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Safety interventions in Swedish small-scale forestry

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Abstract

In private non-industrial forestry, self-employed work has long been associated with high risks for injuries. This thesis is based on four studies that focused on two of the major high-risk activities in this sector in Sweden: two on felling, de-limbing and bucking trees with a chainsaw; and two on off-road use of quad bikes.

The main intervention targeting the risk of chainsaw injuries is promotion of safe work practice, thus chainsaw training is seen an important tool. However, the provided training must effectively transfer knowledge and skill to the trainees, and more knowledge of the effectiveness of this transfer is required.

Thus, half of this thesis is devoted to the Swedish chainsaw license and training. The results show that chainsaw training increases relevant knowledge and skill, and seems to result in changes in chainsaw users' behaviour. Although knowledge retention was found to be relatively poor just a year after obtaining a licence (which generally involves training as a theoretical and practical examinations must be passed), no clear further effect of time in the period between one and nine years after receiving one was detected. The results also revealed no clear effect of time on skill retention.

The use of quad bikes is associated with high risks for rollover injuries. A suggested intervention targeting this risk is to use an operator protective device (OPD) intended to create a safe space for the operator during a rollover incident, thus preventing the quad bike from crushing the operator. Although such devices have been available for a long time, none have been widely accepted, and many questions regarding optimal kinds of OPDs, their effects and implementation have not been adequately addressed. The other half of this thesis is thus devoted to the development and implementation of quad bike OPDs. The results showed, inter alia, that many quad bike users' understanding of quad bike safety is characterized by a belief that not all users are at risk and that risks are not equally distributed. Thus, several participating users decided to acquire an OPD not necessarily to increase their own safety but rather to increase the safety of others.

Keywords: ATV, Chainsaw, Injury prevention, Non-industrial forest owners, OPD, Training, Quad bike.

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Åtgärder för bättre arbetssäkerhet säkerhetsarbete i småskaligt - skogsbruk

Sammanfattning

Självverksamt småskaligt skogsarbete är förknippat med hög risk för skador. Den här avhandlingen har fokuserat på två av de främsta riskfyllda aktiviteterna inom detta område, nämligen fällning och upparbetning av träd respektive körning med fyrhjuling i terräng. Två studier har genomförts inom respektive område.

En av de viktigaste säkerhetsaspekterna rörande motorsågsanvändning är en säker arbetsmetodik och därför anses utbildning vara en viktig säkerhetshöjande åtgärd. Hälften av avhandlingen handlar därför om det svenska motorsågskörkortet och utbildning i anslutning till det. Resultaten visar att utbildning i motorsågsarbete ökade både kunskapen och förmågan, vilket resulterade i förändringbeteende. Ett år efter att motorsågskörkortet erhållits hade kunskaperna försämrats, men därefter fanns inte någon tydlig ytterligare kunskapsförsämring.

Användningen av fyrhjulingar associeras ofta med en hög risk för vältningsolyckor. En åtgärd för att minska olycksrisken är att använda skyddsbåge, vilken minskar risken för att bli klämd av fyrhjulingen vid en vältningsolycka. Den typen av utrustning har funnits tillgänglig under lång tid, men har inte börjat användas in någon större omfattning. Hur skyddsbågar effektivt kan utvecklas och implementeras är därför fortfarande en öppen fråga. Den andra delen av den här avhandlingen har således ägnats åt utvecklingen och implementeringen av skyddsbåge för fyrhjuling. Resultaten visar att fyrhjulingens stabilitet tydligt beror på vilken typ av skyddsbåge som används. En lätt skyddsbåge gav bara en marginell negativ effekt på stabiliteten, och motverkades lätt av en smärre ökning av fyrhjulingens spårvidd. Resultaten visade också att många fyrhjulingförares förståelse av säkerhet karaktäriseras av synsättet att inte alla användare är riskutsatta, och att risk därför inte är jämt fördelad. Många förare ansåg det därför inte nödvändig att införskaffa en skyddsbåge för att öka den egna säkerheten, utan snarare för att öka säkerhet en för andra som kunde tänkas köra fyrhjulingen.

Nyckelord: ATV, Fyrhjuling, Motorsåg, Olycksprevention, Självverksamt skogsbruk, Skyddsbåge, Terränghjuling, Utbildning.

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Safety interventions in Swedish small-scale forestry

Björn Edlund

Akademisk avhandling som för vinnande av skoglig doktorsexamen kommer att offentligt försvaras i sal Björken, SLU I Umeå, fredag den 13 dec 2019 klockan 13.00

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Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Häggström, C.*& Edlund, B. (2019). Knowledge Retention and Changes in Licensed Chainsaw Workers' Risk Awareness. *(*manuscript)

II Edlund, B.*, Häggström, C., Andersson, E. Nordfjell, T. & Lindroos, O. (2019). A longitudinal case study of skill retention in Swedish chainsaw training (manuscript)

III Edlund, B.*, Lindroos, O. & Nordfjell, T. (2019). The effect of rollover protection systems and trailers on quad bike stability. Accepted for publication in *International Journal of Forest Engineering.*

IV Edlund B.*, Andersson, E., Nordfjell, T & Lindroos, O. (2019) Quad Bike Riders' Attitudes toward and Use of Safety Technologies. *Journal of Agricultural Safety and Health*, 25(4), pp 169-187.

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The contribution of Björn Edlund to the papers included in this thesis was as follows:

I Planned the study and developed the questionnaire together with the co-author. Wrote a substantial part of the manuscript with input from the co-author.

II Planned the study together with the co-authors. Carried out the main part of data collection, interviews and transcriptions. Preformed the analysis and wrote the manuscript with input from the co-authors.

III Planned the study together with the co-authors. Carried out the experiment in study part A, and together with Tomas Nordfjell in part B. Preformed the analysis and wrote the manuscript with input from the co-authors.

IV Planned the study together with the co-authors. Conducted all interviews, transcriptions, coding and analyses. Developed the interview guide and final coding scheme together with the co-authors and wrote the manuscript with input from the co-authors.

Abbreviations

PPE	Personal protective equipment
ROPS	Roll over protective structure
CPD	Crush protective device
OPD	Operator protective device
CoG	Centre of gravity

1 Introduction

For a long time, self-employed work in non-industrial forestry has been associated with high risk of injury (Lindroos and Burström 2010). The work is both difficult and dangerous for various reasons, including use of chainsaws, complex risk assessments when felling big trees and both operating and working around dangerous machinery. Moreover, this is all often done in difficult terrain, fully exposed to the weather, often alone, seldom (with long intervals between occasions) and often without formal training. Thus, in working environments of self-employed forest owners, risks are high and risk management potentially very difficult (Axelsson 1998; Lindroos et al. 2008; Lindroos and Burström 2010). Hence, research on the safety of self-employed workers in small-scale forestry is an important element of elucidating reasons for, and reducing frequencies of, injuries in small-scale forestry. Two of the main high-risk activities in Swedish small-scale forestry are felling and de-limbing trees with chainsaws and the use of quad bikes in hazardous terrain. There is a need for effective interventions targeting these risks, thus this thesis focuses on safety interventions in Swedish small-scale forestry. The interventions studied are: training for felling, de-limbing and bucking timber with chainsaws, and quad bike operator protective devices (OPDs) designed to prevent rollover injuries related to use of quad bikes in forestry.

1.1 Swedish small-scale forestry

Swedish small-scale forestry is closely linked to a long tradition of self-sufficiency in the old Swedish agrarian society (Törnqvist 1995). There are about 330,000 non-industrial forest owners in Sweden, who own approximately half of all Swedish forest land (Swedish Forest Agency 2014). Most forestry tasks are done by contractors, but still two thirds of these forest owners perform some self-employed small-scale forestry work on their own estate (Lindroos et al. 2005). In general, these self-employed forest owners are more likely to be men and to live on their forest estate compared to the non-industrial private forest owners in general (Lindroos et al. 2005; Eriksson 2018). Moreover, the non-industrial self-employed forestry workforce includes not only the formal owners, but also family members, relatives, employees, neighbors and friends working on the owners' forest land (Swedish Forest Agency 2014). Common self-employed forestry tasks are planting, pre-commercial thinning, harvesting and extraction of trees. About a third of all non-industrial forest owners engage in harvesting and extracting trees (Lindroos et al. 2005). In Swedish non-industrial small-scale forestry, this is usually done using a chainsaw for felling, de-limbing and bucking, and a farm tractor or quad bike with a trailer for extracting logs (Lindroos et al. 2005). Although amounts of saw logs and pulpwood on the Swedish market produced by self-employed non-industrial private forest owner are relatively small (ca. 11 % of total amounts in 2012), the proportion of time involved in their production is much larger (39 % of all hours of forestry work in 2012) (Swedish Forest Agency 2014). This discrepancy is likely partly due to use of less productive methods (e.g. chainsaws instead of harvesters) and partly to large quantities of the trees harvested in Swedish small-scale forestry being used for personal firewood production rather than sold as pulpwood or saw logs (Lindroos et al. 2005; Lindroos et al. 2008). However, despite the relatively small quantities of saw logs and pulpwood produced, the high amounts of time involved in high-risk activities show that safety in Swedish small-scale forestry is not a marginal issue. For example, fatalities related to self-employed forestry work accounted for 7% of all occupational fatalities in Sweden during the years 1996-2001 (Lindroos and Burström 2010).

1.2 Risks in small-scale forestry

1.2.1 Risks in the use of chainsaws

Chainsaws are the main tools for felling in many parts of the world (e.g. Di Fulvio et al. 2017; Tadeusz Moskalik 2017; Tobita et al. 2019). The chainsaw quickly became the main tool in logging after its introduction in Sweden during the early 1950s (Ager 2017). However, today in the Nordic countries and many other places with high levels of mechanization and small proportions of harvesting in steep terrain, the chainsaw is mainly used in small-scale forestry operations (Axelsson 1998; Ager 2017; Bonauto et al. 2019). In small-scale forestry, the chainsaw is the main tool for felling, delimbing and bucking trees, as well as often for cutting logs into pieces of firewood. The continuation of work with chainsaws in Swedish small-scale forestry is illustrated by the sales of chainsaws. Although they are not widely used in industrial forestry, approximately 48,000 chainsaws were sold in Sweden in 2002, and this annual sales number had not significantly changed for 20 years (Lindroos et al. 2005).

Several risks are associated with chainsaw work. Three main ones are risks of: chainsaw cutting injury, workers being injured when working in the vicinity of heavy machinery, and workers being hit by a tree or parts of a tree during felling (Peters 1991; Driscoll et al. 1995; Thelin 2002; Neely and Wilhelmson 2006; Tsioras et al. 2014). Incidents associated with felling onto neighboring trees, including hang-up, butt rebound, and dislodgement of dead trees, limbs or tops, accounted for more than half of all tree felling fatalities examined in a US study (Peters 1991). Relative frequencies of injuries among professional forestry chainsaw workers has decreased over time (Axelsson 1998), at least partially due to increased development and use of personal protective equipment (PPE) and safer chainsaws (Sullman et al. 1999; Lindroos and Burström 2010; Tsioras et al. 2014). In contrast, frequencies of accidents related to work with chainsaws among self-employed private forest owners has tended to remain rather high and stable (Axelsson 1998; Lindroos and Burström 2010).

1.2.2 Risks in the use of quad bikes

Although quad bikes, also known as all-terrain vehicles (ATVs), were formally created as recreational vehicles, their size and versatile nature soon made them popular in many rural areas in both agricultural and forestry applications (Nordfjell 1995; Fragar et al. 2005). Quad bikes are light vehicles designed to be ridden in terrain. They commonly weigh around 300-375 kg and have a track width of less than 100 cm. They have a seat that is straddled, handlebar for steering and big soft tires designed to provide good traction in terrain. Quad bikes can be divided into two types of vehicles, a work type and a sports/recreational type. The latter is not considered in this thesis and will not be further described. The term quad bike henceforth refers to the work type of quad bike used in forestry and agricultural applications.

A work-type quad bike commonly has four-wheel drive, differential locks, load-racks at both the front and rear, and a trailer hitch. They are commonly used in many rural occupational activities, such as agriculture, hunting and forestry. Agricultural activities they are commonly used in include livestock operations, transportation of goods and personnel, and crop operations (Goldcamp et al. 2006; Fragar et al. 2007; Geng and Adolfsson 2013). In hunting they are mainly used for transportation of larger game (Nordfjell 1995). In forestry applications they are mainly used in small-scale forestry activities, such as transportation of logs, personnel or equipment off-road (Nordfjell 1995; Updegraff et al. 2000; Russell and Mortimer 2005; Vaughan and Mackes 2015). In industrial forestry, they are exclusively used as auxiliary vehicles, e.g., for transportation of personnel, spare parts, fluids, seedlings or equipment (Edenhamn 1990a; Nordfjell 1995). Heavy loads (e.g. spare parts, seedlings or logs) are often transported by quad bikes on an attached trailer. For example, payloads of over 500 kg of logs are commonly transported on quad bike trailers in Swedish small-scale forestry, reportedly up to approximately 570 kg (Loftäng 1991). Thus, together with the weight of typical log trailer (approximately 160 kg), the total towed weight is often more than twice the weight of the quad bike itself.

