, a common method for the mechanical extraction of trees is to use a cable yarder, which is ideally suited for steep-slope harvesting.[17] In cable yarding, trees are cut using chainsaws, and rigging choker setters set up cables around them by hand, which are used for extraction uphill to a landing field.[6] The choker setter operation is associated with potentially fatal accident risks, such as pinch-point and rollover injuries, because a yarder and a worker work simultaneously on a steep terrain.[18] Therefore, this technology has not been adopted in places where choker setters are exposed to these occupational hazards, particularly in the United States.[19]

Several previous studies have determined the performance of cable yarders to expand and improve the efficiency of wood production and supply chains in South Korea.[6,20,21] However, to our knowledge, none of the previous studies explicitly determined the physical workload of choker setters. Therefore, in this study we aimed to (1) determine HR and VO_{2max} variability for choker setters and the specific work process that incurs the highest workload, and (2) evaluate the total physical workload during cable yarding operations using a HAM300 tower yarder during the tree-length harvesting method.

2.   Materials and Methods

2.1   Overview of the study area

The target site of the study was at 11 Ungyo-ri, Bangrim-myeon, Pyeongchang-gun, Gangwon-do (37°26′21″ N and 128°15′44″ E), which is forest of age class VI (51–60 years) and has been the site of clear-cut operations over an area of 2.1 ha, producing an average tree volume of 0.92 m^3/tree in a *Larix kaempferi* stand (Table 1, Fig. 1). In addition, a 100 hp tractor-attached HAM300 tower yarder was used to implement cable yarding operations. The average lateral distance of the uphill cable yarding operation was 11 m, the average yarding distance was 91 m, and the average slope was 40%.

Table 1
Description of the study area.

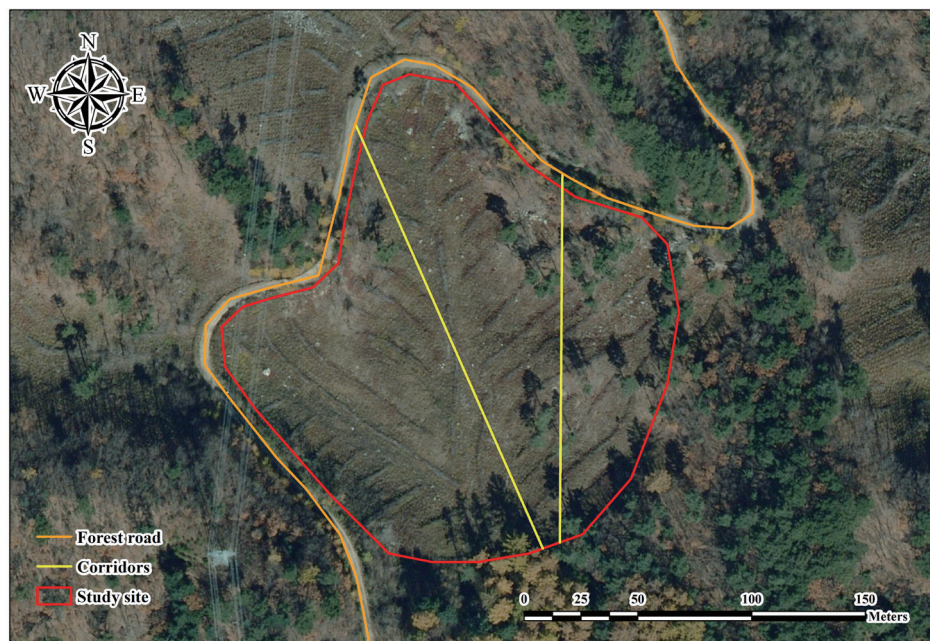| Item	Contents
Area (ha)	2.1
Type	Coniferous forest
Species	*Larix kaempferi*
Age class	VI
Average slope (%)	40
Average height (m)	23 (range: 16–29)
Average diameter at breast height (cm)	34 (range: 14–60)

Fig. 1.   (Color online) Study site.

2.2 Anthropometry and body composition of choker setters

Cable yarding operations were performed by groups of four workers (one operator and three choker setters), and the workload was measured among the three choker setters in the stump area. Experiments were conducted after explaining the purpose and methods of this study to the choker setters. The age and experience of each choker setter were examined, and the height, weight, and body mass index (BMI) were measured using the Lookin' Body Health Care System. BMI was classified into four categories based on the World Health Organization's classification:[22] underweight (<18.5), normal weight (18.5–24.9), overweight (25–29.9), and obese (≥30).[3,23]

2.3 Maximum oxygen consumption

First, an indoor exercise load test was conducted at Baengnyeong Sports Center at Kangwon National University to estimate the VO_{2max} of the choker setters. For the test, an M400 H7 cardiometer (Polar Global, Kempele, Finland), a treadmill (MTM-1500; Schiller, Baar, Switzerland) to change the exercise intensity, and a gas analyzer (Quark Cardio Pulmonary Exercise Test; Cosmed, Rome, Italy) were used to measure the O_2 and CO_2 concentrations (Fig. 2).

