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Lacrosse Helmet Facemask Removal

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Context: Facemask removal (FMR) is required to access the airway of a catastrophically injured football or ice hockey athlete. However, the best method of caring for the helmeted lacrosse athlete with suspected catastrophic injury remains unclear.

Objective: To evaluate the effects of sex and grip strength on the speed and ease of use of various FMR methods across different lacrosse helmet types.

Design: Cross-sectional study.

Setting: Athletic training laboratory.

Patients or Other Participants: Fourteen athletic trainers (7 men, 7 women).

Intervention(s): Removal method (cordless screwdriver [CSD], Face Mask Extractor 2 [FMX], pruner, Trainer's Angel [TA]), helmet type (Cascade CPX, Cascade Pro7, Riddell Revolution, Brine Triumph, Warrior Venom), and sex.

Main Outcome Measure(s): Facemask removal time and participant-reported ease of use of the removal method (6-point Likert scale).

Results: We found a 2-way interaction for removal method and sex only for the ease-of-use scores ($F_{3,246} = 4.67$, $P = .01$). A main effect for removal method for time ($F_{3,200} = 19.41$, $P < .001$) and ease of use ($F_{3,200} = 53.78$, $P < .001$) was seen. The fastest times (32.32 ± 11.70 seconds) and highest ease-of-use scores (4.94 ± 0.30) were recorded for the CSD. We noted a main effect for helmet type only for time ($F_{4,200} = 5.34$, $P < .001$), with the fastest removal times (72.75 ± 74.67 seconds) recorded for the CPX. We discovered a main effect for sex only for time ($F_{1,200} = 17.57$, $P < .001$), with slower times recorded for women (115.51 ± 110.80 seconds) than men (75.71 ± 83.87 seconds). We found correlations between FMR time and grip strength only when using the FMX ($r = -0.40$, $P = .001$), pruner ($r = -0.26$, $P = .04$), and TA ($r = -0.26$, $P = .047$).

Conclusions: Based on our results, FMR of lacrosse helmets should be attempted with a CSD. We recommend carrying a pruner as a backup cutting tool in case the CSD fails, practicing FMR regularly, and inspecting helmets for faulty hardware to reduce the chance of CSD failure.

Key Words: emergency care, catastrophic injury, cervical spine

Key Points

- Participants removed the facemasks of 5 different types of lacrosse helmets with a cordless screwdriver (CSD), which was fastest with helmets that do not require a cutting step, and reported this method was easier to use than the Face Mask Extractor 2, pruner, and Trainer's Angel.
- Grip strength and FMR times were strongly associated for the 3 techniques using cutting methods but not for the CSD.
- Facemask removal on lacrosse helmets should be attempted first with a CSD and second with a pruner if screw removal fails.
- Athletic trainers should practice regularly, be prepared to perform FMR on various types of helmets, and perform FMR using the tool with which they are most comfortable.

The number of participants in men's lacrosse has risen steadily at all levels of play, making it one of the fastest growing sports in North America.[1] Although catastrophic injury rates are lower in lacrosse than other contact sports, these injuries can have fatal consequences.[2] Eleven collegiate male lacrosse players and 13 high school male lacrosse athletes have had catastrophic injuries in the past 25 years.[2] Given the possibility of these injuries, athletic trainers (ATs) for men's lacrosse are required to know the proper procedure for gaining access to the airway of the helmeted lacrosse athlete.

When a catastrophic injury occurs during play to a helmeted football or ice hockey athlete, facemask removal (FMR) is indicated to gain access to the airway.[3,4] Although some researchers support leaving the helmet and shoulder pads in place until they can be removed in a controlled environment to avoid increasing upper cervical spine flexion due to helmet removal,[5] we still do not know how the helmeted lacrosse athlete with a suspected cervical spine injury should be treated immediately.[6] The lacrosse helmet may need to be removed if neutral cervical alignment cannot be attained, the helmet is fitted improperly, or the facemask cannot be removed easily. Unfortunately, given that we do not know if immobilizing an athlete with a lacrosse helmet in place allows neutral cervical alignment or how quickly lacrosse helmet facemasks can be removed, coming to a consensus on the care of the catastrophically injured helmeted lacrosse athlete is difficult.[6]

The US Lacrosse Sports Science and Safety Committee released facemask/chin guard removal hints for specific helmet types.[7] The committee did not recommend a particular method but listed a cordless screwdriver (CSD), the Face Mask Extractor (FMX; Sports Medicine Concepts, Inc, Livonia, NY), the Trainer's Angel (TA; Trainer's Angel, Riverside, CA), an anvil pruner, modified pruning shears,

Table 1. Participant Demographics (Mean ± SD)