Quad bike incidents are typically single-vehicle crashes and occur in all types of terrain, both while driving on the road and off-road (Persson 2013; Williams et al. 2014). In a situation where the rider loses control of a quad bike it is more likely to overbalance and roll than slide across the surface. This is because quad bikes have a high center of gravity (CoG) and big soft tires with treads designed to provide high traction (Moore 2008). Approximately half of all quad bike related incidents are classified as rollover incidents (Krauss et al. 2010; Milosavljevic et al. 2011; Jennissen et al. 2013). In about half of rollover incidents, riders are reportedly thrown clear of the bike, while in the other half the riders fail to throw them-selves clear of the vehicle and are hit, crushed, or pinned by the quad bike as it rolls (Moore 2002). In forestry and agricultural activities, the use of quad bikes often involves towing equipment or trailers, and in substantial proportions of agricultural incidents a trailer or other towed attachment is involved (Moore 2008). These activities introduce additional risks to riding a quad bike, such as the risk of the trailer folding in on the quad bike while going downhill (jack-knifing). During such incidents, the rider is at high risk of being struck, hit or pinned by or between the quad bike and the trailer or its load (Nordfjell 1995; Moore 2008; Clay et al. 2015).

1.3 Perspectives on risk

To understand how people relate to safety interventions, understanding of both the nature and perceptions of risk is important. The concepts of risk and safety vary somewhat depending on perspectives, e.g. technological, psychological, or socio-cultural. From a technological perspective, risk is merely the probability of an adverse event occurring (Lupton 2013), while from a socio-cultural perspective the emphasis is on cultural elements of people's understanding of hazardous situations and associated risks. According to Wall and Olofsson (2008) the understanding of risk is always connected to our social context. It is connected to who we are, our personal experience and our spatial and social context. As Douglas (1994, p. 31) noted, "A risk is not only the probability of an event but also the probable magnitude of its outcome, and everything depends on the value that is set on the outcome. The evaluation is a political, aesthetic, and moral matter". From a cognitive psychological perspective, risk could be understood in two ways. From a cognitive psychological perspective, risk can be assessed either through the analytical system, through reasoning (which is slow and requires justification through logic and evidence) or rapidly, intuitively, and holistically through the experiential system. The latter relies on our previous experience of related events and the associated emotions and responses. These two systems work in parallel and are interdependent, e.g. the analytical reasoning cannot function efficiently without the support of emotions and responses (Slovic et al. 2004). In the research underlying this thesis, especially Study IV, three aspects of sense-making of risk have been addressed (personal experience, blame, and self-regulation), that must be elucidated in order to understand the complex issue of safety in Swedish small-scale forestry.

1.3.1 Risk and personal experience

As already mentioned, our personal experience plays a fundamental role in how we perceive risks. It has also been found that lack of personal experience of related incidents can increase the effect of optimism bias, resulting in underestimation of experienced risks (Caponecchia 2010). Personal experience is likely to play an important role in our perceptions of a risk and how we act upon it (Slovic et al. 2004; Wall and Olofsson 2008). For example, if we choose to acquire a rollover protective structures (ROPS) for our quad bike or not. The importance of personal experience has also been found in studies of the decision to retro-fit old farm tractors with ROPS (Franklin et al. 2006).

1.3.2 Risk and Blame

Another important element to address in efforts to understand how we act upon risk, and cultural effects of our sense-making of risk, is the process of blame allocation. According to Douglas (1992), blame constitutes one of the first reactions to an unfortunate event in any society. For every death, society tries to define the danger, determine the cause, and hold someone accountable. This process promotes protection of the public good in a society, and helps to ensure that the society's members contribute and are held accountable. Furthermore, according to Douglas (1992) societies commonly have a 'repertoire' of three main types of explanations for misfortunes: moralistic, individual adversaries, and externalistic. If there is a 'moralistic' cause, victims must have broken a taboo, transgressed, or ignored a social convention and therefore have only themselves to blame (e.g., intoxicated victims may have violated safe practices as well as regulations, and thus brought misfortune upon themselves). If 'individual adversaries' were the cause, victims may be to blame because they were not sufficiently well equipped (e.g., insufficiently intelligent, skilled, strong, or quick) to face an opponent. If the cause was 'external', the misfortune is seen to have been caused by an outside adversary, e.g., someone outside of the community, and that external agent or enemy was to blame rather than the victim. These means of explaining misfortune and apportioning blame vary within, as well as between, societies, but explain the actions needed to identify people who are at risk and agents or things responsible for risks, and thus prevent further misfortune.

1.3.3 Risk and Self-Regulation

According to Beck (1992), the modern western culture is strongly individualistic, which greatly affects the way we act upon risks. Every member of our society is expected to self-regulate, use an analytical system, listen to expert advice, and take actions to reduce excessive risks. Consequently, individuals' responsibility for their own life outcomes and actions is emphasized more than the society's responsibility to keep its members safe (Foucault 1979). To be good members of society, individuals must take responsibility for their own safety and for managing everyday risks, as well as heeding the advice provided by experts (Lupton 2013). This responsibility to act and ensure that you and your loved ones are safe is an important part of our everyday risk management, and plays a major role in how we treat risk-related advice and manage risk.

1.4 Safety interventions in small-scale forestry

1.4.1 Models of safety interventions

Preventive measures can be roughly divided into two categories: active and passive (Haddon 1980). A passive intervention does not involve active collaboration of the individual, e.g. a chain brake on a chainsaw is activated in certain circumstances, irrespective of the operator's intentions. Such interventions are commonly considered more effective than active interventions, which require active collaboration of the individual, e.g. safe work practice (Haddon 1980). A more detailed categorization model for safety interventions is the 'hierarchy of injury prevention'. This is a conceptual model categorizing safety interventions based on their effectiveness (*Figure 1*). The hierarchy consists of five categories, ranging from the most efficient to the least efficient. The first category is eliminating a hazard and the second is reducing and controlling it. The third, fourth and fifth categories are regulation/enforcement, education, and lastly development and provision of personal protective equipment (PPE) (Donham and Thelin 2016).

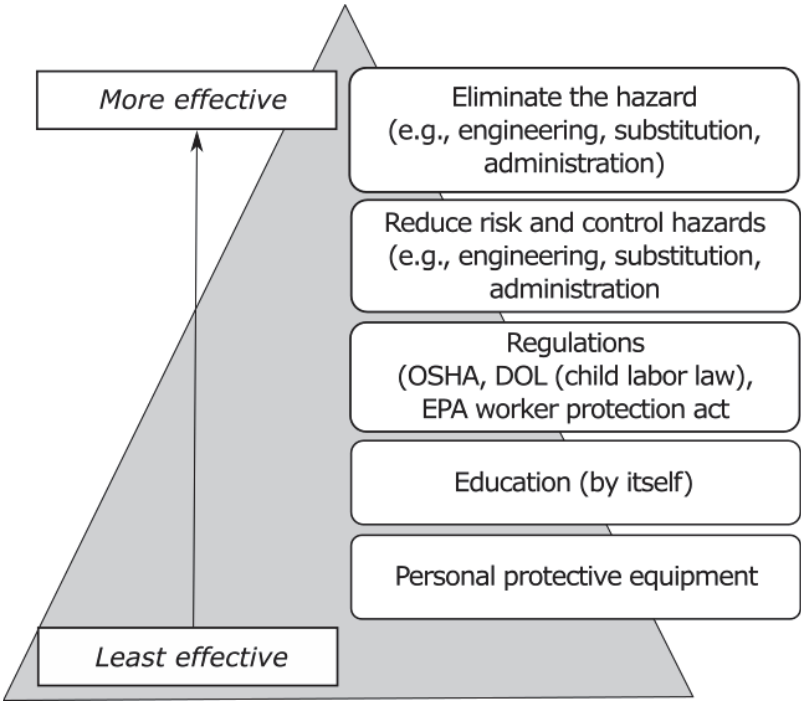

Figure 1. Hierarchy of injury prevention (Donham and Thelin 2016)

Another model suggested by Hollnagel (2004) categorizes interventions based on the main barrier used. Four categories of barriers are recognized: physical, functional, symbolic and immaterial. Physical barriers, such as the safety cabin on a farm tractor or protective legwear for chainsaw operators, are designed to prevent or mitigate the effect of a specific danger by their presence. Functional barriers, such as an airbag in a car or 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 or signs and immaterial barriers such as training in safe work methods (Hollnagel 2004). These two models, despite the use different nomenclature and somewhat different perspectives, are similar in many respects, e.g. passive interventions are categorized as more effective than active interventions. Another important aspect of these models of safety intervention is that neither recommends the selection of one intervention and neglect of all other kinds. Effective injury prevention often requires a multitude of interventions at all levels in the hierarchy. This is manifested in interventions designed to improve the safety of chainsaws and quad bikes. However, although a multitude of interventions are needed, these models can help in the development and prioritization of effective safety interventions.

1.4.2 Chainsaw safety interventions

Assessing self-employed non-industrial chainsaw users' safety is currently difficult as limited injury data are available and it has only been specifically addressed in a few studies (Lindroos and Burström 2010). However, there have been studies of logger safety from across the world that are relevant to all work involving the felling and extraction of trees. Several major safety interventions have also been described in the literature on chainsaw safety. Two important interventions targeting chainsaw cutting injuries are the protective trousers protecting chainsaw users' legs from cutting injuries and the chainsaw chain brake, which have together substantially reduced the risk of cutting injuries due to kickback (Sullman et al. 1999; Dabrowski 2012). The use of high-visibility garments is another intervention that has enhanced logger safety, by reducing frequencies of incidents involving heavy machinery and injuries due to interactions with other fellers (Sullman et al. 1999). The risks of falling trees, tree tops and branches have been found to be more difficult to address. Safety helmets provide some protection against falling objects, but little protection against large branches, whole trees or tree tops hitting their wearers. In the absence of effective passive interventions for eliminating or reducing this risk, training in safe work practices is the major intervention targeting its reduction, and an important element of prevention of all types of chainsaw injuries. It is also the intervention at the highest level of effectiveness targeting this risk, according to the hierarchy presented by Donham and Thelin (2016). In up to half of all forestry incidents, a lack of safe work practice has reportedly been a major cause (Thelin 2002; Melemez 2015). In cases such as the use of chainsaw for felling and de-limbing trees, where lack of skill and knowledge is considered a strong causal factor for incidents, training has been found to be an important intervention (Khanzode et al. 2012).

Training as a chainsaw safety intervention

Studies of logger safety training have shown that training results in an increase in knowledge (Helmkamp et al. 2004), but this does not necessarily correlate with a reduction in number of injuries (Bell and Grushecky 2006). It has also been shown that training retention, the transfer of knowledge and skill, declines substantially over time (Saks and Belcourt 2006). Thus, there are the two major challenges in relying on training as a safety intervention; increasing knowledge and skill does not necessarily result in fewer incidents, and acquired knowledge and skill often decline over time, so continuous training is needed. Another challenge in the safety of self-employed forestry is similar to that of farm safety. Most farmers' socialization into farming does not start in formal education. Most farmers are socialized into farming from a young age by living on a farm and observing daily farm practices (Mazur and Westneat 2017). In many farm safety interventions it is necessary to disrupt this observational apprenticeship to shift ingrained behavior towards safer practices (Mazur and Westneat 2017). The same applies to self-employed forest owners; most have inherited their forest property and lack formal forestry training, but have been socialized into forestry and chainsaw work from a young age by observing and working with the older generations. Thus, many self-employed forest owners already have established work practices before taking a formal chainsaw course, like farmers starting formal agricultural education. This potentially makes training self-employed forest owners more difficult as the training needs not only to establish new, safe work practices but also in many cases change unsafe behavior.

This is the context in which the Swedish chainsaw license program was developed. The program has developed a standardized form for chainsaw training and licensing in Sweden, and the first chainsaw license was issued already in 2005 (Lindroos 2009). Since 2015 acquisition of a license has been a legal requirement for anyone working with chainsaws in Sweden, with some exceptions, e.g. forest owners working on their own estates (AFS

2012:1). There are several chainsaw licenses. Level A certifies that the holder has acquired the basic knowledge needed to maintain and use a chainsaw safely, while level B (for which level A is a prerequisite) certifies that s/he has acquired the knowledge needed to fell, de-limb and buck timber safely. Chainsaw license levels A and B are normally required for working with chainsaws in Swedish harvesting operations. A chainsaw course is usually led by a certified instructor, lasts 3-4 days, covers both levels A and B, and is followed by written and practical examinations. However, a course is not mandatory. Experienced users can prepare themselves for the examination, and another common alternative to a traditional course is preparation through a study circle (a group-based learning activity involving participatory learning without a formal tutor).

