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Ergonomics in apiculture: A case study based on inspecting movable frame hives for healthy bee activities

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ABSTRACT

The agricultural sector suffers from high risk of injury and damage to human health. There is considerable research not only identifying these risks but also finding ways to mitigate them. Beekeeping or apiculture, recognised as part of this sector, has many risk factors such as heavy lifting, high degree of manual materials handling, twisting, and awkward positioning common to all agriculture areas. It also has some unique risks such as those resulting from bee stings and smokers. However, there is much less attention focused on the health and safety of apiculture to the human beekeepers, and much more attention focused on bee health and safety. An ergonomics case study on beekeeping inspection tasks involving three independent, local beekeepers showed that many tasks involve awkward positions of the body, arms and hands, excessive lifting well beyond recommended weight limits, eye strain, and chemical and sting exposure. In addition, beekeepers are more interested in bee and hive health rather than reducing human-centred risk factors such as those due to excessive lifting. Standard ergonomics interventions such as a magnifier inspection and lift assist systems as well as interventions unique to beekeeping such as a smokeless method of calming bees are recommended. The beekeeping industry seems to have been forgotten in the modernisation of technology and agricultural practices. This paper offers some initial insights into possible points for research, development and improvements.

1. Introduction and background

Beekeeping (apiculture) has been an important part of human society since around 4500 BCE (Crane, 2013). When non-destructive methods of honey removal appeared in the mid-1800s with the development and dispersal of the Langstroth removable frames hive design, apiculture evolved into a wide-spread individual and commercial practice. While other areas of agriculture have experienced significant technology innovations since the 1800s, innovation in some areas in beekeeping has essentially stagnated. However, the practice of beekeeping and hive management is not without problems and issues that could be resolved with technological or management interventions and innovation.

Beekeeping can be broken down into three main operational stages: 1) population of hives which involves starting new hives and ensuring over-populated hives are separated; 2) management of hives which includes acquisition and maintenance of a healthy egg laying queen bee, and inspection of hives for queen health and pests, and hive integrity; and 3) honey extraction, bottling and sales. At all stages of a beekeeping operation, there is a considerable quantity of manual materials handling that entails potential risk to human health similar to other agricultural and industrial operations. There is also exposure to specific chemical and biological containments (e.g., smoke and insect stings), which are unique to apiculture.

Ergonomics and human factors have been employed in many industries to measure, assess and resolve problems and risks to humans at the intersection between humans, and machines and their environment or systems (Proctor and Van Zandt, 2018). In resolving these problems, harm can be reduced, processes and products can become more efficient and effective, and profits may even increase. The agriculture industry is recognized as one of the most dangerous and high risk industries to human health (OSHA, 2013). Beekeeping is considered to belong to this sector (Hurst and Kirby, 2004).

According to the 2014 US Occupational Injury Surveillance of Production Agriculture (OISPA) and (Davis and Kotowski, 2007), there are approximately 1,743,145 individuals working on livestock oriented farms from the household (not hired or migrant employees) in the US. (Rautiainen and Reynolds, 2002) reported injury estimated to be between 0.5 and 16.6 per 100 workers, the upper end considered high

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compared to other high-risk industries such as healthcare which is estimated to be 6.8 injuries per 100 workers (OSHA, 2013). Types of injuries in the agricultural sector include acute injuries such as falls, eye injuries, lacerations, musculoskeletal sprains and bruises, and chronic injuries such as back and joint pain, repetitive strain injuries, and injuries related to long term chemical or environmental exposure (Naeini et al., 2014). Many of these injuries are caused by ergonomic risk factors such as awkward positioning, heavy lifting and twisting, repetitive motion, excessive force, use of hand tools, and cold or hot environmental temperatures (Kirkhorn et al., 2010), pesticide use and insect stings (specific to beekeepers).

While there is a considerable quantity of literature examining the ergonomic risk factors and rates of injury in the agricultural sector, much of this research is focused on livestock farming/handling such as cattle or dairy or on fruit/vegetable and grain harvesting. There is very limited research related to beekeeping. In fact, much of the academic literature and popular press related to beekeeping focuses on bee health, identification and ways to protect bees from pathogens (e.g., Berenbaum, 2014; Formato and Smulders, 2011), and the impact on the environment (mostly related to pollination) resulting from the destruction of bees and bee colonies (Neumann and Carreck, 2010). However, it is expected that beekeeping has similar types of ergonomic risks as other agricultural practices.