Participants	Lacrosse Experience, y	Football Experience, y	Grip Strength, kg	Age, y
Women	3.57 ± 3.21	5.57 ± 5.06	37.90 ± 3.32	32.14 ± 6.04
Men	4.14 ± 9.32	8.00 ± 6.86	55.52 ± 7.23	34.14 ± 8.90
Total	4.07 ± 6.62	7.79 ± 5.92	46.71 ± 10.84	33.14 ± 7.38

and any other tool the AT may prefer as appropriate choices. Given the importance of providing cardiopulmonary resuscitation as soon as possible[8] to limit hypoxic damage, FMR must be completed within 60 seconds.[9] These guidelines do not clarify the fastest way to remove the facemask of a lacrosse helmet or which removal methods are the easiest to use based on sex and grip strength.

Researchers have reported that the design of football helmets influences which removal method is most appropriate based on the time necessary for FMR and the perceived difficulty of the various removal methods.[10] Several investigators[10–12] also have examined the effect of grip strength and participant sex on the time necessary to remove a football facemask using different removal methods with varying results. Exploring the effects of sex and grip strength on speed and ease of using different FMR methods on lacrosse helmets is important to ensure prompt care for the catastrophically injured lacrosse athlete. With a wide variety of FMR methods from which to select, the decision about which method to use may be difficult for the AT providing athletic training services for men's lacrosse. No researchers have evaluated the speed or ease of lacrosse helmet FMR with various removal methods. Furthermore, no researchers have examined the effects of sex or grip strength on lacrosse helmet FMR with various removal methods. Therefore, the purpose of our study was to evaluate the effects of sex and grip strength on the speed and ease of use of various FMR methods across different lacrosse helmet types.

METHODS

We used a 4 × 5 × 2 cross-sectional study design to determine the effect of removal method (4 methods possible), helmet construction (5 helmets possible), and sex (female, male) on time required for FMR and the ease of performing lacrosse helmet FMR. We chose time for FMR and reported ease of use for each removal method as the dependent variables, whereas removal method, helmet type, and sex were the independent variables.

Participants

We contacted ATs within the Mid-Atlantic region by e-mail to request their participation. A convenience sample of 14 ATs (7 men, 7 women; collegiate work setting = 6, high school work setting = 8) volunteered by responding to the e-mail and scheduling a data collection time and date. Participant demographics are presented in Table 1. We determined the number of participants after completing a power analysis ($1 - \beta = 0.80$) using the means and standard deviations of FMR time of 2 previous studies.[13,14] Participants had a minimum of 2 years of experience as certified athletic trainers working with either football or men's lacrosse within the 5 years before the study and had no hand or wrist injury that would preclude them from fully participating. We set no other inclusion or exclusion criteria.

All participants provided written informed consent, and the study was approved by the Institutional Review Board at the host institution.

Instruments

We used a standard stopwatch (Sportline; EB Sport Group, Yonkers, NY) to time the FMR trials to the nearest hundredth of a second; a 6-point Likert scale with the anchors of 0 (*extremely hard*) and 5 (*extremely easy*) to measure the participants' perceived ease of using each tool, and a handheld dynamometer (Jamar Hand Dynamometer; Sammons Preston, Inc, Bolingbrook, IL) to measure grip strength. We used the CPX (Cascade, Liverpool, NY), Pro7 (Cascade), Riddell Revolution (Onyx Lacrosse, East Hanover, NJ), Triumph XP (Brine, Warren, MI), and Venom (Warrior, Warren, MI) because these helmets were popular models on the market at the time of data collection (Figure 1). We acquired 15 new helmets for each helmet type to use throughout this study. We used a CSD (model HP41LK; Ryobi Technologies, Inc, Anderson, SC), a pruner (model 61106966J; Fiskars Brands, Inc, Madison, WI), the Face Mask Extractor 2 (FMX; Sports Medicine Concepts, Inc, Livonia, NY), and the TA (Trainer's Angel, Riverside, CA) to remove the facemasks because these tools have been recommended for FMR of lacrosse helmets (Figure 2).[7] We used 2 CSDs, 2 pruners, 2 FMXs, and 2 TAs throughout data collection. We ensured both CSDs were charged fully and adjusted to the highest torque

