



Coupling forces exerted on chain saws by inexperienced tree fellers



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ABSTRACT

Prolonged, intensive exposure to vibrations produced by vibrating tools could cause non-specific disorders in upper extremities of the operator, referred to as hand-arm vibration syndrome (HAVS). The severity of HAVS is affected by the magnitude of coupling forces exerted on the tool handle. The aim of the study was to measure the coupling forces exerted by inexperienced tree fellers on chain saws. Forces exerted by inexperienced tree fellers were compared to those of professional lumberjacks to investigate the relationship between the coupling forces and the experience of the chain saw operator. Coupling forces exerted on chain saws by inexperienced workers, using right and left hands, were measured in a group of 19 students. All measurements were done in forest environment. Coupling forces registered among trainees were about 5 N higher than forces exerted by professional lumberjacks. Our findings suggest that experienced workers use smaller forces than trainees.

Relevance to industry: This study shows that inexperienced tree fellers exert larger coupling forces on chain saws than professional forestry workers. Transmissibility of vibration to the hand and arm, which depends on coupling forces, is increased in a group of non-experienced lumberjacks. These results may constitute a starting point for the further development of more effective methods for assessing the risks of vibration exposure and for developing better tools and vibration-reducing devices.

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1. Introduction

Petrol chain saws, widely used in forestry, produce vibration. Prolonged, intensive exposure to vibration may lead to the development of vascular, sensorineural, and musculoskeletal disorders in the upper extremities of the tool operator, referred to as hand-arm vibration syndrome (HAVS) (Färkkilä et al., 1986). Currently, the vascular disorders caused by hand-transmitted vibration are called “vibration-induced white finger” (Griffin, 2008). The hand-arm vibration damage does not depend only on the magnitude and frequency of vibration, direction of propagation, and duration of exposure. Numerous studies have suggested that the magnitude of coupling forces exerted on the handle of vibrating tool affects the severity of HAVS and hand-wrist cumulative trauma disorders (Bovenzi et al., 2000; Radwin et al., 1987). The human body can be affected by different couplings of hand and vibrating tool in two different ways. Firstly, tight hand-tool coupling increases the transmissibility of vibration to the hand and arm (Aldien et al., 2006; McDowell et al., 2006). Secondly, coupling may produce a synergistic effect with vibration exposure, affecting the vascular

system, nerves, joints and tendons of the worker's body (Bovenzi et al., 2006; Hartung et al., 1993).

Coupling forces involved in the operation of a vibrating machine generally consist of two different components. The first component is the force applied by the hand-arm system, which is used to provide necessary control and guidance of the machine and to achieve the desired productivity. The second component is the biodynamic force resulting from the biodynamic response of the hand-arm system to the vibration (Dong et al., 2005; International Standard Organization, 2007). Biodynamic response is a function of frequency, and it varies with hand and arm posture, applied forces and tool operating orientations (Kihlberg, 1995; Xu et al., 2011). International standard ISO 15230:2007, concerning the measurement of forces exerted on vibrating tools by their operators, provides the simplified definition of coupling forces and describes it as the sum of the gripping force and the push or pull force (International Standard Organization, 2007).

The risk assessment of HAVS is currently based on International Standard ISO 5349-1, 2001. This standard suggests measuring the acceleration of mechanical vibrations emitted by a tool according to its frequency components and time of exposure; the contribution of the force exerted by the hand is ignored. Moreover, other factors that may modify the intensity of mechanical vibration transmitted through the body, i.e. position of the body, hand size, condition of

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the machines, are not described in risk and health assessment. Therefore, epidemiological studies have not shown a correspondence between the observed risk of HAVS and that predicted by the ISO-5349 model (Bovenzi, 1998; Griffin, 1997).

Vibration produced by vibrating tools and forces applied to the tools by their operators should be measured simultaneously. Contact forces are not considered in the risk assessment yet, because a reliable method for direct measurement of coupling forces has not been developed so far. Attempts have been made to obtain laboratory measurements using dynamometric, tensometric, and electromyographic methods (Carvalho and Radwin, 1996; Dong et al., 2005; Welcome et al., 2004; Valentino et al., 2004). Correction factor depending on coupling forces has been proposed as needed in evaluation of vibration exposure (Kaulbars, 1996). However, coupling factor does not provide adequate estimates of hand forces (Welcome et al., 2004).