There have been very few research papers published in English on assessing human risk levels in beekeeping (Aiyeloja et al., 2015; Maina et al., 2016). The paper by Maina et al. (2016) is focused on biomechanical risk factors for musculoskeletal disorders (MSD). While MSD injuries are the predominant macro-ergonomic (Hendrick, 2000) injuries in the agricultural sector, there are individually-based micro-ergonomic factors to consider as well. Maina et al. (2016) focus their work on four commercial operations and their processes involved in honey extraction and bottling. Their main findings include that honey gathering and production could be divided into a small set of basic tasks despite a variety of settings, conditions (e.g., weather) and operation size where standard ergonomic analysis tools could be applied to assess biomechanical risk levels (e.g., ISO 11228-1 and 3). They identified points for risk reduction and possible solutions (e.g., job rotation for mitigating the impact of repetitive tasks). Aiyeloja et al. (2015) carried out a participatory study focused on the impact of two different hive heights and two hive designs (Langstroth and Kenyan) on self-reported worker stress loads during the honey extraction process. They found a negative impact on worker stress from; 1) protective clothing that affected worker dehydration due to high temperatures inside the clothing; 2) the manipulation of hand tools for honey harvesting that caused wrist, shoulder, back and neck pain; and 3) wrist and upper arm pain from lifting regardless of height of the hive placement. The Langstroth hive required more handling effort than the Kenyan hive design and as a result required more work and bending at the torso from workers. Neither paper evaluated the hive inspection process where the hive must be completely disassembled and then reassembled, or the interactions between technology, design and work practices which may lead to increased risk factors.

1.1. Hive design

The latest widespread innovation in hive design occurred in 1852 when L.L Langstroth developed and patented a box and inner frame system with sufficient space between the frames (beespace) for the bees to create honeycombs filled with honey, protein and eggs on a frame, and that a beekeeper could remove with his hands for inspection and honey recovery without damaging the bees or the integrity of the beehive (Langstroth, 1857) Alley (1885). The dimensions for box and frame size were standardised and became the most prevalent form for the domestic beehive. He also specified that the boxes, called brood boxes and supers, could be stacked so that the bottom level would be for the queen to lay eggs (brood) and have them fed until hatching, and the upper levels (supers) would be where the worker bees would store protein and honey as food for the developing larvae. Access to the frames was from the top of the box. Honey could be removed from the hive by humans without disturbing the brood by only accessing the upper level boxes. Smoking bees to calm them was also introduced by Langstroth at this same time. While there have been other derivative designs (e.g., Dadant design; (Crane, 2013), the original Langstroth design is the most commonly used throughout the world (Crane, 2013).

The design specifications for a Langstroth 10-frame hive can be found on many different bee supply and build-it-yourself websites such as Quality Beekeeping Supplies (2017) and Beesource (2017). For this paper, the following dimensions are used to estimate vertical and horizontal lifting dimensions for the NIOSH lifting calculations. A full height (deep) 10-frame Langstroth box used by all beekeepers in our study has a height of 241 mm, width of 362 mm and length of 480 mm. There are other box depths (medium and shallow) that can be used but they only vary in height and not the other dimensions of the Langstroth design. For example a shallow box (height of 144 mm) can be used as the honey box so that it is lighter when full. There are other components that are also specified such as lids/covers (flat or migratory) to protect bees from the elements and allow for air circulation, a bottom board or floor of the hive where the bees enter, queen and bee excluder components, bellows-based smoker, and a hive tool for prying frames apart, lifting lids and scraping wax off frame components. Since the time of Langstroth there have been surprisingly few innovations and additions to this basic design, such as lifting cleats and small hand-holds, which were missing from his original design (see Fig. 1).

This paper provides an exploration of some of the physical, micro and management ergonomics issues for the inspection process in beekeeping using three case studies. Interviews and video recordings are assessed for standard physical ergonomics issues such as those associated with lifting as well as those that are unique to beekeeping such as the management of insect health. Recommendations for further research and design directions are also outlined.

2. Method

Upon obtaining ethics approval from the Research Ethics Board at Queensland University of Technology, three beekeepers with a variety of management models were interviewed using a semi-structured interview process, and observed completing standard beekeeping tasks involved in maintaining the hives. Interview timing ranged from about 1.5 to 2 hours. All interviews and demonstrations were video recorded.

Participants were selected from a convenience sample of beekeepers in the local areas. We selected beekeepers who represented a variety of

Fig. 1. Hive box design from J2 that includes a migration lid, lifting cleat and customised sliding bottom board with pull pin.

beekeeping approaches and styles in order to procure as wide a range of practices as possible given the time limitation. The honey extraction and processing tasks were not sampled in this study. Protective clothing was donned by all participants and consisted of a hooded suit with a mesh veil, gloves (optional) and rubber or steel-toed boots to protect the beekeeper from stings and other injuries.

All participants were asked a range of questions covering topics such as current hive and equipment stocks, MSD or other injuries, pest and disease factors and the apiarists' day-to-day practices. Examples of these questions included open-ended questions such as; "What challenges do you face in manipulating hives?", "What tasks are performed when entering hives and why?" and "What manual handling issues do you face, if any?"

The audio-visual data were analysed using Noldus Observer version 13 and subjected to a thematic analysis (Miles et al., 2013). Using a consensus method with three different evaluators, data were grouped into ergonomic risk factors and practices, innovation activities, communication and educational practices and analysed for occurrence and time to completion where appropriate. Results are presented using a human-centred *case study* methodology (Gerring, 2006) to explore patterns and unique aspects of beekeeping practice centred on the tasks and activities of the human element of beekeeping. In addition, gaps and possible areas for innovation, technologies and education are identified from these cases.