1.4.3 Quad bike safety interventions

In the mid-1980s, an increase in quad bike-related incidents was noted by US authorities. This eventually resulted in the major quad bike distributors consenting (among other things) to immediately stopping sales of three-wheeled quad bikes, equipping all new quad bikes with warning labels, promoting age restrictions and providing safety information material. This was one of the first big safety interventions in the use of quad bikes (Yuma et al. 2006). Examples of other important interventions promoted by several researchers are the use of a helmet while riding a quad bike, which research suggests increases rider safety (e.g. Wood et al. 2013; Bethea et al. 2016; Jennissen et al. 2017). This has resulted in some legislative action (Basham et al. 2006; Hafner et al. 2010; Miller et al. 2012; Persson 2013). Another important intervention is quad bike rider training, as riders' experience is reportedly linked with lower risks of injuries. The quad bikes' perceived easiness to use and lack of regulation results in many riders having no formal training, thus many are not well prepared (for example) to ride a quad bike through difficult terrain safely (Shulruf and Balemi 2010; McBain-Rigg et al. 2014). As rollover is a common problem, many suggested safety interventions address this issue (e.g. Bouton et al. 2009; Rönnbäck and Johansson 2011; Frisk and Nordfjell 2012; Richier et al. 2012; Lower and Trotter 2014; Grzebieta et al. 2015a; Drugge et al. 2019; Strohfeldt 2019). These interventions focus on reducing either the likelihood of a rollover incident, or the consequences of one. Examples of interventions of the first category include systems that actively increase quad bikes' stability (Rönnbäck and Johansson 2011) or warn the rider of imminent risk (Richier et al. 2012; Drugge et al. 2019) and training to promote safer rider behavior

(Edenhamn 1993; Balogh and Fischer 2013).In the second category, the main type of intervention is the construction and use of operator protective devices (OPDs) to reduce the impact of a rollover incident (Snook 2009; Frisk and Nordfjell 2012; Wordley S. 2013; Grzebieta et al. 2015a; Myers 2016; Strohfeldt 2019). According to the hierarchy presented by Donham and Thelin (2016), engineering interventions targeting risk reductions are among the most effective safety interventions, given that elimination of hazard is not possible. Thus, engineering interventions targeting rollover, either to increase stability or reduce the consequences of a rollover incident are, according to the hierarchy, potentially more effective than training or PPE as safety interventions for reducing rollover injuries.

Increasing quad bike stability

The lateral stability of a vehicle largely depends on the height of the vehicle's center of gravity (CoG) and track width (Mengert et al. 1989). A vehicle´s static stability is defined as the angle at which its stationary tipping point is reached. In practice, other forces influence the dynamic stability of a vehicle traveling off-road, e.g. dynamic forces arising from passing an obstacle or cornering, steering geometry, suspension, tires etc. However, even though knowledge of the dynamic forces is crucial for understanding specific rollover cases, static stability has proven to be closely related to dynamic stability. Moreover, low static stability for any type of vehicle is a strong predictor of high risk of rollover incidents (Mengert et al. 1989; Grzebieta et al. 2015b). Thus, interventions targeting quad bikes' stability should reduce the height of the CoG or increase track width to effectively increase their stability and reduce risks of rollover incidents.

Operator protective device (OPD) as a safety intervention

Rollover protective structures (ROPS), Operator protective devices (OPD) and Crush protective devices (CPD) are all terms for mechanical devices made to create a safe space and thus prevent the operator being crushed by a vehicle in the event of a rollover (e.g. Wordley S. 2013; Schwab et al. 2019; Strohfeldt 2019). The use of such structures as safety interventions has proven efficacy in reducing farm tractor rollover fatalities (Thelin 1998). This corresponds well with the models of injury prevention as they are passive, engineering interventions designed to reduce the risks and control a hazard (Haddon 1980; Donham and Thelin 2016). Among these types of protective structures, ROPS are the most well studied and are standard equipment on most tractors used in farming, forestry, landscaping and construction. They are typically constructed as a two-post ROPS, four-post ROPS or safety cabin (protective enclosure), as illustrated in *Figure 2*. ROPS are designed to create a protective zone around the operator in a rollover situation and should be equipped with a restraining system to keep the operator within it (Stockton et al. 2002). ROPS with seatbelts, or safety cabs where the driver is securely held inside the ROPS, have been found to be very effective in farm tractor rollover incidents (Reynolds and Groves 2000). For example, the legal requirement for ROPS on all farm tractors has reduced deaths in rollover incidents by 99 % in Sweden (Springfeldt et al. 1998). However, in terms of rollover incidents with farm tractors, even the simplest ROPS with no additional driver restraining device substantially increase safety for the operator in the event of a rollover (Ayers 1997; Reynolds and Groves 2000). CPDs or OPDs also include simpler forms of structures designed for quad bikes that, like a ROPS, are intended to create a safe space for the operator during a rollover but may not fulfill all the criteria of a standard ROPS. The Australian Competition and Consumer Commission (2019) defines CPDs as structures that "aim to prevent the weight of the upturned vehicle coming to rest on the rider by holding the upturned vehicle off the ground and creating in effect a 'crawl out' space. Some CPDs are also designed to limit the number of quarter rolls (90 degree rolls) and to avoid the quad bike 'rolling over' the operator."

It also notes that OPDs is a wider term that includes both CPD and ROPS (Australian Competition and Consumer Commission 2019).

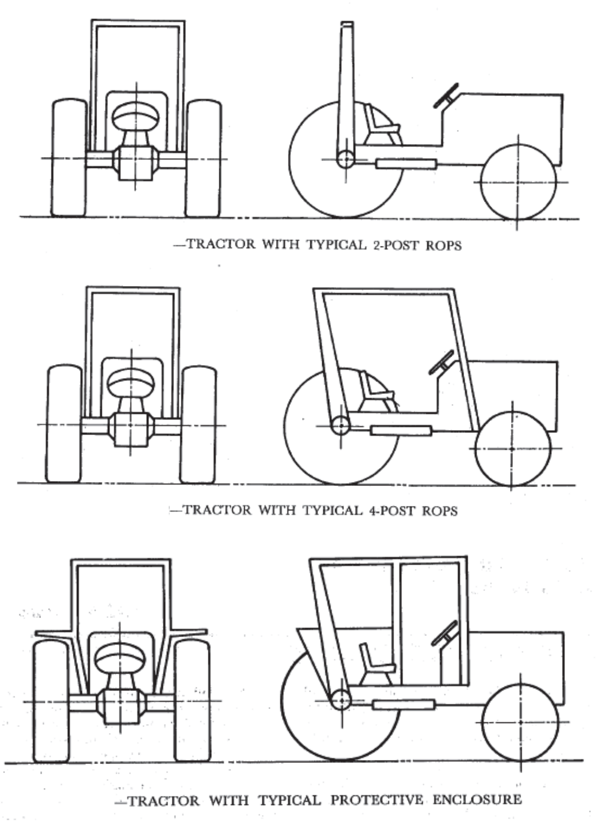

Figure 2. Typical tractor ROPS configurations (SAE Standard 1983)

Equipping quad bikes with OPDs is not a new idea; it has long been proposed by researchers, and several models have been developed in the last 30 years (Dahle 1987; Edenhamn 1990; Rizzi 2010; Shulruf and Balemi 2010; Grzebieta, Rechnitzer, Simmons, et al. 2015). In addition, quad bike OPDs have been available on the market with various designs and sizes from four-post roll cages with a roof and windshield, to simple one-post rear-mounted CPDs. However, the use and sales of quad bike OPDs are very low. Moreover, designing a quad bike OPD that creates a protective space for the rider during a rollover without significantly decreasing the vehicle's stability, and thus increasing risks of rollovers occurring or substantially limiting the quad bike's normal use, is a major challenge (Edenhamn 1990b; Lower and Trotter 2014; Grzebieta et al. 2015b). Another challenge is to create a market in which manufacturers choose to equip quad bikes with OPDs or riders are willing to acquire and retro-fit an OPD to their quad bikes.

1.5 Objective

Motivated by the many accidents and limited amount of research in the field, the overall objective of this thesis was to investigate barriers, perceptions and safety interventions in Swedish small-scale forestry. Practical aims were to increase safety, and hence reduce injuries in (and hopefully beyond) the studied sector. Two major hazards in small-scale forestry in Sweden today are use of chainsaws for felling, de-limbing and bucking timber, and use of quad bikes off-road. Therefore, aspects of the Swedish chainsaw license were examined in two studies, and another two studies focused on quad bike OPD.

The main objective of the first two studies was to investigate effects of time since training on chainsaw user’s knowledge and skill retention. Study I specifically focused on long-term effects of acquisition of a Swedish chainsaw license on the chainsaw user's theoretical knowledge and perceived change in behaviour. In Study II, the longitudinal effects on skill and knowledge retention were evaluated by following a group of chainsaw users through a chainsaw training course and re-evaluating their skill and knowledge a year later.

The main objective of the other two studies was to improve knowledge of the development and implementation of quad bike OPDs. Study III addressed the mechanisms that affect a quad bike’s static stability, including effects of OPDs on stability. The last study (IV) explored the underlying reasoning behind the decision to install ROPS on quad bikes, and quad bike riders’ general understanding of quad bike injury prevention and use of OPDs.

2 Materials and methods

2.1 Multiple methods for multiple purposes

Due to the varied nature of the research underlying this thesis, diverse research methods were used: survey methodology in Study I, observational longitudinal case study in Study II, experimental study methodology in Study III, and interview methodology in Study IV. These different methods provided opportunities to approach the subject of safety in small-scale forestry from a wide range of perspectives using both quantitative and qualitative data.

2.2 Paper I

Survey methodology was used to investigate the knowledge retention of Swedish chainsaw license holders. Invitations to participate were sent out to a stratified sample of persons listed in the register of chainsaw license holders. In 2016, a sample of 600 persons was randomly selected from candidates who received their level AB-licenses in 2007, 2009, 2011, 2013 and 2015 (and thus 1, 3, 5, 7, and 9 years, respectively, since their chainsaw licenses were issued). A web questionnaire was developed with three parts: a theoretical test for levels A and B; a more descriptive part, aimed at describing and categorizing the respondents; and a self-assessment part allowing each respondent to assess their own experienced change in behavior.

The first part was designed to test the respondent's declarative knowledge. It consisted of a written exam which included 16 questions for level A theoretical examination and 20 questions for level B theoretical examination, which were provided by *Säker Skog [Safe Forest]*, the organization responsible for developing and issuing the chainsaw license, the courses and preparing the examinations.

All questions in this part were multiple choice questions with three options, one of which was correct. The pass mark was the same as for the regular examinations (80 % correct answers) for both level A and B. The second part of the questionnaire consisted of questions regarding the respondent's age, gender, dyslexia, Swedish skills, educational level, previous experience of chainsaw courses, whether they had previously failed a chainsaw license test and their frequency of chainsaw use. This part also contained questions regarding the respondent's preparations for the chainsaw license exam, e.g. the form of courses they attended. The third part of the survey assessed the change in behavior following courses, in terms of both risk-awareness and changes in work practice. All three parts provided possibilities for the respondents to comment on their responses. Any participant could also withdraw from the study at any time.

Descriptive statistics were calculated, and differences among groups were explored and linked to considered factors by statistical techniques (including t-tests, chi-square tests, one-way between-subject ANOVA and regression analysis) using Minitab 18 software (Minitab Inc. 2017).Non-response bias was assessed by comparing known properties and responses of non-respondents with respondents in terms of: age, geographical area (home address aggregated to region), gender and the form of training attended (e.g. regular course, or study circle). Respondents were slightly older (47.3 ± 14.6 years) than non-respondents (45.2 ± 14.5 years, $t(1108) = -3.24$; $p = 0.001$), and they had more frequently chosen to study for the license through study circles ($X^2(5, N= 2921) = 42.595$ $p < 0.01$), but there were no other significant differences between the groups ($p > 0.05$). Beside the tested variables, the database of license holders provided the name of the holder as well as date of approval.

2.3 Paper II

To evaluate skill and knowledge retention, this study focused on experienced, self-employed chainsaw users without a formal chainsaw license. In total, 16 chainsaw users were recruited through an advertisement to participate, with informed consent, in the study and attend a regular three-day chainsaw course, including examination, at a reduced fee. The participants were also informed that all results would be anonymized. This study was based upon the formal examination process employed by the certified examiners working in accordance with the Swedish chainsaw license program. The 16 chainsaw users were divided into two groups of eight (a more typical course group size). Each group was examined three times: once before the course, in the formal examination at the end of the course, and a year after the course examination. During the examinations, the examiners (who are trained to terminate an examination and fail a student who acts in any unsafe way) were responsible for the students' safety. According to the praxis of the chainsaw license, a chainsaw user did not have to attend a formal course prior to an examination. Thus, an experienced chainsaw user could chose to take the examination directly without attending a course. As all participants who participated in this study defined themselves as experienced chainsaw users, they fulfilled the requirement to take the examination prior to the course. According to praxis, the examiners continuously evaluated the situation during each examination, and were expected to abort an examination if they deemed it unsafe to continue.

In order to measure the user's pre-course skill and knowledge, the study began with a regular chainsaw license examination prior to the course. In addition to the theoretical and practical examinations for both levels A and B a short interview was conducted. Each interview included questions concerning the participants and their previous experience of chainsaw use, courses etc. The participants were not allowed to discuss the content of, or their performance in the examination with each other, and they were not given any feedback to minimize any learning effect of this initial examination.

