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ORIGINAL RESEARCH

Knowledge Retention and Changes in Licensed Chainsaw Workers' risk awareness

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Abstract

Work with chainsaws is hazardous and felling trees is the activity with the highest risks for injuries and fatalities. While industrial forestry is increasingly mechanized, manual felling is still the main work method for private, small-scale forest owners. During this work, the workers' safety heavily depends on their skill and safe practice, so training is presumably important for preventing injuries and reducing fatalities. Unfortunately, private forest owners have been difficult to reach with this kind of safety intervention. Moreover, target chainsaw users are not likely to repeat the training very frequently. Hence, the training must both be effective and be so for many years to come. This paper addresses the knowledge retention and self-reported changes in behaviour of 682 chainsaw users who passed the exam for the Swedish chainsaw licence 1, 3, 5, 7 or 9 years previously. Acquisition of the licence resulted in a strong increase in 98% of the participants' risk awareness and safe work practices. Less than half (45%) of the participants passed a re-test equivalent to the theoretical examination for the chainsaw licence. Private forest owners performed somewhat better than employees did. The main indicator of retained knowledge of safe chainsaw handling was frequency of practice the previous year. After one year, the test results did not deteriorate with additional time. Based on those results, the best practice is to ensure regular usage of the chainsaw and refresher training when the chainsaw has not been used for a year.

Keywords Forestry · Occupational training · Safety intervention · Sweden · Tree felling

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Introduction

Felling and bucking timber with a chainsaw is high-risk, hazardous work. Both professional forest workers or farmers and self-employed small-scale private forest owners are exposed to high risk of injury when working with chainsaws (Albizu-Urionabarrenetxea et al. 2013). Chainsaws are commonly used in professional and nonprofessional logging around the world. Due to a high degree of mechanisation and absence of harvesting in steep terrain, the chainsaw is used increasingly rarely in industrial forestry in Sweden. Hence, frequencies of accidents in the Swedish forestry sector have declined (Axelsson 1998). However, about two-thirds of the 330 000 non-industrial private forest (NIPF) owners in Sweden undertake some forestry work on their estates and more than a third engage in cutting trees (Lindroos et al. 2005). The cutting is mainly directed towards thinning operations or removal of windthrow or single trees which on rare occasions could exceed 30 m of height and 45 cm in diameter at breast height. This work of NIPF owners on the family farm is generally referred to as 'self-employed' work (Lindroos et al. 2005). NIPF owners are small-scale forest owners who together own approximately half of the forestland in Sweden with an average estate of 34 ha of forest (Swedish Forest Agency 2021). Unlike industrial forestry workers, it is difficult to ensure self-employed forest workers are aware of and comply with preventive measures (i.e., safety interventions) and their tree felling work mainly involves the use of chainsaws (Lindroos and Burström 2010). Moreover, they are unlikely to change to mechanised operations anytime soon (Lindroos and Burström 2010), as illustrated by the number of chainsaws sold in Sweden in the last 35 years (Lindroos et al. 2005; Mawdsley & Helbig, 2021).

Injury prevention schemes involve the use of various types of barriers (physical, functional, symbolic or immaterial) between humans and potential dangers (Hollnagel 2004). Physical barriers, such as safety cabins on farm tractors and chainsaw protective legwear, prevent or mitigate effects of a specific danger through their presence. Functional barriers, such as an airbag in a car or the chain brake on a chainsaw, differ from physical barriers, as they need to be activated, either by the user or autonomously. Examples of symbolic barriers include warning labels and signs, while immaterial barriers include training in safe work methods (Hollnagel 2004). A broader distinction of injury prevention measures is between passive and active interventions, which do and do not require active collaboration of individuals, respectively, to be effective (Haddon 1980). Physical and most functional barriers are examples of passive interventions, while symbolic and immaterial barriers are examples of active interventions. Physical barriers and passive interventions are generally considered the most effective, and immaterial barriers and active interventions less effective (Haddon 1980; Hollnagel 2004).

Although still high, frequencies of accidents and chainsaw related injuries among professional chainsaw workers have declined in recent decades (Axelsson 1998; Sullman et al. 1999; Albizu-Urionabarrenetxea et al. 2013). This can be seen as a success of implemented intervention schemes creating physical, functional and immaterial barriers between the user and chainsaw, e.g., use of personal protection equipment (PPE) such as protective legwear and high visibility garments, safety-promoting changes in chainsaw design, safety regulations and training schemes (e.g. Sullman et

al. 1999; Lindroos and Burström 2010; Montorselli et al., 2010; Tsioras et al. 2014; Ferreira et al., 2022). In contrast, frequencies of injuries and death among European self-employed NIPF owners have remained relatively high (Axelsson 1998; Lindroos and Burström 2010, Robb & Cocking, 2014), which supports the view that they are hard to reach with those interventions.