Typical tasks include: 1) inspecting hives for infections/infestations, brood health and queen laying patterns, swarming activities, queen location, hive health including moisture levels and temperature, and honey production; 2) removing excess wax and honeycomb that can build up on tops and bottoms of frames and box lids; and 3) inspecting for external and internal damage such as wood rot. Management tasks involve maintenance and use of tools and protective clothing, innovation activities, and repair and construction of hives, scheduling of various beekeeping activities, supply chain management, communicating with government bodies, and participation in clubs.

For estimating the recommended weight limits for beehive boxes that are being manipulated (lifted or lowered) in this study, the revised NIOSH lifting equation (Waters et al., 1993) is used.

2.1. Participant descriptions

2.1.1. J1

J1 is an urban beekeeper in his 30's who runs a five year old Brisbane, Australia based business specialising in rooftop and inner-city beekeeping. The apiarist works full time in the company and manages a large number of beehives (100+) and harvests, process and sells the honey and wax from the operation. J1 uses standard 10-frame Langstroth type hives constructed of wood and/or high density polystyrene with modifications including lifting cleats. J1 only uses 9 frames in the hives to ensure sufficient space for the bees to move. The hives are untreated hoop pine that are oiled with linseed oil and painted externally only. The majority of the hives are in the urban area around Brisbane, Australia and located on the roofs of participating businesses who take a share of the honey in return for roof space rental. J1 also maintains a medium sized apiary of 20+ hives at his home on a small city block.

2.1.2. J2

J2 is a self-described and mostly self-taught hobby/commercial beekeeper in his 50's running a business for five years. The apiarist works at a full time non-beekeeping job during the week and manages the hives on the weekends. There are 30 honey generating hives involved in the operation. In addition, queens are bred and raised using natural breeding techniques and specialised breeding hives.

Hive boxes (supers and brood boxes) are built onsite for the operation as well as being for sale to others. Hive design follows the standard 10-frame Langstroth model (using 9 frames per box to ensure sufficient bee space) with modifications including lifting cleats, customised bottom board design, and migration lids. All boxes are made from copper naphthenate treated pine and then painted with an oil-based paint to prevent cracking, moisture build-up, and wood rot. Fig. 1 shows an example of a standard box design from J2.

The hives are mainly located in the backyard area of J2's home and placed so that they are shaded from the hot afternoon sun. Some hives may be moved closer to water (pond/dam area) during drought times, and/or different locations closer to specialised flowering plants (e.g., macadamia trees) when in season.

2.1.3. B1

B1 is an amateur beekeeper in his 70's with over 30 years' experience. B1 is the president of a local amateur bee association that has monthly meetings to discuss beekeeping. B1 is also active in the local apiary network. Fifteen hives are kept in the backyard of B1's own home located in the suburbs of Brisbane, Australia. Standard Langstroth 10-frame boxes are used to create the hives although only nine frames are used to ensure sufficient bee space. The boxes are predominantly constructed of hoop pine with a small number of plastic and other material types with the majority being self-constructed (see Fig. 2). Additional modifications include customised screened bottom boards and oil-trays to catch small hive beetle, and metal sheet roofing to protect from sun and rain.

3. Results

3.1. Manual materials handling

Many tasks in beekeeping involve various types of manual materials handing activities including lifting and moving box components and frames from various heights, twisting, tool use, and handling of bees (including individual queens) and bee products such as honeycomb, and honey. A full super of honey can weigh up to 35 kg.

Inspections are often carried out on a regular schedule. Full inspections of the entire hive collection are carried out semi-annually or quarterly. Partial inspections occur at a higher frequency (e.g., every 2–3 weeks). A full inspection is carried out for all hives and involves disassembling the hive, removing each frame and visually inspecting it for infections, brood patterns (where appropriate), and physical damage to hive materials (e.g., wood rot), and removing excess materials such as honeycomb (wax) and unwanted queen eggs (swarm potential). Once complete the hive is reassembled. A single bee egg is approximately 2–3 mm long and about 0.5mm diameter. Eggs are laid in honeycomb spaces and form patterns in a frame that are indicative of hive and queen health.

Fig. 2. Organisation and height variety of B1's hives.

Fig. 3. a: Variety of hive heights. b: Lift between waist and shoulder. A clamp and band holds the box together with the lid and bottom feet. c: Lift at shoulder height of super full of honey.

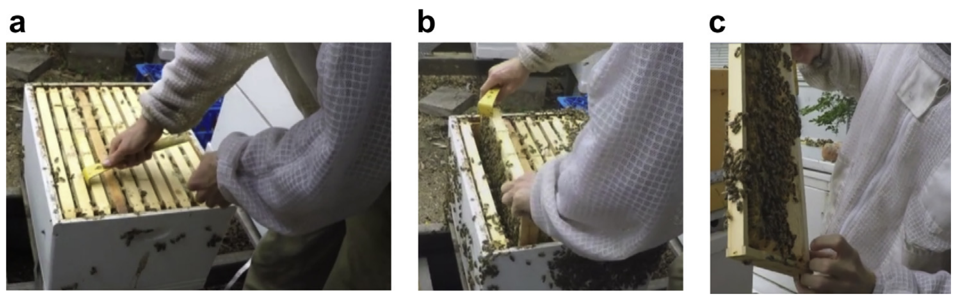

Fig. 4. a: Prying frames apart below waist. b: Lift single frame with fingers and hands. c: Frame inspection – wrists, hands and fingers engaged and in awkward positions.

