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Measuring Coupling Forces Woodcutters Exert on Saws in Real Working Conditions

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Prolonged exposure to hand–arm vibration (HAV) generated by chainsaws can cause HAV syndrome, i.e., disorders in the upper extremities of forestry workers. Progress of HAV syndrome depends on the intensity of mechanical vibration transmitted throughout the body, which is directly proportional to coupling forces applied by the woodcutter to a vibrating tool. This study aimed to establish a method of measuring coupling forces exerted by chainsaw workers in real working conditions. Coupling forces exerted by workers with their right and left hands were measured with a hydro-electronic force meter. Wood hardness, the type of chainsaw and the kind of forest operation, i.e., felling, cross-cutting or limbing, were considered.

coupling forces hydro-electronic force meter chainsaw vibration exposure

1. INTRODUCTION

In many countries forestry is defined as hard work with a high risk of work-related fatalities and serious injuries [1]. Work load often exceeds ergonomically accepted limits.

Prolonged exposure to hand–arm vibration (HAV) generated by chainsaws used in forestry is associated with a wide range of disorders in the upper extremities, called the HAV syndrome (HAVS). The progress of HAVS depends on the intensity of vibration transmitted to the hands from a chainsaw, which is directly proportional to coupling forces exerted by the woodcutter on a hand-held tool. Many studies proved the effect of coupling forces on the transmissibility of vibration to the hand [2, 3]. Nevertheless, coupling forces are still not considered in the risk assessment of forestry workers exposed to HAV because the methodology for measurements of those forces has not been evaluated yet. Occupational exposure limits for vibration are still based only on the frequency-weighted acceleration measured on the surface of the chainsaw. Hence, there is often no correspondence between vibration exposure and health effects in exposed woodcutters [4].

Standard No. ISO 5349-1:2001 requires simultaneous measurement of vibration on a hand–tool surface and coupling forces applied on a vibrating tool [5]. According to the standard, coupling forces at the human–machine interface should be measured and estimated, although there are no standard methods. All factors which can increase the magnitude of vibration and influence health effects caused by exposure to vibration should be measured. All test results can help in the future to find a proper relationship between health effects, coupling forces and exposure to vibration.

Standard No. ISO 15230:2007 recommends simultaneous measurement of coupling forces and vibration at the surface of the hand-held tool or separate measurements in the same initial conditions [6]. Simultaneous measurement of coupling forces and vibration is necessary because different

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coupling forces applied by operators on hand-held vibrating tools influence differently the stage of transmission of vibration in the upper limbs [7]. Coupling forces modify exposure to vibration and the health effects it causes [8]. Moreover, the synergic impact of force and vibration on the cardiovascular system, nervous system and the joints and muscles should be considered [9].

It is necessary to measure simultaneously vibration on the chainsaw and coupling forces exerted by woodcutters, but there is no standard method of measuring coupling forces yet. The aim of this study was to establish a method for measuring coupling forces exerted by chainsaw workers in real working conditions.

TABLE 1. Mass, Body Mass Index (BMI) and Some Anthropometric Descriptors of Woodcutters (*n* = 32)

Parameter	*M*	*SD*	Range
Mass (kg)	78.1	12.1	55–110
Height (m)	1.7	0.1	1.62–1.93
BMI (kg/m^2)	25.7	3.6	20.0–34.7
Right hand (cm)			
length[a]	19.5	0.8	17.5–21.7
width[b]	9.3	0.5	8.2–10.3
Left hand (cm)			
length[a]	19.3	0.9	17.1–21.4
width[b]	9.3	0.5	8.2–10.3

Notes. a—from tip of third finger to crease at wrist, b—at metacarpals.

2. MATERIALS AND METHODS

2.1. Subjects

The source population for this study was a cohort of 32 chainsaw operators. The mean age of the woodcutters was 43 years (range: 28–64) and they had a mean seniority of 13 years (range: 2–41). Table 1 lists the subjects' mass, body mass index and anthropometric descriptors.

2.2. Measuring Instrumentation

Coupling force was measured with a hydro-electronic force meter [10, 11]. It consisted of an ALP (active liquid pad), a type FD821412A pressure transducer (Ahlborn, Germany) and an Almemo type 2290-8 electronic manometer (Ahlborn, Germany) (Figure 1).

An ALP is a specially designed chamber filled with an incompressible medium. Force exerted by a chainsaw operator on an ALP deforms it and increases pressure in it. Pressure in ALP reflects

Figure 1. Hydro-electronic force meter. *Notes.* 1—active liquid pad, 2—pressure transducer, 3—electronic manometer.

force exerted by the forestry worker. The changes in pressure are later transformed into an electric signal, which is measured and registered with an electronic manometer. The hydro-electronic force meter was calibrated before and after every measurement with a specially designed calibration system [12, 13].

2.3. Measuring Method

Coupling forces were measured for each hand of a chainsaw operator while he was logging. Woodcutters had to apply sufficient coupling force to operate a given saw properly and safely. During logging the forest worker held the chainsaw firmly with his right hand on the rear handle and his left hand on the front handle whether he was right- or left-handed. He wrapped his fingers and thumbs around the handles. The left arm was straight and the elbow was stiff. Coupling forces were measured for each hand. The ALP of the hydro-electronic force meter was placed under the hand of the forestry worker (Figure 2).