Moreover, the danger of falling trees and branches is difficult to eliminate and continues to result in fatalities and severe injury. Safety helmets provide some protection from smaller objects, but little protection from falling trees, big branches or tree parts, and assuming that the use of chainsaws for felling cannot be eliminated, immaterial barriers need to be considered the most effective barriers. The safety of the feller, particularly in terms of avoiding injury by falling trees, tree parts or big branches, is highly dependent on the worker's skill, knowledge and safe practice. In up to half of all accidents in forestry, a lack of safe practice can be considered a major cause (e.g. Peters 1991; Thelin 2002; Melemez 2015). Moreover, in such cases where lack of skill and knowledge is a strong causal factor of accidents, training has been found to be an efficient intervention (Khanzode et al. 2012).

Previous studies of logger training have shown that it increases relevant knowledge (Helmkamp et al. 2004), but does not necessarily result in a reduction in frequencies of injuries (Bell and Grushecky 2006). It has also been shown that knowledge retention decreases over time (Saks and Belcourt 2006), indicating a need for continuous training and follow-up. This highlights the difficulties in the use of training in injury prevention. Another challenge in the safety of self-employed forestry is the observational apprenticeship, similar to that of farmworkers. Most farmers' socialization into farming does not start in formal education. Instead, they are socialized into farming from a young age by living on a farm and observing daily farm practices. To change behaviour to safer practice it is often necessary to disrupt this observational apprenticeship (Mazur and Westneat 2017). Similarly, many small-scale forest owners who work in their forests, have been socialized into forestry and chainsaw work from a young age by observing and working with the older generations from whom they later inherit their forest property.

To meet the need to ensure that chainsaw users work safely, a Swedish licence and chainsaw training program was developed. Since 2015, a licence has been a legal requirement for personnel (not only those formally employed) working with a chainsaw in a shared workplace, such as a harvesting site. Exceptions are self-employed forest owners and their family members working on their own estates (Användning av motorkedjesågar och röjsågar 2012). However, many self-employed forest owners are partaking in the licensing courses for other reasons such as an interest in the training or as demanded from their spouse.

In Sweden, there are four levels of licence for tree felling and five work specific licences covering competencies for using chainsaws close to powerlines, roadwork, industry, civil protection, and on a high platform. There is currently no expiration date on those licenses. Level A covers the basic competence needed to maintain and use a chainsaw safely. Level B (for which level A is a prerequisite) covers the competence needed to fell, de-limb and buck timber. Level S and the more thorough C-level both address advanced tree felling with damaged trees and in storm-felled forests. This study focuses specifically on effects of the standard exams for level A

and B licences. A level A and B chainsaw licence is normally required for working with a chainsaw in a Swedish harvesting operation and is typically acquired through a 3–4 day training course led by a certified instructor followed by written and practical examinations (both of which must be passed) for each level. Instead of attending a formal course, students can prepare for the examinations on their own, via a web course, or by joining a study circle. The latter is a group engaged in participatory learning without a formal tutor: a common form of learning for various courses and subjects in Sweden that is subsidised by the government. The study circle is hereinafter referred to as a self-study group.

Previous evaluations of the chainsaw licence have indicated that participants are happy with the courses and have higher perceived risk awareness after finishing (Bergkvist 2008; Lindroos 2009). However, the cited studies involved small, regional samples (31 and 145 participants, respectively). Hence, there is a need for a fuller investigation of the chainsaw licence-related knowledge possessed and retained by different groups of users. This study aimed to elucidate long-term effects of the standard exams and training associated with the acquisition of a Swedish chainsaw licence (level A and B) on users' declarative knowledge and risk awareness in chainsaw work.

Materials and methods

Population and sample

During the autumn of 2016, a stratified sample of candidates listed in the register of Swedish chainsaw licence holders was formed by randomly selecting sets of 600 persons awarded a level B licence in each of 2007, 2009, 2011, 2013 and 2015 (1, 3, 5, 7 and 9 years previously, respectively). Two of the candidates did not have a Swedish address, and 2998 invitations were sent out by post. Eight per cent of the sample was female and 92% male (Table 1). Approximately half (54%) paid their licence fee privately, indicating that they were self-employed (non-industrial) chainsaw users, as employers generally pay for their employees' professional education in Sweden.