After this first stage, the course began. The course was held by an experienced certified instructor for three days before the regular course examination. In all three examinations (pre-course, end of course and post-course) a separate certified instructor was preforming the examination. After the course examination the participants were asked to answer a course evaluation survey, designed to evaluate the course content, course leader, examinations etc.

About a year after the course examination all participants were invited to a retest, including full level A and B examinations followed by a short interview concerning chainsaw use since the course. The participants were asked to not prepare in any way for this post-course examination. Thirteen of the 16 participants participated in the theoretical examination for levels A and B and the practical examination for level A. Eleven of the 16 participants participated in the practical examination for level B.

2.3.1 Theoretical examination for levels A and B

The theoretical examinations for levels A and B were tests with 16 and 20 multiple-choice questions, respectively. Only one choice for each question was correct, and 80 % correct answers was required for approval for a license in both cases. The level A theoretical examination included questions concerning rules and regulations, safe work practices and appropriate chainsaw maintenance for basic chainsaw work (e.g. cutting firewood). The theoretical examination for level B included questions concerning use of felling tools, safe work practice whilst felling and bucking, safety in general and ergonomics.

2.3.2 Practical examination for levels A and B

In the practical examination for level A, the participants were asked to assemble and mount a chain and bar on a chainsaw and to sharpen a cutter and a depth gauge. They were then asked to cut a disc from the end of a log with both pulling and pushing chain. Finally, they were asked to make a horizontal and vertical plunge cut. For each of 13 examination points, the participants could receive the grade *failed, approved with a minor fail* or *approved*. If a participant received one *failed* examination grade or at least four *approved with a minor fail* grades, s/he failed the test according to the praxis for chainsaw license level A.

The practical examination for level B included risk assessment and the participants had to choose a direction for felling. They then had to decide an appropriate width of the hinge and height of fell cut in mm. The participants were then asked to fell a tree within the allowed deviations from the chosen direction, with a hinge close to the initially decided dimensions. After the felling the participants had to de-limb and buck the tree. A total of 23 points were evaluated, for each of which the participants could receive the grade *failed*, *approved with a minor fail* or *approved*. In addition to these regular examination grades the participants in this study could get the grade *approved with praise* for 12 points (e.g., risk assessment, direction, cutting of the hinge, de-limbing). If a participant received one *failed* examination grade or at least five *approved with a minor fail* grades, s/he failed the test according to the praxis for chainsaw license level B. However, if the examiner considered it safe to continue, the examination would continue even after a failed point. For example, if the user failed to fell the tree within the allowed deviation from the chosen direction and was failed, but the examiner assessed it to be safe, the examination would continue with the de-limbing and bucking of the tree.

2.4 Paper III

To investigate the quad bike´s static stability an experimental study methodology was chosen. This study was conducted in two parts, designated Parts A and B. Part A focused mainly on measuring effects on a quad bike's static stability of: an attached trailer with varying load sizes and distributions, the approach angle of the bike (with and without attached trailer) to a slope, and mounting a heavy OPD on the bike.

Based partly on results from part A and previous studies (Edenhamn 1990b; Nordfjell 1995; Grzebieta et al. 2015c), a light prototype OPD was developed and used in part B. The main objective of this part was to investigate effects of mounting the light prototype ROPS on the quad bike, and various hardware configurations intended to increase the static stability and thus counteract the negative impact of retrofitting a ROPS.

To measure the static tilt angle, a tilt table designed for testing heavy machines was used. Before raising the tilt table, the quad bike was positioned and secured with safety lines attached to the front and rear load racks as well as to the trailer (when one was attached) to prevent a complete overturn. The quad bike's brakes were mechanically locked by inserting a bolt through the ventilation holes on the brake discs. Sliding was prevented in both Studies A and B, but by different means (for details see the sections below regarding each study). The static tilt angle was defined as the angle at which two of the quad bike's wheels or two of the trailer's wheels were no longer in contact with the tilt table's surface. The angle was measured with an inclinometer with a scale of 360° per turn, and 0.25° accuracy.

The same rider, weighing 97 kg including clothes and shoes, was used in both Studies A and B. The rider simulated normal riding by leaning into the slope, but with both feet in contact with each footrest and both hands on the handlebars. For one test, the rider's weight was increased by strapping 20 kg to the rider's upper torso to investigate possible effects of this variable on stability.

2.4.1 Study Part A - Effects of approach angle, heavy ROPS and trailer load

The quad bike used in this part of the study was a Honda TRX500FA Foreman, with a weight of 301 kg and tire pressure set to 25 kPa. The trailer was a Honda LT10 bogie timber trailer. The trailer weighed 161 kg without load, and its tire pressure was also set to 25 kPa. The vertical hitch load was set to the manufacture's recommendation, a vertical downwards force of 137 N (14 kg). This was used in all trials except when the effect of a negative hitch load was tested. In negative hitch load tests the load was set to a vertical lifting force of 196 N (-20 kg). The trailer load consisted of conifer pulpwood cut to a length of 380 cm, with log diameters ranging from 9 to18 cm. Two load sizes were used in this study: recommended (224 kg, 0.3 m^3) and normal (570 kg, 0.7 m^3). This resulted in total (trailer and load) towed weights equal to the maximum towing weight recommended by the manufacturer (385 kg) and 731 kg, respectively. The ROPS used was the heavy 44 kg Atvbow (ATV-Bågen AB), one of the very few quad bike ROPS sold in Sweden, consisting of a four-posted cage attached to the quad bike's front and rear loading racks. The total height of the ROPS from the attachment points was 100 cm, resulting in an approximate height of 185 cm from the ground. The ROPS was certified according to the EU directive for rear-mounted rollover protection structures for narrow-track wheeled agricultural and forestry tractors (86/298/EEC 1986).

To prevent the quad bike and trailer from sliding as the table was lifted, a 45 mm thick board was mounted on the tilt table in front of and to the side of the vehicle.

2.4.2 Study Part B - Effects of hardware configuration and a light ROPS

The quad bike used in this part of the study was a GOES 320, weighing 345 kg. It was equipped with adjustable suspension for all wheels and the hardest and softest settings for suspension stiffness were used in this study. The OPD used was an experimental two-post prototype, center mounted to the front and rear loading racks as well as to the hitch. It weighed 14.7 kg and was 94 cm above the loading rack, giving it a maximum height of 205 cm above the ground.

The quad bike was placed perpendicular (approach angle 0°) to the slope in all trials. To prevent it sliding, chains were attached to its wheels. This method was based on the experience from Study A; it allowed the quad bike to overturn while negligibly affecting its stability. The chains were placed under the tires and attached to the outside of the rims.

2.4.3 Analysis

Since the experimental setup was expected to result in minimal variation in static tilt angles for a given combination of factors, replicate tests, with up to five repetitions, were only applied to the key combinations under investigation. For combinations with repetitions, arithmetic mean values and standard deviations of the results were calculated. Effects of the fixed factors quad bike weight and approach angle were evaluated using a full two-way Analysis of Variance (ANOVA) model, including five levels of weights and two levels of approach angle. Pairwise differences were analyzed with Tukey's simultaneous test of means. Effects of the fixed factors quad bike weight and track width were also evaluated using two-way ANOVA and Tukey tests, again with five weight levels, and two width levels. Linear regression was used to establish the relationship between track width and static stability, which was best described with a quadratic model. The critical level of significance was set to 5%.

2.5 Paper IV

To explore reasons for decisions to install a quad bike OPD, and examine quad bike riders' general understanding of quad bike injury prevention and use of OPDs, this study was conducted in two parts. In the first, quad bike riders attending Sweden's two major forestry fairs were recruited to participate in a short interview concerning quad bike injury prevention and the use of quad bike OPDs. The second part comprised in-depth interviews with quad bike OPD owners, focusing on their decision to install a quad bike OPD.

2.5.1 Forestry fair interviews

Due to the lack of available records on quad bike owners or users, participants meeting these criteria were sought at annual events that they were expected to attend in sufficient numbers for efficient data gathering. These were two major Swedish forestry fairs in 2015: SkogsElmia (June 4-6, outside the town Jönköping, in southern Sweden), and Skogsnolia (June 11-13, outside the town Umeå, in northern Sweden). All major actors in the forestry sector, including quad bike manufactures and retailers, are represented at these fairs, which also attract forestry professionals, but mainly non-industrial private forest owners, farmers, and other rural people interested in forestry. The fairs play important roles in the Swedish forestry community, and both forest governance and operation (Törnqvist 1995; Appelstrand 2007).

At both fairs, the same interviewer (author of this thesis) approached visitors with the same street intercept survey method. Visitors were arbitrarily selected and approached by the interviewer and asked if they used quad bikes. Thus, not only owners, but other types of quad bike users (e.g., employees, spouses, and other relatives) were eligible respondents. Thus, anyone answering positively was eligible and invited to participate in an interview on quad bike safety. The respondents were not offered any form of compensation for their participation, and were interviewed immediately after providing informed consent to participate. If an interviewee was a member of a group, it was ensured that s/he was not disturbed or influenced by the group. There was no time limit for the interviews, but they typically lasted 10 to 20 min.

In total, 158 persons were approached, 59 of whom (34 at the northern fair and 25 at the southern fair) participated in the study and 99 declined to participate, mostly without responding to the initial invitation. Hence, no data were collected from the non-participants, so it was not possible to determine if they were members of the population of interest (i.e., quad bike riders, but not interested in participating in the study), nor was information available on the proportion of fair visitors who were quad bike riders.

Given the street intercept survey method, the interviewees could not prepare themselves for the interview. Each interview followed a guide with 15 open-ended questions split into three sections. The first section concerned the respondent, with questions about the respondent's age, gender, quad bike use, and previous experience of dangerous quad bike incidents. Follow-up questions asked respondents to categorize reported incidents as resulting in an injury or damage, or not resulting in an injury or damage.

In the second section of each interview, the respondents were asked to suggest what they thought were the most important ways to reduce injuries and deaths in quad bike-related incidents. The structure of the interview ensured that the interviewer had not mentioned anything about the nature of quad bike incidents or injury prevention before asking this question. Therefore, the respondents' answers were expected to provide more information than might have been suggested by the interviewer. This question was expected to reveal the respondents' views on major issues in quad bike safety, including who is at risk and who should be targeted by interventions.

In the last section, the respondents were asked about their own use of specified safety equipment and their reasons for using or not using OPDs on their quad bikes. The specific order of the questions between and within the three sections of the interview was used to minimize the interviewer's influence on the answers. Thus, the responses were considered more likely to reflect the respondents' own opinions when asked about ways to reduce injuries and about their use of PPE and OPDs.

Data analyses were initiated after the second fair. Responses to each question were inductively coded, and these initial results were subsequently used to develop a final coding scheme, based on similarities of the responses. The data were quantitatively treated by compiling frequencies, sums, and mean values. All interviews were conducted, recorded, coded, and analyzed by the same person, while the interview guide and final coding scheme were the result of a joint effort by all authors of paper IV.

2.5.2 Quad bike OPD owner interviews

A record of persons owning quad bikes equipped with OPD was compiled using information from OPD manufacturers, importers, and dealers as well as through personal recommendations, thereby combining mixed and emergent sampling strategies (Patton 2002) and incorporating purposive and snowball approaches (Noy 2008). The search aimed at covering the whole country, but yielded only 15 potential respondents. When contacted, these respondents were informed that they had been contacted due to their experience with quad bike OPDs and invited to participate, as interviewees, in a quad bike safety study. Of the 15 potential respondents, 11 agreed to participate and provided informed consent. The respondents were not offered any compensation for their participation. Because the respondents were spread throughout the country, two interviews were conducted in person, and the other nine were conducted by phone. All interviews were audio-recorded with the consent of the respondents and conducted by the author of this thesis, who also (as already mentioned) conducted the forestry fair interviews.

The OPD owner interviews were semi-structured, the questions were open-ended, and the interview guide was based on the theoretical framework, with emphasis on the experiences and perspectives of the interviewees. Each interview had four parts. The first part included questions concerning the respondent, such as age, gender, experience with quad bikes and other vehicles, frequency of quad bike use, type of work, living situation, etc. The second part included questions concerning personal experience of incidents related to quad bikes and their implications. The third part included questions concerning injury prevention, such as education, use of PPE (e.g., helmet, gloves, boots, googles), and use of OPDs. The fourth part included questions concerning the respondents' experience with quad bikes equipped with OPD.

The interviews were transcribed as they were collected, and coding was initiated after the last interview. Responses to each question were inductively coded, and these initial results were subsequently used to develop a final coding scheme, based on similarities of the responses. Based on the refined coding, the results were structured into three themes based on the theoretical framework: personal experience in the sense-making of risk, blame, and self-regulation of risk. The interviews were conducted, coded, and analyzed by the same person who conducted the interviews, while the interview guide and final coding scheme were the result of a joint effort by all authors of paper IV.

3 Results

3.1 Paper I

3.1.1 Respondents

The 682 chainsaw license holders participating in this study were mainly infrequent chainsaw users, felling some trees on their own land a few days each year. The vast majority were men (90%). About 40 % had prepared for the examinations through a study circle with or without support from a certified instructor. A third prepared for the test through a course over 3 days or more, provided by a certified instructor. Only 4 % took the test without any prior subject studies.

