United States
Consumer Product Safety Commission
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CPSC Staff's[1] Statement on Fors Marsh Group's Report, "Research into Riding Mower Back-Over and Run-Over Hazards"

February 2023

The following contractor report titled, "Research into Riding Mower Back-Over and Run-Over Hazards," presents the results of research conducted by Fors Marsh Group (FMG), under a CPSC contract.

FMG and their partner, Safety Research & Strategies, Inc. (SRS), conducted a literature review, product evaluation, and research of online media to identify hazard patterns associated with residential riding lawn mowers backing over or running over children. Specifically, the report details the product hazards, human behaviors, and existing voluntary standards covering residential riding mowers. Findings from the research suggest a need for modifications to residential riding mower safety design, as well as enhanced educational messaging about safety information.

The report finds that even after many years of implementation of both voluntary and mandatory safety standards and warnings, lawn mowers remain a considerable cause of morbidity and mortality among children. More than 9,000 children are injured by lawn mowers every year in the United States, and one study found that more than 7 percent of lawn mower-related pediatric injuries require hospital admission, which is two times the admissions rate for children with consumer product–related injuries overall. Literature indicates that riding mower injuries are more severe than walk-behind mowers, resulting in limb loss, permanent disabilities, and life-long psychological and financial effects.

The product evaluation found that safety-related riding mower characteristics varied among mower configurations and fuel types; and that where a no-mow-in-reverse (NMIR) system can be overridden, to enable the mower to move in reverse at full speed with powered blades, the override remained activated in almost all models when the mower moved from reverse to forward and back to reverse repeatedly. The report noted at least two factors that could increase the risk of injury: the effectiveness of the NMIR system, and the speed of the mower in reverse. In addition, there is no requirement in the voluntary standard for consumer riding mowers, ANSI/OPEI B71.1-2017, for where the override control should be located; but some literature suggests that locating it behind the operator's seat would force the operator to look backwards before mowing in reverse. The evaluation recommended that other potential design changes to improve mower safety include placement of a rear-facing camera or a proximity alert system on the riding mower. However, these suggested design changes require more testing and evaluation to determine whether they will be successful.

[1] This statement was prepared by the CPSC staff, and the attached report was produced by FMG for CPSC staff. The statement and report have not been reviewed or approved by, and do not necessarily represent the views of, the Commission.

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Other studies have shown that educational programs, safety campaigns, and safety lessons taught by family members are effective in influencing changes in operator and bystander behavior. One study recommends that education campaigns intended to protect younger children should target the operators (parents, grandparents, older siblings) and emphasize the importance of keeping children out of the yard while lawn mowers are in use; while education for older age children should emphasize safe mowing techniques and parental supervision. A multifaceted approach is also recommended to increase consumer awareness of the dangers that riding mowers pose.

In-depth interviews with medical professionals and a mechanical design engineer were conducted by FMG, which provided additional perspectives about injuries and hazards associated with riding lawn mower injuries, including prevention opportunities. Some of the doctors interviewed had conducted a study using data from the U.S. Nationwide Emergency Department Sample (a component of the Healthcare Cost and Utilization Project) for lawn mower–related emergency department visits and hospitalizations from 2006 through 2013. The data showed that lawn mower injuries occurred at a constant rate over that period, and therefore, the interviewed professionals believe that there is more work to be done to prevent these injuries from occurring.

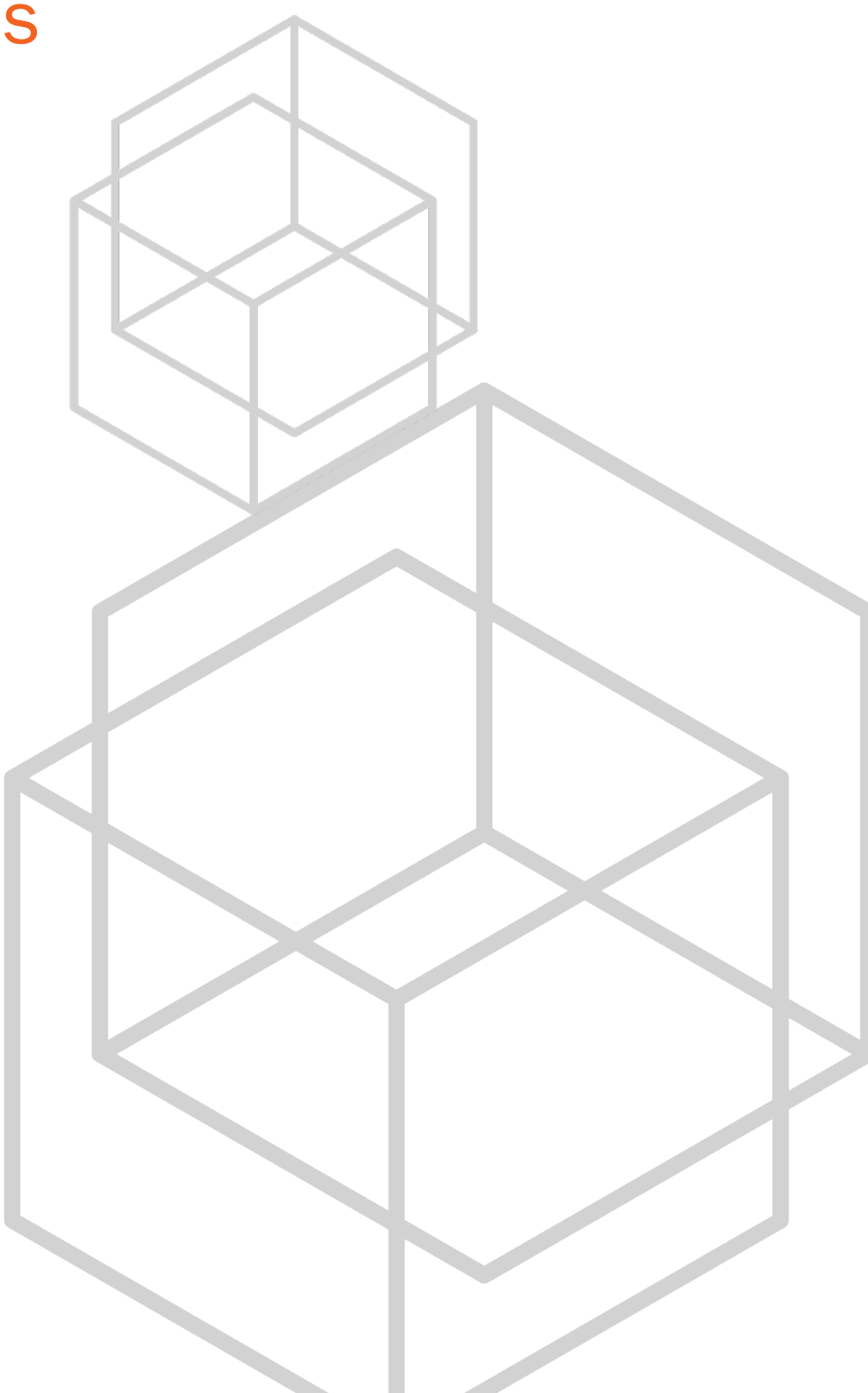
The interview participants expressed that designing safer mowers, providing more education and awareness, and collaborating with multiple stakeholders are critical steps to reducing lawn mower-related pediatric injuries. Several noted that the responsibility to raise awareness of lawn mower-related injuries should be a joint effort among the members of the medical community, the government, and manufacturers.

This report will assist CPSC staff as they continue to collaborate with the Outdoor Power Equipment Institute (OPEI) and other interested parties on potential voluntary standard requirements and educational campaigns aimed to reduce the likelihood of run-over and back-over injuries associated with riding lawn mowers, and continue to advance the Commission's mission of improving consumer safety.

Attachment

Research Into Riding Mower Back-Over and Run-Over Hazards

September 30, 2022



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Introduction

Study Background

Although the use of riding mowers and lawn mowers has become commonplace in consumer households over the last several decades, their use presents considerable risk both to those who operate the machinery and to bystanders. From 2005 to 2015, an estimated 934,394 lawn mower–related injuries were treated in emergency departments across the United States, averaging 84,944 injuries annually (Harris et al., 2018). Research shows that lawn mowers are more likely to cause severe injury to bystanders and passengers than to operators; bystanders and passengers are almost four times more likely than operators to be admitted to hospitals (Ren at al., 2017; Nationwide Children's Hospital, 2017).

Despite warnings from the American Academy of Pediatrics and the voluntary safety standard in the American National Standards Institute/Outdoor Power Equipment Institute (ANSI/OPEI) B71.1-2017 to improve lawn mower safety, lawn mowers remain a considerable cause of morbidity and mortality among children. More than 9,000 children are injured by lawn mowers every year in the United States (Bachier & Feliz, 2016), and the pediatric lawn mower hospital admission rate is 7%, which is two times the admissions rate for consumer product–related injuries overall (Vollman & Smith, 2006). Of note, from 2004 to 2013, riding mowers specifically accounted for about one-fifth (21%) of all pediatric mower-related injuries (Bachier & Feliz, 2016). Other pediatric mower-related injuries during that time were caused by walk-behind mowers (8.4%) or an unspecified mower type (70.4%). Additionally, children are more likely to be admitted to a hospital if they were injured as a passenger or bystander of a riding mower (Vollman & Smith, 2006).

Compared to push mowers, riding mowers have been shown to produce more severe injuries and cause longer hospital stays (Hammig et al., 2009; Nguyen et al., 2008). The most common injuries sustained in lawn mower–related accidents include laceration, eye injury, soft tissue injury, burns, fracture, and amputation. In accidents caused by riding mowers, injuries to individuals are most often incurred by being struck by a projectile object, being trapped by the mower after tip-over/rollover, or being run over or backed over with the mower blades engaged and rotating.

Riding mower back-over and run-over accidents regularly cause severe injuries, often resulting in major amputations or other permanent disabilities, and are also associated with additional financial burden (Ren et al., 2017). In their review of lawn mower–related injuries from 1990 to 2014, Ren et al., (2017) found that children under 5 years old accounted for more than half of riding mower back-over injuries. Even though incidence of back-over injury in children is high, back over–related injuries occur across all age groups (Hammig et al, 2009; Nakamoto et. al, 2020). For example, a review of injuries associated with riding mowers from 2002–2007 found that most run-over incidents impacted older children and adults (Hammig et al, 2009).

These findings describe a large-scale problem that necessitated further evaluation of lawn mowers, specifically the risk of run-over or back-over of children from riding mowers. Therefore, the U.S. Consumer Product Safety Commission (CPSC) led an effort to fill this gap to enhance the safety of these machines. Specifically, this report details the product hazards, human behaviors, and existing voluntary standards covering residential riding mowers. This thorough evaluation will be used to produce critical recommendations for design and use standards to protect consumers.

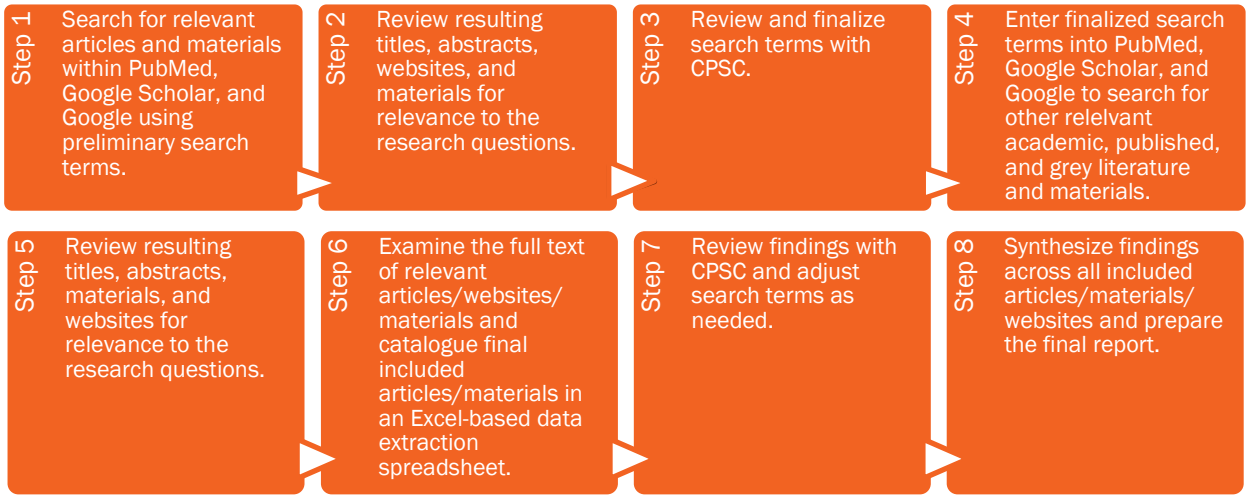
Methodology

Fors Marsh Group, LLC (FMG) and their partner, Safety Research & Strategies, Inc. (SRS), were contracted to conduct a literature review, task analysis, and environmental scan to identify hazard

patterns associated with residential riding mowers backing over or running over children. Additionally, Team FMG sought to determine (a) whether current voluntary standards address the common hazard patterns for back-over and run-over incidents, and (b) recommendations for best practices in technology that may improve riding mower safety. Findings from the literature review, task analysis, and the environmental scan reveal a need for modifications to residential riding mower safety design, as well as clear and educational messaging about safety information. Team FMG compiled recommendations for communicating the risks associated with residential riding mowers and potential design changes to enhance safety in a separate recommendations document.

Team FMG employed a systematic approach to ensure that the most relevant articles, websites, and materials were included in the literature review and environmental scan (see Figure 1).

Figure 1: Literature Review and Environmental Scan Process



The research questions that drove the literature review, task analysis, and environmental scan are outlined below:

Literature Review Research Questions

1. Who is most likely to operate a riding mower? For what purpose? When?
2. What types of children, besides those who are younger and who live in rural areas, are at greatest risk of being injured by riding mowers?
3. What are the most common types of injuries?
4. What features of riding mowers place operators at greatest risk of injuring children?
5. What behaviors of riding mower operators place them at greatest risk of injuring children?
6. What standards related to the design of riding mowers currently exist?
7. What standards related to the operation of riding mowers currently exist?
8. How are the standards communicated to riding mower developers?
9. How are the standards communicated to riding mower operators?
10. What technological advances for riding mowers are currently under development?

Task Analysis Research Questions

1. What are the most common/representative riding mowers on the market today?
2. What safety features or safety guidance is included in operator manuals and on the machines?
3. What safety features are present in the riding mowers on the market today?
4. What are the potential safety hazards present in the riding mowers on the market today?

Environmental Scan Research Questions

1. Who is most likely to operate a riding mower? For what purpose?
2. What types of children are at greatest risk of being injured by riding mowers?
3. What are the most common types of injuries?
4. What features of riding mowers place operators at greatest risk of injuring children?
5. What behaviors of riding mower operators place them at greatest risk of injuring children?
6. What standards related to the design of riding mowers currently exist?
7. What standards related to the operation of riding mowers currently exist?
8. How are the standards communicated to riding mower operators?

Using the predetermined research questions, Team FMG considered search terms that yielded relevant literature, websites, and materials. Team FMG first tested broad search terms (e.g., riding lawn mower accidents) and then gradually tested more specific terms (e.g., back over mower hazards, riding lawn mower safety measures). Through this process of refinement, Team FMG identified terms that produced results most relevant to the research questions. Team FMG presented CPSC with a list of articles gleaned from this process for their review. CPSC and Team FMG came to an agreement on the final search terms for the literature review and environmental scan (Appendix A: Literature Review and Environmental Scan Search Terms).

Literature Review

Team FMG thoroughly reviewed academic, published, and grey literature through PubMed, Google Scholar, and additional academic databases using the approved key search terms. Grey literature refers to unpublished information that has not been through peer review. Government reports, conference proceedings, technical papers, and theses and dissertations are all examples of grey literature. To ensure that we captured the latest research, Team FMG set a date range of 10 years (2010–2020) as a criterion for the literature review. While using this criteria, Team FMG noted that especially relevant literature often fell outside of the initial year limit, and Team FMG made an exception for seminal articles in the field published prior to this date range. Team FMG assessed the article titles and abstracts of all search results for relevance to the research questions and then examined the full text of relevant articles. We included a total of $N = 43$ articles in the final literature review.

After assessing an article's alignment to the research questions, the team made a final decision to include or exclude the article, prioritizing publications that discussed riding lawn mower injuries. To fill in gaps, articles about the types of injuries caused by garden tractors were included to better understand what measures have been taken to prevent those specific injuries. We then cataloged all articles selected for inclusion in a Microsoft Excel data extraction spreadsheet. The extraction spreadsheet captures the following information for each article: (1) author(s); (2) publication year; (3) publication title; (4) journal title; (5) journal volume, issue, and page numbers; (6) key topics/keywords; (7) study design/methodology; (8) sample characteristics; (9) a concise summary statement of main article findings; and (10) any limitations of the study.

Literature Review Definitions

Though the focus of this report is on consumers and "residential riding mowers," there are several instances within the literature in which it is unclear what type of mower is being analyzed or discussed. Often, we found "lawn mower" to be an "umbrella" term—that is, much of the research does not clearly differentiate between push mowers or riding mowers, and researchers interchangeably use terms like "ride-on mower" or "lawn tractor" to indicate a variety of riding mower. For clarity, wherever possible, we will differentiate between literature that discusses push

and riding mowers, but otherwise will use the term “lawn mower” or “mower” to emphasize at times when this distinction is not clear.

Task Analysis

Team FMG, led by SRS, conducted a task analysis, also known as a product evaluation, to identify and document relevant features, potential product hazards, and potential failure modes across a sample of consumer riding lawn mowers. Team FMG identified and selected 20 riding lawn mower models (see Figure 2) for inspection (referred to as “the sample” in this section). Riding lawn mowers were selected based on the following criteria: mower configuration (e.g., lawn tractor or zero-turn; see Figure 3); manufacturer, brand, and model market share; price point; fuel type (e.g., gas or electric; see Figure 4); and other characteristics based on a review of trade journals, press releases, manufacturer specifications, retailer websites, and other public sources. The final sample of mowers was selected to represent a variety of mower configurations and fuel types like those available to consumers. A majority of the sample comprises large brands available at major retailers, but several machines from smaller manufacturers were included to provide a wider variety of machine characteristics.