Fig. 5. Prying frames with box at waist height.

3.1.1. J1

During the interview J1 carried out frame inspections for one hive as well as explaining and demonstrating his inspection technique and procedures. In general, J1's frame inspection process began with disassembling the hive into separate boxes and ended with reassembling the hive (see Fig. 3a–c). This involved lifting each box off the top and placing it on a hip-height table (760 mm) near the hive, or on the uneven and cluttered ground surrounding the hive, with the boxes containing honey being on the top of the hive and the brood boxes being the lower boxes. It also involved lifting individual frames from each box, with an average weight of 5kg each. Lifting occurred above the shoulder height on 2 occasions (1 of lifting full boxes, 1 lid), 7 instances between the waist and shoulder (3 lifts of full boxes, 4 were of box lids or screens), 11 at waist level (2 full boxes, 9 other items such as lids or screens), and 13 below the waist (3 full boxes, 10 other items such as bricks and lids) that required J1 to bend at the waist and knees. All lifts occurred over a 55 minute interview period. Six box lifts involved a twisting motion of between 45 and 90^{o}. There were between two and five boxes (see Fig. 3a) placed on an 89 mm piece of wood positioned on a single standard cement block (200 mm high). The total range of lifting height then was 241 mm (box sitting on the ground) to 1494 mm (top of the fifth box where the lifting cleats are located). Some of J1's hives had lifting cleats (see Fig. 3a) and others did not (see Fig. 3b). Lifting a box without lifting cleats must be carried out by lifting the bottom of the box or using the standard hand holds which are slight indentations that only fit finger tips. J1 also uses a clamp system around each box to hold the hold the bottom, box and lid together (see Fig. 3b). The clamp must be released to access the frames in a box.

During the interview the inspection process was focused mainly on visually inspecting the brood boxes for brood health and queen activity, although J1 mentioned once using humidity, temperature, and sound during inspections, and other tools or technology (seven occurrences). A visual inspection involved lifting each frame from a box with the fingers, bringing the frame close to the face/eyes to look at one side and then twisting the frame with the wrists and hands to look at the backside (see Fig. 4a–c). Often the frames were stuck together and had to be pried apart using a hand tool (see Fig. 4a). This is a multi-purpose hand tool and is kept in the hand during frame inspections for various tasks including scraping and pressing. The hand tool was used on 45 occasions during the interview. Seventeen frame inspections were carried out where the lift was initiated above the waist (see Fig. 5) and six below the waist (see Fig. 4a). A frame inspection had a mean duration of 36.5 seconds (s), SD = 23.19s where the lift was initiated above the waist, and 42.4 s, SD = 16.05 s for the lift beginning below the waist.

There are other items which must be removed from boxes and handled including lids, queen and bee excluders (see Fig. 6a–b). Various tasks must be carried out with these items including lifting, prying loose, scraping or cleaning excess material and inspecting.

As part of the inspection process, J1 had to shake the frames using his arms over the box to remove most of the bees in order to see the brood pattern. This occurred on eight occasions during the observation/interview. J1 also used the hand tool to open queen cells to inspect for unwanted queen eggs and when found destroy them by pinching/scraping the eggs with the fingers while balancing the frame between the top of the box or J1's hip and hand (see Fig. 7).

J1 reported five types of injuries he has experienced while handling the hive boxes: 1) shredded or bent nails; 2) hand injuries from being caught on or between boxes; 3) shoulder and lower back pain from lifting and carrying heavy boxes, particularly up and down ladders in the urban environment; 4) foot injuries from dropping boxes even though J1 wears steel-toed boots; and 5) stings. He occasionally enlists another person to help lift the full honey supers but states that it is “difficult to coordinate” and “if one person trips, it throws everything off.” He considers that his greatest problem is lifting and carrying boxes up/down ladders from rooftops that are between three and eight stories high.

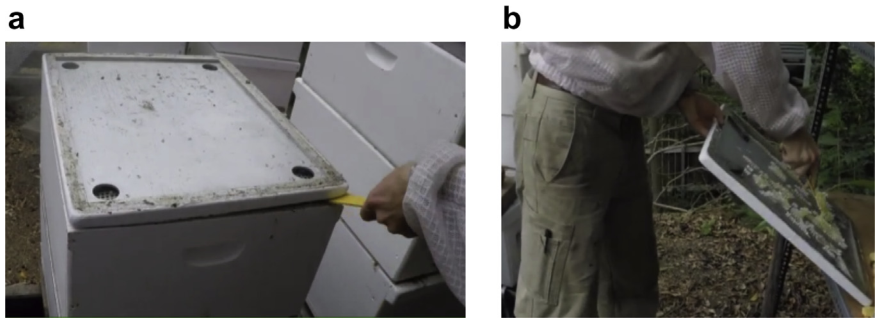

Fig. 6. a: Prying the bee excluder from box. b: Scraping excess wax off box lid.

Fig. 7. Removal of an unwanted queen cell.

3.1.2. J2

The manual materials handling tasks for J2 are similar to J1. J2 carries out a full inspection quarterly. He estimated that it takes one day to fully inspect 10 hives. J2 will carry out partial inspection more frequently but only removes two or three frames. During honey extraction, J2 will also remove two to three frames to inspect for brood patterns.