Table 1 The average age of the candidates in the sample when they received their chainsaw licence

Licence	All			Males			Females		
(year)	Age	SE Mean	N	Age	SE	N	Age	SE	N
2007	37.6	0.57	600	37.9	0.6	539	35.3	1.6	61
2009	38.9	0.59	600	39.2	0.6	529	36.7	1.4	71
2011	38.1	0.60	600	38.3	0.6	528	36.3	1.5	72
2013	43.5	0.58	599	43.8	0.6	568	37.0	2.3	31
2015	45.4	0.63	599*	45.6	0.6	580	39.0	3	18
All years pooled	40.7	0.27	2997*	41.1	0.3	2744	36.5	0.8	253

* One missing value

Study design

A web questionnaire was developed with three parts: a theoretical test for levels A and B, a more descriptive part, designed to elicit data for describing and categorising the participants, and a self-assessment part inviting participants to assess their experienced change in behaviour since the licence examination.

The first part was a recognition task and a test of the participant's declarative knowledge. It consisted of a written exam including 16 questions for level A and 20 questions for level B. The questions were provided by *Säker Skog [Safe Forest]*, the organisation responsible for developing and issuing the chainsaw licence, the courses and preparing the examinations. The test addressed safety features and maintenance of a chainsaw, safe work practice, use of felling tools and PPE, as well as ergonomic aspects of chainsaw use. All questions in this part were multiple-choice questions, with three options, one of which was the correct answer. The pass criterion, for both levels A and B, was the same as for the regular examinations: 80% correct answers. The second part of the questionnaire comprised questions regarding the participant's age, gender, dyslexia, Swedish skills, educational level, previous experience of chainsaw courses, if they had previously failed a chainsaw licence test and their frequency of chainsaw usage. This part also included questions regarding the participant's preparations for the chainsaw licence exam, i.e., forms of courses they attended. The third part assessed changes in behaviour, both regarding risk-awareness and changes in work practice. All three parts provided possibilities for the participants to comment on their responses. Any participant could also withdraw from the study at any time.

First, a pilot test of the survey was conducted with nine participants to alter questions according to the experience gained. The final web questionnaire could be accessed by the 2998 invited people for three months. During this period they were each sent a postal reminder, and to increase the response rate those who completed the survey had chances to win safety garments and T-shirts in a lottery. Forty-five invitations sent by post were returned because the addressees had moved to unknown locations or died. A total of 700 participants responded to the survey, 18 of whom started but did not complete the survey and were excluded from this study. Hence, complete answers were received from 682 participants, corresponding to a response rate of 23%.

Descriptive statistics were calculated, and differences among groups were explored and connected to considered factors by statistical techniques (including t-tests, chi-square tests, Kruskal-Wallis tests, ANOVA and regression analysis) using Minitab 18 software (Minitab Inc. 2017). Test results from the survey's first part were pooled not only for the longitudinal effect (year of licence) but, also based on respondents' answers to the second part of the questionnaire (age, gender, dyslexia, Swedish skills, educational level, previous experience of chainsaw courses, if they had previously failed a chainsaw licence test. their frequency of chainsaw usage and forms of courses they attended). Results from the third part of the survey, the self-assessed changes of behaviour, was summarized for the respondents.

Non-response bias was evaluated by comparison of known properties and responses of participants and non-participants. Tested properties included par-

ticipants' age, geographical area (home address aggregated to region), gender and category of attended training (e.g., regular three-day course or no training at all). Participants were older (M = 47.3, SD = 14.6 years) than non-participants (M = 45.2 SD = 14.5 years; t(1108) = -3.24, p = 0.001), and a higher percentage had chosen to study for the licence in a self-study group ($X^2(5, N=2921)=42.595$, $p<0.01$), but there were no other significant differences between groups ($p>0.05$).

Table 2 Shares of participants that engaged in employed (industrial) and self-employed (non-industrial) cutting activities, grouped by the number of years (1, 3, 5, 7 or 9) between their chainsaw licence examination and the re-test

Number of years since examination	Did not use chainsaws (%)	Only self-employed use (%)	Mainly self-employed use (%)	Mainly usage during employment (%)	Only use during employment (%)
1	1	53	21	21	3
3	1	51	25	20	3
5	1	51	17	27	4
7	1	42	21	32	4
9	2	51	16	25	5
Average	1	50	20	24	4