The exercise load was measured while applying the Bruce protocol, which was developed to induce workers to be active; in this protocol, the speed is increased by 1.28 km/h and the incline is increased by 2% every 3 min (Fig. 3).[24] We developed a model that predicts VO_{2max} according to the changes in HR with the measured data. The workload of the workers was also analyzed using VO_{2max}, increased heart rate (IHR), and relative heart rate (HRR).[21,25]

2.4 HR

The HR of the choker setters was measured during operations in the field using a Polar M400, H7 HR sensor, consisting of a belt-type sensor that is attached to the chest and measures the cardiac rate at 1 s intervals, and a wristwatch-type device that wirelessly transmits and receives the data (Fig. 4).
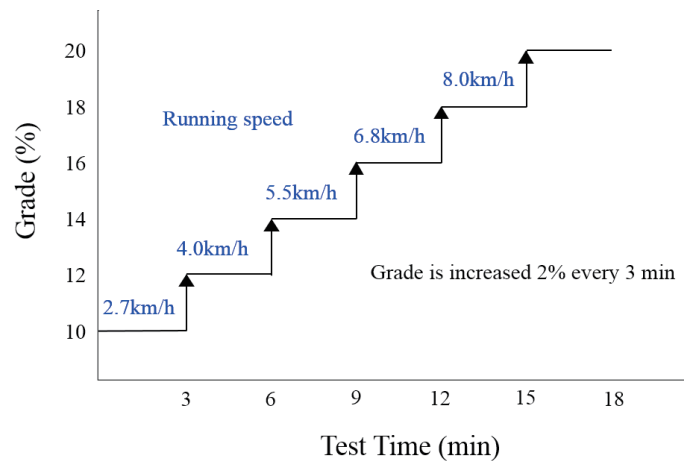

Fig. 2.   (Color online) Indoor exercise load test.

Fig. 3.   (Color online) Bruce protocol according to Myers and Froelicher.[24]

Fig. 4.   (Color online) Polar M400, H7 device used for HR measurements.

The resting heart rate (HR_r, bpm), working heart rate (HR_w, bpm), and maximum heart rate (HR_{max}, bpm) were measured to analyze IHR (%) and HRR (%) as follows:[3,21]

$$IHR = \frac{HR_w - HR_r}{HR_r} \times 100, \tag{1}$$

$$HRR = \frac{HR_w - HR_r}{HR_{max} - HR_r} \times 100. \tag{2}$$

The HR_w measurement required the choker setters to sit and rest for 15 min before starting to work, during which time they were prohibited from talking, consuming food, and smoking.[5] HR_w is the average heart rate during working hours, including breaks. HR_{max} was estimated using the Rodahl formula ($HR_{max} = 220 - $ age),[25] in which heart rate increases linearly with the exercise load, then reaches its maximum limit at exhaustion.[5] IHR was used to assess the workload of each task when workers performed several tasks. However, a direct comparison among different workers was not possible. Instead, HRR was used to correct disparities among workers. Using the HR and HRR of each choker setter, the workload levels were evaluated using the categories in Table 2.[26,27]

Table 2
Classification of workload regarding maximum oxygen consumption (VO_{2max}), HR, and HRR.

Workload level	VO_{2max} (L/min)	HR (bpm)	HRR (%)
Light	<0.5	<90	<30
Moderate	0.5–1.0	91–110	31–40
Heavy	1.1–1.5	111–130	41–50
Very heavy	1.6–2.0	133–150	51–60
Extremely heavy	>2.1	>151	>61

2.5   Time study

A time study was conducted simultaneously with the HR measurements. The work process of each choker setter was videotaped to measure the workload of each element of the cable yarding operations. This information was synchronized with the data recorded by the HR sensor. The tasks were performed consecutively, and the work elements were separated as follows: (1) walk-in: moving from the safety area to a carriage arriving at the yarding location, (2) pulling: pulling the wire rope up, down, left, and right from the carriage to make it easier for other workers to drag; (3) dragging: dragging the wire rope to the yarding area; (4) hooking: wrapping the wire rope around the yarding area; (5) walk-out: moving to the safety area after installing the choker; (6) wait: waiting in the safety area for the carriage to return, and (7) rest: halting work and resting.

3.   Results and Discussion

3.1   Anthropometric and personal information

The physical characteristics of the three choker setters are presented in Table 3. Worker K had a BMI of 27.8 kg/m^2 and was classified as overweight, whereas workers J and U were classified within the normal weight category with BMIs of 21.3 and 21.6 kg/m^2, respectively. The workers had at most 4 years of work experience.