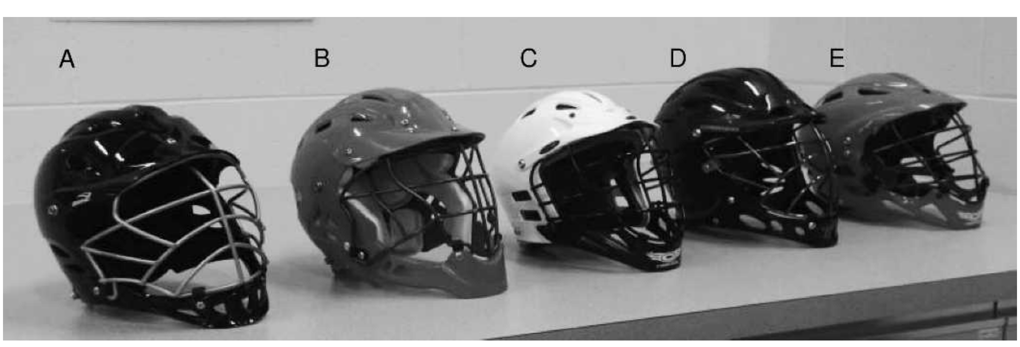

Figure 1. Helmet types used in data collection. A, Triumph XP (Brine, Warren, MI). B, Riddell Revolution (Onyx Lacrosse, East Hanover, NJ). C, CPX (Cascade, Liverpool, NY). D, Venom (Warrior Warren, MI). E, Pro7 (Cascade).

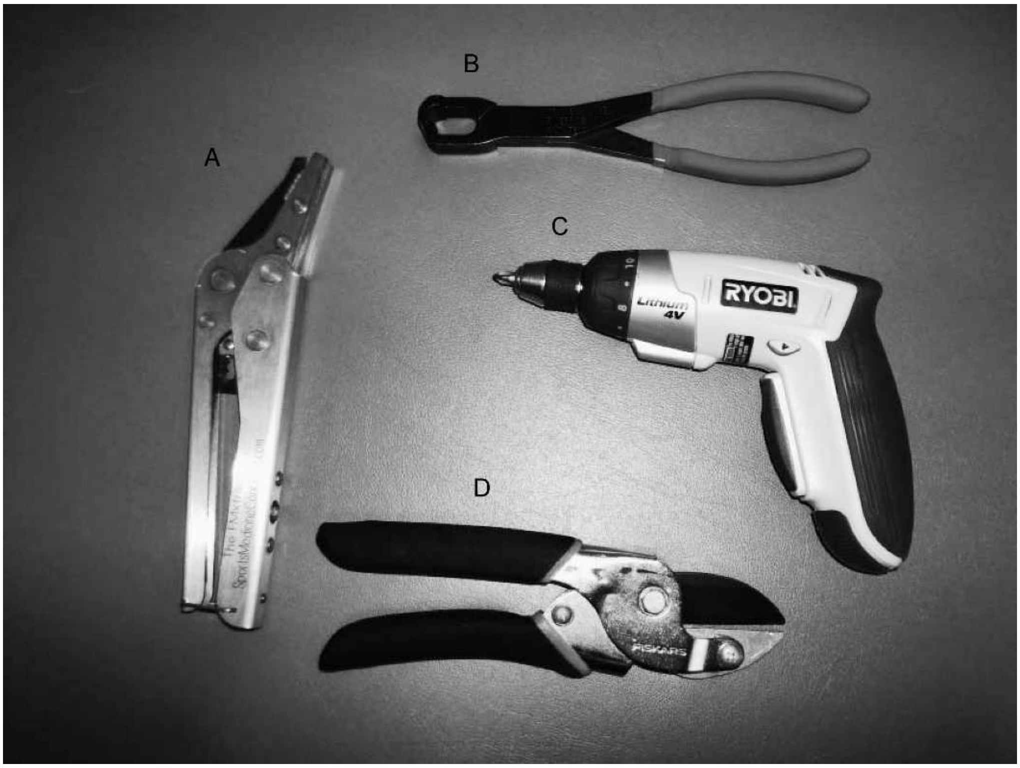

Figure 2. The removal tools used in data collection. A, Face Mask Extractor 2 (Sports Medicine Concepts, Inc, Livonia, NY). B, Trainer's Angel (Trainer's Angel, Riverside, CA). C, Cordless screwdriver (Ryobi model HP41LK; Ryobi Technologies, Inc, Anderson, SC). D, Pruner (model 61106966J; Fiskars Brands, Inc, Madison, WI).

setting at the beginning of each data collection session. Each FMX was sharpened according to the manufacturer's directions after 15 removal trials. We repaired helmets with new hardware and new loop straps that we acquired from the respective helmet manufacturer. After each trial, we used a torque ratchet screwdriver (A-50; Apco Mossberg Co, Attleboro, MA) to tighten the screws to 48-inch-pounds (5.42 N m) of torque.[15]

Procedures

Data collection involved 2 sessions for our participants. The first session included gathering demographic information, measuring the grip strength of the participants' dominant hands by averaging 3 maximal trials with their upper extremities at their sides while standing, and FMR for 2 helmet types with all possible removal methods. The *dominant hand* was defined as the hand with which the participant reported writing. The second session involved FMR for the remaining 3 helmet types with all possible removal methods. The sessions were separated by 7.42 $\pm$ 4.23 days.