Figure 2. Machine sample by broad machine configuration

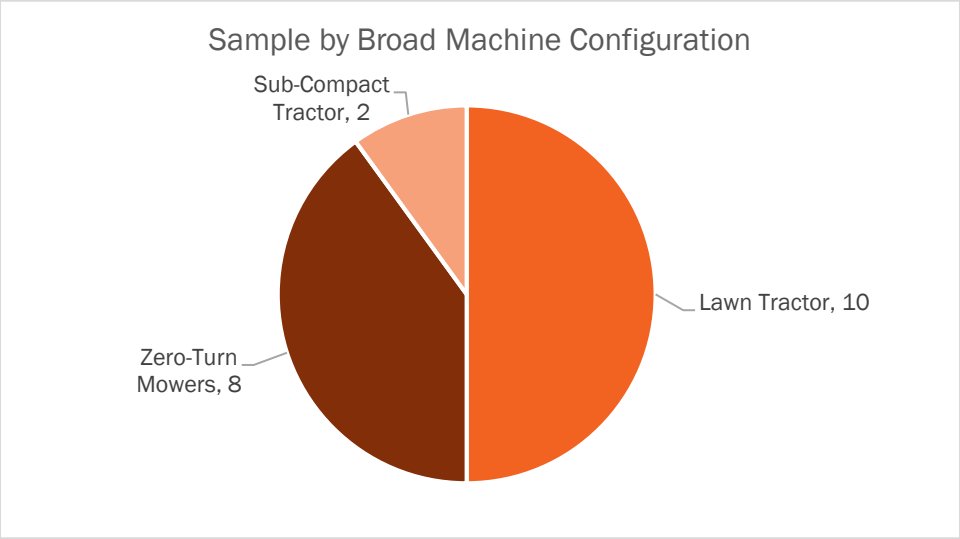


Figure 3. Machine sample by mower configuration

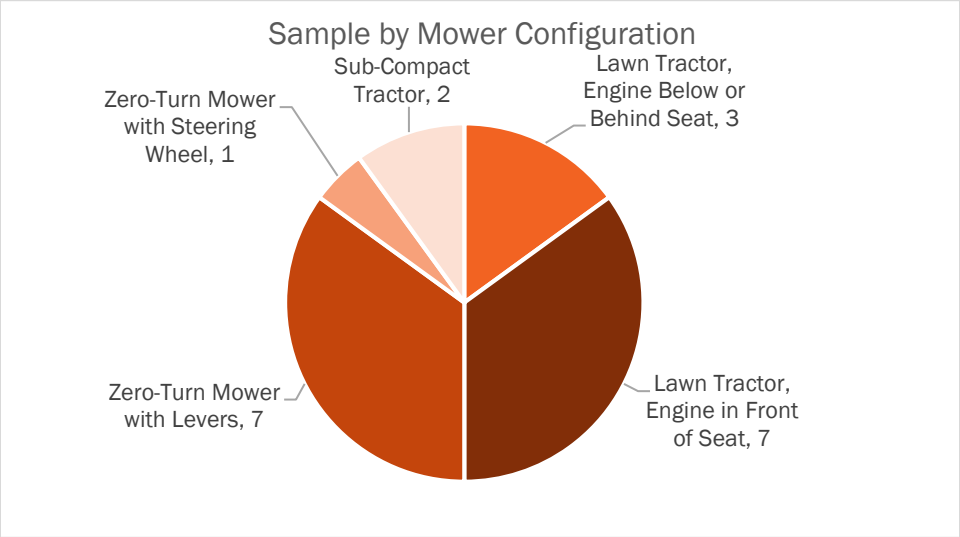
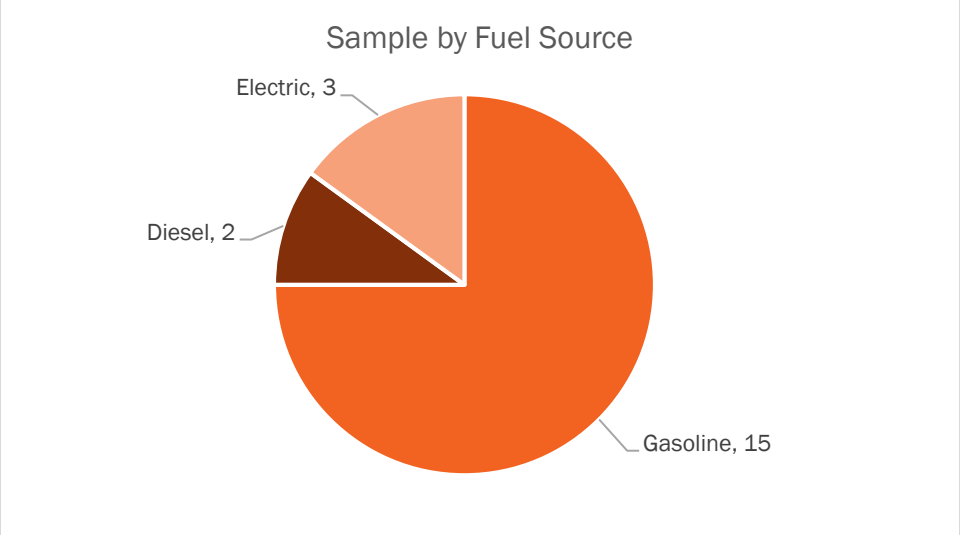


Figure 4. Machine sample by fuel source



To guide the final sample selection, Team FMG compiled a comprehensive list of residential riding lawn mower manufacturers and brands available in the U.S. market in the Winter/Spring of 2022. This list was informed by trade journal articles, consumer buying guides, and manufacturer websites. Team FMG then compiled an index of models of riding lawn mowers described on manufacturer websites. A review of that list suggests that U.S. residential models were evenly divided between lawn tractors and zero-turn mowers with steering levers, with a very small number of sub-compact tractors and zero-turn mowers with steering wheels available. Electric mowers made up a very small portion of the models available but received a disproportionately high amount of press. Therefore, it was determined that to be representative of what was available to consumers, the sample should be relatively divided between lawn tractors and zero-turn mowers, and should contain some electric mowers, sub-compact tractors, and one zero-turn mower with a steering wheel.

Once the ideal sample makeup was determined, Team FMG began locating machines available for in-person inspections by examining online inventory systems for large retailers and calling and

visiting retail locations to determine what mowers were in stock. Ultimately, in-person mower availability impacted which mowers were included in the final sample.

Due to machine availability and an effort to observe a varied sample, fifteen evaluations were based on in-person inspections and a review of the respective operator's manuals (referred to as "inspected" for this section), and five evaluations were based only on a review of the owner's manuals and specification sheets, without in-person inspections. Operator manuals and specification sheets were obtained from the manufacturer's websites. Machine inspections were conducted on new machines at retailer and dealer establishments, except for one inspection of a slightly used machine that occurred on the owner's property.

Observations were conducted between March and May 2022. In-person observations occurred at the following home and garden stores, small equipment dealers, and residential locations:

- Home Depot, Warwick, RI
- Home Depot, Attleboro, MA
- Lowe's, Greeley, CO
- Tractor Supply Company, Lafayette, CO
- Dave's Lawnmower Repair, Swansea, MA
- Universal Tractor, Lakewood, CO
- Residential location, Darnestown, MD

An observation protocol (Appendix B: Task Analysis Protocol) was developed and used to provide a consistent method for documenting safety features, safety instructions, and warnings related to back-over and run-over incidents that were identified during the environmental scan and literature review, and through a survey of lawn mower operator's manuals. Photographs documenting inspected riding lawn mower features and labels were taken during in-person inspections.

Features, safety instructions, and warnings that were determined to be most relevant to back-over and run-over incidents were included in the observation protocol. These included:

- Safety information
  - Warnings in operator's manuals
  - On-machine warnings
- Visibility
- Controls
- Speed
- Deck height and guarding
- Safety feature interlocks
- Safety feature application unique to subcompact tractors

Team FMG was able to identify broad trends among mowers while also noticing anomalies between and unique characteristics of individual machines. In addition to this qualitative observation, key safety feature characteristics measured by the protocol (e.g., compliance with ANSI/OPEI B71.1, type of warning information included in operator's manuals, mower speeds, deck height, interlock application type) were included in the data set. These features were systematically compared across the entire sample to identify trends between mower configuration types.

Task Analysis Definitions

The term "residential riding mowers" describes a class of mowers that encompasses a variety of machines. For clarity in the task analysis, the term "lawn tractor" is used to describe the style of riding mower with a steering wheel and a wide turning radius. "Zero-turn mowers" have a narrow turn radius of nearly zero and are typically steered by a set of two levers, though one zero-turn mower in

the sample has a steering wheel. “Sub-compact tractors” refer to a class of machines marketed to residential users that offer some functionality of commercial tractors (i.e., the ability to use a variety of implements and attachments, including mid-mount and rear three-point hitch mounted mowing decks).

Two styles of lawn tractor were observed in the task analysis—those with the engine mounted in the front, and those with it mounted below or behind the operator. The images below show both orientations.

Lawn Tractor – Front Engine

Lawn Tractor – Rear Engine

Zero-Turn Mower

Environmental Scan

Using the approved search terms, Team FMG used search engines (e.g., Google) to identify and summarize existing voluntary safety standards and advances in residential riding mower technology. CPSC also provided a list of in-depth interview accident reports related to riding lawn mower injuries

that had been reported to CPSC. Additionally, the environmental scan sought to determine (1) whether the common hazard patterns found in the data for back-over and run-over incidents are adequately addressed by voluntary standards and (2) the recommendations for advances in technology that may improve riding mower safety and reduce the risk of back-over and run-over incidents. A team of researchers scanned through the search results to (1) identify relevant organizations, (2) catalog how the identified organizations set standards and advance technology to improve rider mower safety, and (3) highlight gaps in current communications outreach from the organizations. Team FMG included websites and/or materials that provided pertinent information to the research questions. We then catalogued the most relevant materials (N = 54) in a Microsoft Excel extraction file and captured the following information for each source: (1) the justification for inclusion, (2) the URL, (3) the focus/mission, (4) the specific expertise relevant to riding mower safety, (5) the language and origin, (6) the affiliation (e.g., research agency, author), (7) the primary media type (e.g., print, digital, television), (8) the content type (e.g., blog post, YouTube video, study, report, website), (9) the intended audience (e.g., riding mower manufacturers), (10) the intention/designated use, (11) push/pull (e.g., pulling the audience to do something or pushing the audience information/stating facts), and (12) the call to action (e.g., keep your children inside when you are mowing).

In-Depth Interviews (IDI)

Team FMG conducted four 60-minute virtual IDI with medical professionals and an engineer to obtain immediate insight into lawn mower–related injuries in the DC, Maryland, and Virginia region and to capture potential riding mower safety advances for preventing run over injuries. The stakeholders were identified by CPSC as individuals who sought an opportunity to provide feedback about riding mower run-over injuries. Team FMG recruited these stakeholders via email, scheduled and conducted the interview with a guide approved by CPSC, and, upon completion of the interview, Team FMG requested that interviewees share any contact information of other potential stakeholders to interview. Characteristics of IDI participants are described in Table 1. The interviews were conducted from April 13, 2022, through May 31, 2022.

Table 1. Participant Professions

Participant	Professional Title	Area of Expertise
1	Assistant Professor of Anesthesiology and Critical Care Medicine	Pediatric Anesthesiology
2	Director of Pediatric Trauma Program and Division of Pediatric Surgery	Pediatric Surgery
3	Associate Professor of Anesthesiology and Critical Care Medicine, Director of Anesthesiology and Critical Care Medicine Training and Residency Program	Anesthesiology
4	Associate Teaching Professor in the Department of Mechanical Engineering	Design Engineering

Team FMG developed the IDI discussion guide to assess: (1) What injury patterns have medical professionals observed among children injured by lawn mowers?; (2) How can lawn mower injuries among children be reduced?; (3) How do riding mower injuries impact the patient, their family, doctors, and the health care system?; (4) What role do health care professionals play in reducing lawn mower injuries among children?; (5) What does a safe riding mower look like?; (6) What are some potential engineering solutions to make riding mowers more safe?; (7) What challenges have been encountered when design engineering for riding mowers?; and (8) What key safety messages (or messaging strategies) might be effective for communicating riding mower safety to the general population and from whom should those messages come? Additionally, the guide was designed to cover three main topic areas: general background with riding mower injuries and the development of their concern, the extent and severity of riding mower–related injuries they have encountered

(specific to medical professionals), potential engineering solutions (specific to the engineer), and suggested solutions and recommendations to reduce riding mower injuries.

A trained notetaker was present for and listening to each interview to ensure all themes and perspectives were captured. Once all interviews were completed, trained qualitative analysts reviewed the notes from the IDIs and identified key themes.

Overview of Findings

Early in this effort, it became clear that there is a limited amount of published research about injuries and hazards associated with riding mowers. Available findings typically focus on push mowers or combine analyses of injuries sustained from power lawn equipment, including riding mowers, tractors, and push mowers. Though there is limited research about prevention and hazards pertaining to riding mowers, there are several studies that focus on pre- and post-injury contextual factors, (e.g., the type of injuries or body part[s] affected, circumstances that led to the injury). Therefore, this report provides findings from riding mower–specific studies and synthesizes analyses about injuries from both push and riding mowers. To supplement these analyses, this review also includes information about safety guidelines and educational interventions designed to reduce the run-over and back-over hazards of riding lawn mowers.

Observing the real-world application of safety features on riding mowers, including how safety labels, warning information, and instructions are incorporated by manufacturers, is critical. These observations help identify any technologies or strategies currently used to address safety hazards associated with riding mower run-over and back-over. Team FMG systematically observed, documented, and evaluated a sample of 20 consumer riding lawn mowers to discern their applications of safety information, potential product hazards, and failure modes. All mowers observed contained safety labels and warnings related to run-over and back-over hazards, and many addressed the hazards of mowing in reverse and mowing around children in detail. Safety-related riding mower characteristics varied between mower configurations (e.g., lawn tractor, zero-turn mower, sub-compact tractor) and fuel types (e.g., gasoline, electric), and the design and implementation of mow-in-reverse interlocks and overrides on lawn tractors was greatly different between manufacturers.

The environmental scan findings focus on sources that summarize existing voluntary safety standards and advances covering residential riding mowers. Additionally, the scan investigated whether common hazard patterns found in the data for back-over and run-over incidents are adequately addressed by voluntary standards. Recommendations for advances in technology to improve riding mower safety and reduce the risk of back-over and run-over were also captured. Notably, a plethora of online sources discuss riding mower hazards, back-over and run-over injuries, procedures to operate riding mowers, injury prevention methods, and the importance of lawn mower safety. Sources, including CPSC's incident data, cite that mowing in reverse on a riding mower is a common cause of injury, as well as run-over accidents, which typically occur when the operator is unaware of an individual approaching the mower. Although many riding mowers are equipped with safety features that should prevent and/or reduce the risk of riding mower–related injuries, sources and incident reports highlight that riding mower operators override the safety features to fit their needs. To help prevent riding mower accidents from occurring, the medical community is heavily involved in sharing resources (e.g., FAQs, safety videos, statistics on injuries related to riding mower accidents). To help with the recovery process, support groups also exist online for families affected by mower-related injuries.

To provide contextual insight, IDIs with medical professionals and an engineer were conducted. Findings from these IDIs provided additional perspectives about injuries and hazards associated with riding lawn mower injuries, including prevention opportunities. The IDIs identified an observed pattern of riding mower–related injury and the life-long impact that these injuries have on patients and their families. Participants also expressed that designing safer mowers, providing more education and awareness, and collaborating with multiple stakeholders are critical steps to reducing pediatric lawn mower–related injuries. Several noted that the responsibility to raise awareness of lawn mower–related injuries should be a joint effort between the medical community, the government, and manufacturers.

Literature Review Findings

Despite the implementation of safety standards and warnings, both push and riding mowers remain a significant cause of injury among children and adults in the United States (Harris et al., 2018; Ren et al., 2017). Annually, the medical and societal costs associated with both riding and push lawn mower injuries in the United States amounts to $90 million (Fletcher et al., 2018). According to Lau et al. (2006), the average hospital cost of injuries sustained from riding mowers alone amounted to $45,000, compared to the $14,500 cost from injuries sustained from push lawn mowers. The incidence rate, severity of bodily damage, and financial impact of riding lawn mower–related injuries underscore the need for a thorough understanding of their hazard patterns, safety standards, and the technological advances designed to reduce injuries.

Injuries

The CPSC has identified push and riding lawn mower accidents as an underrecognized threat to public health, with approximately 80 to 100 deaths and 80,000 emergency department visits per year (Nakamoto et al., 2020). The risk for severe injury to bystanders and passengers is particularly concerning. Due to their size and lack of awareness of the dangers associated with lawn mowers, children face increased risks for lawn mower–related injuries. In a study of pediatric lawn mower injuries, Love et al. (1988) found the majority of patients (25 of 27) were injured as bystanders. According to the CPSC, an estimated 800 children are run over each year by a riding lawn mower or tractor, and 600 of those injuries require amputation (CPSC, 1999). Substantial injury rates among adults and children during the last 3 decades prove the continued severity and relevancy of these devastating injuries, especially among children.

From 2005 to 2015, there were an estimated 934,394 lawn mower injuries treated in U.S. emergency departments (Harris et al., 2018), and between 9,000 and 17,000 children sustain injuries related to lawn mowers each year in the United States (Khansa et al., 2021). Injury patterns from riding mowers among adults and children are often catalogued by injury severity, injury type, machine type, and demographics.

Severity

Lawn mower–related injuries are devastating and often have life-long implications, resulting in substantial preventable morbidity and mortality among adults and children. The most severe injuries are often associated with riding mowers (Vosburgh et al., 1995; Laing et al., 2011). CPSC's 1993 and 2004 report on riding mower hazards reported that riding lawn mower blade contact injuries appear to be more severe than walk behind mowers (Adler & Schroeder, 2004). This is due to the number of victims treated and transferred to other hospitals was nearly twice as high with riding lawn mowers (21%) compared to push mowers (11%; Adler & Schroeder, 2004). More specifically, accidents in which children are injured by lawn mowers may be the result of user error or limited parental supervision. Children are most likely to sustain injuries from riding mowers from falling off while riding in the operator's lap or being run or backed over. This is particularly concerning, as children younger than 5 years old are disproportionately affected by severe injuries caused by lawn mowers; they are more likely to be burned from touching a hot surface on a mower, backed over or run over by a riding mower, or hit as a bystander or passenger (Ren et al., 2017).

Children are at risk for severe injury due to their smaller size, continued skeletal growth and development, and early stages of motor skills. When injured by a lawn mower, younger children often sustain more severe injuries than older children, frequently requiring extensive surgery and often amputation (Khansa et al., 2021). For example, of patients ages 0 to 17 admitted to Pennsylvania trauma centers for lawn mower–related injuries between January 2002 and January 2014, 53% had at least one amputation during their hospital stay (Garay et al., 2017). Furthermore, researchers found that among these patients, younger children experienced longer hospital stays and were more

likely to be admitted to an intensive care unit. Riding mowers were associated with 92% of the lawn mower–related accidents for which the type of lawn mower was documented (Garay et al., 2016). In a retrospective case series examining pediatric lawn mower injuries treated at level 1 trauma centers from 1995 to 2005, Fletcher et al. (2018) found that out of 157 cases, 40% of patients required at least one traumatic amputation and 13% required a prosthesis after their traumatic injury. Furthermore, riding mowers were responsible for twice as many injuries as were push mowers (Fletcher at el., 2018). Evidence from these studies provides support that riding mowers are a source of severe, life-long injury among children.

A major concern with riding mower run-over and back-over accidents is amputation. In their study of pediatric injuries incurred by being run over by a riding mower, Hammig and Jones (2010) found that almost one quarter of run over injuries required amputations. Longer inpatient hospital stays and multiple operations are required for severe injuries to the extremities because of trauma to the bone and soft tissue (Hammig & Jones, 2010; Garay et al., 2017). Initial treatment for lawn mower injuries in children is based on surgical management for the mangled extremity determined by a team of medical professionals. Management involves the combined intervention of a host of hospital services (e.g., emergency care team, general, plastics and orthopedic surgeons, nurses, rehabilitation therapists; Laing et al., 2010). The medical care team assesses the viability of the limb, followed by aggressive irrigation of the wound site, removal of damaged tissue and nonviable fragments, and bone stabilization (Kroening & Davids, 2000). Reconstruction of the extremity may include split-thickness skin grafting or placement of tissue flaps, free tissue transfer, nerve grafting, and tendon repair (Love et al., 1988; Branch et al., 2018; Fletcher et al., 2018; Talathi et al., 2018). In the event of severe trauma to the soft tissue and bone, the limb may be unsalvable and require amputation.