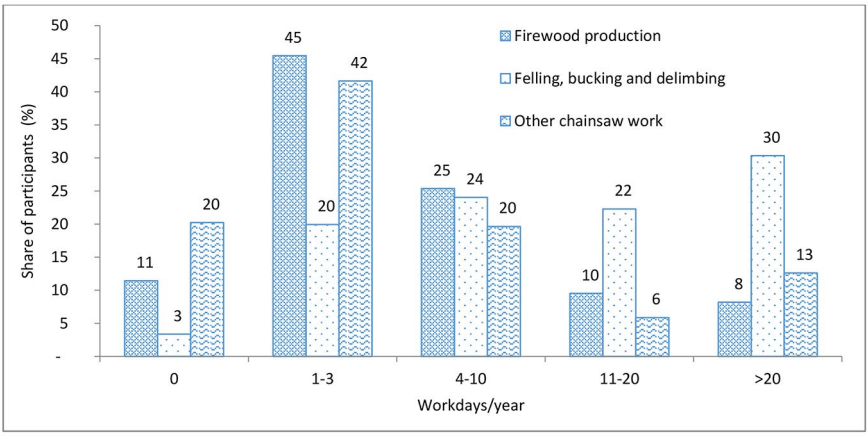

Fig. 1 Percentages of participants by frequencies of chainsaw use (days/year) in felling, bucking and delimbing, firewood production, and other chainsaw work. Each kind of chainsaw work sums up to 100%, or 682 participants

Results

Participants

The participants were mainly infrequent chainsaw users, felling some trees on their own land a few days each year (Table 2; Fig. 1). More than a third utilized a chainsaw less than 10 days a year in total and 12 participants had not used a chainsaw at all the last year. Almost a third (220 participants) were working more than 20 days in at least one task (firewood production, felling, bucking and delimbing, and other chainsaw work). The vast majority were men (90%). About 40% had prepared for their licence examinations through a self-study group with or without support from a certified instructor. A third prepared for the test through a 3-day (or longer) course, provided by a certified instructor. Only 4% took the test with no prior subject studies. In addition, 10, 9, 9, and 1% respectively prepared for their examinations through attending a training school (e.g. forestry/logger training school), a shorter course for experienced users, self-studies, or a web-based course, respectively.

Self-assessed behavioural change

The vast majority of participants reported that their training prior to examination strongly enhanced their risk awareness and use of safe working practices (Fig. 2). Less than 2% reported no positive effect of the training on these aspects.

Retest results

Only 45% of participants met the criteria for both chainsaw licence levels A and B during the retest: 75% passed the A level retest, but only 52% passed the B-retest. Participants with dyslexia obtained lower mean scores in the theoretical (A and B)

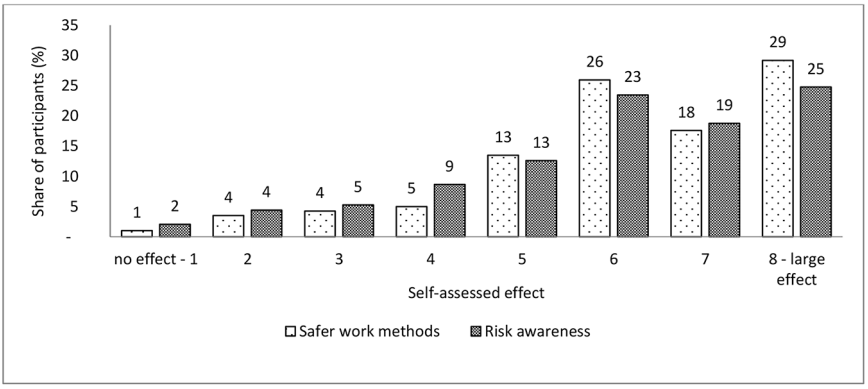

Fig. 2 Self-assessed change in participants' risk awareness and use of safe working methods after their chainsaw licence training from 1 (no increases in safe behaviour or risk awareness) to 8 (large increase in safe behaviour or risk awareness)

re-test (t(44)=2.84, p=0.01) than non-dyslexic participants (M=27.1, SD=4.42 and M=29.1, SD=3.61, respectively). No significant differences in test results due to age were detected (p>0.05, R-Sq=0.1%).