Similar to J1, some of J2's hives are placed on an 89 mm piece of wood positioned on a single standard cement block (200 mm high) and others are placed at table top height consisting of two saw horses and 200 mm × 200 mm wood beam (see Fig. 8a and b). Hive heights range from one to three boxes. Single boxes are used for making new hives and raising queens.

J2 demonstrated that he attempts to lift/lower using his knees rather than his back but acknowledges that he has a "bad habit where I lift up and rotate hives around." He reported one incident where he put his knee through the side of a box while lifting but did not consider this to be a serious accident. He reported no other injuries.

3.1.3. B1

B1 visually carries out a partial hive inspection once per month during the summer months and does not open the hives during the Australian winter months between April and August due to cooler winter air temperatures that could harm the bees. A partial inspection process consists of removing two to four frames from each box, and checking for honey flow and infections, particularly small hive beetle.

Typical hive height is two or four boxes high with the bottom box sitting on a shelf made of three stacked bricks and a piece of plywood (about 380 mm in height), or a metal table standing at about 600 mm high (see Fig. 2). A piece of metal roofing that extends about 100 mm from the walls of the box, and a brick or rock is placed on the lid of the topmost box for protection against sun and rain. The lid of the topmost box is then at a height between about 860 – 1320 mm.

B1 does not lift an entire box alone but takes several frames out at one time for extracting honey. When inspecting the entire hive set, B1 enlists other people to assist with lifting, particularly those wanting to learn about his practice. B1 recognises the limitations of being in his 70's. B1 recounted only one incident of injury where several full frames fell on his legs while trying to release stuck frames from a box and resulted in about "90 stings." He does not relate any strain or bruising injuries from the incident.

3.1.4. Theoretical lifting values using NIOSH lifting calculator

Using an online NIOSH lifting calculator to assess risk levels for manual materials handling risks (Ergonomics Plus, n.d.), Table 1 shows the Recommended Weight (RWL), the Frequency Indicator for RWL (FIRWL), the Lifting Index (LI) and Frequency Indicator for LI for the poorest lift condition with angle of asymmetry = 45^{o}, coupling is poor for standard hand holds, frequency less than one per minute over a 15 minute interval (<0.2 in NIOSH calculator), average load is 30 kg, maximum load is 35 kg (as estimated by J1 but not objectively measured). Table 2 shows the RWL, FIRWL, LI and FILI for a better condition where a hip height table (760 mm) is used and lifting cleats are available on the boxes (rated as fair coupling as grip only relied on fingers and hands).

3.2. Other risk factors and management practices

3.2.1. J1

J1 uses a standard bellows smoker (see Fig. 9). Using this tool involves handling a smoking fire (usually made from burning leaves and other ground debris) and increasing smoke levels using a bellows. J1 used the smoker on 39 occasions.

During the interview/demonstration J1 was stung three times and received a cut on the hand from the edge of a frame. J1 does not use gloves in order to feel whether bees are being harmed when boxes are reassembled. He stated "I do not get many stings working without gloves."

3.2.2. J2

J2 also uses a standard bellows smoker similar to J1 but prefers to use it sparingly. He prefers not to wear protective gear for partial inspections and honey extraction, particularly he avoids wearing gloves and long sleeves to protect the bees from being damaged and to avoid overheating due to hot weather respectively. He wears more protective gear for full inspections but often lifts the veil of the head gear as the mesh interferes with his ability to see small eggs.

He also stated that he does not use pesticides on small hive beetles as it poses an occupational health and safety risk stating "it is bad for the lungs."

3.2.3. B1

A standard bellows smoker (see Fig. 9) is used to "smoke" bees during inspections, similar to J1 and J2. Wax removed from the hive is melted down on site and then taken to a third party for sale or to exchange for foundation for new hive frames.

Weather and shade were determinants of hive placement as well as work schedules. B1 faces all hives north away from prevailing winds and

Fig. 8. a: J2's hives placed at table top height. b: J2's hive placed on cement block and wood.

Table 1
NIOSH values for lowering 10-frame boxes weighing and average 30 kg from different hive heights to ground. Angle of asymmetry 45°, coupling is poor, frequency is less than once per hour, duration is short (about one hour).

Height	RWL (kg)		FIRWL (kg)		LI		FILI	
	Origin	Dest.	Origin	Dest.	Origin	Dest.	Origin	Dest
5-box hive height	14	13	14	13	2.16	2.31	2.52	2.46
4-box hive height	15	13	15	13	1.98	2.31	2.31	2.69
3-box hive height	17	13	17	13	1.79	2.25	2.09	1.63
2-box hive height	20	15	20	15	1.46	1.98	1.71	2.31

Table 2
NIOSH values for lowering 10-frame boxes weighing an average of 30 kg from different hive heights to a 760 mm high table. Angle of asymmetry 45°, coupling is good using lifting cleats. The same average and maximum loads are used as Table 1.