Medical treatment for amputations places significant economic burden on patients' families and the health care system. In 1997, Loder et al. found that the average prosthetic from the time of injury to 18 years of age costs an average of $73,140 to $116,040 per single lower extremity in children with traumatic lawn mower amputations. In addition to healing the wound, children must undergo physical therapy to maintain motion and strength of the affected limb. Furthermore, these life-altering injuries can have detrimental effects on the mental and psychological well-being of a child (Shah et al., 2020).

Injury Type

Many studies have examined injury type and body parts affected by both riding and push lawn mowers. Common injuries from both riding and push mowers include lacerations of skin muscle, tendon, and joint; burns; soft tissue injury; direct and indirect injuries to the head; fractures; and amputations (Robertson, 2003). Using data from the National Electronic Injury Surveillance System (NEISS) captured between 2002 to 2008, Hammig and Jones (2010) examined injuries among children admitted to an emergency department after being run over by a riding lawn mower. During this period, an estimated 1,893 U.S. emergency department visits occurred due to a person being run over by a riding lawn mower. Hammig and Jones (2010) found that the most prevalent injuries were lacerations, contusions, abrasions, and amputations. Amputations accounted for 23% of all injuries, with 95% of amputations occurring to the foot or toes. Overall, most injuries occurred to the lower extremities (65%).

Lawn mower injuries to the lower extremities in children are devastating and often result in amputation (Vosburgh et al., 1995). Further, these injuries can be complex depending on how the injury was incurred, and they may require prolonged medical treatment as the child ages. In a series of cases examined by Love et al. (1988), extremities were the most common injury site, specifically the forepart of the foot, in children who were injured by lawn mowers. Hendrickson et al. (2004)

found similar patterns after examining 190 case reports of pediatric lawn mower–related injuries from the National Pediatric Trauma Registry, determining that all reported lawn mower accidents associated with ride on mowers resulted in severe damage to the torso and lower extremity. A 7-year study of 1,893 emergency department visits for riding lawn mower–related injuries also found most (65%) injuries occurred to the lower extremities (Hammig et al., 2009). In a retrospective review of pediatric patients admitted to a level 1 trauma center with lower extremity lawn mower injuries, riding mowers were responsible for 96% of injuries, where lower extremity injuries included amputations (56%) and fractures (59%; Branch et al., 2017). Similarly, Vosburgh et al. (1995) found that riding mowers were associated with 20 out of 33 lower extremity injuries of all patients admitted to the Children's Hospital of Oklahoma between August 1981 and May 1993. Out of the 20 injuries sustained from riding mowers, all but one involved contact with the mower blade. Further, the study of patients admitted to the Children's Hospital of Oklahoma found that all cases of below the knee amputation, ankle disarticulation, and free vascularized grafting resulted from riding mower injuries (Vosburgh et al., 1995).

Results from these studies highlight the severity and frequency of riding mower injuries to the lower extremities in children. These studies also show that most riding lawn mower injuries among children are due to the child being run over either from falling off the mower or because the operator failed to see them. In their analysis of data pulled from the January 2006 to December 2013 U.S. Nationwide Emergency Department Sample for lawn mower–related emergency visits and hospitalizations, Hottinger et al. (2018) found an injury pattern based on the age of the patient; specifically, children between 0 and 4 years old were more likely than teenagers (15 to 19 years old) or adults to be injured on the foot or toe and sustain an amputation injury. They believed these findings correspond to injury scenarios in which young children run into a yard where a lawn mower is being operated, or are sitting on the lap of a riding mower operator and fall with their foot becoming trapped in the machine (Hottinger et al., 2018).

Lawn Mower Type

Riding mowers can cause different injury patterns than push lawn mowers, with riding mowers being more dangerous due to their size, blade-cutting diameter, and complex mechanisms (Hammig et al., 2009). CPSC's 1993 and 2004 report on riding mower hazards identified the following major hazards associated with power mowers: blade contact, thrown objects, mower stability among others (e.g., fell/being thrown, starting-related, hit/contact stationary object, burns from hot surface, fuel ignition, entrapment in mower moving part, etc.) (Adler & Schroeder, 2004; Smith & Committee on Injury and Poison Prevention, 2001). According to Smith and the Committee on Injury and Poison Prevention, (2001) approximately 13% of injuries that occur during riding mower use are associated with loss of mower stability and 20% of those injuries require hospitalization. They also note that the weight and size of a riding mower poses significant risk for rollover incidents. Injuries are typically incurred during rollover accidents as the weight of the machine can pin the operator or bystander, or contact is made with the rotating blades. For example, in their review of accident data from riding mowers, Sevart (2017) found that asphyxiation and drowning (e.g., being pinned underwater) are the most common causes of death during a riding mower rollover.

As noted, riding mowers pose a greater risk than push mowers for severe injury, amputation, or death among children (Laing et al., 2011; Garay et al., 2017). Between 1994 and 2019, the three most common causes for lawn mower–related injuries as documented from patients admitted to a level one pediatric trauma center included being hit by a forward-moving lawn mower, falling from a riding lawn mower, and being hit by a lawn mower moving backwards (Khansa et al., 2021). Specifically, children can be trapped under a mower and sustain severe injuries from the mower blade; riding mowers are built to cut, and are therefore capable of chopping off hands, feet, or other parts of the body that interact with the rotating blades (Laing et al., 2011). Additionally, results from

Khansa et al (2021) highlight that riding lawn mowers were responsible for more operative procedures and soft tissue defects than were push mowers. A systematic review also noted that patients injured by riding lawn mowers were significantly younger, required substantially more operative procedures, were more likely to have soft tissue defects requiring reconstruction, had longer hospital stays, and had a higher average number of digits amputated than were patients injured by push mowers (Talathi et al., 2018).

Demographics of Injured

Children account for a high proportion of push and riding lawn mower–related accidents and injuries (Klein et al., 2018). It is estimated that 9,400 to 17,000 pediatric lawn mower injuries occur each year in the United States, and from 1990 to 2014, there were an estimated 212,258 lawn mower–related injuries incurred by children under 18 years old (Vollman & Smith, 2006; American Academy of Pediatrics Grand Rounds, 2017).

The demographics (e.g., age, gender) of children injured by riding lawn mowers are often captured through hospitals and emergency departments. Similar patterns have emerged regarding the age and gender of children who sustain lawn mower injuries. In one review (*N* = 157), the median age at the time of injury was 6 years old, with observed peaks for lawn mower–related incidents at 4 and 15 years of age, and 75% of the pediatric patients were male (Fletcher et al., 2018). Similarly, another study *(N* = 199) found that the median age at the time of injury was 6 years old, with peak incidences for hospital admission for pediatric patients at 4 and 17 years old (Garay et al., 2017). A review of pediatric lawn mower injuries from 1990 to 2014 observed that the mean (9.9 years) and median (10.6 years) age of injured patients was slightly higher than other studies, and most patients who sustained injuries from lawn mowers were male (77%; Ren et al., 2017). A systematic review of pediatric lawn mower injuries by Talathi et al. (2018) similarly reported that peak frequencies for age of injury were at 3 and 16 years.

Research also suggests that numerous geographic and locale disparities exist in relation to pediatric lawn mower risk and injury. While lawn mowers are hazardous to all children, studies have found that children living in rural areas are at increased risk of severe injury (Kim et al., 2012; Wright et al., 2013). Further, children living on farms are at a higher risk of injury than hired workers, and are unprotected by child labor laws (Wright et al., 2013). Agriculture is a hazardous occupation, and in many rural environments it can be difficult to separate work from non-work activities, exposing children to multiple hazards. Pickett et al. (2005) observed that young, non-working children are particularly at risk of death on farms due to drowning and lawn mower run-over. In a review of 934 cases of pediatric farm injuries, the most common mechanisms of injury included: bystander and passenger machinery (e.g., riding mower or tractor) run-over (22.5% and 21.7% of fatalities respectively); drowning (12.4% of fatalities); machinery entanglements (19.7% of hospitalizations); and falls from heights (27.0% of hospitalizations; Pickett et al., 2005). The observed percentage of run-over injuries sustained by children living on farms by Pickett et al. (2005) supports the need for more research on the geographic disparities that exist in lawn mower–related injuries.

Additionally, more research is required to understand injuries sustained by children who are not engaged in agricultural work or who live in non-rural areas, as current data are limited. Using 2005 to 2007 data from Pediatric Health Information System, Shah et al. (2020) found that urban areas had an incidence rate of 1.47 injuries per 100,000 cases, whereas rural areas had a rate of 7.26 injuries per 100,000 cases. Further, patients injured in rural areas had an overall amputation rate of 15.5%, compared to 9.6% in urban areas. These findings are evidence that educational efforts for lawn mower safety may be more effective if targeted for rural communities, though more research should be conducted on urban and suburban data.

Differences in risk of a riding lawn mower injury have also been observed among adults. A retrospective review of Cabell Huntington Hospital's January 1, 2010, to December 31, 2019, trauma registry for riding lawn mower accidents sustained by patients over 16 years old found that patients over 75 years old had a significantly higher mortality rate (14%) than did patients under 75 (2%) (Nakamoto et. Al., 2020). Though studies that examine lawn mower injuries among older populations are limited, Hammig et al. (2009) found similar evidence that "the rate of [emergency department] visits for riding mower injuries tended to increase with age, with those aged 70 and older having more than twice the rate of those aged 15 to 39." This suggests an opportunity to increase awareness among elderly individuals about the risks of operating lawn mowers and proper safety to prevent injury.

Safety Standards

Safety guidelines concerning the use of lawn mowers were promoted and implemented by professional organizations, including CPSC, starting in the early 1970s (Buchele & Baldwin, 1978). In 1974, CPSC published a statement citing that "hazards associated with power mowers present unreasonable risk of death or injury and one or more consumer product safety standards are necessary to eliminate or reduce those unreasonable risks of injury." In response to this, manufacturers began implementing blade guards in 1973 to prevent accidental contact with rotating blades. In 1974, blade guard development evolved to include designs that reduced run-over, back-over, and fall-over injuries (Buchele & Baldwin, 1978). CPSC's review of power mower injuries from 1983 to 1986 found that a number of incidents involved issues with the design, selection, placement, and/or operation of power mower controls (Heasly et al., 1989). Using this data, CPSC conducted a feasibility examination to ensure consistent control placement, and also developed recommendations to revise the American National Standard for Turf Care Equipment - Power Lawn Mowers, Lawn and Garden Tractors, and Lawn Tractors - Safety Specifications (ANSI/OPEI B71.1-1986). A review of the effect of CPSC's safety standards on injuries related to lawn mowers examined two regulations implemented in 1982: 1) a hazard label on mowers and 2) a deadman control for mower blades (Moore & Magat, 1996). Per these regulations, lawn mowers manufactured in the United States since 1982 are required to have a deadman control that makes operators of push mowers hold a lever down from the operator position to keep the engine running. When analyzing data from before, during, and after implementation of these regulations, researchers found that the deadman control regulation was effective in reducing lawn mower injuries (i.e., more months with zero injuries), however, the labeling regulation did not have a significant impact on injury rates.

As noted, riding mowers are responsible for a specific injury pattern in which children are backed over by a riding lawn mower with the cutting blades engaged. Various design features have been implemented to attempt to reduce or eliminate injuries related to this scenario. One such feature is the no-mow-in-reverse (NMIR) system developed in conjunction with ANSI B71.1 1986 which provided suggestions for instructions for operators to "disengage the power to the mower before backing up" (Ferrone et al., 2009). The intent of the NMIR is to prevent reverse drive operation of riding mowers with the cutting blades engaged. ANSI/OPEI B71.1 2003 required all riding mowers manufactured after September 1, 2004 to have a NMIR feature, but the standard allows for the feature to be temporarily disabled (Ren et al., 2017;Hottinger et al., 2018).

There are several styles of NMIR design, and each differs by how the NMIR system is activated, the location of the control to activate the NMIR override, and how or when the NMIR system is deactivated. Ferrone et al. (2009) reviewed 10 lawn mowers with NMIR features to compare system offerings and suggest alternative designs. The only similarity found between the lawn mowers was that the NMIR systems do not require operators to look behind the lawn mower during the activation of the override function. Specifically, the control mechanism to activate the NMIR override was

always located in front of the operator, adjacent to the steering wheel. This directly contributes to the number of back-over injuries caused by riding lawn mowers. To respond to this issue, Ferrone et al. (2009) designed three NMIR override systems that include mechanical and human factor methodologies attributed to riding mower injuries:

1. In the first design, the control to activate the NMIR override system is located on the rear of the machine and requires the operator to continuously hold down the "hostage control" while moving in reverse. The NMIR override is then deactivated when the operator releases the control. The design also features a tamper-resistant mechanism that does not allow the lawn mower to be operated if someone has tampered with the NMIR system.
2. The second design incorporates the same NMIR override control and tamper resistant mechanism but also includes an electric solenoid that physically blocks the directional shift from going into reverse if the blades are engaged and the NMIR override is not activated.
3. The third design includes an additional sensor that senses when the directional shift is put into the reverse position.

Continued investigation of lawn mower safety regulation provides insight into what more needs to be accomplished to make riding mowers safe, as better riding lawn mower design can reduce hazard exposure and improve operator safety (Alexander, 1990; Deng et al., 2019). To address the pattern of injury among young children, Vollman and Smith (2006) suggested that the lawn mower voluntary safety standard ANSI B71.1-2003 should be revised to include more rigorous performance provisions regarding: 1) prevention of penetration of feet and toes under the mower and into the path of the blades; 2) shielding of hot mower parts from access by young children; and 3) equipping all riding lawn mowers with a NMIR default feature with the location of its override control behind the seat of the operator. The most up-to-date voluntary safety standards, ANSI/OPEI B71.1-2017, include the NMIR feature, but the standards allow for the ability to temporarily disable this safety mechanism. There is also no requirement for where the override control should be located.

Education and Campaigns

To reduce lawn mower injuries, various interventions and educational programs have been implemented and tested. For example, Mayer et al., (1998) employed a randomized pre–post control group design to test the effect of a video intervention on parents' prevention intentions and understanding of the severity of lawn mower accidents involving children. The video intervention was found to be successful in changing parents' attitudes and behaviors across several key metrics; specifically, the percentage of parents who kept their children inside while mowing before the intervention (26.7%) more than doubled after the intervention (63.3%), while the control group saw no significant change (34.4% pre and 37.5% post). Additionally, parents in the intervention group were more likely to understand and state that child lawn mower injuries are severe than were parents in the control group.

In another randomized control intervention trial, Jinnah et al. (2014) evaluated the effectiveness of a parent–child educational farm safety intervention. Farm families who had children between 10 and 19 years of age were randomly assigned to either of two intervention groups (parent-led or staff-led instruction) or the control group. In the parent-led intervention group, the primary parent farmer taught the tractor safety lesson to their family, while in the staff led intervention group, a project staff member and peer farmer from the local community taught the tractor safety lesson to the family. Participants assigned to the control group did not receive the lesson but completed the same pre- and post-tests. The parent-led intervention yielded encouraging results: Parents reported being more likely to implement tractor safety measures themselves and communicate these measures to their

children, and the vast majority (95%) of youth reported that learning about farm safety directly from a parent was important. The findings from these studies demonstrate the potential of parent education and family-based interventions to reduce lawn mower injuries in children.

The Ohio State University, in partnership with other sponsors, created a statewide farm safety camp program for rural youth, an at-risk population, and collected evaluation data from 12,270 campers and 79 camp sessions over 10 years. Using the data that captured camper's perceptions following their participation in the Farm Safety Round Up, it was determined that the top five sessions of the program covered the following topic: livestock safety (77.2%), ATV safety (69.9%), lawn and garden safety (65.8%), tractor/PTO/equipment safety (64.4%), and electricity safety (62.0%; (Jepsen & Beaudreault, 2012). Campers generally found the program to be educational (76.0%) and relevant to their needs (71.2%), and most (75.0%) would participate in future day camp programs. As highlighted earlier, children living in rural areas are more at risk for severe injury from lawn mowers. Farm safety programs and camps could be used in rural/non-metropolitan areas to tailor education efforts to communities in which children are exposed to agricultural hazards.

Campaigns are another effective tool to raise awareness of the hazards and dangers associated with riding lawn equipment and tractors. Tractor safety has become a priority for several communities, spawning several successful safety campaigns. Using these campaigns as models to develop riding-mower safety-specific educational campaigns may be a useful next step for preventing riding mower–related injuries.

In the United States, 45 children are injured every day and another child dies every 3.5 days from agricultural-related incidents (Rathje et al., 2017; Wright et al., 2013). The leading cause of those deaths are tractors. Youth safety specialists at the National Farm Medicine Center in Marshfield, Wisconsin found that tractors are responsible for more than 40% of farm fatalities in children under age 15 (Barrett, 2014). Children riding in the lap of tractor operators are also at risk of injury from being thrown off the tractor or the tractor overturning. In response to this, the Childhood Agricultural Safety Network (CASN), formed in 2001, developed the educational campaign "Keep Kids Away from Tractors," aimed at keeping children younger than 12 years old off of tractors (Barrett, 2014). Messaging for the campaign includes statements such as "The tractor is not the place for quality time," "Your 75 lb. child has no chance against your 10,000-lb tractor" and "It's easier to bury a tradition than a child" (National Children's Center for Rural and Agricultural Health and Safety, 2014). While these messages have been regarded as blunt and controversial, Morgan et al. (2002) found that narrative-based messages and messages that incorporate fear are more favorably evaluated by farmers than messages that solely inform or rely on statistics. In an external evaluation, Cramer and Wendl (2015) found that another CASN campaign, the Tractor Safety Campaign, was a frequently cited example of a campaign with successful impact. Further, CASN members are cited as looking to CASN for overall direction and provided examples of how their own organization had benefited from CASN resources.

To make mower safety campaigns, interventions, and educational programs more effective, more research is needed to determine individual's perceptions toward mower safety and how to best communicate with operators. Witte et al. (1992) analyzed the safety practices of farmers and their beliefs about farm equipment accidents and safety. Data were collected through face-to-face interviews (n = 46), telephone interviews (n = 48), and mailed surveys (n = 177). Witte et al. (1992) found that farmers believe farm equipment accidents to be severe and dangerous, but also believe themselves to be invulnerable to these accidents. Although farmers reported using safety measures in a general sense, when asked about specific safety measures, it became clear that many of those surveyed fail to use the most important safety measures that would prevent accidents or serious

injuries. However, overall, attitudes toward safety messages and intentions to use safety measures were positive.

Public awareness of run-over and back-over hazards is imperative to decreasing the incidence of riding mower–related injuries. Fletcher et al., (2018) recommends that injury prevention should be tailed to specific age groups. Education for the younger population should target the operators (parents, grandparents, older siblings) and emphasize the importance of keeping children out of the yard while lawn mowers are in use. Education for older age groups should emphasize safe mowing techniques and parental supervision. A multifaceted approach is also recommended to increase consumer awareness of the dangers that riding mowers pose. Garay et al., (2016) suggest promoting lawn mower safety during the spring through annual educational campaigns via television and the internet.