3.2   Time study and HR variability

The average yarding time of a single volume of cable yarding was 533 s/cycle, and the times required for each choker setter to perform the different tasks are listed in Table 4. For all workers, the greatest amount of time was spent on the "wait" element, i.e., waiting for the carriage to return from the safety area (67.4–69.7%). The analysis of the time taken on each primary task showed that worker K pulled the rope in 54 s (10.1%), worker J dragged the rope in 13 s (2.5%), and worker U hooked the choker installation in 38 s (7.2%) (Table 4). Moreover, worker J took a longer time pulling and hooking than dragging, while the time taken delivering wires was between those required for workers K and U.

HR_w, HR_r, and IHR data per work element for the three choker setters are also shown in Table 4. Workers K, U, and J had HR_w values of 90 ± 10.3 bpm, 94 ± 18.3 bpm, and 79 ± 14.5

Table 3
Characteristics of the choker setters.

Choker setter	Age (years)	Height (cm)	Weight (kg)	BMI[a] (kg/m^2)	Body fat (%)	Skill level	Job experience (year)
K	60	169	80	27.8	29	Medium	3
J	41	162	57	21.3	16	Medium	4
U	54	165	59	21.6	16	Medium	2

[a]Reference values of body mass index (BMI): underweight (<18.5), normal weight (18.5–24.9), overweight (25–29.9), and obese (≥30).

Table 4
Time consumption, frequency, HR$_W$, IHR, and HRR for each work element.

Choker setter		Walk-in	Pulling	Dragging	Hooking	Walk-out	Wait	Rest	Mean (±SD[e])
K[a]	Time[d] (s)	42	54	16	1	43	359	19	—
	Frequency (%)	7.8	10.1	2.9	0.2	8.0	67.4	3.5	—
	HR$_W$ (bpm)	91	104	102	103	100	87	82	90 (10.3)
	IHR (%)	30	49	46	47	42	24	17	29 (14.7)
	HRR (%)	23	37	35	36	33	19	13	22 (11.3)
J[b]	Time[d] (s)	51	23	13	4	37	365	40	—
	Frequency (%)	9.6	4.3	2.5	0.7	7.0	68.4	7.5	—
	HR$_W$ (bpm)	93	107	101	102	107	89	76	94 (18.3)
	IHR (%)	56	79	68	70	79	47	27	57 (30.5)
	HRR (%)	28	40	34	35	40	24	13	29 (15.4)
U[c]	Time[d] (s)	32	3	17	38	43	372	28	—
	Frequency (%)	5.9	0.6	3.2	7.2	8.1	69.7	5.3	—
	HR$_W$ (bpm)	87	95	83	87	94	76	64	79 (14.5)
	IHR (%)	49	63	42	49	62	31	10	35 (25.0)
	HRR (%)	26	33	22	26	33	16	5	19 (13.2)

Resting heart rate (bpm): [a]70, [b]60, [c]58
Total time: [d]533 s
[e]Standard deviation

bpm (mean ± standard deviation), respectively. Kim *et al.*[28] and Kirk and Sullman[29] found that HR$_w$ ranged between 88 ± 4.7 bpm and 106 ± 6.9 bpm in choker-setting operations and confirmed the primary effect of BMI on HR$_w$. Similar results were found in our study except for worker J.

Worker K had the highest HR$_w$ at 104 bpm while pulling, followed by hooking (103 bpm), dragging (102 bpm), walk-out (100 bpm), walk-in (91 bpm), wait (87 bpm), and rest (87 bpm) (Table 4). The HR$_w$ of worker J was higher during pulling (107 bpm) and hooking (102 bpm) than during dragging (101 bpm). Worker U had the highest HR$_w$ at 95 bpm while pulling and the lowest at 76 bpm while waiting, excluding rest. The HR$_r$ values of workers K, J, and U were 70, 60, and 58 bpm, respectively. Moreover, the calculated IHR based on HR$_w$ and HR$_r$ was found to be 57 ± 30.5% for worker J, which was higher than those for workers K (29 ± 14.7%) and U (35 ± 25.0%) (Table 4).

HRR for each work element was found to be 22 ± 11.3% for worker K, 29 ± 15.4% for worker J, and 19 ± 13.2% for worker U (Table 4). These results were consistent with previous studies by

Kim *et al.*[28] and Kirk and Sullman,[29] who reported HRRs ranging from 26.6 ± 3.7% to 36.4 ± 3.1%, respectively. In addition, the HRRs obtained for pulling (33–40%), dragging (22–35%), and hooking (26–36%), which required transport, were higher than those obtained for all the other tasks (5–28%), which did not require transport, except for the task of walk-out, which involved supporting the weight of the wire rope and choker (Table 4). These results are similar to those reported by Spinelli *et al.*,[5] who evaluated HRR on the basis of whether the equipment was used in choker-setting operations. HRR for equipment-driven choker-setting operations was found to be 35–54%, which was higher than the value of 32–44% observed when no equipment was used.[5] HRR for walk-out was also found to be high at 33–40%. These results demonstrate that the preceding workload (pulling, dragging, and hooking) affected the following work element (walk-out).