Knowledge and Frequency of practice

One-way between-subject ANOVA was applied to compare effects on AB-retest performance of frequency of chainsaw use (four categories of days per year) in three types of activities (felling, bucking and de-limbing; firewood production; and other) (Fig. 3). It was also applied to compare effects of five categories of employment-related use (use only or mainly as an employee or self-employed, and no use at all) on retest performance. A significant effect of type of chainsaw use was detected (p<0.01), and post hoc comparisons with the Tukey HSD test showed that participants who did any type of chainsaw work for more than 20 days per year obtained significantly higher scores than those who did no chainsaw work at all. This positive correlation was strongest for felling type of work (ANOVA: p=0, R-Sq=10.84%; Fig. 3). Participants who used a chainsaw in felling-type work more than 20 days a year obtained higher scores (M=30.0, SD=3.53) than those who worked 4–10 days (M=28.7, SD=2.23) or less according to the Tukey HSD test. Participants working 4–10 days also obtained higher scores than those who worked less than 4 days a year.

Categories of employed or self-employed work also had significant main effects (p<0.01; R-Sq=3.22%). Participants who used a chainsaw privately to a high degree (self-employed) obtained higher retest scores (M=29.0 SD=3.64; M=29.3 SD=3.13) than those who never used one (M=24.7 SD=5.48) or only used it in employed work (M=27.0 SD=3.62) according to Tukey's pairwise comparisons. The group that mainly used a chainsaw in employed work, but also to some extent privately (M=28.9 SD=3.93), only differed from the group that never used a chainsaw. The higher scores for self-employed users were also reflected in a higher frequency of retest passes (Fig. 4).

Fig. 3 Average combined scores in the A and B retests for groups by frequencies of chainsaw use in felling, bucking and de-limbing, firewood production, and other purposes. Each kind of chainsaw work sums up to 100%, or 682 participants. Max score was 36, the minimum score to pass were 13 and 16 for the A and B exams, respectively

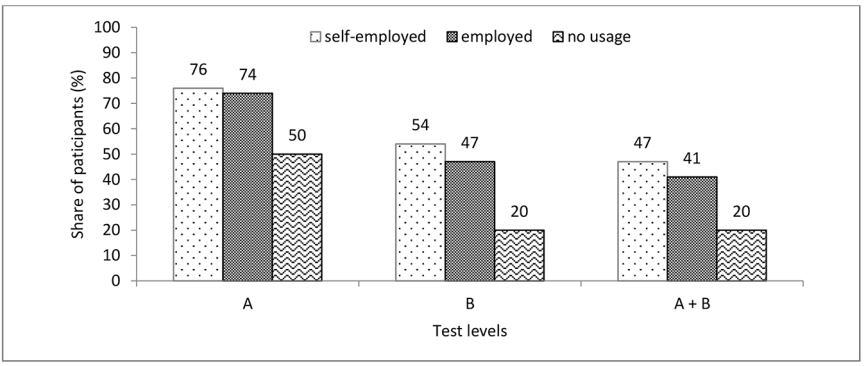

Fig. 4 Shares of participants in three categories of chainsaw use (self-employed or mainly self-employed, employed or mainly employed, and no chainsaw use) who passed the chainsaw licence A and B level re-tests. Self-employment refers to non-industrial work, and employment refers to industrial work

Gender and theoretical knowledge

Effects of, and interactions between biological gender (male or female), and use of chainsaw during felling type work (days/year) on AB-retest performance were tested with an ANOVA (General Linear Model). Due to the unbalanced data, this test was conducted for only four categories of usage: 0–3 days 4–10 days, 11–20, and >20 days. The analysis showed significant main effects ($p<0.001$, R-Sq = 11.84%) for gender and usage, but no interactions. Tukey's pairwise comparisons ($p<0.05$) revealed that the scores of men and women did not significantly differ within respective tree felling frequency (days/year). Hence, women were less frequent chainsaw users than males ($H(1)=9.55$, $p=0.002$; Kruskal-Wallis test, h-value adjusted for ties). There was no effect, or interactions, between gender and the year the chainsaw licence was approved (Table 3).

Table 3 Male and female participants' average scores in the level A and B chainsaw licence retests

NOTE: Different letters indicate significant differences in mean scores between groups in the same column and category ($p<0.05$, according to Tukey's pairwise comparisons)

		Scores on the retest	
Gender	A (max 16)	B (max 20)	A and B (max 36)
Male	13.5[a]	15.6[a]	29.1[a]
Female	13.0[b]	14.0[b]	27.1[b]
Both genders pooled	13.5	15.5	28.9

Knowledge and Educational level

One-way between-subject ANOVA also showed that the highest completed level of education (in five categories from up to nine years of primary school to more than 3 years of university education) had a significant main effect on AB-retest performance ($p < 0.01$ R-sq = 3.04%). The mean score of participants who had only primary school education scored significantly lower than those with more education ($p < 0.05$), according to Tukey's HSD test. On average, participants with the least formal education scored almost 2 points less than the others, and only about 30% passed the retest while 45–50% of the others passed. However, no significant differences were found between groups in the other four educational categories. Moreover, those who had taken one or more courses in chainsaw use before their studies for a chainsaw licence obtained higher retest scores then than those who had not taken any previous course (M = 29.7, SD = 3.8 and M = 28.7, SD = 3.63, respectively; $t(266) = -2.84$, $p = 0.005$).