Conclusion

Automatic safety measures that are incorporated into the design of riding mowers are critical to preventing injuries from mowers. An important step to reducing the number of back-over injuries caused by riding mowers is placing the NMIR override control on the back of the mower behind the operator's seat (Vollman & Smith, 2006; Ren et al., 2017). This placement will force the operator to turn around and look behind them before reengaging the mower blades. Another potential design change to improve mower safety is placement of a rear-facing camera or proximity alert system on the riding mower. Alerting operators of children or adults in the path of riding the mower helps to reduce the risk of back-over and run-over injuries. In addition to passive protection through safer mower designs, there are other strategies to prevent lawn mower–related injuries. Several studies show that educational programs, safety campaigns, and family-based interventions are effective in influencing changes in operator and bystander behavior (Mayer et al., 1998; Morgan et al. 2002; Jepsen and Beaudreault, 2012; Jinnah et al., 2014). Operators must be made aware of the dangers riding mowers pose and the potential for back-over/run-over accidents. Parents should be educated on the risk and severity of injuries to children that can be caused by riding mowers. Amputations caused by riding mowers are often severe, can require multiple surgical interventions, and result in permanent disability (Vosburgh et al., 1995; Love et al., 1988).

Limitations

The most significant limitation in this literature review is the gap in research on injuries related to riding lawn mowers. In total, two studies were identified that focused exclusively on riding mower–related injuries among children or adults (Hammig et al., 2009; Nakamoto et. al, 2020). Although there are several studies that examine injuries caused by “lawn mowers” (i.e., push and riding mowers), only a few provide breakdowns of injuries that are specific to lawn mower type. Another limitation is the lack of data collected on this topic; many of the studies included in this review use the same databases to analyze push and riding mower injuries. These databases include the NEISS, the National Pediatric Trauma Registry, and the U.S. Nationwide Emergency Department Sample. These sources do not always code the mechanism of injury, and therefore it is unknown whether the cause of injury is from a push or riding mower. The number of lawn mower injuries is also likely underestimated because databases like NEISS do not capture injuries treated in medical settings other than emergency departments, or incidents in which medical attention is not sought.

Another limitation of the research is evaluating whether placing the NMIR override control on the back of the mower behind the operator's seat will prevent back-over. More implementation and examination will be required to understand whether this design is successful. Similarly, more research will need to be conducted to determine whether the inclusion of sensors and cameras would also provide more safety.

Task Analysis Findings

Overall Trends

Team FMG conducted a task analysis to document and evaluate the real-world application of relevant safety information and features, and potential product hazards and failure modes across a sample of consumer riding lawn mowers. The following section summarizes findings from in-person inspections and reviews of owner's manuals of a sample of 20 riding mowers comprising gasoline, diesel, and electric-powered lawn tractors with engines located at the front and rear of the mowers; zero-turn mowers; and sub-compact tractors. Overall, all types of mowers evaluated present similar run-over and back-over hazards, but the characteristics creating and mitigating those vary by mower type.

Of note, sub-compact tractors are discussed separately, as they incorporate some different warnings and safety features that are not comparable to lawn tractors and zero-turn mowers.

Safety Information

ANSI/OPEI B71.1.22 2017 provides general requirements related to safety messaging both on the machines and in the operator's manuals. Specifically, the standard requires both "on product" and "owner manual" safety messages and instructions, as all messaging cannot be on the machine alone. This requires an extensive amount of safety information in the manuals. ANSI/OPEI B71.1.22.1 requires on-machine messaging to include in-text and/or pictorial instructions in locations where they can be viewed by the operator while they are in their normal operating position. Required messaging includes: 1) read operator's manual; 2) maintain safety devices; 3) keep bystanders away; 4) look behind while backing; 5) avoid steep slopes; and 6) never carry children.

ANSI/OPEI B71.1.22.2 includes information that must be included in the operator's manual including the instructions for operation as well as instructions for checking the function of the starter interlocks, operator presence controls, and back-over protection system and override. Any pictorials used must be labeled and explained in the operator's manual.

Our analysis revealed that labeling on the machines and safety language in operator's manuals varied greatly between mowers, which was not unexpected given that the standard specifically states that additional statements or pictorials of safety practices are allowed and should be tailored to the specific mower design and manufacturer's recommendations of use.

Three primary types of safety information were observed: 1) clearly visible language noting compliance with ANSI/OPEI B71.1 as an on-machine label, in the operator's manual, and/or in the manufacturer's specifications, 2) extensive on-machine labeling and safety information in operator's manuals related to interlocks and mowing in reverse, and 3) extensive child safety–specific warnings in operator's manuals.

Out of the 20 machines evaluated, 14 of the machines stated that they met the entire ANSI/OPEI B71.1 standard via an on-machine label, in the operator's manual, or in the manufacturer's specifications. We were unable to confirm whether one machine had an on-machine label with safety information confirming compliance with the standard because it was unavailable for in-person inspection. However, all other machines from this manufacturer had on-machine labels documenting compliance; therefore, it is likely that 15 out of 20 mowers in the sample confirmed compliance with the standard. The other 5 mowers did not state they met the standard with an on-machine label (for the machines inspected) or in the operator's manual.

Two electric lawn tractors inspected in person did not provide information about compliance with the ANSI/OPEI B71.1 standard. One of the machines had extensive on-machine safety labeling, but it was small and not easily readable from the operator's position. The other machine did not provide extensive, readable on-machine labeling, and what was provided was in small text and not in a position the operator could read from their seat.

Each of the lawn tractors (*n* = 10) and zero-turn mowers (*n* = 8) included in the evaluation met the sections of the ANSI/OPEI B71.1.22.2 standard related to safety instructions. Additionally, every lawn tractor and the zero-turn mower with a steering wheel provided very specific messaging about the hazards of mowing in reverse in the operator's manuals. This is discussed in detail below.

Warnings in Operator's Manuals

At a minimum, each machine included the suggested language from ANSI/OPEI B71.1.22.2 2017, which provides general recommendations for safety instructions to be included in the operator's manuals, as discussed above. Although ANSI/OPEI B71.1 A.22.2 requires that the manufacturer include instructions for safe operation of the mower "to maximize the possibility that the instructions reach the operator," it is likely that warnings in the manual are less effective than warnings on the actual machine; prior research on self-reported use of owner's manuals for automotive vehicles found that operators rarely reference the manual after the first use unless it is to address a specific issue (Mehlenbacher et al., 2002).

Child Safety Information – Operator's Manuals

Most manufacturers provided a specific section in their manuals that focused on child safety, which were often much more extensive than specified in the standard. However, the level of detail and method of labeling varied greatly between manufacturers. Manufacturers of all 20 machines provided specific warnings regarding children in the operator's manual, although there are fewer references in the sub-compact tractor's operator's manuals. Below are examples from operator's manuals demonstrating variations in the child safety– and NMIR-specific warning sections.

Gas Power Lawn Tractor with Engine in Rear, Child Safety in Manual

Children

1. Tragic accidents can occur if the operator is not alert to the presence of children. Children are often attracted to the machine and the mowing activity. They do not understand the dangers. Never assume that children will remain where you last saw them.
   a. Keep children out of the mowing area and in watchful care of a responsible adult other than the operator.
   b. Be alert and turn machine off if a child enters the area.
   c. Before and while backing, look behind and down for small children.
   d. Never carry children, even with the blade(s) shut off. They may fall off and be seriously injured or interfere with safe machine operation.
   e. Use extreme care when approaching blind corners, doorways, shrubs, trees, or other objects that may block your vision of a child who may run into the path of the machine.
   f. To avoid back-over accidents, always disengage the cutting blade(s) before shifting into reverse. If equipped, the Reverse Caution Mode should not be used when children or others are around.
   g. Keep children away from hot or running engines. They can suffer burns from a hot muffler.
   h. Remove key when machine is unattended to prevent unauthorized operation.
2. Never allow children under 14 years of age to operate this machine. Children 14 and over should read and understand the instructions and safe operation practices in this manual and on the machine and should be trained and supervised by an adult.

Gas Power Lawn Tractor with Engine in Front, Child Safety in Manual

Preventing Injuries

Protect Children

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- Children can be killed or seriously injured by riding mowers when operators do not follow safe operating practices.
- Do not mow in reverse. Operating with the mower engaged while backing up is discouraged.
- Never give children a ride on a mower or in a cart behind the mower, even when the blades are off. They can fall off and be run over or cut by the mower blades. Children can interfere with mower operation. Children who have been given rides in the past can suddenly appear in the mowing area for another ride. If you are not aware, they can be run over or backed over by the mower.
- Children are often attracted to lawn mowers and mowing activities, especially if they have been given rides before. They do not know if the blades are rotating or understand that they can be killed or seriously injured even if the blades are not rotating.
- Keep children indoors and out of the mowing area when the mower is being operated. Keep children under the watchful eye of a responsible adult, other than the operator. If there is not a responsible adult to ensure that children stay indoors, DO NOT mow.
- Be alert to the presence of children or others. Turn off the mower blades and stop the machine if someone enters the mowing area.
- Look in the direction the machine is traveling. Before and while backing, turn off the mower blades and look down and behind the machine carefully, especially for children.
- Use extreme care when approaching objects that block your view, such as blind corners, shrubs, or trees, especially while backing. They can hide a child.

Gas-Powered Zero-Turn Mower, Child Safety in Manual

Children Specific
Tragic accidents can occur if the operator is not alert to the presence of children. Children are often attracted to the machine and the mowing activity. NEVER assume that children will remain where you last saw them.
Keep children out of the operating area and under the watchful care of a responsible adult other than the operator.
Do not carry children, even with the blade(s) shut off. Children could fall off and be seriously injured or interfere with safe machine operation. Children who have been given rides in the past could suddenly appear in the mowing area for another ride and be run over or backed over.
DO NOT allow children under the age of 18 to operate any outdoor power equipment.

Electric Lawn Tractor Rear Engine, Child Safety in Manual

- Keep children away — Keep all bystanders, children, and pets at least 100 ft. away. Stop the mower and turn off the machine if anyone enters the area.
- Tragic accidents can occur if the operator is not alert to the presence of children. Children are often attracted to the machine and the mowing activity. **NEVER** assume that children will remain where you last saw them.

  - Keep children out of the mowing area and in the watchful care of a responsible adult other than the operator.

  - Be alert; stop and turn machine off if a child enters the area.
  - Before and while backing, look behind and down for small children, bystanders, and pets.
  - Never carry children, even with the blades shut off. They may fall off and be seriously injured or interfere with safe machine operation. Children who have been given rides in the past may suddenly appear in the mowing area for another ride and be run over or backed over by the machine.

WARNING:
CHILDREN CAN BE KILLED OR SERIOUSLY INJURED BY THIS EQUIPMENT. The American Academy of Pediatrics recommends that children be a minimum of 16 years of age before operating a riding lawn mower.

Gas-Powered Zero-Turn Mower, Child Safety in Manual

CHILDREN

Tragic accidents can occur if the operator is not alert to the presence of children. Children are often attracted to the mower and the mowing activity. NEVER assume that children will remain where you last saw them.

2.36 Keep children out of the mowing area and in the watchful care of a responsible adult other than the operator.

2.37 Maintain Alertness and turn mower off if a child enters the area.

2.38 Before and while backing, look behind and down for small children.

2.39 Never carry children, even with blades shut off. They may fall off and be seriously injured or interfere with safe mower operation. Children who have been given rides in the past may suddenly appear in the mowing area for another ride and be run over or backed over by the mower.

2.40 Never allow children to operate the mower.

2.41 Never leave the key in the ignition, especially around children.

2.42 Use extreme care when approaching blind corners, shrubs, trees, or other objects that may block your view of a child

Electric Zero-Turn Mower, Child Safety in Manual

CHILDREN SPECIFIC

- Tragic accidents can occur if the operator is not alert to the presence of children. Children are often attracted to the machine and the mowing activity. Never assume that children will remain where you last saw them.
- Keep children out of the operating area and under the watchful care of a responsible adult other than the operator.
- Do not carry children, even with the blade(s) shut off. Children could fall off and be seriously injured or interfere with safe machine operation. Children who have been given rides in the past could suddenly appear in the mowing area for another ride and be run over or backed over by the machine.
- Keep the area of operation clear of all bystanders, particularly small children. Stop the machine and attachment(s) if anyone enters the area.

Mow In Reverse Warnings – Operator Manuals

All machines that were equipped with a mow-in-reverse override feature (*n* = 11; i.e., all lawn tractors and the zero-turn with the steering wheel) provided very specific messaging about the hazards of mowing in reverse in the operator's manuals. Below are examples of safety messages included in the operator's manuals from the sample.

Gas-Powered Lawn Tractor, Mowing in Reverse in Manual

Reverse Mowing Option (RMO)

DANGER

Mowing in reverse can be hazardous to bystanders. Tragic accidents can occur if the operator is not alert to the presence of children. Children are often attracted to the machine and the mowing activity. Never assume that children will remain where you last saw them.

- Keep children out of the operating area and under the watchful care of a responsible adult.
- Do not carry passengers, especially children, even with the blade(s) shut off. Children can fall off and be seriously injured or interfere with the safe machine operation. Children who have been given rides in the past can suddenly appear in the mowing area for another ride and be run over or backed over by the machine.
- Do not mow in reverse unless absolutely necessary. Always look down and behind before and while backing.
- If the machine mows in reverse without Reverse Mowing Option activated, see an authorized dealer immediately.

Gas-Powered Lawn Tractor, Mowing in Reverse in Manual

NOTE: Mowing in reverse is not recommended.

WARNING! Use extreme caution while operating the tractor in the REVERSE CAUTION MODE. Always look down and behind before and while backing. Do not operate the tractor when children or others are around. Stop the tractor immediately if someone enters the area.

Gas-Powered Lawn Tractor, Mowing in Reverse in Manual

WARNING: Backing up with the attachment clutch engaged while mowing is strongly discouraged. Turning the ROS "ON", to allow reverse operation with the attachment clutch engaged, should only be done when the operator decides it is necessary to reposition the machine with the attachment engaged. Do not mow in reverse unless absolutely necessary.

On-Machine Warnings

Information provided in warnings directly on lawn tractors and zero-turn machines was relatively consistent across models. Each lawn tractor and zero-turn mower in the sample met the requirements of ANSI/OPEI B71.1 A.15 and A22.1 2017, which requires "durable labeling of the mower to provide the operator with a constant reminder of safety precautions to avoid frequently encountered hazards."

Labels related to child safety, driving in reverse, and mowing in reverse are typically located near the operator's feet when in operation. However, these labels often contain a great amount of visual information, and some contain text too small to be readable from the driver's seat. Most labels included the symbols recommended in ANSI/OPEI B71.1 Annex B 2017, but the machines vary in their presentation. Below are examples of on-machine labeling observed in the sample.

Gas-Powered Lawn Tractor, on Machine

Electric Lawn Tractor, on Machine

Gas-Powered Lawn Tractor, on Machine

Electric Zero-Turn Mower, on Machine

Key Chain Warnings

As noted, warning information observed on the machines contained a lot of content. Therefore, it is possible that the warnings regarding potential child injuries and mowing in reverse do not draw significant attention. Alternatively, machines with keys present (*n* = 9) during inspection had warning information on the keychains. Safety information attached to keys may be a more effective way to communicate to the operators as they must hold the warnings in their hands every time they use the machine. Below are examples of safety labeling included on key chains.

Gas-Powered Lawn Tractor, Key Chain

Electric Lawn Tractor, Key Chain

Reverse Override Control Warnings

On-machine warnings and instructions located at the mow-in-reverse override mechanism location were not always clear if present at all. Below are a few examples of warnings and instructions present near the mow-in-reverse override mechanism.

Electric Lawn Tractor

Gas Powered Lawn Tractor

Deck Warnings

Safety messages are required on the mower deck and near the discharge opening by ANSI/OPEI B71.1 .24.1.5 and .24.2 2017. Each of the lawn tractors and zero-turn mowers in the sample met the standard and provided warnings on the decks and discharge openings. The images below are examples of safety warnings on the decks and discharge openings.

Gas-Powered Zero-Turn Mower, Deck

Gas-Powered Lawn Tractor, Deck

Gas-Powered Lawn Tractor, Deck

Safety Information Summary

In summary, we observed extensive on-machine labeling and safety language in operator's manuals and on all machines included in the sample, but the implementation and nature of that information varied greatly between mowers. Three primary safety information categories were observed: 1) clearly visible language noting compliance with ANSI/OPEI B71.1 as an on-machine label, in the operator's manual and/or in the manufacturer's specifications, 2) extensive on-machine labeling and safety information in operator's manuals related to interlocks and mowing in reverse, and 3) extensive child safety–specific warnings in operator's manuals.

Visibility

Riding mower visibility varies significantly between machine types, with zero-turn mowers having relatively better visibility than lawn tractors. Lawn tractors fitted with the engine/battery in the rear and/or under the operator's seat are typically smaller and have a better field of view in all directions than do front engine lawn tractors. Lawn tractors fitted with engines/batteries in front of the operator are typically larger and have a smaller field of view to the front and sides of the machine. All observed zero-turn mowers were fitted with the engine/battery behind the driver and, as a result, had an extensive field of view forward and to the sides.

For all types of machines, operators must turn around to have a rearward field of view. However, machines with the engines/batteries located under the seats and an unobstructed view of the entire mowing deck had the best overall field of view. Relative to lawn tractors, zero-turn mowers have an

advantage of a decreased need to operate in reverse because the controls allow the operator to turn the machine 360 degrees without reversing. This allows operators of zero-turn mowers to have a better field of view, unless they use the option of moving the machine in reverse by positioning both levers rearward.

Controls

Although the operational controls for each machine type evaluated varied in the observed mowers, they all met the requirements for controls in ANSI/OPEI B71.1.16.2 2017. These include the requirements that a key or similar device must be provided to prevent the unauthorized use of the machine and slip resistant surfaces should be at and around the foot pedals.

All machines also appeared to meet the general ANSI/OPEI B71.1.16 2017 requirements for the clutch controls, brake controls, speed controls, steering controls, and power take off (PTO) lift controls, all of which are integrated into the interlocks. Of note, steering wheel–controlled machines each had a separate parking brake engaged by either a foot pedal or hand control. Zero-turn machines with levers incorporate the parking brake in the lever controls such that the parking brake is engaged when levers are positioned outward.

All in-person observed machines well exceeded the ANSI/OPEI B71.1.21.1.2 2017 requirements for a seat back support height of 4.5 in (11.4 cm), having seat back heights ranging from 11 to 20 in (27.9 to 50.8 cm). Additionally, every machine in the sample included a notation in the operator's manual that stated that the blades stop rotating within 5 seconds of when they are commanded to disengage, as per the ANSI/OPEI B71.1.23.2 2017 standard.

Speed

Machine speeds vary consistently by mower type (see Table 2). For the overall sample, maximum forward driving speeds ranged from 3.7 mph to 8 mph (6.0 kph to 12.9 kph), and maximum rearward speeds ranged from 2.2 mph to 4 mph (3.5 kph to 6.4 kph). Manuals for the two mowers (an electric lawn tractor and a zero-turn mower with levers) reported the fastest forward driving speed, but also cited a reduced maximum forward speed when the PTO was engaged. None of the other machines reported a reduction in speed in their manuals when the PTO was engaged. Table 2 provides the range of maximum forward and reverse driving speeds for each mower type, as well as the maximum forward speed with the PTO engaged.