3.1.2 Self-assessed behavioral change

The vast majority of the respondents considered that the training prior to the examination strongly improved their risk awareness and use of safer work methods (*Figure 3*).

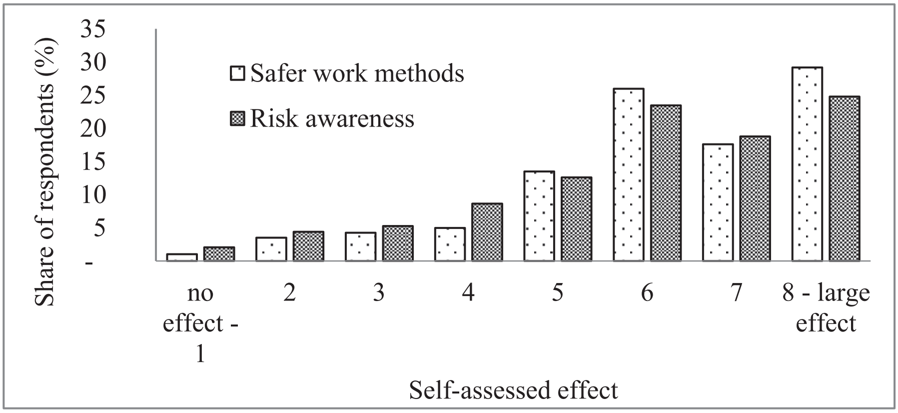

Figure 3. Percentages of respondents reporting self-assessed change in risk awareness and safer work methods after the chain saw license training, on a scale from 1 (no safer behavior or increased risk awareness) to 8 (highly increased risk awareness or much safer work methods).

3.1.3 Test results

Out of all 682 respondents 45 % passed the theoretical retest for both chainsaw license levels A and B, 75 % passed the level A retest, and 52 % passed the level B retest.

Testing effects of the respondent's level of education on the retest results showed that those who only had completed primary school performed significantly less well than those with higher education levels, scoring almost 2 points less than the others, and only about 30 % passed the retest compared to 45-50 % of those with higher (more) education (Tukey HSD, $p<0.005$). However there were no significant differences in this respect among respondents with the other four categories of education above primary school.

Respondents who had previously attended, some sort of formal chainsaw training (before the chainsaw license course) scored significantly higher (Mean = 29.7, SD = 3.8) then the others (Mean = 28.7, SD = 3.63). In contrast, those who had failed the chainsaw license examination at least ones before being approved performed significantly less well than the others (ANOVA and Tukey HSD test, $p < 0.01$, R-sq = 1.94 %), scoring on average 7 points less in the re-test, and only 27 % passed this retest, compared to 46 % of those who passed the chainsaw license examination at their first attempt.

The retest scores were significantly positively related to amount of chainsaw use ($p < 0.01$). Respondents who did any type of chainsaw work for more than 20 days obtained a significantly higher mean score than those who did no chainsaw work at all (Tukey HSD, $p < 0.05$). This positive relationship was strongest for felling type work (ANOVA: $p < 0.01$, R-Sq = 10.84 %; *Figure 4*). Those engaged in felling more than 20 days a year obtained higher scores (Mean = 30.0, SD = 3.53) than those who worked 4-10 days (Mean = 28.7, SD = 2.23) or less according to the Tukey HSD test. Moreover, those working 4-10 days obtained significantly higher scores than those who worked less than 4 days a year.

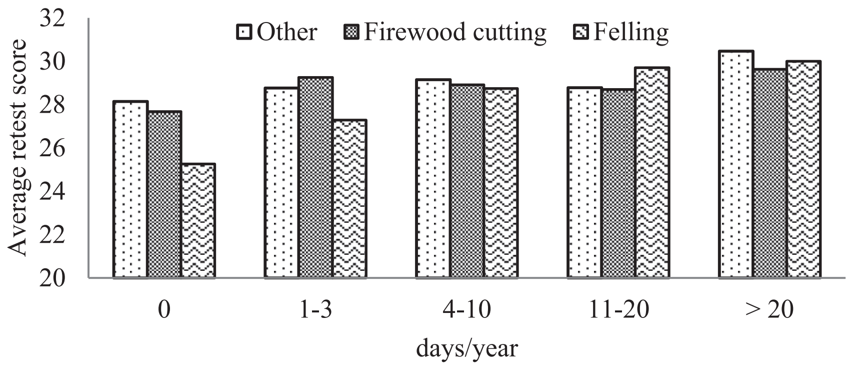

Figure 4. Average combined scores in the A and B retests for groups with indicated frequencies of chainsaw use in: felling, bucking and de-limbing; firewood production; and other purposes.

Time had a significant main effect on retest results ($p < 0.01$ R-sq = 3.14 %) (*Figure 5*). Post hoc comparisons using the Tukey HSD test indicated that mean scores of those had taken their license examination 5 or 7 and 3 years previously significantly differed ($p<0.05$), but those who had taken it nine years previously did not significantly differ from any other group in this respect. However, the difference between those who had taken it 5-7 and 3 years previously was due to two questions in the retest regarding new regulations for chainsaw use introduced 2012. Hence, they were not covered in the test seven years before the retest. When those questions were ignored there was no significant difference in retest performance between groups who had taken the test three, five and seven years previously. Interactions between usage (days/year) and time since obtaining a license were also tested, but no interaction effect was found between these variables. The average number of persons who passed followed the same distribution as average score variables.

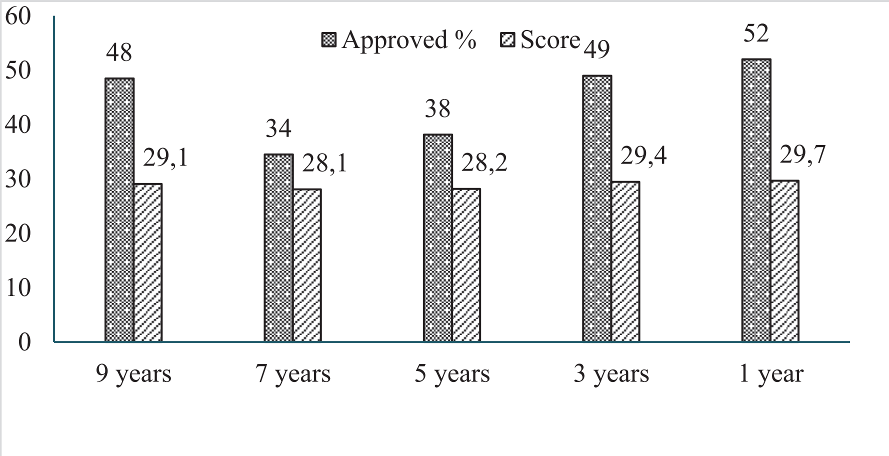

Figure 5. Average combined scores in the A and B retests for those who obtained licenses 1-9 years ago and proportions of persons passing the retest.

3.2 Paper II

3.2.1 Course participants

The mean age of the self-employed chainsaw users participating in this study was 56 years (range 31-70 years). All 16 participants were men, all but two were forest owners, and all worked mainly with a chainsaw on their own forest estate or someone else's forest estate (e.g., helping out their father on his estate). At the time of the course, the participants reported that they normally worked with a approximately 14 days a year, on average. The respondents' main use of chainsaw was in felling, de-limbing and bucking in thinning and cutting of firewood.

On average, the 13 participants who took the one-year post-course examination had worked with a chainsaw for three days during the year since completing the course. None of the participants had attended any further chainsaw courses during this time.

3.2.2 Knowledge retention

During the pre-course theoretical examinations, 6 and 8 of the 16 participants obtained at least the 80 % threshold approval scores for levels A and B, respectively. In the course examination, 14 and all 16 of the respondents met the approval requirements for level A and level B theoretical examination, respectively. A year later in the post-course examination, 11 out of the 13 participants attending met the approval requirements for level A and 10 of 13 for level B. Proportions of pooled correct answers for level A and B questions in the pre-course examination, course examination and post-course examination were 75 %, 88 % and 85 %, respectively (*Figure 6*).

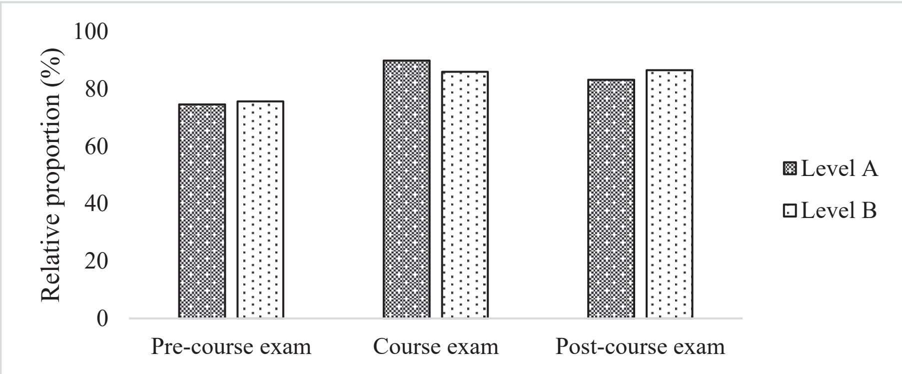

Figure 6. Proportions of correct answers (of all participants pooled) in the level A and level B theoretical elements of all three examinations

3.2.3 Skill retention

Scores of all respondents showed major improvement in skills after the course (*Figure 8*). In each practical examination, the attendees were graded for a total of 36 examination points (13 for level A and 23 for level B). The total number of failed grades (for all participants pooled) decreased from 25 % of the total in the pre-course examination to 2 % and 3 % in the course and post-course examinations, respectively (*Figure 7*). However, despite the high scores, the failed grades would have resulted in failure of the examinations (for which a single failed grade may be sufficient) in substantial proportions of cases. No respondent met the approval thresholds for both levels A and B in the practical pre-course examination, but 8 out of 16, and 8 out of 11 did in the practical course examination and post-course practical examination, respectively.

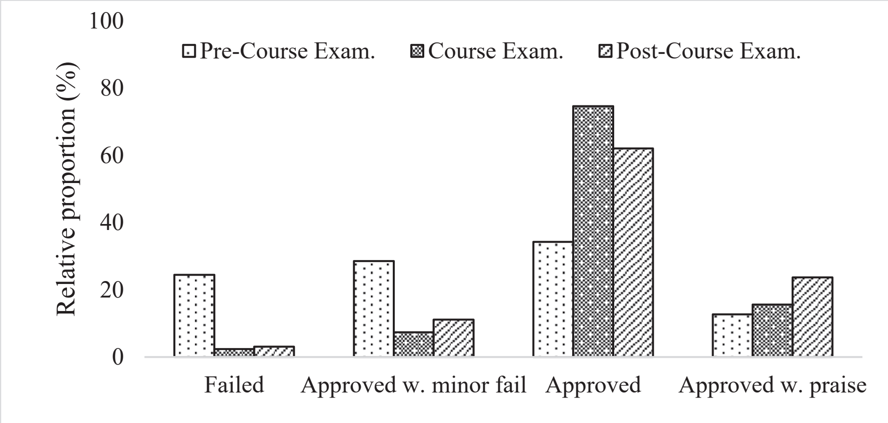

Figure 7. Proportions of grades (pooled for all participants) for all level A and B practical examination points in each of the three practical examinations. The sum of all grades for a given examination equals 100 %.

Four respondents improved after the course, i.e. obtained higher scores in the practical post-course examination than in the course examination. Four respondents did not improve but scored maximum scores in both the course examination and post-course examinations. Three respondents performed less well in the post-course examination than in the course examination and five participants did not attend the post-course practical examination (*Figure 8*).

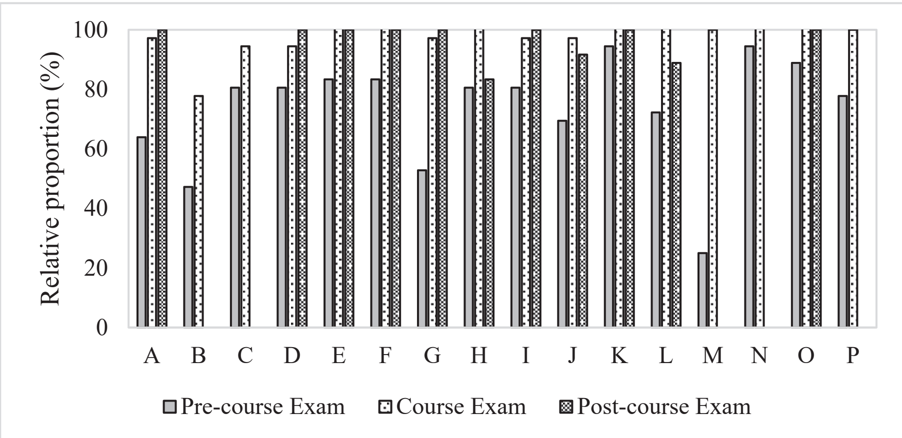

Figure 8. Proportion of examination points for which each respondent (A-P) obtained Approved (Approved, Approved with minor fail and Approved with praise) grades for examination points in the combined level A and B practical examinations.