An understanding of the nature of coupling forces and their measurement is essential for developing appropriate working procedures to minimize the risk of HAVS and hand-wrist cumulative trauma disorders. One possible method of measuring the forces exerted on vibrating tools, included in ISO 15230 standard annex, is based on hydro-electronic force meter (Harazin and Sztapa, 1999; International Standard Organization, 2007). Previous experimental studies by the current authors have explored the variables that influence the coupling force exerted by lumberjacks on a chain saw. Different chain saws, type of wood, and cutting technique influence the coupling forces (Malinowska-Borowska et al., 2011). The aim of this study was to measure forces exerted by inexperienced chain saw operators in field conditions, taking into consideration factors modifying the value of force exerted, namely the type of the tool as well as the type of the logging operation.

Current interdependencies between the value of forces exerted by inexperienced and experienced chain saw operators, subjectively felt and determined with the use of psychophysical methods, have not been quantitatively presented in literature. It is known from other studies that minimization of grip forces is recommended (Bovenzi et al., 2006); however, the forces exerted on chain saws by non-professional workers have not been measured in real work conditions. The relationship between coupling forces and experience of the worker may prove useful in the future in extending our knowledge on the assessment of vibration exposure among lumberjacks. Moreover, understanding how the form of the chain saw and changes in harvesting technique affect the magnitude of coupling forces exerted by inexperienced tree fellers should lead to improvements in ergonomic design of the tool and the workplace.

2. Material and methods

2.1. Methods, subjects and design

Measurements of coupling forces were performed with hydro-electronic force meter according to the previously described method (Malinowska-Borowska et al., 2012).

The source population for this study was a group of 18-year old men ($n = 19$; Table 1), students at a secondary school with agricultural profile enrolled in chain saw courses, with no practical experience in logging and no prior exposure to hand-transmitted vibration from chain saws. Their mean body height was 1.8 m ($SD = 0.1$) and mean weight was 73.8 kg ($SD = 10.6$). All subjects in this study were right-handed.

Measurements were performed on the last day of practical part of chain saw trainings in forest wards located in Silesia Voivodeship in Poland. Every trainee was supervised by an instructor during harvesting.

Table 1

Mass, Body Mass Index, and anthropometric descriptors of participants ($n = 19$).

Parameter	Mass (kg)	Height (m)	BMI (kg/m ²)	Right hand		Left hand	
				Length ^a (cm)	Width ^b (cm)	Length ^a (cm)	Width ^b (cm)
Mean Value	73.8	1.8	22.6	19.6	8.9	19.5	8.8
SD	10.6	0.1	3.2	0.8	0.5	0.9	0.4
Minimum	60.0	1.74	19.0	17.8	8.0	17.8	7.9
Maximum	95.0	1.93	30.7	20.7	9.7	21.0	9.4

Notes:

^a From tip of third finger to crease at wrist.

^b At metacarpals.

Coupling forces were measured during three different kinds of cuts, i.e. felling, cross-cutting and limbing. Felling is the action of cutting down a tree. Cutting the lying trunk into logs is called by forestry workers cross-cutting. Limbing is removing branches from the trunks with the use of a chain saw. During logging the cuts were sequential. The tree was firstly felled (felling), later the branches were cut off (limbing) and finally the tree was cut into logs (cross-cutting).

The duration of all cuts was set at 21 s. Measurements of coupling forces were carried out for left hand holding the front handle of the chain saw, as well as for the right hand placed on the rear handle. Temporary forces were measured every second and the mean value was calculated for every measurement cycle. Temporary forces were measured 798 times. Average forces exerted on the chain saw by the students were measured 38 times, 19 times for the right hand and 19 for the left hand.

2.2. Tool characteristics

All cuts were performed on pine trees (considered to possess moderate hardness) with the use of Husqvarna chain saws; most commonly model 365, although the trainees also used models 346 XP, 353, and 372.

All the chain saws used by students in this work were divided into 2 groups according to the size and power (Table 2). HM group comprised two small, versatile chain saws produced by Husqvarna (model 346 XP and 353) with 2.5 kW of power. Models 365 and 372 had power output larger than 3 kW and were categorized as large, high-power chain saws (HL). Routine maintenance of chain saws, such as cleaning and sharpening of cutting teeth, were performed the day before the measurements in the same authorized servicing dealer.

2.3. Statistical analysis

Data analysis was performed with the statistical software Statistica version 10 (StatSoft Poland, 2011). The data were

Table 2

Characteristics of tools used in the study (HM – Small Husqvarna chain saws, HL – Large Husqvarna chain saws).

Producer	Husqvarna			
	346 XP	353	365	372
Type	HM	HM	HL	HL
Cylinder displacement (cm ³)	45.0	51.7	65.1	70
Power output (kW)	2.5	2.4	3.4	3.9
Fuel tank volume (cm ³)	500	500	770	770
Oil tank volume (cm ³)	280	280	400	400
Weight (kg)	4.8	5.0	5.9	6.1
Weight to Power ratio (kg/kW)	1.9	2.1	1.7	1.6

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