Wood has got a typical unhomogeneous and fibrous structure, which varies according to the type of wood. Its mechanical and shear properties depend on the force applied and the cutting direction with reference to the direction of wood fibres [14]. That is why coupling forces were measured during felling, cross-cutting and limbing. The same amount of time was established for all cuts and types of wood. It was assumed that the measurement cycle for every hand should last 21 s because the shortest forest operation, cross-cutting, took on average 21 s. Standard No. ISO 15230:2007 suggests measuring forces at the workplace for at least 8 s [6].

Pressure exerted by forestry workers on the ALP was measured every second of the measurement cycle. Data for each cycle were stored in a manometer memory. Later they were transferred to the computer with the Almemo interface (Ahlborn, Germany). A string of alphanumeric characters was edited and data were analysed with a custom computer program.

The magnitude of coupling forces can depend on wood hardness, so various trees were considered. Soft, moderately hard and hard wood was measured. An aspen was the most common soft wood in the examined forest areas. Pines and spruces dominated in medium-hard-wood trees. Hard types of wood such as a birch, a beech and an oak were also measured.

Figure 2. Measurement of coupling forces applied by a forestry worker with his right hand. *Notes.* The active liquid pad is circled.

Forces woodcutters exerted on a chainsaw were measured 231 times, 118 times for the right hand and 113 for the left one. In five cases it was impossible to measure forces exerted by the operator with his left hand during felling because there was a risk of serious injuries the falling tree would cause.

2.4. Statistical Analysis

Data were analysed with Statistica version 7. They were summarized with the mean as a measure of central tendency and standard deviation or range as a measure of dispersion. The Shapiro–Wilk normality test was used to find the distribution of data. A single factor analysis of variance (ANOVA) was used to study the influence of wood hardness and type of cut on the magnitude of coupling forces. The significance level was set at $p = .05$.

3. RESULTS

The distribution of mean values of forces measured for the left and right hands deviated from normal distribution ($p < .001$, Shapiro–Wilk test) (Figures 3–4).

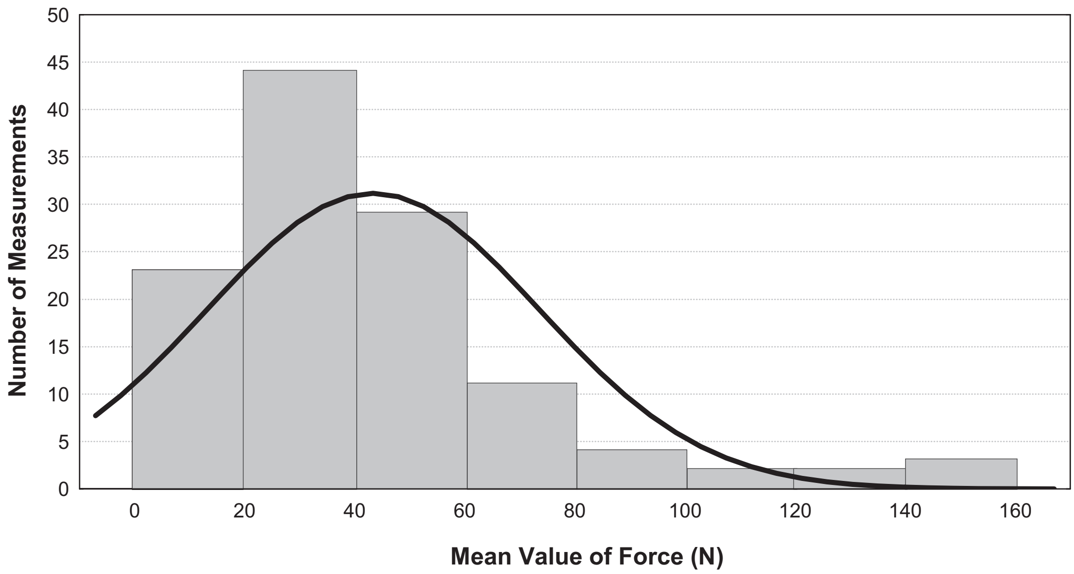

Figure 3. Histogram of mean values of force applied by woodcutters with their right hand.