Specific areas of skill

The point for which the respondents obtained the lowest score overall in all examinations combined concerned use of PPE. Most commonly this was due to repeatedly neglecting to use the helmet face shield. One point for which the average score was low in the pre-course examination, but not the course or post-course examination concerned the quality of the hinge. Especially concerning was the by-pass cuts while cutting the face notch in the pre-course examination (Table *1*). However, most of the behavior causing the low scores in the pre-course examination was corrected during the course (Table *1*). During the course examination, *felling precision* was an examination point that caused difficulties for several respondents, who failed to fell within the approved deviation. Two major elements of poor performance by respondents during the post-course examination were deficiencies in using PPE, for which two respondents failed, due to repeatedly forgetting to use the helmet face shield, and poor de-limbing technique.

Table 1. *The 10 examination points (out of 36) for which the highest numbers of respondents failed in the pre-course examination. 16 participants took the pre-course and course examination and 11 took the post-course examination*

Examination point	Failed respondents (n)				Approved with minor fail (n)			
	Pre-course	Course	Post-course	Sum	Pre-course	Course	Post-course	Sum
Use of PPE	13	2	2	17	1	3	0	4
File of depth gauge	10	0	1	10	5	1	1	7
Saw handling, de-limbing	9	0	1	10	3	3	1	7
Felling, precision	4	4	1	9	3	3	2	8
Correct start of chainsaw	8	0	0	8	6	0	3	9
Horizontal cut by-pass	8	0	0	8	2	1	2	5
Angled cut by-pass	8	0	0	8	2	1	1	4
Use of escape route	7	0	1	8	1	0	0	1
De-limbing technique	3	3	1	7	8	6	4	18
Saw handling, plunge cut	7	0	0	7	7	0	2	9

3.2.4 Self-reported change in behavior

At the end of the course the respondents were asked to fill a course evaluation form. Over all, the participants reported that the course had substantially improved their knowledge and skill. And In the post-course examination the participants were asked if (and if so how) the course had changed their behavior. The reported self-assessed changes in behavior a year after the course were: improved de-limbing techniques (eight respondents), improved felling technique, e.g. routine use of a plunge cut (six respondents), better saw handling in general (five respondents), better ergonomics (four respondents), use of chain brake during moving (three respondents) and better chain sharpening techniques (two respondents).

3.3 Paper III

3.3.1 Study A

The quad bike's static stability increased with increasing approach angle. When changing from a position perpendicular to the slope (0° approach angle) to facing the slope at a 45° approach angle, the static stability increased by between 5.8° and 7.7° (Table 2). However, increasing the approach angle from 0° to 15° only had a marginal effect on static stability. Equipping the quad bike with the heavy ROPS and a rider reduced the static stability by between 4.8° and 5.8°. Increasing the rider's bodyweight by 20 kg (from 97 kg to 117 kg) further reduced the quad bike's static stability by between 1.8° and 2.2° (Table 2).

When the quad bike had the light trailer attached, its static stability remained similar to that of the quad bike alone. The loaded trailer even increased the stability of the vehicle slightly compared to the stability of the quad bike without the trailer (Table *2*). At a position perpendicular to the slope (0° approach angle) the light trailer tilted before the quad bike, but with approach angles of both 15° and 30° the quad bike tilted before the trailer. At an approach angle of 45° the tilt table's maximum tilting angle (48.5°) was reached before the quad bike or the trailer tilted (Table *2*). The heavy trailer, with a gross weight of 731 kg, reduced the vehicle's stability by between 6.6° and 9.8° compared to the light trailer (385 kg). In all trials, the heavy trailer tilted before the quad bike. The static stability of the quad bike with rider and heavy ROPS was considerably lower than it was for the quad bike with a rider and an attached heavy trailer, which in turn had considerably lower stability than a quad bike with an active rider but without a trailer or ROPS (Table *2*).

Table 2. *Static tilt angles (°) recorded for different approach angles and quad bike configurations. Means and standard deviations (SD) are reported for repeated tests.*

Treatment				Approach angle			
				0°	15°	30°	45°
Rider	ROPS	Trailer	Hitch load	mean (sd)	mean (sd)	mean (sd)	mean (sd)
-	-	-	-	43.5 (0.08)^{c}	43.9	46.9	> 48.5 (0)^{a}
-	Heavy	-	-	36 (0.08)^{f}	36.3	38.7	43.6 (0.17)^{c}
Rider	Heavy	-	-	33.5 (0.36)^{g}	34.1	35.7	39.8 (0.17)^{d}
Rider	-	-	-	38.6 (0.22)^{e}	38.9	41.5	45.6 (0.32)^{b}
Heavy	-	-	-	36.4	37.0	39.7	43.7
Rider	-	Heavy	Rec.	36.5	37.5	38.5	42.3
-	-	Heavy	Rec.	36.4	37.6	38.9	42.7
-	-	Heavy	Neg.	37.2	38.2	39.4	44.6
-	-	Light	Rec.	43.0	45.4	48.5	> 48.5

Note: In some cases the tilt table's maximum tilt angle of 48.5° was reached without the vehicle tipping over. Values with different superscripted letters are significantly different ($p \leq 0.05$) according to ANOVA and Tukey's test.

3.3.2 Study B

The stiffness of the suspension had no significant effect on the vehicle's static lateral stability, whereas increasing the tire pressure resulted in a slight increase in lateral stability. Increasing tire pressure from 20 to 50 kPa generally increased the static tilt angle by 1° both with and without a light ROPS mounted.

Neither adding skid plates alone (14.9 kg), nor skid plates plus an additional 20 kg of wheel weights (4 × 5 kg), had any significant effect on the quad bike's lateral stability. Increasing track width by 86.4 mm resulted in a 3.8° increase in static tilt angle for the quad bike equipped with a light ROPS (Table *3*).

Table 3. *Static tilt angle for quad bike with mounted rider, hard suspension and a tire pressure of 35 kPa with different weight configurations and increased track width.*

Treatment			Increase in track width (mm)			
			0 (Standard)		86.4	
Skid plates	Light ROPS	Wheel weights	mean	sd	mean	sd
No	No	No	31.9[a]	0.22	-	-
Yes	No	No	32.1[a]	0.22	35.3[c]	0.43
No	Yes	No	30.9[b]	0.14	34.7[d]	0.29
Yes	Yes	No	31.3[b]	0.27	34.6[d]	0.11
Yes	Yes	Yes	-	-	34.9[d]	0.22

Note: Values with different superscripted letters are significantly different ($p \leq 0.05$) according to ANOVA and Tukey's test.

Increasing track width by 20 mm resulted in a static tilt angle of more than 32° (*Figure 9*), which compensated for the reduction in stability due to the mounted light OPD (cf. Table *3*).

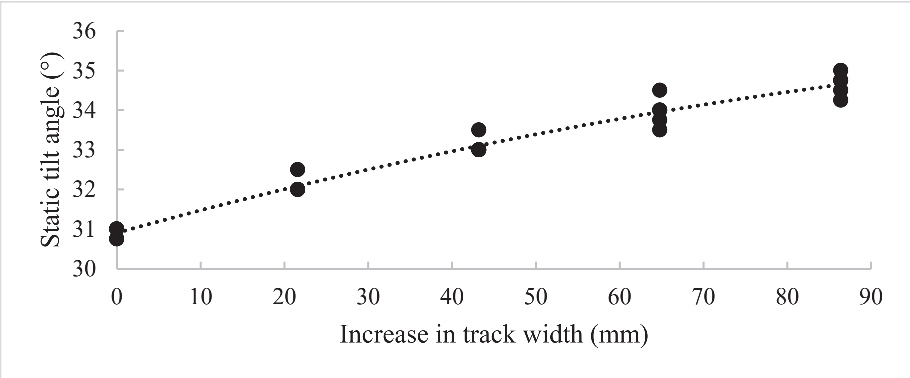

Figure 9. Static tilt angle (°) required for lateral roll for quad bike with active rider and mounted light ROPS as a function of increase in vehicle track width. Curved linear relationship (y = -0.0002x2 + 0.0585x + 30.906). $R^2 = 0.9703$, $p < 0.001$).

3.4 Paper IV

3.4.1 Non-OPD users' quad bike use and perceptions of safety

The mean age of the 59 non-OPD users' participating in the forestry fair interviews was 53 years. Most (78%) had been using quad bikes for more than three years, and 87% reported using the quad bike a few times a month or more often. The most commonly reported use was in small-scale forestry, including activities both with and without a trailer. Nineteen (32%) respondents reported a total of 22 situations in which they lost control of a quad bike. There were 12 reported rollover incidents resulting in injury, six non-injury rollover incidents, three incidents related to towing, and one collision resulting in injury.

Perceptions of quad bike injury prevention

The respondents' four most common suggestions for efficient ways to reduce quad bike injuries were to limit the vehicle's top speed, general risk awareness campaigns, drunk driving risk awareness campaigns, and a legal requirement for quad bike OPDs. Categorization of the respondents' suggestions in terms of targeted problems (Table *4*) showed that the respondents most commonly targeted rider's recklessness (36 respondents, 61%) and lack of skill (25 respondents, 42%). Poor vehicle design was highlighted by 18 (31%) of the respondents, and nine (15%) suggested actions targeting the lack of PPE use. Analysis of the respondents' suggested interventions showed that 25 (42%) of the respondents only suggested actions targeting rider behavior (e.g., lack of skill, uninformed riders, drunk driving, use of PPE), while 11 (19%) only suggested actions targeting vehicle design (e.g., OPD, protection against jackknifing, emergency ignition switch). The remaining 18 (31%) of respondents suggested actions targeting a combination of both rider behavior and vehicle design.

Table 4. *Classification of the respondents' suggestions for reducing quad bike-related injuries in terms of targeted problems. Respondents could suggest several different actions and thus be represented in several categories (N=59)*

Suggested target problem	n	%
Rider recklessness (Speeding, excessive risk-taking in recreational riding, drunk driving)	36	61
Rider lacking in skill (Uniformed riders, uninformed parents, lacking skill)	25	42
Poor vehicle design (Roll-over, jackknifing, emergency ignition switch, excessive engine power)	18	31
Deficiency in use of PPE (Helmet, boots)	9	15
Don't know	4	7

Seventeen of the respondents (31%) considered OPD unnecessary due to the small risk of a rollover injury they perceived. However, 29% of the OPD-less respondents were open to using ROPS. Seven (13%) of the OPD-less respondents reported that they were uncertain of the safety benefits associated with OPD on a quad bike. In addition, 9% of the OPD-less respondents were opposed to OPD, arguing that it increased risks for the rider. When asked why they did not use OPD, a main reason mentioned by 13% of the ROPS-less respondents was that their quad bike dealer failed to recommend a specific model of OPD. One respondent was unaware that OPD was available for quad bikes, while 24% of the OPD-less respondents believed that OPD would hinder their conventional quad bike use and therefore opposed use of OPD. Five percent of the OPD-less respondents argued that price was a major issue, i.e., the available OPD were too expensive.

3.4.2 Risk perception and management by quad bike OPD owners

Respondents

Eleven respondents (10 male, one female) with experience of using quad bikes equipped with OPDs were interviewed. These respondents had a mean age of 63 (range, 31 to 92 years old). They had been riding quad bikes for an average of 14 years and had, on average, 2.6 years' experience of riding quad bikes equipped with OPDs. Their estimated frequency of quad bike use varied from a dozen times a year to almost daily. The most commonly reported use was in forestry, as seven respondents stated that they regularly used quad bikes for small-scale forestry activities.

Personal experience of quad bike-related incidents

Nine of the 11 interviewed respondents had been involved in, or knew someone who had been injured in, what they considered a quad bike-related incident. In accordance with the general view that an individual's personal experience is a fundamental element of the sense-making of risk (Wall and Olofsson 2008), several respondents revealed that their previous experience influenced this sense-making. And that the experience acted as a catalyst in the decision to install an OPD. These experiences also affected the respondents' perceived responsibility for the safety of others, whom the respondents considered less experienced and thus lacking their understanding of quad bike risks.

Blame

The perception of risk and need for intervention are influenced by an individual's understanding of incidents and allocation of blame. All three categories of blame allocation moralistic, individual adversaries, and externalization (Douglas, 1994), were encountered during the OPD owner interviews.

Several respondents largely applied a moralistic allocation of blame. Inappropriate riders, drunk driving, and careless operation were recurring themes in many interviews. Several respondents emphasized that if riders would act with care, the vehicles would not be dangerous. In other words, they considered the problem to be an issue of riders driving carelessly and taking inappropriate risks. In this construction of the problem, a careless rider is considered a breaker of social norms. The problem and the risk are therefore individualized and associated with people who have only themselves to blame.

The second category of blame, individual adversaries (Douglas, 1994), was also a recurring theme in the responses. In this category, the importance of skill and training was emphasized. As in the moralistic category, quad bike incidents and risks are attributed to the riders, i.e., from this perspective the quad bike is harmless, and the riders lack the requisite skills. Therefore, quad bike safety is once again individualized.