A highly significant main effect of previously failed chainsaw licence tests on retest performance was also detected ($t(51) = -3.11$, $p = 0.003$). Participants who had previously failed the theoretical examination obtained lower scores than those who had passed at their first attempt (M = 27.06, SD = 4.36 and M = 29.01, SD = 3.61, respectively). Only 27% of the participants who reported that they had previously failed the theoretical test at least once passed the retest, compared to 46% of those who reportedly succeeded in their first attempt.

Knowledge retention

Linear regression showed no effect of the number of years that passed since licensing (in five categories: 1, 3, 5, 7 and 9 years) on knowledge retention. In contrast, one-way between-subject ANOVA did show a significant effect of time since acquiring a licence on retest performance ($p < 0.01$ R-sq = 2.21%). Post hoc comparisons using

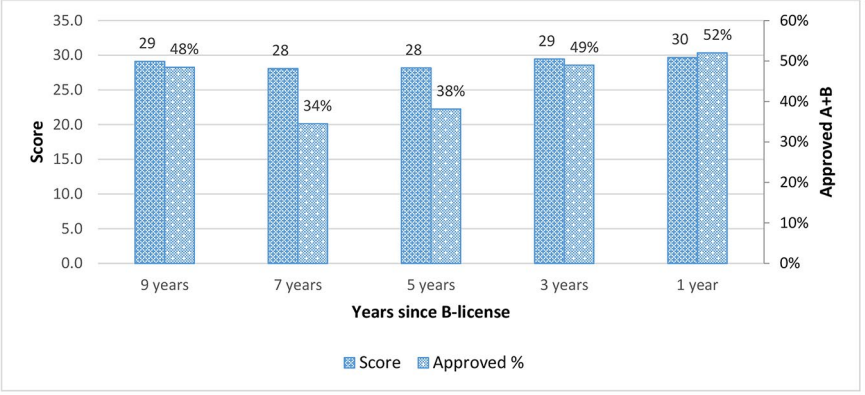

Fig. 5 Average retest scores obtained by participants who obtained a chainsaw license 1–9 years previously and shares of participants in these categories passing both retests

the Tukey HSD test showed that participants who had received their license one year previously obtained higher scores than those who obtained it five or seven years previously ($p < 0.05$). However, those who had received their licence nine years previously did not significantly differ from other groups in this respect. Post hoc analysis showed that participants who received their license after 2012 scored higher on the two questions in the retest that were concerning the new regulations for chainsaw use that were introduced in 2012 (X^2 (1, $N = 682$) = 7.35 & 27.026, respective, $p < 0.01$).

The average number of persons who passed followed the same distribution as for average score (Fig. 5). We detected no significant interactions between frequency of use (days/year) and time since receiving a licence.

Difficult knowledge areas

The participants found some questions harder to answer correctly than others; seven out of 36 questions (two in level A retest, and five in the level B retest) had a correct response frequency of less than 60%. For example, only 38% of the participants knew the minimum legal age for working with a chainsaw. Four of the questions they found most difficult concerned felling processes, more specifically, how forces are applied and their consequences for felling. For instance, substantial forces must not be applied to a tree before the felling cut (to minimize risks of 'barber chairing'), however, 48% of participants did not answer a question related to this part of the process correctly.

They found other questions easier to answer correctly, and correct response rates for six of the 36 questions (four in the A level retest) exceeded 95%. Most of these six questions concerned required features of the equipment. All of the participants knew that a chainsaw must have a stop switch, and 98% knew that it must have a chain catcher. Most of them also knew the most common types of accidents: 96% knew that most lethal accidents involved being pinned under a tree and 97% that risks of accidents increase with increases in work hours and lack of breaks.