Height	RWL (kg)		FIRWL (kg)		LI		FILI	
	Origin	Dest.	Origin	Dest.	Origin	Dest.	Origin	Dest
5-box hive height	16	17	16	17	1.90	1.72	2.22	2.01
4-box hive height	18	18	18	18	1.69	1.67	1.97	1.94
3-box hive height	21	20	21	20	1.42	1.52	1.65	1.77
2-box hive height	23	20	23	20	1.32	1.52	1.54	1.77

Fig. 9. Use of a smoker with hand operated bellows.

places hives under trees for shade (see Fig. 2). B1 does not open hives when it is raining as bees are too aggressive. During summer months, hives are only opened in the morning or evening when it is cooler making it safer for the bees and easier for B1 to work.

3.3. Technology acceptance and innovation

Technology acceptance is a widely used term to describe the uptake of technology by users based on a number of constructs such as perceived ease of use and usefulness as well as user attitude or compatibility as exemplified by the Technology Acceptance Model (Davis, 1986). This model has been used to measure and predict technology acceptance across a number of technologies and industries (Venkatesh et al., 2007).

3.3.1. J1

J1 discusses several different technologies that he would like to employ to improve the hive management process including using sound, pheromone changes and vibration levels to determine potential bee swarming activity, and using a "beecam" to decrease the frequency of inspections. He also mentioned the desire for better handles and handle placement that support lifting. He rounds the corners on his boxes so they do not have so many "sharp edges."

3.3.2. J2

J2 believes that the Langstroth hive design is the best for honey production and is critical of other hive designs (e.g., horizontal hives do not allow for efficient temperature management of hive by bees and affects their productivity, and other hive designs such as the Flow Hive (Flow, 2017) do not allow for efficient inspection techniques). He uses standard tools as well as employs two other inspection technologies: 1) "little Chinese plastic thing to scoop out individual cells;" and 2) reading glasses.

J2 constructs his own hives and suggests that his method is novel as a slightly modified version of the 10-frame Langstroth design (see Fig. 8b). This design revolves around a 9-frame design to ensure sufficient bee space and has specialised internal elements to support bee management such as marking where queen is placed. Hand holds are rectangular, larger, and recessed more than the standard handholds (see Fig. 8b). He also may include lifting cleats but places them in the standard location along the width of the box. He is concerned about purchasing boxes from other bee keepers due to uneasiness about spreading infections.

Migratory lids are used on all J2's hives to manage humidity but these lids can result in wax build-up and small beetle infestations. In order to prevent both, he uses a sheet of black paper on top of frames.

J2 mentioned the use of a lift assist device but did not demonstrate it.

3.3.3. B1

B1 considers “technology” to be “crap” because he states that “people don't know what they are talking about and have not had enough experience with bees,” that “the bees haven't changed,” and “it is better to rely on people with experience.”

B1 considers that the standard Langstroth hive design is acceptable and efficient except for the need to use a specialised bottom board design to manage small hive beetle infestations. He also suggests that using the standard hive design allows for interchangeability and ease of accessing replacement parts.

3.4. Hive health

3.4.1. J1

The majority of discussion (about 40%) in the interview revolved around hive and bee health particularly risks of hive infections, particularly regarding American foul brood bacterial infection and small hive beetles. Methods of pest control involved physical destruction such as squishing small hive beetles with fingers, ensuring that wax was removed from lids so beetles cannot hide from bees, and inspecting all frames.

If J1 discovers a hive infected with American foul brood, all tools and hands are washed so as not to spread to other hives, and the infected frames are removed and destroyed. J1 ensures that any materials removed from a hive are not left out for bees to land on in case of infection. Finally, J1 informs the government Ministry of Agriculture if hives are found to be infected although he does not believe the government acts on this information (e.g., to warn other apiarists in the area). In addition, J1 critiqued other hive designs for not encouraging inspection for disease.

Regarding queen health, J1 is careful to monitor for the appearance of the queen during inspections so as not to cause harm when re-assembling boxes. The laying pattern of eggs (brood pattern) provides information about the queen's health; a poor brood pattern indicates either an old or weak queen that must be replaced if the hive is to survive, and be protected from invaders (other bees or small hive beetle).

3.4.2. J2

Similar to J1 and B1, about 40% of the interview was focused on bee and hive health, particularly the management of small hive beetle, regardless of the question asked. J2 has designed a pull out tray bottom board (see Fig. 1) in an attempt to mitigate them. He states the “the beetles usually just go in the bottom board, run around and die.” He also has found geckos in the hives but is unsure whether they are eating the bees or the small hive beetle.

J2 is particularly concerned about the effect of weather on hive health and is learning to understand bee behaviour in various weather conditions. For example, bees stop flying when temperature reaches above 40 °C. As a result, hives may need to be moved to shadier areas or closer to water.

3.4.3. B1

Regardless of the interview questions posed, much of the discussion (about 50% of the interview time) resorted to concerns over and possible innovations to managing pests and hive health, in particular the control of small hive beetle. Concerns regarding hive placement and allowing honeycomb to build up on lid as a place for small hive beetle to hide were prevalent. B1 made numerous comments about best practices and demonstrated his own oil beetle trap bottom board solution (see Fig. 10), suggesting that other existing solutions were ineffective for various reasons (e.g., did not trap enough beetles at one time, etc.).