The last category of blame, externalization, was also detected in the respondents' opinions of quad bike incidents. In Sweden, such externalization is mainly aimed at the state, which has a long history of safety regulation and risk prevention. These respondents stated that safety problems were due to poor engineering or lack of legislation, rather than rider recklessness or lack of skill. Thus, these respondents placed the responsibility for quad bike injuries with the manufacturers or legislators, rather than the individual rider.

Individual responsibility and self-regulation

Although several respondents in both sets of interviews clearly stated that the main responsibility for accidents lies with the victim, they still supported the use of ROPS. However, this support was predicated on the responsibility of riders for protecting their family, friends, or employees from danger, as they might lack knowledge, skill, or care. Regarding quad bike safety, a dominant viewpoint of the respondents was that, in terms of responsibility for the safety of others, OPD are mainly needed to address the riders' lack of skill, rather than a flaw in the vehicles' design.

4 Discussion

4.1 Prevention of injuries in small-scale forestry

The overall objective of this thesis was to investigate barriers to, perceptions of, and interventions promoting safety in Swedish small-scale forestry. More specifically, interventions regarding two high-risk activities: the work with chainsaws in felling, de-limbing and bucking trees, and use of quad bikes for off-road transportation of personnel, equipment and logs. For this, four studies were conducted: two on longitudinal effects of chainsaw education, and two on the implementation and development of quad bike OPDs. Despite the high level of risk associated with these activities, several important aspects have not received sufficient research attention; therefore, different approaches were adopted in the four studies to broaden understanding of the major issues. In this section, the main results are discussed in relation to previous research as well as possible practical applications.

4.1.1 Chainsaw safety

As previously shown, two of the most important elements of chainsaw safety are knowledge and use of safe work practices. Thus, chainsaw training could be an important tool in prevention of chainsaw-related injuries. In current Swedish forestry, an examination must be taken to obtain the license required for most chainsaw work, and a three-day training course or similar is usually attended before taking the examination. However, effects of the training associated with acquisition of a Swedish chainsaw license, including its long-term effects on chainsaw users' knowledge, skill and practices, has not been well studied. As previously described, it is in this context that Studies I and II were conducted, with the main objective to investigate effects of time on knowledge and skill retention.

In the first study, responses to a questionnaire, including a re-test of knowledge covered in the theoretical part of the chainsaw examination (levels A and B), revealed two interesting effects of time. First, substantial knowledge degeneration with time was detected: only 45 % of the respondents passed the theoretical parts of both the chainsaw level A and B retests. However, most of this degeneration seemed to occur within the first year. This corresponds well with previous findings regarding knowledge retention (Eisenburger and Safar 1999; Saks and Belcourt 2006; Anderson et al. 2011). It also corresponds reasonably well with a previous study of the chainsaw license, although that study was on participants of a study circle and found slightly higher levels of knowledge retention (Lindroos 2009). All respondents in Study I had obtained a chainsaw license one to nine years earlier, but within this timeframe no distinct effect of time since the exam was detected. However, the amount of respondent's work with a chainsaw had a significant positive effect on the retest results. This is consistent with previous findings that repetition plays a major role in training retention (Arthur Jr et al. 1998; Eisenburger and Safar 1999).

Studies of skill retention have shown that skills seem to deteriorate faster than knowledge (e.g. Arthur Jr et al. 1998). For example, significant deterioration in CPR and first aid skills has been detected after about 30 days (Anderson et al. 2011). Thus, as skill is essential in chainsaw safety as well as the knowledge assessed in Study I, the second study focused mainly on skill retention. This was a longitudinal case study, in which two groups of eight self-employed forest owners were examined before and immediately after a regular chainsaw training course, and re-tested in a post-course examination in the following year. For theoretical elements, the two groups' overall percentage of correct answers decreased from 88 % in the course examination to 85 % in the post-course examination. These are higher levels of knowledge retention than found in Study I and a previous study of retention of Swedish chainsaw training (Lindroos 2009). In terms of skill retention, only three out of 11 respondents performed less well in the practical post-course examination than in the course examination. The other eight either improved or scored maximum points during both the course examination and post-course examination. This does not correspond with previous findings regarding skill retention (e.g. Anderson et al. 2011), but could potentially be due to a combination of factors. For example, experienced users being in a different learning phase from beginners (Kim et al. 2013), continuous learning after the course (Saks and Belcourt 2006), and test anxiety (Cassady and Johnson 2002) could all have potentially contributed to this effect. This was an interesting result, showing again that time is not as powerful a degenerative factor in terms of knowledge and skill retention as one may believe, and that complex issues are associated with both training intended to prevent injury and the retention of acquired knowledge and skills.

4.1.2 Quad bike safety

It has long been known that use of quad bikes is associated with high risk of rollover incidents (e.g. Allan et al. 1988; Teret and Jagger 1991; O'Connor et al. 2009; Shulruf and Balemi 2010; Lower and Trotter 2014; Hicks et al. 2018). As already mentioned, for several decades the main suggested solution for reducing rollover injuries has been to equip quad bikes with some sort of operator protective device (OPD) (Dahle 1987; Edenhamn 1990b; Nordfjell 1995; Rechnitzer et al. 2003; Snook 2009; Rizzi 2010; Shulruf and Balemi 2010; Frisk and Nordfjell 2012; Wordley Scott and Field 2012; Richardson et al. 2013; Wordley S. 2013; Lower and Trotter 2014; Grzebieta et al. 2015c; Myers 2016; Australian Competition and Consumer Commission 2019; Strohfeldt 2019). However, use of OPDs on quad bikes has generated intense debate between researchers and an alliance of manufacturers and some quad bike users, who strongly oppose equipping quad bikes with OPDs (Lower and Trotter, 2014; Wordley and Field, 2012). No OPD has yet been widely adopted, and many questions regarding the optimal kinds of OPDs, their effects and implementation have not been adequately addressed. Thus, aims of Studies III and IV were to add knowledge that may contribute to the development and implementation of quad bike OPDs.

Study III resulted in two findings of major interest. First, the weight and construction of an OPD can have major effects on a quad bike's stability, but the prototype OPD tested also showed that a light OPD only slightly reduces its stability. This corresponds well with results of a previous study of quad bike stability, including tests with three different quad bike OPDs (Grzebieta et al. 2015b). The second main finding was that an effective way of increasing quad bikes' stability is to increase their track width. An increase of less than 20 mm compensated for the negative impact of the light OPD on the quad bike's stability. To summarize results of the third study, the design of a quad bike OPD may involve a trade-off between enhancing safety and increasing risks of rollover incidents. However, a well-designed OPD minimizes the additional risk, and countermeasures to increase the vehicle's stability are readily available. The prototype OPD used in this study was later crush-tested outside the scope of Study III. The quad bike (the same as in

Study II, part B) was equipped with the prototype OPD and placed perpendicular to the slope on a tilt table 150 cm from the table's axis of rotation. As the quad bike rolled off the tilt table and hit the ground, the prototype OPD took the full load of the impact, and was substantially deformed by the force generated in the fall. However, it still created a 'crawl out space' big enough for a potential operator. After landing heavily on the OPD the quad bike settled on its side and had only turned 90°. This crash test was later repeated with the same quad bike, but without any OPD. The quad bike hit the ground and rotated a full 360 degrees, before ending up standing on its wheels on the ground. The handlebar and its rear luggage rack were substantially deformed after this crash test with no OPD. This test indicates that despite being light, the prototype OPD used in Study III is strong enough to enable a ride to survive a sever rollover incident.

The fourth study addressed quad bike riders' understanding of quad bike injury prevention and decision to acquire an OPD. The results showed that the way quad bike riders allocate blame and responsibilities is a major element of their understanding of quad bike safety, as suggested by Douglas (1992) in her description of blame. The main notion the respondents expressed was that some, but not all riders, are at risk, i.e. risk is not equally distributed. Thus, although they knew that quad bike injuries pose problems, and that an OPD would significantly reduce risks in the general population, most do not act upon this knowledge, as they do not think these risks will affect them personally. A similar tendency has been found in studies of barriers to acquisition of a tractor ROPS (e.g. Sorensen et al. 2008). Many associate that risk with unskilled, inexperienced, reckless, drunk or excessively speeding riders. For similar reasons, several respondents had decided to acquire an OPD to increase the safety of others, e.g. a child or grandchild who was seen as exposed to that risk, rather than their personal safety. These results indicate that low use of quad bike OPDs is not merely due to lack of knowledge, but also much more complex factors involving quad bike users' understanding and evaluation of risk.

4.1.3 Synthesis – The role of human factors in safety

Safety in small-scale forestry involves complex issues. As previously described, the work is often done by self-employed forest owners, in their spare time and with long intervals between occasions, often with no formal training. Moreover, the safety of self-employed forest workers falls somewhere between the occupational safety and the consumer safety, which poses further complications for injury prevention. They perform the same tasks as professional chainsaw users, but their work is often excluded from occupational health and safety regulation and consumer safety interventions (e.g. engineering, product development) may not always be sufficient. To increase safety in this sector, an array of interventions is needed, covering several dimensions of safety on all levels, e.g., engineering, regulations and training (as illustrated in *Figure 1*). Two interventions have been addressed in this thesis, chainsaw training and quad bike OPD, but they are intertwined with other interventions at all levels of the hierarchy.

It has become increasingly apparent in the research that understanding the role of human factors in safety is essential to elucidate the complexities involved. We all act in a cultural context, in relation to a community and other people. To effectively design regulation and technologies, we must first know how people respond to risks and safety technologies. To effectively use training as a safety intervention, knowledge of how people relate to risk and respond to training is essential. Thus, all prevention must be rooted in a human perspective.

4.2 Strengths and limitations

In Study I, a web questionnaire was used to explore chainsaw users' knowledge retention by re-retesting knowledge tested in the chainsaw license examination. This provided opportunities to reach a large stratified sample from all parts of Sweden who had held a license for 1-9 years and participated in all types of chainsaw courses. With no indications of potential non-response bias, this provided scope for generalization that otherwise would have been difficult to obtain. However, it also imposed some limitations, because there was no control over the re-test environment and thus no knowledge of whether participants were cheating. This could potentially have resulted in overestimation of the respondent's knowledge, although the respondents had no incentive for cheating and the relatively low scores indicate that this was not an extensive issue. The examination part of the questionnaire including both level A and B theoretical questions made this part rather extensive. This limited the space for additional parts in the survey and the possibility of collecting data with greater depth, which may have enhanced understanding of effects of time on knowledge. However a more extensive survey may also have resulted in a lower response rate.

In Study II, longitudinal observational case study methodology was chosen. Following two small groups of chainsaw users provided opportunities to gather data with a level of detail that would have been excessively time consuming with other methods. By following these groups over time, effects of training on knowledge, skill and training retention could be studied. This also provided insights into the participants' weaknesses in knowledge and skills when starting training, at its completion and a year later. The case methodology has clear limitations, especially in terms of generalizations. However, the study still provided interesting results, although they must be treated with care. Clearly, characteristics of the individuals participating in a case study such as this affect the results. The studied groups appeared to reflect the general population of Swedish self-employed chainsaw users rather well, but as they were all experienced self-employed chainsaw users, they would have been in a different stage of learning (Kim et al. 2013) from beginners, and thus their degree of retention may have been higher.

In Study III an experimental design was chosen to measure the static stability of quad bikes, and investigate effects of OPDs and trailers. The chosen test is a well-established method for evaluating a vehicle's general stability, as the measured static stability parameter is closely related to its dynamic stability. Moreover, it is fast and easy to reproduce. However, it does have some limitations. For example, one aim of the study was to assess effects of attaching a trailer to the quad bike, and it proved difficult to capture the full interaction between a trailer and quad bike due to the static environment in the experimental setup. Thus, risks associated with towing heavy loads may have been substantially underestimated. A method to measure a quad bike's dynamic stability with or without towed equipment could therefore provide valuable complementary information to measurements of static stability.

In Study IV, two sets of interviews were conducted, one with non-OPD quad bike users and one with quad bike owners with experience of using an OPD. The non-OPD quad bike users were recruited from people attending the two major annual Swedish forestry fairs, while the OPD quad bike users where recruited using purposive and snowball sampling approaches. This combination enabled the possibility to address quad bike safety from the perspectives of both general users and the few who have chosen to use an OPD despite the lack of suitable records on such users. Few options were available that could have produced a more random sample. For instance, given the limited use of OPDs, any randomized inclusion criteria from a register of quad bike owners would have yielded few OPD-owning respondents or required a very large-scale data gathering effort. In addition, to reach quad bike users who did not use an OPD, the efficiency of sampling and data collection at the forestry fairs was considered to outweigh the shortcomings.

4.3 Conclusions and practical applications

The results presented in this thesis can be applied in general small-scale forestry injury prevention. In this section, applications of the results are considered in relation to the five categories of safety interventions presented by Donham and Thelin (2016), from the most effective (eliminating a hazard), through reducing risk and controlling the hazard, regulations, and education, to the least effective (PPE) (*Figure 1*).