In this sample, zero-turn mowers with levers and electric lawn tractors operate at the highest speeds while driving forward. For these groups, the maximum forward speed is reduced when the PTO is engaged. The sub-compact tractors and zero-turn mowers operate at the fastest maximum forward speed with the PTO engaged. In addition, the sub-compact tractors in the sample had the highest reversing speed (driving with and without the PTO engaged). This speed was significantly greater than the lawn tractors with gas-powered rear engines and zero-turn mowers, which had the second and third fastest rearward speeds respectively.

Table 2. Observed machines' maximum forward and reverse driving speeds

Mower Type	Max Forward Speed mph (kph)*	Max Forward Speed with PTO Engaged mph (kph)**	Max Speed Rearward mph (kph)*
All Mowers (Excluding Sub-Compact)	3.7–8 (6-12.9)	3.7–7 (6-11.3)	2.2–4 (3.5-6.4)
Electric Lawn Tractor	3.7–8 (6-12.9)	3.7–5 (6-8)	3–3.1 (4.8-5)
Gas Powered Lawn Tractor Rear Engine	4 (6.4)	4 (6.4)	4 (6.4)
Gas Powered Lawn Tractor Front Engine	5.2–5.5 (8.4-8.9)	5.2–5.5 (8.4-8.9)	2.2–3.3 (3.5-5.3)
Zero-Turn with Steering Wheel	7 (11.3)	7 (11.5)	2.5 (4)
Zero-Turn with Levers	6-8 (9.7-12.9)	6–7 (9.7-11.3)	3–3.5 (4.8-5.6)
Sub-compact Tractor	7.8 (12.6)	7.8 (12.6)	5.9–7.8 (9.5-12.6)

*Speed ranges provided are between observed mowers within machine class.
**Maximum forward speed used if no designation is made between speeds with and without PTO engaged.

ANSI/OPEI B71.1.16.2.1.8 2017 does not provide recommendations for speed limits except for the speed at which a machine can travel in reverse while the PTO is activated without engaging the mow-in-reverse override feature. Each of the evaluated lawn tractors and the zero-turn mower with a steering wheel turn the PTO off when traveling in reverse without engaging the mow-in-reverse override feature. Additionally, the zero-turn mowers are not required to turn off the PTO when traveling in reverse. Therefore, all mowers met this part of the standard.

Deck Height and Guarding

With respect to the observed deck height, the measurements were not consistent enough across observed machines to conclusively identify trends. However, for the machines observed, when the deck was in the highest position, the distance from the lower edge of the deck to the ground surface ranged from 3.25 to 5.25 in (8.26 to 13.33 cm). With the deck positioned in the lowest setting, the distance between the lower edge of the deck to the ground surface ranged from 1–2 in (2-5.08 cm). Assembly accuracy, leveling and tire position, type of ground surface, tire pressure, and operator weight affect these measurements.

ANSI/OPEI B71.1 24.1 2017 details that the blade is required to be enclosed except on the bottom, and that the enclosure shall extend a minimum of 3 millimeters (0.12 inches) below the lowest cutting point of the blade in the lowest blade position. The area of the discharge opening must be guarded so that the blade does not enter the operator zone. For each observed machine, the distance from the bottom of the lower edge of the deck housing to the lowest point of the blade consistently measured between 0.25 to 0.75 in (0.64-1.91 cm), exceeding the requirements of the standard. Of note, these measurements were highly variable because of the difficulty of access and therefore should be considered approximate.

ANSI/OPEI B71.1 17.1 2017 provides requirements for blade guards and shields to minimize the possibility of injury from inadvertent contact by the operator during normal operation of the machine. Based on visual observation, components of the power drive, such as belts and chains, that could pose injury to the driver were shielded or guarded by location for each of the machines inspected. No specific measurements were taken, since this was not a component of the protocol.

Safety Features and Interlocks

Safety feature interlocks are the riding mower safety features that are most relevant to real-world back-over and run-over incidents. Team FMG observed interlocks associated with mower startup, operator presence detection, and mow in reverse functions. ANSI/OPEI B71.1 16.2.2.3 2017

requires that specific safety interlocks be engaged for a mower engine to be started. The safety interlocks include features that prevent the engine from being started unless the PTO is disengaged and the parking brake is engaged.

ANSI/OPEI B71.1 16.2.1.5-2.1.6 2017 also requires an operator presence interlock feature to address unintentional machine movement and certain types of blade contact injuries. This requirement is intended to prevent blade contact injuries that occur when the operator deliberately leaves the normal operating position without first disengaging the PTO or stopping the engine in accordance with the manufacturer's operating instructions. It also does not allow the machine to power the drive wheels when the operator is out of the normal operating position. However, the ANSI/OPEI B71.1 16.2.1.5 2017 specifically states that this feature "is not intended to protect the operator from sudden access to the blades, as would occur because of jumping or falling from the machine."

Additionally, ANSI/OPEI B71.1 16.2.1.8 2017 requires that the PTO not be engaged while the vehicle is driven backward to reduce the possibility of inadvertent blade contact during reverse operation. The standard states that the intent is to increase the operator's awareness of reverse operation and to find other ways to accomplish the task without mowing in reverse. However, the standard allows for a temporary override feature to allow for the PTO to be engaged as the machine is operated in reverse. Zero-turn mowers are excluded from this requirement because the design inherently provides greater maneuverability characteristics that limit the need for reverse use.

The following sections provide a detailed description of our findings when observing safety interlocks related to run-over and back-over issues. Interlock application and characteristics are broken down by mower type and/or mower power source when appropriate. Some interlock designs are manufacturer- or model-specific, and the relevant sections below have been subdivided accordingly.

Application of Interlock Safety Features by Mower Type

Table 3 summarizes the application of interlock safety features, by mower type, on the mowers included in the sample. Many of the basic interlocks are applied across all mowers in the sample, with variations in application occurring.

Table 3. Interlock safety feature application by mower type

Interlock Type	Condition/Result	Electric Lawn Tractors	Gas-Powered Lawn Tractors, All	Zero-Turn with Steering Wheel	Zero-Turn with Levers	Sub Compact Tractors
Start Interlock	Fuel powered engine will not start unless parking brake is ON and operator is in seat		X	X	X	X
	Fuel powered engine will not start if PTO is engaged		X	X	X	X
	Battery powered acceleration control will not engage if operator is not in seat.	X				
Operator-Presence Control	Fuel powered engine will remain ON when operator leaves seat if parking brake is ON		X	X	X	X
	Fuel powered engine will turn OFF if operator leaves seat and parking brake is OFF		X	X	X	X
	Fuel powered engine will turn OFF if operator leaves seat and PTO is engaged, even if parking brake is ON.		X	X	X	X*
	Battery powered acceleration control will turn off if operator leaves seat.	X				
	PTO turns OFF if operator leaves the seat under all conditions.	X	X	X	X	X
Mow-in-Reverse Interlock	PTO will not engage when machine moves in reverse if mow-in-reverse override feature is not engaged.	X	X	X		
	Fuel powered engine will turn OFF if operator attempts to reverse without engaging the reverse override control.		X	X		
	Audible beep when in reverse	X				
General	When PTO is turned OFF by an interlock feature (occupant leave seat and/or direction is moved in reverse), the PTO control must be turned off, the interlock corrected (occupant in seat and/or direction control in neutral), and then the PTO control turned back on to reengage the PTO.	X	X	X	X	X*

*Excludes stationary rear PTO, which can be engaged while the operator is not in the seat.

Mow-in-Reverse Interlocks – Lawn Tractors and Steering Wheel Equipped Zero Turn Mower

The mow-in-reverse override feature incorporated into ANSI/OPEI B71.1 2017 is described this way:

> **16.2.1.8** A means shall be provided that limits reverse drive operation with powered blades to ground speeds no greater than 0.3 m/s (1 ft/s). An override capability may be provided to permit reverse drive with powered blades at ground speeds greater than 0.3 m/s (1 ft/s). If an override capability is provided, the override shall automatically deactivate when at least one of the following three actions occurs:
>
> a) The blade(s) is (are) re-engaged or
>
> b) The engine is restarted or
>
> c) The directional control is moved from reverse.
>
> Ride-on mowers with zero-turn radius capability and machines with front mount mowers are excluded from the requirement.

On all observed lawn tractors and zero-turn mowers with steering wheels, the PTO disengages if the operator attempts to mow in reverse without using the mow-in-reverse override feature. Overall, Team FMG observed five different reverse mow override designs on lawn tractors in the sample. The term "control" is used throughout the section below to describe the mechanism that overrides the mow-in-reverse interlock, which is typically in the form of a switch or a button.

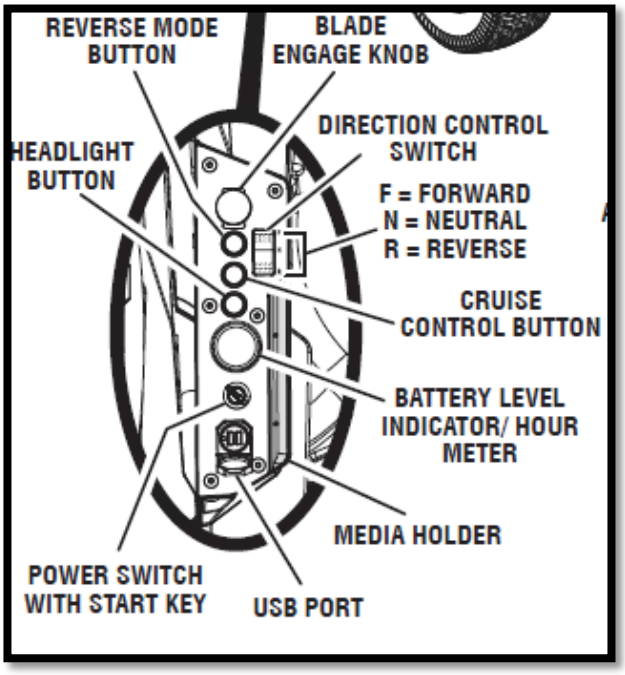
The feature design was identical in each of the electric-powered lawn tractors. However, the gas-powered lawn tractors and zero-turn mowers with a steering wheel incorporated four different types of ignition and reverse key controls, each with a different mow-in-reverse override method.

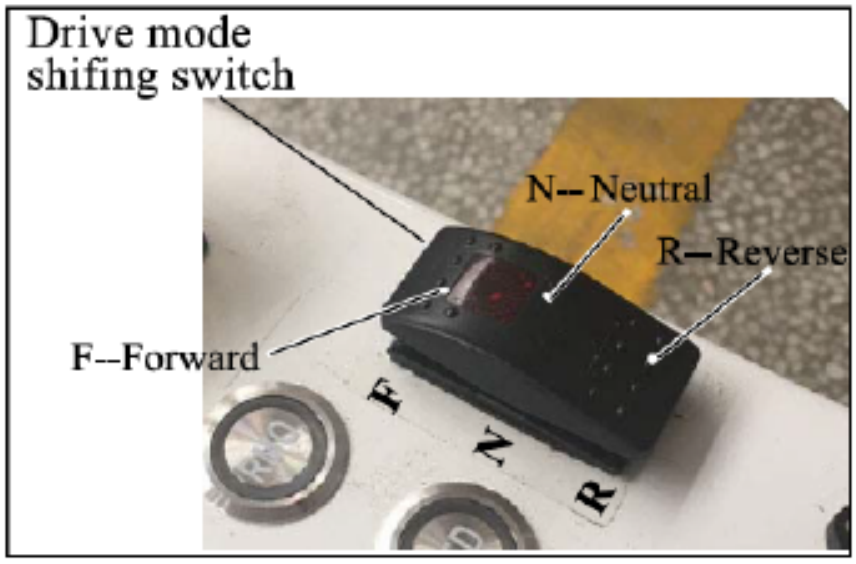
Within that sub-sample of lawn tractors and zero-turn mower with a steering wheel, all except for one incorporates a mow-in-reverse override feature that, once engaged, remains active through forward and reverse operation without requiring re-engagement of the override. In those mowers, the mow-in-reverse override mode remains active until the feature or the power to the mower is turned off. In one observed design, the mow-in-reverse override is deactivated when the reverse pedal is released and must be reset to move in reserve again. Each of these different systems are described in detail below.

Electric Lawn Tractor Reverse Mode

Each of the electric lawn tractors in the sample has a slide directional control switch with forward, neutral, and reverse (F/N/R) positions on the right side of the control panel next to the PTO engagement control. To mow in reverse, the operator must press the "reverse mode" control to the left of the directional control switch to allow the blades to operate when the control switch is in the R position. However, once the reverse mode control has been turned ON (i.e., depressed), the operator can switch between F/N/R until the reverse mode control is pressed again to turn it OFF. Both electric mowers beep when moving in reverse. The diagram and images in Images Series 1 depict this design.

Image Series 1. Electric lawn tractor reverse mode controls

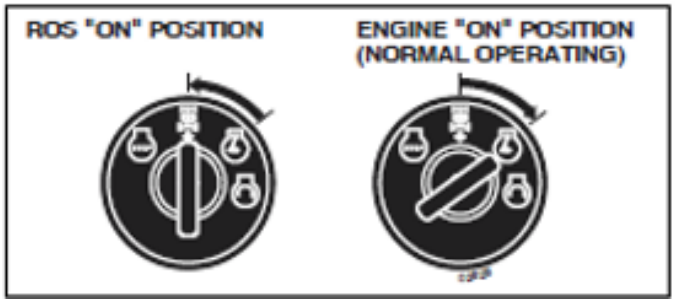




Gasoline-Powered Lawn Tractors Mow-In-Reverse Ignition Key Control

Two observed gasoline-powered lawn tractors are fitted with ignition key control positions that incorporate a mow-in-reverse setting (Stop/ROS ON/Engine ON/Start) and do not have a separate reverse mode control. These machines can alternate mowing backward and forward if the key remains in the reverse operating system (ROS) ON position (see Image Series 2). Reverse mode is turned off when key is turned to the “engine ON” position. The diagram and image below demonstrate the key control in the mow-in-reverse override and engine ON positions.

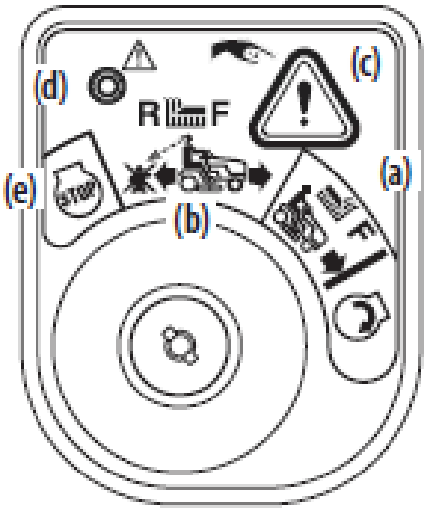
Image Series 2. Gasoline-powered lawn tractor key control mow-in-reverse override and engine-on positions, diagram, and photo.



Gasoline-Powered Lawn Tractors Mow-In-Reverse Ignition Key Position in Conjunction with Reverse Mode Control

Four observed lawn tractors and the zero-turn mower with a steering wheel (which was not inspected in person), all from the same manufacturer, use the design shown in Image Series 3, which incorporates ignition key control positions [Stop/R-F/F/Start] and a separate reverse mode control (c) on the keypad. Once the key is turned to the R-F (b) position, the machine can mow backward and forward without pressing the Reverse Mode control again. Reverse Mode is deactivated when the ignition key is turned to the F position (a).

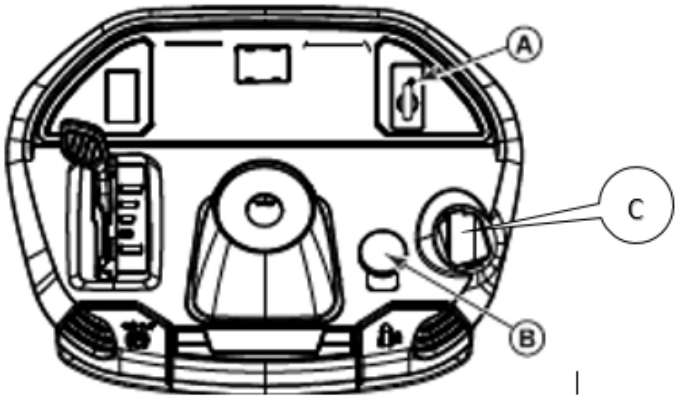
Image Series 3. Gasoline-powered lawn tractors mow-in-reverse ignition key position in conjunction with reverse mode control.



Gasoline-Powered Lawn Tractor Dual Ignition Key Mow-In-Reverse

One gas-powered lawn tractor in the sample uses a design (see Image 4) with key control positions (c) [Stop/Run/Start] controlled by one key and a second reverse key (A) controlled by a second, separate key. This mower can mow rearward and forward if the reverse key (A) is in the ON position. Reverse mode is turned off when the reverse key (A) is turned to the OFF position.

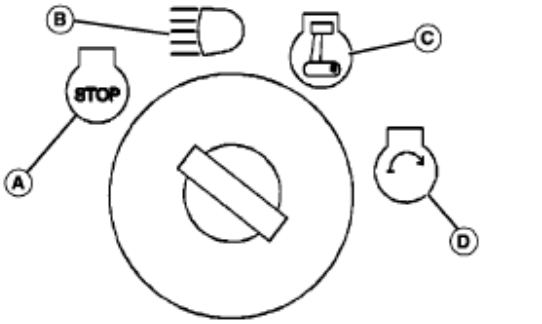
Image 4. Gas-powered lawn tractor separate reverse key.



Gasoline-Powered Lawn Tractor Reverse Mode Control with Reset

One gas-powered lawn tractor in the sample incorporated a design (see Image Series 5) with key control positions [Stop/Run/Start] and a separate reverse mode control (labeled “A” in Image Series 5) away from the keypad that resets when the reverse pedal is released. The reverse mode control must be pressed again to be able to mow in reverse. As noted above, this is the only design observed that requires a reset every time the mower is operated in a forward direction.

Image Series 5. Gasoline-powered lawn tractor reverse mode control with reset, diagram and photos



A—STOP Position
B—HEADLIGHTS ON Position
C—RUN Position
D—START Position

Safety Feature Application Unique to Subcompact Tractors

Two sub-compact tractors were observed and included in the sample. These machines are marketed primarily to residential operators, but they differ from lawn mowers included in the task analysis due to the increased functionality that allows sub-compact tractors to be used with a variety of tractor implements and attachments, including mid-mount and rear three-point hitch mowing decks. The mid-mounted mowing deck is similar in configuration to those featured on lawn tractors. These machines also feature a rear PTO that behaves differently regarding interlocks; safety issues and interlocks related to the rear PTO are not addressed in this report.

The scope of ANSI/OPEI B71.1 2017 includes powered "ride-on lawn tractors with mower attachments," and the standard is "intended to apply to products specifically intended as consumer products for the personal use of a consumer around a house." The standard is not intended to apply to commercial products customarily used by hired operators or to products designed primarily for agricultural purposes. The standard applicability provides no limitation in gross vehicle weight. However, the documentation associated with the two sub-compact tractors observed for this task analysis does not indicate that they met the standard.