4. Discussion

As seen by the three cases, there are some noteworthy and significant risks in standard beekeeping and management techniques. Similar to other agricultural industries (Naeini et al., 2014), manual material handling, in particular the lifting and lowering of brood and honey boxes, exposes people to high risks of physical harm (e.g., lower back injury). There was not one lifting/lowering condition in Tables 1 and 2 that showed a nominal level of risk to “healthy” people; LI is above 1.0 for all conditions with the lowest level being for a two box hive located at table top height (the minimum number of boxes for a Langstroth hive is two; one for brood and one for honey). The risk of lower back injury increases as LI increases above 1.0 and thus according to Tables 1 and 2, the inspection process involved in beekeeping is a high risk activity that can lead to lower back injury.

While each beekeeper in our study recognised that there were potential hazards with lifting such heavy boxes, few mitigation strategies were used. These strategies were limited to obtaining assistance from others, placing hives at table top heights, restricting the height of hives to two or three boxes, and adding lifting cleats to some boxes. J1 did not use any lifting support system other than lifting cleats nor did J1 consider reducing the quantity or height of the hives. Thus, manual materials handling in current beekeeping practices potentially poses a high risk to the apiarist. Substantive modifications to hive and box designs as well as supportive lifting techniques are required to mitigate this high risk. Examples could include improving the handle design so that weight is supported by the hand rather than the fingers (Drury, 1980), using lifting harnesses/belts (Reddell et al., 1992) or appropriate lifting support systems (Resnick and Chaffin, 1997), and reducing the box size and shape. Although boxes are available in smaller sizes (e.g., ¾ size or 5-frames), the three beekeepers in this study seem reluctant to change to these smaller sizes because of productivity concerns. Considering alternative designs must ensure that other aspects of beekeeping such as the inspection or honey extraction processes are not hampered.

Other risks involve exposure to smoke from the burning materials in smokers that are in constant use when disassembling and assembling the hives, risks from stings which can have short and/or long-term damage (Celikel et al., 2006), lacerations and pinching when handling frames, and eye strain in searching for and examining small eggs/larvae and queens. Lacerations and punctures are reported as common injuries in farming (K. G. Davis and Kotowski, 2007) so it is not surprising that they are also prevalent in beekeeping. However, gloves form part of the protective gear found in beekeeping, but all three cases advocated against wearing them because they dampened the tactile sense so the apiarists

Fig. 10. Sliding tray filled with oil as small hive beetle trap.

could not feel when the bees were in danger of being physically harmed.

The apiarists seem to be reluctant and resistant to change, particularly relating to the introduction of new technologies. In each case in this paper, human instruction, mentoring and support seemed to be preferred and trusted. According to technology adoption models such as the Technology Acceptance Model (TAM2) (Venkatesh and Davis, 2000), technologies must be perceived as useful and easy to use in order for them to be used. Perceived usefulness is driven by a number of factors including relevance, quality, results demonstrability, experience and subjective norms. Any new technology, including processes, introduced to this industry must be measured against these requirements.

While there are many existing lifting solutions that are in use in other related industries, and that have been shown to be useful and easy to use, it is surprising that none has been integrated into standard beekeeping practices. It is unclear why this is the case; possible reasons could be that beekeeping has a very "macho" culture (Sanford and Tew, 2008; Gilmore, 1987), or that there is a strong resistance-to-change attitude among people who become beekeepers. Age or other demographic factors such as education level may also influence attitudes but further systematic research with more apiarists must be carried out. Further research on attitudes towards technology and change by beekeepers should be carried out to better understand the adherence to high risk techniques and practices despite existing solutions, and training opportunities being available. There are also opportunities for occupational health and safety interventions and training that could be made widely available through beekeeping organisations and governments. For example, part of the registration of apiarists could require mandatory occupational health and safety training specifically designed for beekeeping.

All apiarists in our study seemed to be most concerned about the bees and bee health particularly around infections and other invaders in their hives, as well as about preventing bee deaths while handling the hives, which can lead to awkward postures and consequent ergonomic risks. Not only did they spend much of the interview time talking about this subject but also most of their innovation projects revolved around detecting and preventing bee harm. It would seem then that apiarists are focused on the insects in their care rather than themselves; a bee-centric altruism where they are willing to overlook personal risk in favour of caring for bees. Other care professions such as animal husbandry and human care (e.g., physicians and nurses) also exhibit this attitude and behaviour where they are willing to trade-off their own safety with care for others. For example, according to Pratt et al. (1992) and Meyers et al. (2000) workers in the animal husbandry area of agriculture (e.g., sheep, cows, pigs, poultry and dairy) are at high risk of injury and resulting lost time. In research on lifting and back pain in nurses, Pheasant and Stubbs (1992) suggest that nurses are often willing to risk their personal safety in order to better care for patients. Colman (1994) presents an economic argument that agricultural stewardship is altruistic and involves a willing trade-off between commitment to protecting "the land and animals," and economic gain and profit. We could argue that beekeepers exhibit altruistic behaviours towards bees and beekeeping practices, and are willing to sacrifice their own health (and perhaps profit) for that of the bees. Beekeeping has many risks factors for human health that seem to be ignored in favour of an interest in bee health. However, if human health is not considered, ultimately it will affect bees, which may suffer when their human keeper is injured and cannot care for them.