Discussion

Self-assessed effect

Acquisition of a chainsaw licence contributed to a substantial increase in perceived risk awareness and use of safe work practices in the vast majority of chainsaw users that participated in this study. Remarkably, since they included not only inexperienced chainsaw users but also skilled professionals, less than 2% of the participants reported no improvement through taking the licence examination with or without associated courses. In addition, only about 15% of the participants who took the licence examination with no prior formal training reported no increase in risk awareness or use of safe practices. This indicates that the safety intervention itself had a positive effect even without targeted training and education, likely, due to publicity regarding the new regulation and self-reflection when preparing for and taking the examination raising awareness of risks involved in work with chainsaws. Neverthe-

less, there was a 25-percentage points increase in shares of participants reporting moderate to large effects of the license when combining the test with studies and training.

Knowledge retention

The main indicator of retained knowledge on safe chainsaw handling was frequency of recent practice, especially in felling, bucking and de-limbing work. This could be due to frequent chainsaw users continuously learning and developing their knowledge base, or at least maintaining their knowledge sufficiently for them to retain more of their knowledge than infrequent users. This hypothesis is consistent with the concept of *distributed*- or *spaced practice* (Donovan and Radosevich 1999), i.e., that frequent users perform better in tests since they learn during multiple sessions distributed in time. One explanation for the effect of distributed practice is that individuals' schemata, i.e., mental structure and organisation of generic information (Bartlett et al. 1995), are enriched through development in various contexts or strengthened by reactivations, according to the encoding variability (Glenberg 1979) and study-phase-retrieval (Gerbier and Toppino 2015) theories, respectively. The improvements in schemata provide a better cognitive context, which facilitates the encoding and retrieval of information in memory. Hence, the schemata affect what is remembered and what is forgotten – or at least the accessibility of information, since it is inherently problematic to draw any conclusions about the availability of knowledge.

In total, less than 50% of the participants in this study passed the retest, but 61% of the self-employed forest owners. A substantially larger proportion (74%) passed a retest a year after receiving a Swedish chainsaw license in a similar, but smaller, study (Lindroos 2009). However, the cited study only included self-employed forest owners (non industrial private chainsaw users in small-scale forestry) and that retest involved a formal pen-and-paper examination. Our main hypothesis explaining why the self-employed participants obtained higher scores than the employees who never used a chainsaw in their spare time is that it could be due to differences in the frequency of use between the groups, but due to unbalanced data we could not test this hypothesis. Another possibility is that the difference between groups may have been due to differences in levels of interest or engagement in the training, as self-employed users take a chainsaw course on their own initiative rather than to meet employers' requirements. However, these groups differ in many other respects for which we have no data, so further studies on effects of differences between the groups are warranted.

The small effect that elapsed time since the licence was issued had on retest performance explained only 1% of the variation in retest results. It is possible that a longer time series of data may have yielded a more realistic nonlinear model of memory performance that explained more of the variation in the results. In addition, the chainsaw licence was previously voluntary but became obligatory for professional users in a law passed in 2012, with a three-year transition period. This could also have resulted in differences between licence holders who acquired their licence before the law was passed, during the transition period ended, and after the transition period. Hypothetically, those who took the licence prior to the law might have been more interested and engaged than those who took the licence after the law. However, this is not clearly

supported by the data. Our results are consistent with previous findings that both knowledge and skills deteriorate rapidly, i.e., within 6–12 months of a learning situation (Eisenburger and Safar 1999; Saks and Belcourt 2006; Anderson et al. 2011). Previous studies have also shown that increased training and learning (overlearning), or repetition at least once increase knowledge retention (Arthur Jr et al. 1998; Eisenburger and Safar 1999), which is consistent with the concept of *distributed practice* (Donovan and Radosevich 1999). We detected an effect of repeated chainsaw courses on retention. Hence, best practice would include more (and distributed) training, but there is not necessarily an urgent need to retake the test until recommended practices or regulations have changed significantly.

Lindroos (2009) found indications that older participants, and people who obtained high scores in the first test, retained the acquired knowledge less well than younger participants and those who obtained lower scores, respectively. This study did not corroborate those findings.

Further studies on skill retention are recommended since skills seem to deteriorate even more rapidly than knowledge (Mahony et al. 2008; Anderson et al. 2011), possibly due to the possibility of mental practice (Arthur Jr et al. 1998). For example, Anderson et al. (2011) detected significant deterioration in CPR and first aid skills within 30 days after training, but not in theoretical knowledge even after eight years. Moreover, skill retention may be a better measurement of the training transfer, i.e., how well the training is implemented in practical work (see e.g. Saks and Belcourt 2006), than knowledge retention on this practical task. Also, as can be seen in Borz et al. (2014), economic aspects can have a greater impact than recommendations on the choice of cutting practice. Hence, studies on skills versus practice would provide insight into the effectiveness of training and the reasons behind deviations from recommended practice.