Startup and Operator Presence Interlocks

According to the documentation associated with the sub-compact tractors in the sample, the mid PTO can be engaged with the machine in reverse without an override. The associated documentation for these sub-compact tractors does not provide a separate maximum operational speed when the machine is in reverse with the PTO engaged, so this task analysis cannot determine whether the observed sub-compact tractors meet the requirement of the ANSI/OPEI B71.1 16.2.1.8 2017 standard by not exceeding 1 ft/s (0.3 m/s).

One of the sub-compact tractors observed specifically provides an override for the operation of the PTO without the operator in the seat when using attachments that require stationary operation, which is permitted by the ANSI/OPEI B71.1 16.2.1.9 2017 standard. The sub-compact tractors in the sample incorporated other interlocks like those in the riding mowers.

Rollover Protective Structures (ROPS) and Seat Belts

Although documentation associated with the sub-compact tractors in the sample did not reference compliance with ANSI/OPEI B71.1 2017, the ANSI/OPEI B71.1 21.1.3 2017 standard provides a requirement for a rollover protective structure (ROPS) in conjunction with seat belts for machines with a mass greater than 600 kg (1323 lbs), and the observed machines met that requirement. More specifically, both observed sub-compact tractors are equipped with a ROPS in conjunction with seat belts, and both associated operator's manuals recommended the use of the ROPS. ROPS and seat belts are outside of the scope of this task analysis but are noted here because they comply with ANSI/OPEI B71.1 2017.

Conclusion

As findings from this task analysis indicate, the observed sample of lawn tractors and zero-turn mowers marketed to residential operators comply with the sections of voluntary standard ANSI/OPEI B71.1. There was no evidence that manufacturers that claimed to comply with the standard did not meet the standards. This compliance with voluntary standard ANSI/OPEI B71.1 is notable because it is the only standard addressing issues related to riding mower run-over and back-over hazards.

All observed lawn tractors and zero-turn mowers incorporated extensive on-machine safety labels and safety messaging in operator's manuals, including information specifically addressing the hazards of mowing in reverse and mowing around children. All observed lawn tractors, zero-turn mowers, and sub-compact tractors were fitted with start interlocks and operator presence controls, and all lawn tractors and the steering wheel-equipped zero-turn model incorporated mow-in-reverse interlocks with overrides.

The task analysis highlighted the weaknesses of some of those features, particularly the characteristic observed in all but one mow-in-reverse override systems that allowed them to remain in place while the mowers moved from reverse to forward and back to reverse repeatedly. In addition, the task analysis highlighted the fast speeds that each of the machines could travel in reverse, which could increase the risk of back-over injury.

Run-over and back-over riding mower incidents continue to occur despite the real-world application of these prevention strategies and technologies and adherence to voluntary standard ANSI/OPEI B71.1 by manufacturers. Therefore, additional measures are needed to address the issues of riding mower run-over and back-over incidents. These measures could include requiring more consistent and concise messaging on the machine and in the operator's manual, reduced rearward operating and mowing speeds, and specific language addressing the loopholes in mow-in-reverse override features.

Limitations

This task analysis, by design, provides detailed information about safety information, feature application, and potential hazards and failure modes across a varied sample of 20 consumer riding lawn mowers. As such, the sample size does not allow for statistical analysis and associated observations of trends across all riding lawn mowers or between mower types. Additionally, retailer inventory limited the pool of riding mowers available for in-person inspections, and some mower makes and models could not be inspected due to a lack of access, though full access to operator's manuals and instructions was available for the entire sample. Lastly, operating the mowers to confirm safety features functioned as intended and as they are detailed in operator's manuals was not possible, as most retailers do not put fuel in mowers for safety and logistical reasons. Therefore, real-world testing of these features could not be performed.

Environmental Scan Findings

Team FMG conducted an environmental scan to identify and summarize discussions about existing voluntary safety standards and advances covering residential riding mowers. Additionally, the scan sought to determine (1) whether the common hazard patterns found in the data for back-over and run-over incidents are adequately addressed by voluntary standards and (2) the recommendations for advances in technology that may improve riding mower safety and reduce the risk of back-over and run-over incidents.

Sources Summarizing Mower Standards

The search terms (see Appendix A: Literature Review and Environmental Scan Search Terms) used for the environmental scan uncovered a variety of sources (e.g., webpages, blogs) that provide detail and summarize observations and discussions about current riding mower safety standards. Specifically, these sources highlight current standards and details about how standards have been updated. Additionally, several sources offer additional ways to ensure safe usage of mowers that also adhere to the voluntary standards.

Webpages

In 2004, Louisiana State University's Ag Center published a web page on mower safety standards. Author Richard L. Parish noted that "the standards for riding mowers and small tractors are industry consensus standards developed by engineers and safety specialists working for the manufacturers and universities." However, these standards are not enforced, and manufacturers must elect to implement them. At the time of the page's publication in 2004, the standards included:

- ***American Society of Agricultural and Biological Engineers (ASABE)*** – formerly American Society of Agricultural Engineers (ASAE). ASAE and ASABE standards cover safety related to several elements, ranging from safety related to specific design elements, such as "drawbars, 3-point hitches, sleeve hitches, hydraulics" and safety related to operation including braking, operation slopes, and owners' manuals.
- ***American National Standards Institute (ANSI)*** – ANSI standard B71.1, Walk-Behind Mowers and Ride-On Machines with Mowers - Safety Specifications, is the primary safety standard for homeowner riding mowers and small tractors. This standard requires the following: 1) use of the operator presence control, "a device that will stop the mower blades if the operator leaves the seat without disengaging the blade drive (PTO)"; 2) blades to turn off within 5 seconds of PTO disengagement or when the operator leaves the seat; and 3) seat height of at least 4.5 inches (11.4 centimeters) to prevent the operator from falling backward. Additional standards include: a maximum blade speed, braking, and standards for mower stability when turning.
- ***Outdoor Power Equipment Institute (OPEI)*** – Over 95% of manufacturers of power lawn equipment are members of Outdoor Power Equipment Institute (OPEI), a trade organization. OPEI helped develop the ANSI standards and has instituted a decal system. Machines that meet ANSI standards carry the decal (Parish, 2004).

OPEI's own website lists the current prevailing product standards by machine type: "ground supported standards," "handheld standards," "utility and light transportation vehicle standards." "Ground supported standards" cover standards for riding mowers. Specifically, ANSI/OPEI B71.1 2017 – American National Standards for Consumer Turf Care Equipment – Pedestrian-Controlled Mowers and Ride-On Mowers – Safety Specifications include safety specifications for "(a) reel and rotary pedestrian-controlled lawn mowers, (b) reel and rotary ride-on lawn mowers, (c) ride-on lawn tractors with mower attachments, (d) ride-on lawn and garden tractors with mower attachments, and (e) lever-steer and zero-turn ride-on mowers" (OPEI, 2021)

Blog

One ANSI blog post, "Standard Specifications for Pedestrian-Controlled Mowers and Ride-On Mowers," describes in detail the updates to the 2017 standards (Kelechava, 2017). The blog post describes that the updates were designed to place mowers in alignment with other ANSI standards. Noted updates included 1) revisions to other openings and updated definitions; 2) moving grass catcher durability message to the instructions; 3) defining an operator target for grass catcher structural integrity test; 4) redefining an operator target for thrown object test; 5) single color–only safety warnings are not permissible; 6) requirements added for mowers not subject to CPSC 1205 regulation; 7) adding ROPS exemption for Out-Front Zero-Turn mowers, 400-600 kg (881.8-1322.7 lbs), stability >25 degrees 21.2.4.1; 8) limiting sudden traction test to fixed-ratio transmission units; and 9) adding figure for new operator target for grass catcher.

Fact Sheets and Other Sources Aimed at Riding Mower Operators

Other sources and fact sheets were found that were specifically designed for push mower and riding mower operators. These sources are published by a variety of institutions and organizations, including universities, agricultural programs, and municipalities.

Fact Sheets

In 2015, CPSC issued a fact sheet specific to riding lawn mowers. The fact sheet identifies 1) the voluntary safety standard for walk-behind and riding mowers as ANSI/OPEI B71.1, and 2) provides a list of safe operating practices for riding mowers, including general operation, slope operation, keeping children safe, towing, and properly servicing the machine. The fact sheet raises awareness of how dangerous mowers can be for children and notes that "tragic accidents can occur if the operator is not alert to the presence of children. Children are often attracted to the machine and the mowing activity. Never assume that children will remain where you last saw them (CPSC, n.d.)."

Texas Division of Worker's Compensation also published a Riding Lawnmower Safety Fact Sheet that details guidelines for safely operating riding mowers and addresses a range of hazards, including rollover accidents, finger dismemberment, oil burns, and back-overs. The fact sheet also describes "case studies" of real-life Occupational Safety and Health Administration- (OSHA) published mower-related accidents that happened on the job. One case study describes a tip-over accident on a riding mower and an incident in which an operator lost fingers in a sliding accident (TDI, 2021).

Lastly, trade associations have published fact sheets and checklists for supervisors. The National Association of Landscape Professionals published a web page that includes guidelines that supervisors can use to ensure employees operating riding mowers are safe. They also include a bulleted list of "Dos and Don'ts" related to mower safety. Recommendations for supervisors include trainings for each mower type, records of trainings, and supplying personal protective equipment (e.g., safety goggles, steel-toed footwear, gloves) to mower operators (NALP, n.d.).

Safety Manual

The 2009 instructional safety manual titled *Mowing and Trimming Safety: For the Landscaping and Horticultural Services Industry* published by Kansas State University Research and Extension was reviewed for the scan. The manual addresses safety practices to use when mowing with a range of equipment, including agricultural mowers, riding lawn mowers, walk-behind (push) mowers, string trimmers, and brush trimmers. The safety manual is organized into six lessons, with quizzes after each lesson and a comprehensive quiz at the end of the manual. The lessons in the manual include 1) understanding safety signs and symbols; 2) safety equipment; 3) how to inspect equipment for safe usage; 4) preparing mowing area for safety; 5) safe start up and shut down of equipment; 6)

preventing rollover accidents; 7) avoiding being caught in moving parts; and 8) other common dangers like: run-overs, hitching attachments, obstacles, thrown objects, traffic, electrical safety, environmental hazards like heat and cold, and lightning precautions. The manual illustrates specific hazards by offering brief descriptions from actual OSHA accident inspection reports (Lind & Ricketts, 2009).

Article

Employers may choose to publish information about lawn mowers and lawn mower safety for their employees' use. For example, Middlebury College's website posted an article, which has since been removed, about the college's lawn mower safety policies and lists the college's policies and procedures for safe lawn mower operation. It designates the manager/supervisor as responsible for proper training of all employees in the operation of mowers. The page lists five requirements for operating mowers, including 1) the deflector to be in the down position to avoid any stray objects hitting pedestrians; 2) operators must wear safety shoes, gloves, and eye protection; 3) operators are not allowed to use headphones when operating the mower; 4) operators must stop when a pedestrian passes so as to avoid "discharge" going in the pedestrians' direction; and 5) operators must go up and down a slope instead of parallel across it to avoid tipping over (*Workplace Safety*, n.d.).

Blog Posts and Traditional Media Coverage About Riding Mower Accidents and Prevention

This section examines traditional media outlets' coverage of riding mower incidents. Most coverage reports about local accidents, either at the state or city/town level, and focuses on the injuries sustained. Often, a narrative about who was hurt and how is also included in the reporting.

Blogs

The Mower Project is a blog written by a lawn mower hobbyist who aims to develop robot-operated lawn mowers, believing the safest mowers are those that separate the operator from the machine. A post from November 16, 2019, "Lawn Mower Safety Regulations: A Brief History," notes the high number of riding mower injuries that occurred from 2005 to 2015 (Mr. Mower, 2019).

Bill Kitzes, a product safety management specialist, re-published a post he originally released in 2001 in the CCH Consumer Product Safety Guide. The post summarizes the history of debates within the mower equipment industry about whether or how to restrict reverse-mowing or backup features. Kitzes writes that most injuries to children happen when the operators are backing up to turn around. Since 1965, manufacturers have been aware that thousands of children die each year from being run over by a mower going in reverse. As a result, since 1965, there have been debates about how to restrict operation of blades, which move at 200 mph (321.0 kph), when the mower is going in reverse. Although some in the industry felt that consumers would not accept a mower whose blade disengaged when going in reverse, at the time the article was written, other manufacturers had developed "systems to prevent mower blades from rotating when traveling in reverse." Kitzes writes: "[Systems to prevent mower blades from rotating in reverse] have been technically feasible and economically practical for many years. I applaud the manufacturers efforts. Thousands of disfiguring injuries later, it's about time" (Kitzes, 2001).

Enabling the Future is a blog for e-NABLE, "an online global community of 'digital humanitarian' volunteers from all over the world who are using their 3D printers to make free and low-cost prosthetic upper limb devices for children and adults in need." e-NABLE devices are 3D printed prosthetics. Since 2013, e-NABLE has received continued requests for prosthetic hands, arms, and fingers due to mower accidents. The blog reports that 800 children in the United States are run over by riding mowers each year, and 600 of those incidents result in amputation. Additionally, major limb loss for children under 10 is most commonly caused by lawn mowers (Owen, 2017). The blog post

also presents a safety checklist developed by the Amputee Coalition. The checklist includes the following guidelines to use when mowing: 1) make sure children and pets are indoors; 2) remove debris to prevent projectile objects; 3) wear shoes; 4) wear protective eyewear and hearing protection; 5) refuel when the machine is off and cooled down; 6) for riding mowers: "Make sure your mower includes an auto shut off when the rider is not in the seat"; 7) have children stay away from the exhaust, and 8) be cautious of hills and sharp turns (Owen, 2017).

The Ohio State University's Agricultural Safety and Health Program website posted an article about lawn mower safety in 2018. The article summarizes the Nationwide Children's Hospital report on the extent and type of child injuries sustained from riding mowers. The article also shares the American Academy of Pediatrics list of recommendations to prevent serious injury from riding mowers. Notably, they recommend keeping the interlocks system in place. This feature stops the blades when the operator is away from the machine. Additional recommendations include avoiding disabling the override; use of the "no-mow-in reverse mechanism," if one is featured in that mower; keeping children away from the lawn mower and not allowing them to ride or operate mowing equipment; clearing the mowing area of sticks or debris before beginning mowing; and wearing sturdy shoes if mowing (Jepsen, 2018).

Leading Gear describes itself as "an independent organization that reviews the best indoor and outdoor gear for users to make their buying experience seamless and efficient." The article titled "Lawn Mower Injuries [Statistics You Must Know]" presents findings from various sources, including CPSC and the American Journal of Emergency Medicine, that describe causes of mower injuries and what can be done to keep children safe when a mower is in operation. *Leading Gear* recommends 1) a minimum age of 16 for operating riding mowers; 2) avoiding using lawn mowers for fun; 3) always mowing in a forward direction; and 4) avoiding sharp turns. The article also offers instructions on how to safely turn off the mower, refill fuel, and avoid burns from exhaust (Editorial Board, 2020).

This blog post "Zero-Turn Mower Safety" published by the Lawn EQ blog identifies some safety considerations that operators should be aware of when operating zero turn mowers. These include awareness that the weight distribution of zero-turn mowers is unique; the weight is over the rear wheels, which affects how one makes turns. Operators should know that turning on a slope can be difficult in a zero-turn mower. One should only mow up and down, avoiding making turns on a slope. Operators should also be aware that rollovers are a risk when making sharp turns at a high speed. Zero-turn mowers can make jerky movements, so one should avoid cutting too close to objects, according to the blog's author (Andrew T., 2013).

Traditional Media

National News

Newsweek reported that Lawn Starter, a lawn and gardening resource, collected data from CPSC's NEISS to analyze the frequency of mower-related deaths. Lawn Starter found that an average of 90 Americans die each year from mower-related injuries, which includes injuries from walk-behind (push) mowers and riding mowers. *Newsweek* reports that among all "freak accidents," only deer attacks, electrocution, carbon monoxide poisoning, and unintentional falls result in more annual deaths than death by lawn mowers (Williams, 2020).

Newswise published a press release issued June 2017 that presents findings from a study from the Center for Injury Research and Policy at Nationwide Children's Hospital published in the *American Journal of Emergency Medicine*.[1] The press release reports that every day in the United

[1] This article is also referenced in the literature review on page 13.

States "13 children receive emergency treatment for a lawn mower–related injury," but there has been a decrease in the number of children injured by mowers (Nationwide Children's Hospital, 2017). Cuts (39%) and burns (15%) were the most common injuries from lawn mowers and hand/fingers were injured most, followed by legs, feet and toes. This is different from what was discerned in the literature review, but this study does not differentiate between riding mower and push mower accidents and uses an umbrella term of "lawn mower" to encompass all of the accidents that they reviewed.

In 2008, ABC News reported on the danger of mower injuries, drawing from a 2007 Johns Hopkins press release. It was reported that 95% of lawn mower accidents treated at Johns Hopkins Children's Center from 2000–2005 "involved amputations that required reattachment or reconstructive surgery." Carol Gentry, Pediatric OR Nurse Manager, said: "The No. 1 advice to parents is: Treat the lawn mower as hazardous equipment, not a toy. You don't let a child play with an electric saw, and that's exactly what a lawn mower is" (Preidt, 2008). The article also discusses Johns Hopkins Children Center's tips for preventing mower-related injuries. The tips included 1) children younger than age 6 should be kept indoors while a power mower is being used; 2) no child younger than age 12 should use a walk-behind mower; 3) children under age 16 should not be on riding mowers, even if they're with an adult; 4) if you're mowing and see a child running toward you, turn off the mower immediately, as children can fall and slip into the blade, especially if the grass is wet; 5) wear protective goggles and closed-toe shoes when operating a mower or when near one; 6) if someone suffers a mower-related injury, call 911 immediately and apply pressure to the wound to stop bleeding while you wait for an ambulance; 7) buy mowers with a no-reverse safety feature that requires the operator to turn around and look behind before shifting the mower into reverse; and 8) before mowing, clear the lawn of debris such as sticks and stones, which may get caught in the mower blades and be propelled out (Preidt, 2008).

Local News

Anne Hayes of Syracuse.com reported that a 6-year-old boy in the Finger Lakes area of New York was hurt by a riding mower. He ran to his grandfather who was mowing the lawn. The grandfather did not see the boy as he approached the mower. The grandfather ran over the boy's lower right leg when he was reversing the mower to avoid a tree stump. The boy was airlifted to a hospital and had surgery. There was no word on how the boy is currently doing (Hayes, 2021).

WCNC Charlotte reported that a mother was arrested and charged with child abuse when her 8-year-old child fell off a riding lawn mower and was hit by the blades of the mower. The blades hit his left leg and both arms. The mother was operating the riding lawn mower with a small child on her lap and the 8-year-old boy riding on the surface of the zero-turn mower. The mother turned off the mower as the boy was falling, but the blades continued to turn. The boy was airlifted via helicopter to the hospital. The article cited the statistic that 9,000 children in the United States go to the ER each year due to lawn mower–related injuries (WCNC Staff, 2019).