4.3.1 Reducing risk and controlling a hazard by engineering interventions

Other than eliminating the hazard (e.g. through substitution) these interventions are considered the most effective (Donham and Thelin 2016). Several such interventions have been applied to chainsaw design that have substantially improved safety, most importantly introduction of the chain brake, which reduces risks of kick-back cutting injuries. Regarding quad bike safety there is still room for engineering interventions to improve the safety of the user, including development and application of an effective and widely accepted OPD. Results presented in Paper III show that a heavy quad bike ROPS/OPD although it increase the safety of the operator in the event of a rollover, might increase risks of rollover incidents by substantially reducing the vehicle's stability. Thus, the impact on stability must be considered when constructing a quad bike OPD. Another important factor to address in the development and marketing of quad bike OPD emerged in Study IV. A substantial proportion of quad bike users oppose using OPDs in the belief that their benefits would be outweighed by associated hindrance and limitations in routine uses of the vehicle. Thus, OPDs must be designed with the user in mind, minimizing their negative effects on the quad bike's usability.

4.3.2 Regulation

After the categories of eliminating or reducing danger e.g. engineering intervention, regulation is considered the most effective type according to the hierarchy presented by Donham and Thelin (2016) (*Figure 1*). Regarding legislative requirements for training, a constant issue is a certification's \`expiration date´, i.e. the point at which safety-related knowledge and practical skill have deteriorated so much that re-training is needed. Studies I and II explored effects of time on retention of the knowledge and skill required to use chainsaws safely, and there were no clear indication of a decline during the covered timeframes (one to nine years in Study I, and one year in Study II). Instead, knowledge seems to be more closely related to usage, according to the results presented in Paper I. Regarding quad bike OPDs, the results of Study IV clearly indicate that many quad bike riders will not currently acquire an OPD to improve their own safety, as they do not see themselves as being at risk of rollovers. To increase the use of quad bike OPDs, changes in the safety culture within the quad bike community are needed. And regulations could play an important part in facilitating this change. Study IV also showed that concern for others is a powerful motivator in the decision to acquire a quad bike OPD. This could be used in the development of OPD retro-fit information campaigns.

4.3.3 Education

Although less effective than engineering interventions and regulation, education interventions seem to be an important aspect of the prevention of chainsaw injuries. The results presented in Paper I indicate that knowledge is closely related to usage. Hence, organizations of people who use chainsaws, but not frequently, should consider implementing policies that promote regular training for their members. Educators involved in chainsaw safety training could use results presented in Papers I and II to identify specific aspects that respondents found challenging to improve the training. For example, in the theoretical examinations many respondents found questions concerning the use of felling tools and resulting forces difficult. Such questions requiring spatial thinking, understanding of the forces involved and causal relations that are easy to misinterpret. Thus, these are important elements to focus on in teaching and the design of examination questions. Similarly, in the practical examinations many participants seemed to struggle with the use of PPE, for example remembering to always pull down their face shield before cutting. It is difficult to create an automated safety pattern for something that is partly non-intuitive (e.g. a face shield reduces vison) in such a short time as a course, but creating safe work practices that continue after the course is important for the safety of chainsaw users.

4.4 Future studies

Several subjects for future studies emerged during the work underlying this thesis. Regarding chainsaw training, a major focus of the studies was on training retention, particularly whether participants retained the knowledge and skill required to use chainsaws safely 1-9 years after taking a course and acquiring a license. The results presented in both Papers I and II show that the course changed participants' behavior. However, complementary information on compliance, i.e. when and why chainsaw users knowingly transgress safe praxis, would be valuable. Close examination of chainsaw training material, recommended practices, and variations in practices recommended in chainsaw training courses around the world would also be valuable in the future development of chainsaw training.

Another issue that has received insufficient attention, despite a recognized need in the research community, is the development of effective and widely accepted OPDs for quad bikes. Among other factors, more knowledge is required about the aspects that are most important for the users, in terms of both usability and ease of retro-fitting OPDs to their quad bikes. It would also be interesting to identify groups within the quad bike community and study variations in their understanding of safety (e.g. effects of a 'macho' culture) and how that relates to their understanding of risk. Another aspect related to OPDs' usability that warrants more attention is the most effective design of OPDs to minimize roll and ensure that an effective `crawl out space´ is created in a rollover incident, with minimal cost and negative impacts on stability and usability. Thus, there is a clear need to develop standards specifically for quad bike OPDs. Many OPDs do not conform fully to tractor ROPS standards, so new international standards that define the criteria for an effective quad bike OPD are required.

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Popular science summary

The forestry activities of Swedish land owners on their own estates are associated with high risk of injuries. This thesis is based on four studies that focused on two such activities: two on felling, de-limbing and bucking trees, and two on off-road use of quad bikes.

There are several risks associated with felling, de-limbing and bucking using a chainsaw, hence several safety interventions have been introduced to reduce chainsaw-related injuries, including cut-resistant trousers, safety helmets with face shields and other PPE. Several engineering interventions have also been applied in chainsaw design to reduce risks of cutting injuries. Another major safety intervention aimed at preventing chainsaw incidents, which warranted further attention, is training in safe work practice. Thus, half of this thesis addresses the Swedish chainsaw license and associated training.

To acquire a Swedish chainsaw license, a candidate must pass a theoretical and practical examination to show that s/he has adequate knowledge and skill to work safely with a chainsaw. Although it is not mandatory, this is usually taken after participating in a chainsaw course. In the first study we tested the effect of time on chainsaw license holders' knowledge, by inviting respondents who had obtained their license 1, 3, 5, 7 and 9 years earlier (drawn from a register of chainsaw license holders) to retake the theoretical examination through a web survey. In total, 682 license holders completed the retest and the results revealed some interesting findings. One was that the overall knowledge of the respondents appeared to be rather low: only 45% passed both levels A and B of the chainsaw license retest. However, this loss in knowledge seemed to occur mostly during the first year after receiving the license. During the studied period of 1-9 years since receiving a license there was no clear effect of time. Another interesting finding was that retest scores correlated with the license holder's self-reported amount of work with a chainsaw (especially work with felling, delimbing and bucking trees). In the second study, 16 experienced chainsaw users without a license were recruited, who participated in a regular chainsaw course and took the regular license examination, but were also tested before the course and a year after it. This study also showed no clear effect of time on the participants' knowledge or skill. Only three of the 11 participants who took the post-course examination obtained lower scores than in the course examination, the performance of the others was either the same or better.

The use of quad bikes is associated with high risk of rollover injuries. A long suggested intervention targeting this risk is the use of some sort of roll cage or roll bar (operator protective device, OPD) intended to create a safe space for the operator during a rollover incident, thus preventing the quad bike from crushing the operator. Although such devices have been available for a long time, none have been widely accepted, and many questions regarding optimal kinds of OPDs, their effects and implementation have not been adequately addressed. Thus, the third study focused on OPD design, particularly effects on the static (stationary) stability of the quad bike. The main results concerned effects of two types of OPDs and ways to increase quad bikes' stability. They showed that a heavy OPD substantially affects the bikes' stability. However, tests with a light prototype OPD showed that it had much less negative impact on stability, and could be countered by increasing track width by just 20 mm. The fourth and last study focused on important, but largely neglected, aspects of OPD implementation: quad bike owners' understanding of quad bike injury prevention and the reasoning behind the decision to install a quad bike OPD. The study showed that a major element of many quad bike users' understanding of quad bike safety is that some, but not all, riders are at risk, so risk is not equally distributed. Thus, despite knowing that quad bike injury is a serious problem, and believing that increasing OPD usage would significantly reduce injuries, they do not act upon this themselves because they do not think the risk will affect them personally. Instead, they associate the risk with unskilled, inexperienced, reckless, drunk or excessively speeding riders. Accordingly, several interviewed users had decided to acquire an OPD not for their own protection but to enhance the safety of others, e.g. a child or grandchild perceived as being in one of the at-risk rider categories.

Populärvetenskaplig sammanfattning

Självverksamt småskaligt skogsarbete är förknippat med hög risk för olyckor. Den här avhandlingen baserar sig på fyra studier som fokuserar på olycksprevention för två sådana högriskaktiviteter: två studier på utbildning i trädfällning och två på användandet skyddsbåge till fyrhjuling.

Det finns en mängd risker förknippat med motorsågsarbete, för att öka säkerheten har olika åtgärder använts. Exempelvis bidrar användningen av skyddsutrustning, som sågskyddsbyxor och säkerhetshjälmar med visir, till minskad risk för motorsågsrelaterade skador. Flera olika innovationer i motorsågsdesignen, som kastskydd, har också minskat skaderisken.

Utöver detta så utgör nyttjandet av säker arbetsmetodik en betydande del av olyckspreventionen. Arbetsmetodikens betydelse understryks av det faktum att en betydande del av motorsågsrelaterade dödolyckor är ett resultat av att användaren blir slagen eller klämd av trädet eller en avbruten topp. Därför anses utbildning i säker motorsågsanvändning vara en mycket viktig del i olyckspreventionsarbetet, och hälften av denna avhandling fokuserar därför på den utbildning som är kopplad till det svenska motorsågskörkortet.

För att erhålla ett motorsågskörkort krävs ett godkänt resultat i en både praktisk och teoretisk examination rörande säker motorsågshantering. I den första delstudien testades hur teoretiska kunskaper stod sig över tid, genom att körkortsinnehavare som haft sitt körkort i 1, 3, 5, 7 och 9 år fick göra om teoriprovet via en webbenkät.

Totalt gjorde 682 innehavare av motorsågskörkort om teoriprovet, och analyserna av deras svar visar på några intressanta mönster. Ett var att den övergripande kunskapsnivån var förhållandevis låg: endast 45% uppnådde ett godkänt resultat (på både nivå A och B). Kunskapstappet uppstod dock nära inpå examinationen, eftersom resultatet tydligt hade försämrats 1 år efter att man tagit körkortet. Därefter kunde inte någon tydlig ytterligare förändring av resultaten ses (från 1-9 år). Ett annat intressant resultat var att testresultaten korrelerade med körkortsinnehavarens självrapporterade mängd arbete med motorsåg, och då i synnerhet med arbete med trädfällning och upparbetning. De som arbetade mer med motorsåg presterade också bättre på teoriomproven.

I den andra studien deltog 16 erfarna motorsågsanvändare utan motorsågskörkort. De fick genomföra en vanlig motorsågskurs med sedvanlig reguljär examinationen, men i denna studie fick de också genomföra en examination innan kursen samt en ett år i efter kursens slut. Denna studie visade inte på någon tydlig effekt av tid gällande teoretiska kunskaper eller praktiska färdigheter. Bara tre av de 11 deltagare som gjorde förnyat test efter ett år presterade sämre än under den ordinarie praktiska examinationen, medan övriga deltagare presterade antingen lika bra eller bättre än vid ordinarie examination.

Vältningsolyckor med fyrhjuling är vanligt förekommande och en sedan länge föreslagen skyddsåtgärd är att använda skyddsbåge, vilken minskar risken för att bli klämd av fyrhjulingen vid en vältningsolycka. Skyddsbågen skapar ett utrymme mellan marken och fordonet vid en vältningsolycka, och förhindrar att föraren kläms fast. Dessa har funnits tillgängliga för fyrhjulingar under lång tid, men har inte börjat användas in någon större omfattning.

I den tredje studien fokuserades det därför på utvecklingen av skyddsbågar, och i synnerhet gällande fyrhjulingars stabilitet. De huvudsakliga resultaten visar hur två olika typer av skyddsbågar påverkade fyrhjulingens stabilitet. En tung störtbåge påverkade stabiliteten avsevärd, medan en lätt prototyp bara innebar en marginell negativ påverkan på stabiliteten. och denna motverkades lätt av en smärre ökning (20 mm) av fyrhjulingens spårvidd.

Den fjärde och sista delstudien fokuserade på en viktig, men ofta förbisedd aspekt rörande användandet av skyddsbågar, nämligen på fyrhjulingsförares förståelse av skadeprevention samt på deras beslutsprocess rörande installerandet av skyddsbåge. Studien visar att en vanligt förekommande föreställning rörande säkerhetsfrågor är att risken inte är jämt fördelad och att några, men inte alla förare är utsatta för risk. Trots att de intervjuade personerna kände till de höga riskerna kopplade till fyrhjulingskörning och att ett ökat användande av skyddsbåge skulle minska risken för skador tänker man inte att detta skulle påverka den egna säkerheten.

Istället kopplar de intervjuade förarna samman risk med inkompetenta och oerfarna förare, och med alkoholpåverkade, vårdslösa eller på annat sätt oansvariga förare. Många intervjuade användare av skyddsbåge hade därför inte utrustat fyrhjulingen för att öka sin egen säkerhet, utan för att öka säkerheten för andra som de uppfattade höra till riskkategorin (exempelvis barn eller barnbarn).

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In private non-industrial forestry, self-employed work has long been associated with high risks for injuries. Two safety interventions targeting two high risk activates in the Swedish small-scale forestry work was identified: Chainsaw training and quad bike roll over protective devices (OPD). Half of this thesis was thus devoted to study the Swedish chainsaw license and training with a focus on training retention. While the other half of this thesis was devoted to the development and implementation of quad bike OPDs.

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