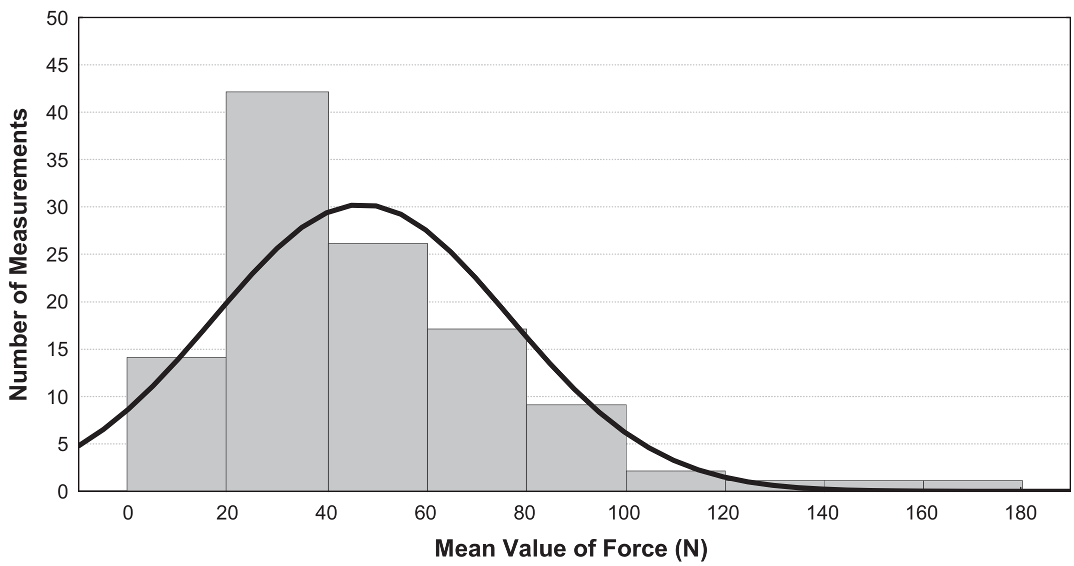

Figure 4. Histogram of mean values of force applied by woodcutters with their left hand.

TABLE 2. Force Exerted by Woodcutters With Their Right Hands ($n = 118$)

Statistic Parameter		Force (N) *M*	*Mdn*	Range	*SD*
Force measured over time (N)	*M*	43.4	36.8	5.9–153.7	30.2
	SD	13.6	11.5	3.3–47.3	8.0
	Range	51.1	44.5	11.8–230.5	32.4

TABLE 3. Force Exerted by Woodcutters With Their Left Hands ($n = 113$)

Statistic Parameter		Force (N) *M*	*Mdn*	Range	*SD*
Force measured over time (N)	*M*	47.2	42.9	4.1–179.4	29.8
	SD	15.7	11.8	1.9–82.2	12.3
	Range	57.7	44.5	6.2–299.6	43.3

Maximal temporary force exerted by woodcutters reached 270 N. The mean value was 43.4 N for the right and 47.2 for the left hand (Tables 2–3).

There was no statistical difference between mean values of coupling forces for right and left hands. An analysis of coupling forces during logging showed that forest operation and wood hardness had an impact on the range of applied forces. Forestry workers exerted the lowest force, 28 N, on saws during limbing. The mean value of force during felling and cross-cutting the wood was 50 N. The magnitude of force also depended on wood hardness. Soft wood, such as aspen, required lower force than moderately hard and hard wood.

4. DISCUSSION

This article presents a method of measuring coupling forces woodcutters exert. The importance of measuring coupling forces exerted on hand-held power tools is often stressed because they have an impact on the development of HAVS. Coupling forces are an important factors affecting the vibration operators perceive [7]. Unfortunately, there are no standard measurement methods for coupling forces. The method based on a hydro-electronic force meter is promising because it can be used in real working conditions. The force meter used in this study fulfilled the relevant criteria [15]. It was small enough to fit a wide array of tool handles and measure coupling forces for various techniques of gripping. It also withstood the rigors of field and laboratory use. The method based on the hydro-electronic force meter does not require additional equipment or software which could impact test results [16]. Moreover, coupling forces can be measured at the same time as vibration without modifying the tool handles.

Scalise, Concettoni, Deboli, et al. measured coupling forces in forestry with pressure sensors wrapped around the handle [17]. The duration of the measurement cycle was comparable with that established in this study and lasted 20 s. The measurements were made in a laboratory with 6 subjects, including 3 chainsaw operators. Scalise et al. measured forces simultaneously for the right and left hands but gave a mean value for both hands only. The mean push force was 31.5 N and the mean grip force exerted by chainsaw operators on chainsaw working at maximal speed but not cutting was 46.7 N. During cross-cutting, loggers used lower grip force, 23 N. Coupling force as a sum of gripping force and push or pull force was ~45 N. Although the type of wood was not discussed, the order of magnitude of the force corresponded to the results obtained in this study quite well.

In 2008, BGIA (Institute for Occupational Health and Safety of German Statutory Accident Insurance) also measured coupling forces exerted by woodcutters on chainsaws. A measurement system from Novel (Germany) was used to measure forces exerted by 6 subjects during a simulated felling operation. The duration of the measurement cycle, wood hardness and other measurement conditions are not known. The mean value of force was 75 N, much higher than in our study [18].

Coupling forces in the forestry workers presented in this study can be compared to forces exerted by rammer operators which were measured with the same method. The mean value of coupling forces measured at rammer workplaces was much higher than those exerted by woodcutters, 72 N [19].

5. CONCLUSIONS

The method of measuring coupling forces with a hydro-electronic force meter can be useful in forestry. It measures coupling forces during various logging operations in real working conditions. The results in this study can be a starting point for evaluating coupling forces and defining occupational exposure limits for vibration, which would also consider coupling forces exerted on vibrating tools.

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