Investigative Journalism

FairWarning, which describes itself as "a nonprofit news organization based in Southern California that focuses on public health, consumer and environmental issues," has produced several news stories to raise awareness about lawn mower accidents that affect children. One article cites a 2017 study by the American Journal of Emergency Medicine that "estimated there were 1,641 back-over injuries in the United States from 1990 to 2014 (Wolfe & FairWarning, 2019)."[2]

[2] FairWarning dissolved in 2021 after the founder was alleged to have made racist statements (Witley, 2021).

Social Media Coverage

In addition to traditional media sources, Team FMG also reviewed riding mower–related content found on social media platforms. The content included individuals who focus on lawn mower–related entertainment for children and adults, riding mower accidents, instructional mower repairs, and descriptions of how to bypass riding mower features.

Mower-Related YouTube Videos with Higher Number of Views

The most popular videos involving mowers involved mower racing for entertainment. For example, "Lawn Mower Racing Battle" had 39 million views and "Mower Mud Runs" had 18 million views (Dude Perfect, 2016; FearlessFront [Todd Christopher], 2018).

Popular videos also included children's entertainment: "Lawn Mower for Kids | Yard Work With Blippi" (28 million views), and "Our tractor is stuck | Playing in the mud with lawn mower | Tractors for kids" (3.5 million views). One popular video depicts a small child riding with their father on a riding lawn mower (Blippi - Educational Videos for Kids, 2016; Hudson's Playground, 2020).

Other videos highlight stories of riding mower accidents. "This Insane Lawn Mower Accident Will Leave You In Tears" (11 million views) depicted the true story of a father whose son was run over by a riding mower. The video featured interviews with the mother, father, neighbor, and doctor. The child survived the accident; his arms required reconstructive surgery and skin grafts, but no amputation (Amazing Stories, 2014).

YouTube Videos Related to Troubleshooting Issues and Bypassing Features

There are several instructional videos located on YouTube, such as "Top Reasons Lawn Mower Not Starting | Troubleshooting" (1.9 million views), which shows viewers how to repair their lawn mower when it does not start.

Several videos provide instructions for tampering with the operator presence control (OPC) seat sensor. These videos include "Quick Tip 4| How To Bypass A Riding Mower Seat Safety Switch" (177k views) and "How To Bypass Your Mower Seat Switch on a Zero-Turn Mower" (141k views). Similar third-party videos exist and include various manufacturers.

Other videos emphasize bypassing no-mow-in-reverse mechanisms. Such videos include "Disable all lawnmower safety switches" (240k views). Similar third-party videos exist.

One YouTube user begins a video by providing a visual overview of the safety controls on certain lawn mowers. The first is the "seat safety switch," which stops the motor if the operator gets off the seat. The poster explains that this is a "weight-sensing type switch." The second is a "reverse operation switch (ROS)" that stops the motor if the lever is placed in reverse. The poster appears to disingenuously explain the purpose of the video as instructions on how to restore a faulty safety control. "This safety feature for me does not work. I am going to show you how not to undo this safety feature." He then shows the viewer how to unplug and reconnect the plug that connects to the reverse lever. He ends the video with a verbal caveat that the video is for "experimental purposes" and that he does not condone changing the control like this. The video has 92,984 views as of 11/19/2021. The user has 24k subscribers.

In a YouTube video titled "Mower PTO Reverse switch Bypass," the YouTube user shows viewers how to override reverse safety PTO that requires an operator to continue to press a reverse push control if they want to mow in reverse. Disabling the reverse safety PTO requires removing a wheel and manually disabling the mechanism, which is "an insulated wire that is waiting to be grounded." One must remove two screws, break a tab off from a switch, and reinstall the switch. He then says

that there is a safety issue with making this modification. He does recommend making the modification only if the person does not have pets, kids, or people around. He says he takes no responsibility for what happens when people make this modification but adds that it will "make your life a lot easier and make your mowing a lot faster." The video has ~231k views, and the poster has ~50k subscribers.

Support Groups and Tate's Army

Because many families have been impacted by the run-over or back-over of children by lawn mowers, several communities and support groups have been formed. One of the largest groups is the Facebook support group "Lawn Mower Accident Support and Prevention Community," which provides community for families and loved ones affected by mower injuries. This group has over 6,500 members. In the "About" section of their Facebook page, the author writes, "Let's advocate solutions and bring attention to this cause for a safer consumer product for the sake of our children. Kids will always be where they shouldn't be, we don't have eyes in the back of our heads." One post on this Facebook page promotes another private Facebook support group named "LMA Survivors & Family Support" which has 693 members. This private group posts about recent lawn mower accidents. The group also posted a news item from CPSC about the recall of Kubota zero-turn mowers (Lawn Mower Accident Support and Prevention, n.d.).

The Lawn Mower Accident Support and Prevention Facebook page has tatesarmy.org listed as their official website. Tate's Army is a nonprofit organization that promotes lawn mower safety awareness and prevention, advocates for children's safety, offers support for life-changing medical traumas, and offers financial assistance to injured children and hurt families. The website tells the story of Tate Manahl, who was 3 years old when he became the victim of a riding mower accident after his father accidentally ran him over with a riding mower. The website reads, *"Tate was just three when he was accidentally run over by a lawnmower. His injuries were severe and life-threatening from the stomach down. He was airlifted to The University of Iowa Stead Family and Children's Hospital, where doctors would fight to save his life and his legs* (*Tate's Army | Lawn Mower Safety & Accident Awareness Foundation*, n.d.)."

Mower-Specific Websites

Tractorbynet.com

Tractorbynet.com includes forums dedicated to individual manufacturers and posts about buying/pricing and owning/operating lawn tractors. There are many conversations from tractorbynet.com users asking about customizing or changing built-in settings and various discussions around Operator Presence Controls (OPC). Specific discussion related to OPCs include users expressing a desire to stand up or get on the edge of the mower's seat to see where they are mowing. Additionally, a few users have reported installing backup cameras on their mowers for an easier view of what is behind the mower.

One tractorbynet.com user posted on the site that they "wired an on-demand (switch activated) seat safety bypass" for their tractor. The same user embedded an instructional YouTube video within their tractorbynet.com post that details how exactly to wire such a switch. The user went on to discuss in their post that they did not want to put the tractor in neutral and engage the parking brake every time they wanted to get off the tractor, and instead wanted the ability to stand up over the tractor for visibility's sake while mowing (mikefd, 2018). Other commentors on the tractorbynet.com post responded with ideas, such as having a warning light or illuminated switch that alerts the operator that the seat sensor has been disabled or adding a timer that reverts the control back to safety mode (Meisenheimer, 2018). Generally, tractorbynet.com users understand the reason for

safety controls and appear to disable them as a last resort. More specifically, they want to be able to customize their machine to enable them to work as efficiently as possible.

Limbs Matter PSA

Limbs Matter is an organization that describes itself as "a group of families who have come together to spread our message about lawnmower safety." Limbs Matter published a video public service announcement to YouTube that included emotional testimony-based detailing the loss of limbs by children who had lawn mower–related injuries. The video indicates the effect that these injuries had on the children and their families. The urgent and emotional tone of the message encourages individuals to practice lawn mower safety (Limbs Matter, 2015).

Medical Community and Publications

This section summarizes publications (e.g., blog articles and online publications) issued by pediatricians or other medical organizations about lawn mower safety. Generally, these sources provide statistical figures on incidents to raise awareness of the danger of mowers and often include tips and guidance for parents and the public on how to avoid mower injuries.

Johns Hopkins University

Johns Hopkins researchers analyzed 2006 to 2013 lawn mower injury data. They found that lawn mower–related injuries occurred at the rate of 6,400 a year. On average, these injuries, which often require hospitalization and surgery, cost $37,000 per patient. The researchers found that "children up to age 4 were six times more likely to have a foot/toe or lower extremity injury and 1.7 times more likely to have an amputation than those age 15 and above. […] Conversely, older teens and adults aged 15 and above were 8.3 times more likely to have an injury to the hand or upper extremities. […] Despite consumer education programs and warning labels, lawn mower injuries in the United States remain a serious public health concern," says Deborah Schwengel, M.D., study author and Assistant Professor of Anesthesiology and Critical Care Medicine at the Johns Hopkins University School of Medicine (Johns Hopkins, 2018). Researchers also identified patterns related to the timing and location of these accidents:

- 37.5% of injuries occurred in the South.
- 66.3% of injuries occurred on a weekday.
- 81.7% of injuries occurred between April and September.

OrthoKids.org and the Pediatric Orthopedic Society of North American (POSNA)

OrthoKids (orthokids.org) is a website for parents and kids who want to learn more about pediatric orthopedics. All information on OrthoKids has been vetted by members of POSNA. On their website, OrthoKids has a page about lawn mower safety that includes a lawn mower safety video that discusses the prevalence of mower accidents and how to prevent injuries, a written overview of common lawn mower injuries, how to prevent lawn mower injuries, and a frequently asked questions (FAQ) section with answers to common parent questions. The site describes many ways that children can be injured from lawn mowers: hurt by objects hurled from the mower; falling near the mower; being struck or run over by the mower; falling or jumping from a riding mower in operation; and burns from touching the hot surface of the mower.

The FAQ section of the website addresses some common questions parents might have about lawn mower injuries. The OrthoKids site was the only source reviewed for this environmental scan that included a FAQ. Below are example questions that are answered in the OrthoKids Lawn Mower Safety FAQ:

- Q: My child is interested in mowing the lawn for extra money – is that safe?
- Q: How are children or adolescents injured by lawn mowers?
- Q: How can we avoid lawn mower injuries?

The site also provides startling statistics to put the danger of mower injuries into perspective. One such statistic is that "the energy of the rotating blade is more powerful than a 0.357 Magnum gun." The website also notes that lawn mowers "are the leading cause of traumatic amputations in children." Other statistics highlighted on this website include: 1) 90% of children are injured at home, 2) 80% of injuries include the usual operator of the mower, 3) 50% of the injuries occur when the mower is in reverse, 4) boys are more frequently injured by mowers than girls, and 5) injuries are more commonly seen in younger children (1–3 years) compared to teenagers. They go on to detail that such injuries "require a team of specialists to treat. They may need multiple surgeries over weeks to years." The site provides the reader with actionable recommendations, such as that children should not be in the yard when a lawn mower is being used, no riders should ever sit with the driver on a riding lawn mower, and a running mower should never be left unattended (*Lawnmower Safety*, n.d.).

American Society for Surgery of the Hand (ASSH) and assh.org

"Handcare: The Upper Extremity Expert" is a website and blog sponsored by the American Society for Surgery of the Hand (ASSH). An undated post on this website about lawn mower safety identifies common lawn mower injuries, including cuts and bacterial infection from cuts; burns from a hot engine, gas tank or exhaust; missile injuries from objects thrown by the blades; fractures; and amputations from the blades or from severe burns or cuts. The post offers guidelines for preventing injury, including maintaining sharp blades, avoiding the removal of safety devices or guards on controls, and never inserting hands or feet in the mower to remove grass or debris but instead use a broom handle or stick.

Importantly, this post acknowledges that lawn mower blades continue to spin even after the motor is turned off, something that other sources do not often mention. The post notes that "the machine must be turned off and the spark plug disconnected (or power cord unplugged for electric models) before attempting to remove an object from the blade. The machine will likely still have one 'turn' remaining in the motor/gears even after the power is disconnected, and the blades/rotors will turn forcefully once the obstruction is cleared. DO NOT assume that you are safe just because the power switch is off."

The post also offers guidance on how to handle injuries, including amputation injuries. The authors note that often the amputated part is unable to be reattached because it is so badly damaged. Additionally, the authors caution that even if reattachment is possible, function is never the same, and that nonsmokers, those without diabetes, and those without many medical conditions also have better outcomes with these injuries (ASSH, n.d.).

University of Missouri Health Care and muhealth.org

The University of Missouri Health Care website published a story about a local boy named Ely who was a victim of a mower accident in 2015. The story reports that during Memorial Day weekend in Bull Shoals Lake, Missouri, 3-year-old Ely Hamilton went outside to see his grandfather who was mowing the lawn. Ely's mother thinks Ely caught his foot under the riding mower and fell when his right leg hit the mower blades. He was rushed to a local hospital and then airlifted 200 miles away to the trauma center of a university hospital in Columbia, Missouri.

According to Dr. Sumit Gupta, the pediatric orthopedic surgeon who treated Ely, Ely's knee was fractured, and he had lost much soft tissue. Gupta said, "His knee was basically wide open. There

wasn't really anything left to close it with because he lost a lot of his tissue in the accident." Gupta also noted that the mower wounds involved grass and dirt, which require washing out several times, as Ely was at risk of bacterial infection. A podiatrist and microvascular surgeon also worked with Ely. In total, Ely underwent a 12-hour surgery, stayed in the ICU for 5 days following the surgery, and stayed in the hospital for 34 days. Luckily, Ely was able to keep both of his legs. He required a brace on one leg and physical therapy several times a week.

Dr. Gupta also noted in the story the importance of doing this kind of procedure at a hospital or medical center where many experts are present, "if I were working by myself, I couldn't have taken care of Ely. I needed the help of foot and ankle specialists and a microvascular surgeon, and that's what you get in an academic medical center." Dr. Gupta also warned of the dangers of mowers to children and noted that his team treats five to six severe mower injuries at MU Children's Hospital each year. He provided three recommendations for lawn mower safety, which include "1. keep your children indoors whenever you or someone else mows; 2. never allow your children to play with a lawn mower, even if it is turned off; 3. never let your child ride on a riding lawn mower" (University of Missouri Health Care, n.d.).

Nationwide Children's Hospital

Nationwide Children's Hospital is a pediatric hospital and research institute located in Columbus, Ohio. Nationwide Children's Hospital have a page on their website, *nationwidechildrens.org*, titled "Lawn Mower Safety." This source urges parents to understand that most of the injuries from lawn mowers can be prevented by following a few simple steps (e.g., never allow a child to ride on a riding mower, keep children inside while cutting the grass). Parents can learn how to practice safety measures to prevent lawn mower injuries by reviewing a lawn mowing safety informational video, the prevention resources, and facts related to lawn mower injuries, which are all included on the page (Nationwide Children's Hospital, n.d.).

Pediatrics Nationwide

Pediatrics Nationwide is published by Nationwide Children's Hospital "to advance the conversation on child health." On July 23, 2021, *Pediatrics Nationwide* published an article titled "Lawnmower Injuries in Children Are Limb-Threatening and Avoidable" written by Ibrahim Khansa, MD, surgeon within the Department Plastic and Reconstructive Surgery at Nationwide Children's Hospital, and Assistant Professor of Plastic Surgery at The Ohio State University. This source summarizes a 25-year longitudinal study regarding pediatric lawn mower injuries involving children. The author notes that most of these injuries occur while the lawn mower is moving forward; however, the third most common cause of injury is a mower operating in reverse. Injuries can be prevented through greater awareness by parents and lawn mower operators. The article highlights specific steps that can be taken to prevent lawn mower injuries (Khansa, 2021).

Healthychildren.org and the American Academy of Pediatrics

Healthychildren.org is website sponsored by the American Academy of Pediatrics. This source has a web page on lawn mower safety, which was last updated on June 18, 2018 (American Academy of Pediatrics). The website highlights that power mowers can be extremely dangerous for use around children, but includes tips for prevention and safety measures that operators can use to prevent life-threatening injuries. The website uses infographics, videos, and clear and concise language to detail safety measures, the appropriate age and mindset for operating a lawn mower, and how to use a lawn mower safely (American Academy of Pediatrics, 2018).

OrthoInfo.org and the American Academy of Orthopedic Surgeons

OrthoInfo.org presents content vetted by the American Academy of Orthopedic Surgeons. OrthoInfo has an article titled "Lawn Mower Safety," last updated April 2020. The article notes that

when used improperly or carelessly, lawn mowers can lead to injuries, as they do for many individuals per year. The source provides information on how to properly operate your lawn mower, maintain your lawn mower, use caution, and keep children safe (American Academy of Surgeons, 2020).

Data Sets and CPSC Incident Reports

Team FMG analyzed a series of incident reports related to riding mower run-over and back-over incidents that were reported to the CPSC.

IDI Riding Mower Injury/Fatality Reports

Thirty CPSC incident reports were reviewed that detailed injuries and fatalities incurred from use of riding lawn mowers. The dates of the incidents ranged from 2010–2021 and the types of tractors involved in the reported incidents are detailed in Table 4. Most victims were not the operators of the riding mower and nearly all accidents took place in the yard of the victim's home, while two accidents took place at a family farm. The age of the victims ranged from 20 months to 68 years old, but 20 of the 30 incidents involved a victim 5 years of age or younger. Most incidents appear to have occurred in smaller towns or rural areas. The subsequent sections detail the severity, hazard patterns, and mechanisms of the riding mower that were involved in the incidents.

Table 4. Tractor types involved in the IDI incident reports.

Tractor Types Involved in Incidents (n = 28)	
Riding Lawn Mowers	16
Tractor and Bush Hog	1
Zero-Turn Mowers	5
Garden Tractor	1
Unidentified	5

Severity of Injury or Fatality

From the incident reports reviewed, it appears that very young children are most at risk for severe injury or death with riding mowers. A total of six fatalities were reported in the IDIs, and of the six fatalities, four were 2-year-old children and one was a 3-year-old child. Table 5 provides a summary of the tractor types involved in the fatalities. Injuries from riding mowers required the most urgent care and, in several incidents, likely due to the severity of the injury and a rural location, victims required Life Flight or an emergency airlift to a hospital. In these incidents, the blades routinely severed fingers, feet, and hands completely. In many cases, the medical professionals were unable to reattach the limbs.

Table 5. Tractor types involved in the fatal accidents.

Tractor Types Involved in Fatalities (n=6)	
Riding Lawn Mower	1
Tractor and Bush Hog	1
Zero-Turn Mowers	4

As noted in these reports, amputations from riding mower run-over and back-over incidents were very common. Nearly half of the incidents reviewed involved amputation or loss of limb/appendage. Common amputations include amputation from knee down, of feet, of fingers, and of hands. The injuries required multiple surgeries, even when amputation was required or when limbs could not be reattached.

Hazard Patterns

Back-overs were the most common hazard scenario and happened in 14 out of the 30 reported incidents. Often, a grandparent, parent, or caregiver would be mowing in the yard, believing the child they were caring for to be playing nearby in the yard or in the house. The child would unexpectedly run up to the mower, often behind the mower. Needing to turn the mower around, the operator would place the mower in reverse, not knowing the child is behind the mower, and the child would be hit and fall underneath the mower. The operators commonly reversed the mower without looking behind them.

Run-overs and falls were also found within the incident reports as a pattern for injury. Run-overs occurred when an operator did not know that a child was approaching the mower and the child fell near the mower or was hit by the mower while the operator was not looking in that direction. Falls involved a child passenger on the mower and the injuries/fatalities occurred when the child fell from the mower and landed near the blades.

Features/Mechanisms of the Riding Mowers Involved in Incidents

Many of the riding mowers were described as zero-turn mowers in the incident reports. There were also a few incidents that involved a mower attachment. In one incident, a father and toddler were standing up on a stand-up riding mower attachment and the young child fell off the attachment.

In several incidents, the operator tried to brake or stop the blades to avoid further injury to a child, but these efforts were often unsuccessful. In one incident, a parent left the mower seat to help the child who had fallen under the mower, but the mower engine did not stop, and the child was dragged further through the yard. In another incident, a mother saw her child was too close to the mower. She stopped the engine, but the child was still hit by the blades, as the blades took 8 seconds to completely stop.