Difficult knowledge areas

The purpose of the chainsaw licence and associated training is to ensure that holders have enough knowledge and skill to use a chainsaw safely. The results of this study, based on a large sample, can efficiently disclose knowledge gaps in the population. The identified knowledge gaps can be utilized in information campaigns and the courses can increase their focus on these areas. However, the method also indicates deficiencies in the formulation of questions used in the formal chainsaw licence test. Thus, testing with multiple users may provide an efficient approach for identifying questions that require further analysis of their content validity to ensure that the questions serve the purpose of the test, i.e., to effectively measure knowledge.

A major knowledge gap identified in this study concerns the way forces are applied to the trees when using felling tools, i.e., the felling tools or wedges that generate appropriate felling forces. The knowledge gap seems to have been enhanced by difficulties in formulating appropriate questions (a content validity problem). This highlights well-known difficulties in designing a theoretical test to measure knowledge. Based on our results, recommendations of improvements in the formulation of questions have been given to the issuing organization.

Strengths and limitations

This study is based on a substantial randomized stratified sample, of 682 responding licensed chainsaw users, divided into five groups with differing times (1, 3, 5, 7 and 9 years) between their license examination and the retest. The required sample size was estimated based on the hypothesis that non-responses would be high due to an old population, the questionnaire format and that the address register had not been updated since the last licencing. Our main goal was to investigate the effect of time on knowledge retention, and knowing that the population of people receiving licenses had probably changed over time, we wanted the sample size to be large enough to enable a-posteriori pooling of properties derived during data collection, i.e., social gender, dyslexia, Swedish skills, educational level, previous experience of chainsaw courses, if they had previously failed a chainsaw licence test, their frequency of chainsaw usage and forms of courses they attended. Nevertheless, resources limited the sample size to 2000 individuals.

We found that the group who received their licences 9 years previously obtained more variable scores than the other groups, possibly due to effects of variables that were not assessed, such as engagement in the work, total years of experience of chainsaw work, and/or profession. The selection may have been biased to some degree towards non-employed chainsaw users due to the incentive to participate and get a chance of winning safety gear on completion of the survey. Two indications of such bias are the larger than expected shares of participants who paid their own licence fee and participants in self-study groups. However, as reflected in this study, a major share of chainsaw users in Sweden today are self-employed private forest owners (Lindroos et al. 2005). This is also a targeted group for whom it is important to improve safety and reduce frequencies of deaths during chainsaw work (Thelin 2002; Lindroos and Burström 2010).

Based on the randomized inclusion method, the large sample, the response rate of 24%, and results of the non-response bias tests, this study provided sufficient data for measuring group differences in retention of knowledge acquired in the Swedish chainsaw training program during the covered period of nine years since examination. Due to the web format, people with dyslexia were not offered a verbal retest, which they may have been offered in a real test situation. However, they may have used software to have the questions spoken to them. The web format also offered possibilities to cheat in the test, but no incentives were given for high scores, so this is not regarded as a major source of bias here. Other measures to counter possible cheating included confidentiality of the results, and lack of possibility to go back and change responses after answering a question. In addition, participants who took longer to answer did not obtain higher test scores. The high number of participants who did not meet the pass criteria also indicates that the tests were performed correctly. Moreover, the objective was to compare the performance of different groups of licence holders, and we have no indications that any of the tested groups were more prone to cheating than the others.

Conclusions

The chainsaw licence and associated training substantially enhance chainsaw users' perceived risk awareness and use of safe working practices. The self-employed small-scale private forest owners obtained higher scores on the retest than the employees who never used a chainsaw in their spare time. However, most of the participating chainsaw users' knowledge retention was poor, with less than half (45%) passing both retests. After one year, the test results did not deteriorate with additional time. The main indicator of retained knowledge about safe chainsaw handling was the frequency of practice, especially in work with felling, bucking and de-limbing, which indicate an effect of practical training on theoretical knowledge. Based on those results, the best practice is to ensure regular usage of the chainsaw and refresher training when the chainsaw has not been used for a year.

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Code Availability N/A.

Declarations

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Both authors contributed to the analysis and writing of the manuscript. The corresponding author conducted data collection and study design.

The study did not include any physical intervention to the human subject. It did not affect a person physically or mentally, and nor did it contain sensitive personal data. Hence, it was not applicable for an ethics approval according to the Swedish Ethics Review Board.

The questionnaire on background information and subjective ratings is published supplementary to this manuscript, however the specific questions on the licensing examination is kept confidential to ensure validity of future licensing examinations.

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