3.3 Prediction of maximum oxygen consumption rate

A regression equation was derived for each of the three workers to predict VO_{2max} using HR from the indoor exercise load test (Table 5). HR and VO_{2max} showed a statistically significant correlation, and VO_{2max} for each work element at the site is shown in Table 6. VO_{2max} was determined to be 1.09 ± 0.28 L/min for worker K, 0.79 ± 0.27 L/min for worker J, and 1.14 ± 0.15 L/min for worker U (Table 6).

3.4 Assessment of physical workload

The level of workload during each task, determined on the basis of HR, HRR, and VO_{2max}, for each choker setter is shown in Table 7. Rope pulling by worker K was assessed as having a moderate workload on the basis of HR (104 bpm) and HRR (37.5%) but as having a heavy workload on the basis of VO_{2max} (1.4 L/min). Rope dragging by worker J was assessed as having a moderate workload on the basis of HR (101 bpm), HRR (34.2%), and VO_{2max} (0.9 L/min).

Table 5
Relationship between heart rate and maximum oxygen consumption (VO_{2max}) during the work load test.

Choker setter	Regression equation for estimating VO_{2max}[a]	R^2	*p*-value
K	$y = 0.032x - 1.929$	0.89	<0.0001
J	$y = 0.024x - 1.508$	0.92	<0.0001
U	$y = 0.014x + 0.049$	0.84	<0.0001

[a]y, VO_{2max} (L/min); x, heart rate (bpm)

Table 6
Maximum oxygen consumption for each work element (L/min).

Choker setter	Walk-in	Pulling	Dragging	Hooking	Walk-out	Wait	Rest	Mean (±SD[a])
K	0.96	1.37	1.31	1.32	1.23	0.82	0.65	1.09 (0.28)
J	0.72	1.04	0.89	0.92	1.05	0.59	0.30	0.79 (0.27)
U	1.18	1.30	1.13	1.18	1.29	1.03	0.86	1.14 (0.15)

[a]Standard deviation

Table 7
Workload level evaluated using heart rate (HR), relative heart rate (HRR), and maximum oxygen consumption (VO_{2max}) for each task.

Worker		Task	HR (bpm)	HRR (%)	VO_{2max} (L/min)	Final workload level
In this study	K	Pulling	104	37.5	1.4	M
		Workload level[a]	M	M	H	
	J	Dragging	101	34.2	0.9	M
		Workload level[a]	M	M	M	
	U	Hooking	87	25.9	1.3	L
		Workload level[a]	L	L	H	
Kim *et al.*[28]		Choker setters	105	32.2	—	M
		Workload level[a]	M	M	—	
Kirk and Sullman[29]		Choker setters	106	36.4	—	M
		Workload level[a]	M	M	—	
Spinelli *et al.*[5]		Choker setters	115	43.3	—	H
		Workload level[a]	H	H	—	

[a]Light (L), Moderate (M), Heavy (H)

Hooking by worker U was assessed as having a light workload on the basis of HR (87 bpm) and HRR (25.9%) but as having a heavy workload on the basis of VO_{2max} (1.3 L/min) (Table 7). According to Policarpo *et al.*,[30] HRR and VO_{2max} are factors that determine the level of workload. However, as the HR ratio increased (50–80%), VO_{2max} tended to overestimate the workload level. Therefore, it is recommended that workload levels are evaluated using HRR rather than VO_{2max}. In the present study, the pulling and dragging operations by workers K and J were assessed as having a moderate workload, and the hooking operation by worker U was assessed as having a light workload. Previous studies such as those of Kim *et al.*,[28] Kirk and Sullman,[29] and Spinelli *et al.*[5] showed that the workload for choker setters ranged from moderate to heavy, and the results of this study showed a similar tendency.

4. Conclusions

In this study, three cable-yarding choker setters of a tree-length harvesting system using a HAM300 tower yarder were evaluated to assess the workload levels on the basis of HR, HRR, and VO_{2max}. During choking operations, the greatest amount of time was spent on the "wait" work element. For all workers, IHR was the highest in the "pulling" work element. The choking operations were determined to have a moderate workload on the basis of HR and HRR and to have a heavy workload on the basis of VO_{2max}. However, these results are limited to applications related to managing the health and safety of forestry crews during cable extraction activities. Further study is required to consider the fitness of workers to reduce the workload. In addition, the use of equipment for cable yarding operations, such as slack pullers, synthetic wires, and walking aids, can also help reduce the workload of workers, which is ultimately expected to improve overall productivity.

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