Mowing in reverse was the most common cause of back-over injury. This was not attributed to any mower mechanical error, as mowing in reverse appears to have been a standard feature of the mowers studied.

Additional Incident Reports

Additional incident reports (*N* = 72) were shared by the CPSC and were reviewed at a high level for additional themes. The median age of the victims reported in the incidents is 4 years old and the average age of the victim reported in the incidents is 16.1 years old. Common consumer behaviors and patterns reported in the additional riding mower incident reports included the following:

Hazard Patterns

- The child becoming accustomed to riding on the mower or being around the mower and is no longer afraid to approach it.
- The child riding on the riding mower/standing on the mower and slipping or falling underneath the riding lawn mower deck.
- A very small child/toddler falling in front of the riding mower and eventually getting stuck underneath the deck.
- An adult operator falling from the riding mower and contacting blades.
- The riding mower operator not looking behind while mowing in reverse and accidentally hitting child with the riding mower.
- The riding mower operator not turning the engine off, and instead placing the riding mower in neutral and getting off the seat to inspect the riding mower blades. This specific behavior can result in operator injury and/or bystander injury because the engine is still running.

+ Operator not being able to stop the engine/blades in time or not knowing how to stop blades.

Additional riding mower features/mechanisms involved in these riding mower accident reports included:

+ The "seat kill switch" did not activate properly and was deemed defective by a technician later after the accident.
+ The OPC disabled, which allowed the operator to leave the riding mower seat while the engine and blades were still actively operating.
    - The OPEI ANSI B71.1 A.16.2.1.5, 16.2.1.6, and 16.2.1.7 2017 sections have safety specifications that attempt to prevent this from happening by requiring the riding mower to have a means to automatically stop the blades while the engine continues to run or stop the engine and the blades when the riding mower operator leaves the normal operating position.
+ The no-mow-in-reverse features were disabled and this caused a riding mower accident.
    - The ANSI/OPEI B71.1 A.16.2.1.8 2017 section includes safety specifications that attempt to prevent this exact accident from occurring by recommending that manufacturers reduce the possibility of inadvertent blade contact at the rear of the machine by removing power from the mower blades during reverse operation. This section of the standard also allows for the provision of a temporary override for when the operator needs to operate the machine or an attachment in the reverse direction.
+ A no-mow-in-reverse safety feature was not included in the mower design and an accident occurred when the operator mowed in reverse and hit a small child accidentally.
    - As stated above, the ANSI/OPEI B71.1 A.16.2.1.8 2017 section includes safety specifications that attempt to prevent this exact accident from occurring by recommending manufacturers to reduce the possibility of inadvertent blade contact at the rear of the machine by removing power from the mower blades during reverse operation.
+ The riding mower operators appeared to assume that the OPC feature would park the machine or immediately stop the engine or power to the blades.

The tables below provide a high-level view of the incident types (Table 6) and the type of riding mower involved in the reported accidents (Table 7).

Table 6. Incident outcome of the reported accidents.

Incident Outcome	#
Hospital Admissions	42
Deaths	26
Emergency Dept. Treatment	4

Table 7. Mower type involved in the reported accidents.

Mower Type	#
Riding Lawn Mower	55
Zero Turn	15
Tractor and Bush Hog	1
Unknown	1

Conclusion

Despite limited studies and research specific to riding mower injuries, a plethora of sources online discuss riding mower hazards, back-over and run-over injuries, procedures to operate riding mowers, injury prevention methods, and the importance of lawn mower safety. The environmental scan revealed that mowing in reverse is a common cause of back-over accidents. Run-over accidents are also common, and typically happen when operators are unaware of someone approaching the mower. In run-over accidents involving children, the child may fall near or be hit by the mower and as a result sustain injuries from contact with the rotating blades. Many riding and push mowers are designed with safety features that should prevent and/or reduce the risk of lawn mower–related injuries. Such features include the NMIR system on riding mowers. Findings indicate that mower operators disable safety features to fit their user needs. YouTube videos are available that illustrate how to disable certain features. OPC and NMIR features appear to be safety features that may frustrate users the most. Databases contain information on emergency department admissions from push and riding mower–related injuries, and national and local news media sources report on individual accidents that occur in the area. Traditional media sources share contextual and detailed information, such as the mechanism of injury, who was involved in the accident, and specific details as to how the accident occurred. The medical community (e.g., pediatric groups, surgeons) are concerned about mower-related safety hazards. Medical professionals want parents to know that these injuries are extremely severe and life-threatening. Injuries and amputations that happen from back-over or run-over accidents require a lifetime a medical care. To help with the recovery process, support groups exist online for families affected by mower-related injuries.

Limitations

This environmental scan was limited to lawn mower–related incident data sets that did not always specify the type of mower involved. Additionally, the qualitive data included in the injury reports did not consistently provide in-depth details on what occurred when the lawn mower–related injury happened. Similarly, preventative support groups and medical communities often shared tips related to general lawn mower safety and did not always provide tips specific to riding mowers. The amount of information for each court case related to riding mower injuries was limited to what each news station shared in their specific articles. Lastly, it is difficult to ascertain the safety features present, or not present, on all riding mowers currently in production, produced in the past, and/or purchased second-hand.

In-Depth Interview Findings

Overall Trends

After reviewing the literature, conducting an environmental scan, and task analysis, Team FMG conducted in-depth interviews (IDI) to further understand injury patterns associated with riding mower–injury patients and methods that could mitigate these injuries. The following section summarizes findings from the interviews with stakeholders who have expertise in the areas of pediatric anesthesiology, pediatric trauma surgery, and design engineering. Overall, many of those interviewed articulated some of the same safety concerns revealed in the literature review and environmental scan.

Physicians

Team FMG spoke with two pediatric anesthesiologists, Dr. S. and Dr. K., and one pediatric trauma surgeon, Dr. N., about their experiences in treating patients with lawn mower–related injuries. They all expressed becoming concerned about the problem of lawn mower injuries after witnessing several pediatric patients sustain traumatic injuries and wanting to help reduce this preventable mechanism of injury. Their concerns come not only from being medical professionals,

but also from being parents. In their professional experience, lawn mower injuries in children are devastating and serve lifelong injuries due to the amount of damage done to extremities. As doctors, they see firsthand the extensive medical treatment needed by these patients and the impact these injuries have on families. These injuries are also a costly financial burden to the health care system and victims' families.

Extent and Severity of Riding Mower Injuries

As far as demographics of the children injured, Dr. N explained that there's no typical age, but patients are toddlers, children who are more mobile, and school-age children. The youngest patient Dr. K has treated for lawn mower–related injuries was 3 years of age. In the physician's experience, these injuries typically occur from children being run over by the mower, a child riding in the lap of someone operating the mower falls off, or a penetrating injury occurs from a projectile object. Other scenarios include an underage individual operating the lawn mower and being injured or children playing near the mower and sliding under it after falling. According to the physicians these injuries are observed more frequently during the spring or summer months. Lawn mower injuries among children are unique due to the nature of the cuts to the lower extremities. Dr. K. explained that lawn mower injuries are different from other types of severe injury due to the higher risk of amputation among pediatric patients (amputation, in general, is seen more among adult patients than among children). Dr. S. added that lawn mower injuries are more severe among children and result in lifelong injuries. In the cases Dr. S. has witnessed, while the medical team works to reconstruct the limb as much as possible, they often cannot preserve the limb because it is severely mangled.

Impact of Riding Mower Injuries

Dr. N, who primarily works with plastic surgeons to reconstruct limbs, blood vessels, and nerves, expressed that where the physical amputation occurs is not where medical care ends and that riding mower injuries lead to lifelong injuries. Treatment for a severe lawn mower–related injury includes an initial surgery, multiple surgeries that follow, pain management, and physical therapy. The treatment over time for amputations in pediatric patients also depends on where the amputation occurs. In some cases, children are given a prosthetic to help with management. The treatment plan for severe injuries caused by lawn mowers requires a lifetime of medical care for the patient. Dr. N. also explained that severe lawn mower injuries are very costly for the health care system, at an average of $40,000 per injury. If the injuries are more extensive, it is a more costly burden for the family and health care system.

The physicians interviewed also reflected on the psychological impact of lawn mower injuries on the family and the devastation they cause. They expressed that this overall experience is traumatic for the patient and their families and often leads to feelings of guilt. Many times, family members are directly involved in the incident, and this alone adds shame to an already horrific situation. Depending on the injury, the child may be chronically injured and/or experience PTSD from the accident.

Recommended Solutions and Next Steps

After witnessing several children sustain lawn mower injuries and amputations, the physicians started to study the nature of the injuries. Dr. S., Dr. K., Dr. N. and their colleagues conducted a retrospective, cross-sectional study using data from the U.S. Nationwide Emergency Department Sample for lawn mower–related ED visits and hospitalizations from January 1, 2006, through December 31, 2013 (Hottinger et al., 2018). During the IDI, Dr. S. mentioned the study researchers hypothesized that the number of injuries would change and decrease over the observed time, but the results and data of their investigation did not reflect that. Instead, lawn mower injuries occurred at a constant rate from 2006 to 2013, and they therefore knew there was more work to be done to prevent these injuries from occurring.

Dr. S. expressed that after reviewing the study findings, the authors decided they now need to switch their efforts over to preventing lawn mower injuries in children and advocating for safer lawn mower design. They agreed that there is a shared responsibility between consumers and manufacturers when it comes to safe use of lawn mower equipment and putting safeguards into place to prevent injury. Although consumers should properly and safely use lawn mowers, the physicians indicated that warning labels are equally important. All the physicians interviewed by Team FMG underscored the need for raising public awareness of the danger and hazards that lawn mowers pose. This includes making parents and caregivers aware of lawn mower safety and the precautionary measures that should be taken to prevent injury. Some examples include reading the operator's manual, keeping children away from the mower, having a sperate individual watch children while a mower is in use, and not allowing children to ride on the lap of someone operating a riding lawn mower. The doctors stressed that these warnings should come from the government, doctors, and manufacturers.

Engineer

Team FMG also spoke with Dr. N. S., an associate teaching professor in the Department of Mechanical Engineering. Dr. N. S. teaches design engineering to undergraduate mechanical engineering students. Dr. S. and Dr. K., whom Team FMG previously interviewed for this study, were sponsors of Dr. N. S. and his students' Lawnmower Safety System project, which researched and developed approaches to creating safer lawn mowers to prevent riding mower injuries.

Development of Riding Mower Prototype

Dr. N. S.'s students developed a final prototype that addressed two common hazard scenarios: 1) back-over injury—a child injured when approaching a mower that is moving in reverse with blades actively rotating; and 2) fall-off injury—a child injured when falling off a mower and getting caught in the mower blades. To mitigate back-over injury, the team installed a computer vision system (camera) on the rear of the mower and a reverse prevention mechanism (RPM) to identify objects approaching the lawn mower while it is actively in reverse and to automatically put the riding mower into neutral to prevent the object from being run over. Dr. N. S. and the engineering students initially wanted to disable the brakes on the prototype, but found it was easier for the team to disable the reverse function. If the lawn mower was going in reverse and the safety system detected an object in view of the camera, the lawn mower went into neutral. Dr. N. S reported that the vision system was successful in identifying children and adults behind the mower and immediately went into neutral to prevent injuries. The computer vision system was also able to draw the exact coordinates of where objects were and recognize things in the vicinity of the lawn mower. To address fall off injury, the prototype featured a guard on either side of the mower that physically blocked a child from contacting the blades if they were to fall off the side of the mower.

Safety Feature Implementation and Challenges

To implement the features designed on the prototype in 2018, the team estimated a cost to manufacturers of $60 for computer vision, $15 for the reverse prevention mechanism, and $15 for the fall-off guard. Dr. N. S. also mentioned that the prototype has never been shown and/or discussed with manufacturers. When asked about the challenges of safety features, Dr. N. S. acknowledged that the fact that safety features can be and have been historically disabled by users is a significant challenge to keeping riding mowers safe. In his view, the best safety features would add value to the user experience and therefore incentivize use and disincentivize tampering. In addition, safety features should be carefully designed to activate only when a specific threat is present, and therefore not further encumber safe use.

Conclusions

As findings from these interviews indicate, lawn mowers are a preventable source of injury among adults and children. Preventing injuries from riding mowers like loss of limbs is extremely important due to the impact these injuries have on the patient and their families. As discussed in the IDIs, back-over and run-over injuries are severe and require a lifetime of medical care. Efforts to prevent lawn mower–related injuries must be taken by a wide range of stakeholders. Lawn mower operators and consumers must assume responsibility for operating technology within the bounds of safety. Manufacturers must provide proper instruction on how to safely operate lawn mowers, place warning labels on the machinery, and implement technology to prevent injury. It's important to make parents and lawn mower operators aware of the dangers associated with improper use of equipment. The responsibility to raise awareness of lawn mower–related injuries and risk of injury for children falls on the medical community, doctors, the government, and manufacturers.

Limitations

These interviews were, by design, intended to further support insights gained from the literature review and environmental scan. As such, participants were recruited for their unique professional perspectives and experience with lawn mower–related injuries. Questions in the moderator guide were tailored to each participant's area of expertise. The physicians interviewed provided their first-hand experiences with the various types of injuries that both the literature review and environmental scan discussed. This affirms that riding mower injuries among children is an issue of concern and action must be taken to prevent these injuries from happening.

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Appendix A: Literature Review and Environmental Scan Search Terms

Literature Review: Search Terms and Keywords
Riding lawn mower accidents
Back over mower hazards
Prevention of riding lawn mower incidents
Riding lawn mower safety measures
Lawn mower run over
Lawn mower safety hazards
Riding mower safety standards
Garden tractor injury
Lawn mower education
Lawn mower children
(Garden) tractor safety
Tractor safety campaign

Environmental Scan: Search Terms and Keywords
Riding mower regulation
Riding mower standards
Mower back over hazards
Riding mower safety standards
Riding mower regulation/standards
Back over mower safety
Mower safety standards
Mower injuries children
Riding mower injuries children
Riding mower fatality
Lawn mower safety

Riding mower reverse safety
Riding mower back over fatality
Lawsuit riding mower safety

Appendix B: Task Analysis Protocol

Evaluator:
Date:
Retailer:
New/Pre-owned
Price:

Prior to visiting the retailer and conducting an in-person observation, review operator's manual and online product information to fill out the initial information.

Mower		**Source**
Manufacturer		
Brand		
Model		
Model number		
Serial number/location		
Engine serial number/location		
Mower type (ZTR, Lawn Tractor, Sub-Compact Tractor)		

Operator's Manual	**Document page in Operator's Manual where information is cited.**
Do you have an electronic version of the manual? If so, document Title, Version, and Date of Printing.	
Document which pages of the Operator's Manual address the safety labels and cautions.	
Is there a safety alert or caution about mowing in reverse?	
Document specifically where the Operator's Manual addresses the protection of children.	

Is there a notation about protecting children and mowing in reverse?	

Mower Specifications		**Source**
Deck Size and location (Front, Center, Rear)		
Engine size		
Engine location: Front, Rear		
Power source: Gasoline, Diesel, Electric		
Power rating (hp, torque)		
Transmission		
Drive system type - RWD, FWD, AWD		
Maximum Speed in Forward		
Maximum Speed in Reverse		
Seat Height		
Dimensions:		
Overall Length		
Deck Cutting Width		
Overall Height		
Weight (no fuel)		
Cruise Control		
Recommended Tire Size:		
Front		
Rear		

Machine Controls	Document page in Operator's Manual where information is cited.	
Operating Controls Layout		
Startup procedure.		
Stopping procedure.		
Note mower on/off control type and location (key, lever, etc.).		
What controls the mower speed and where is it located?		
Is the machine equipped with cruise control? If so, does it work in reverse?		
Does the mower have a gear selector? If so, where is it located?		
What steering mechanism does the mower have (i.e., steering wheel or levers)?		
What type of service brake does the mower have (i.e., combined (1 pedal) or separated (2 pedals) brake and clutch)?		
Where is the parking brake located, and how is it activated?		
Describe the forward and rearward mobility controls.		
Forward Right Turn (Zero Turn)		
Forward Left Turn (Zero Turn)		
Rearward Right Turn (Zero Turn)		
Rearward Left Turn (Zero Turn)		
Zero Turn Clockwise (Zero Turn)		

Zero Turn Counter Clockwise (Zero Turn)		
Blade Configuration and Discharge System		**Source**
Where is the power take off (PTO)/Blade Engagement Control?		
How is PTO/Blade Engagement Control Activated?		
Number of blades		
Where is the blade height adjuster, i.e. height adjustment for full deck?		
Document the number and increments of blade/deck height adjustment.		
Is the mowing deck wheel height position adjustable? Fixed, mechanical, hydraulic, etc.		
Where on the deck (in reference to the operator) is the grass discharge located?		

Safety Interlock System	Document page in Operator's Manual where information is cited.	**Source**
Is the mower equipped with an interlock system?		
Describe the interlock controls.		

Operator Presence Control	Document page in Operator's Manual where information is cited.	**Source**
Does the mower have an operator presence control (OPC): (Yes/No)? Where is it located?		

How does the OPC function (i.e., stop blades with engine, stop blades and keep engine running, does transmission disengage, does machine continue moving - please be specific)?		

Mow in Reverse	Document page in Operator's Manual where information is cited.	Source
What does the manufacturer call the Mow in Reverse option?		
Does the machine engage the PTO/Blades when putting the machine in reverse without any additional procedures?		
Is there a mechanism or procedure that can be done to allow the machine to Mow in Reverse, i.e. to engage the PTO/Blades?		
What warnings are provided with the instructions on how to Mow in Reverse?		
Describe the Mow in Reverse control design, i.e. ignition key position, push button, lever, foot pedal.		
Document the steps the operator must do to Mow in Reverse.		

In-Store Documentation	
Is the Operator's Manual present with the machine at the retailer? Document location, Title, Version and Date of Printing if visible.	
Identification Labels	
What other documentation (brochure, spec sheet, tag, warnings, labels, etc.) is attached to or displayed with the mower?	
Document any labels located on the machine that reference safety standards.	
Subjective Observations:	
Provide your comments about the location of on-machine warnings and instructions while approaching and sitting on the mower, and describe their noticeability, readability, and comprehensibility.	
Provide your comments on the location of warnings in operator's manual and other associated materials, and describe their noticeability, readability, and comprehensibility.	
Describe visibility in all directions from the seat of the mower.	

Photographs:	
Overall	
Serial Number/QR Code/Price Tag	
Photographs from Driver's Perspective	
Labels	
Key	
Manual	
Occupant Presence Sensor	
Instrument Panel	
Hand Controls	
Mow in Reverse Controls	
Parking Brake	
Pedals	
Deck:	
Deck Wheel Position:	Vertical Adjustment – Bolt Slot Location
Front	
Rear	
Deck Height Adjuster (lever and knob)	

Measurements:	
Bottom of Deck to Ground with Deck in Full Up	
Bottom of Deck to Ground with Deck in Full Down	
Lowest Point of Blade with Deck in Full Down	
Seat back height from Seat Pan	
Tire Size:	
Front	
Rear	
Tire Pressure:	
Front Left – Note if Solid	
Rear Left	
Front Right – Note if Solid	
Rear Right	