These is some evidence of innovation for improving beekeeping tasks for the apiarists, for example, J2 used a "small Chinese object" to help with manoeuvring within small honeycomb spaces (e.g., to expose eggs in cells) and the use of "reading glasses" to see the small eggs/larvae in an attempt to avoid eye strain. These seem to be individual solutions to issues for typical and wide-spread tasks (e.g., all beekeepers inspect the eggs/larvae in their hives as part of the standard inspection process). It is surprising that common ergonomic solutions found in other industries are not used. For example, head or table-mounted magnifiers are standard equipment used in other typical visual inspection type tasks involving small target objects (e.g., in electronics inspection tasks Lee and Chan, 2009), and this type of equipment is readily available.

4.1. Design recommendations and future ergonomics research considerations

Understanding common beekeeping inspection practices and identifying ergonomics issues within them seems to be straight-forward tasks. However, developing solutions to these problems that would be acceptable and easy to use is a difficult task due to the resistance to change or technology attitudes that seem prevalent among the three beekeepers in our study. Some design suggestions arising from the case studies are:

4.1.1. Technological

a. Hand holds/handles could be fitted around the entire box and have clearance for the hand to wrap around to ensure good coupling for lifting (Lehto and Landry, 2012). Added or redesigned hand holds should not add much more weight to the box.
b. Construct boxes from lighter materials and/or investigate efficiency and efficacy of smaller boxes. In addition, alternative hive designs or infection control processes to reduce the frequency of physical inspections but maintain or improve hive health could be considered. Lighter materials must be able to withstand various weather conditions as well as protect the bees from extreme heat and cold conditions.
c. Integrate lift assist systems specific to the varying conditions used in frame inspection processes. Common lift mechanisms include manual pulley systems, and mechanical/pneumatic hoist systems. Efficiency will be an important consideration for this solution.
d. Examine the applicability of common manual-materials handling techniques for manual lifting such as use of an abdominal belt, reducing the frequency of lifts, providing training in safe lifting techniques and proper posture, and restricting the hive-heights to waist height (Bridger, 2017).
e. Develop a frame holder system so that frames can be placed in it and then turned for inspection. The system could also integrate a magnifier to support visual inspection of brood. The magnifier must be considered in conjunction with the visual obstructions associated with the mesh netting on the protective head gear.
f. Consider new smoker design (e.g., chemical, electronic) to remove smoke and fumes.
g. Develop or integrate a simple magnification system for inspecting brood.

4.1.2. Management

a. Investigate the relationship between current hive management and bee health.
b. Prepare and disseminate occupational health and safety training.
c. Investigate opportunities and venues to transfer individual/local innovations to the wider community beyond local workshops or club meetings, and an individual's online contributions.

4.2. Limitations

The cases highlighted in this paper were carried out in the field to observe and document actual beekeeping inspection practices, attitudes and human behaviours without interference in order to better understand these factors and find opportunities for ergonomic/design interventions, developments and research. As a result, no objective measurements were taken and all values in this paper are approximations. A next step in quantifying ergonomic risks in beekeeping would be to carry-out a full ergonomics assessment using standardized tools such as those used by Maina et al. (2016), and measure typical lifting heights and frequencies from a variety of beekeepers in different settings (e.g., backyards, commercial setups, forests, and rooftops) as well as for different tasks such as inspection, and honey extraction and processing.

In addition, only male beekeepers from one local location in Australia were involved in our study. Evaluating beekeeping practices for female beekeepers and from different parts of the world would provide a broader perspective and likely provide new insights and innovations.

Finally, the tasks assessed in this paper only related to individual beekeepers carrying out inspection tasks. No commercial operators were interviewed and no other tasks, such as honey extraction, were considered. Commercial operations may involve different equipment and processes because of the scale of operations being much larger than single operators. However, the hive inspection process will be similar to that of the single operator as the hive design and the need to inspect the hives remains the same. Expanding the interview cohort to include commercial producers as well as the task spectrum will likely identify other issues to consider as well as possible solutions.

5. Conclusion

The three case studies in this paper represent a small but illustrative set of examples of typical tasks that are undertaken by beekeepers in the hive inspection process. Even within technologically advanced and modern societies beekeeping has remained mostly unchanged since the 1850's when Langstroth introduced a hive design and beekeeping practices. Beekeepers seem to be somewhat averse to technology adoption, however, they are individually seeking out and using a variety of technologies and solutions to problems they encounter. In addition, they are willing to share their practices and designs with others. Similar to the practices in other care professions such as medicine and animal husbandry, beekeepers seem to be willing to trade-off their own health and safety with the health of the bee, tending to focus on finding ways to increase the health of bees and hives instead of overcoming human health and safety risks in beekeeping. Ergonomics and human factors research and practice can offer the beekeeping industry insights and techniques that could improve beekeeping practice and reduce risk to human beekeepers.

Declarations

Author contribution statement

Fels, D.: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Blackler, A. Cook, D.: Conceived and designed the experiments; Performed the experiments.

Foth, M.: Conceived and designed the experiments.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

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