We provided the participants with FMR guidelines,[7] a brief description of the helmets, an overview of the FMR process, and familiarization time before data collection began. The participants were allowed to compare the helmets, compare the tools, and examine the facemask attachments of all helmets. We repeated the process of providing the FMR guidelines[7] for the participants to review for each helmet and answering questions about the methods before each trial. They were not permitted to remove or make any cuts to the facemasks. The participants were allocated unlimited time before each session for this familiarization time. The session ended when the participants were comfortable with the procedure and they indicated they were certain how to proceed with data collection.

We randomly assigned participants to both a helmet type (5 helmet types possible) and an FMR method (4 methods possible). We counterbalanced the assignment of helmet type and removal method with a Latin square to decrease the possibility of a learning effect or differences due to fatigue. For the Pro7, the use of only a screwdriver was not possible because of the pop rivets attaching the chin guard to the helmet shell. Therefore, our participants only used 3 removal methods with the Pro7 (pruner, FMX, TA). In addition, the attachment of the facemask under the visor at the top of the helmet could be removed only by removing a screw for the Pro7, Revolution, Triumph, and Venom. When using one of the cutting methods on these helmets, the participants removed the top screw with the CSD before continuing with a cutting tool.

A researcher properly fitted all helmets and chinstraps to a model. The model then lay supine on the ground to simulate an injured athlete. We instructed the model not to speak and not to move. The participants knelt and positioned themselves with the helmet between their knees to stabilize the model's head and minimize motion of the helmet and cervical spine during the FMR trial. As other investigators have,[10,14,16,17] we selected this position to simulate the worst-case scenario of a single rescuer simultaneously stabilizing the head and removing the facemask.

We started timing the trial with the stopwatch when the participant picked up the removal tool and stopped when the facemask was removed completely from the helmet. We defined a trial as a *failure* if the participant could not

Table 2. Facemask Removal Failures Based on Removal Method[a] and Helmet Type[b]

Helmet Type	Removal Method					
	Face Mask Extractor 2	Trainers' Angel	Cordless Screwdriver	Pruner	Failure Total	Successful Trials
Triumph XP						
Insufficient time	2	1	0	2	5	48
Frustration	0	3	0	0	3	
Lack of equipment	0	0	0	0	0	
Riddell Revolution						
Insufficient time	0	0	0	0	0	52
Frustration	1	3	0	0	4	
Lack of equipment	0	0	0	0	0	
CPX						
Insufficient time	0	0	0	0	0	53
Frustration	1	2	0	0	3	
Lack of equipment	0	0	0	0	0	
Venom						
Insufficient time	0	0	0	0	0	44
Frustration	0	0	0	0	0	
Lack of equipment	3	3	3	3	12	
Pro7						
Insufficient time	0	0	NA	0	0	40
Frustration	0	2	NA	0	2	
Lack of equipment	0	0	NA	0	0	
Failure total	7	14	3	5	29	
Successful trials	63	56	53	65	NA	237

Abbreviation: NA, not applicable.

[a] Removal methods consisted of the Face Mask Extractor 2 (Sports Medicine Concepts, Inc, Livonia, NY), the Trainer's Angel (Trainer's Angel, Riverside, CA), the cordless screwdriver (model HP41LK; Ryobi Technologies, Inc, Anderson, SC), and a pruner (model 61106966J; Fiskars Brands, Inc, Madison, WI).

[b] Helmet types consisted of Triumph XP (Brine, Warren, MI), Riddell Revolution (Onyx Lacrosse, East Hanover, NJ), CPX (Cascade, Liverpool, NY), Venom (Warrior, Warren, MI), and Pro7 (Cascade).

completely remove the facemask in 8 minutes. We chose 8 minutes as the cutoff because researchers have reported that permanent hypoxic damage occurs in 4 to 5 minutes.[8,18] Based on our pilot work, we thought an 8-minute time limit would allow for accurate representation of the time necessary for each trial without excessively fatiguing the participants or resulting in a substantial number of failed trials. Immediately after each trial, participants rated the ease of using each tool on the 6-point Likert scale by orally responding to the question, "How would you describe the ease of use for this method on this helmet?" The researchers reassembled the helmets using new loop straps and new screws acquired from the respective manufacturer or used a new helmet for each trial. After a minimum 4-minute rest, participants continued to the next helmet type, and they repeated the data collection steps until they completed all combinations of helmet types and removal methods for the particular session. We used the same procedures for the second data collection session as for the first data collection session except we did not measure grip strength during the second session.

Statistical Analysis

We gathered demographic data for the participants and calculated an overall failure rate for the FMR attempts with 95% confidence intervals (CIs) using Excel 2007 (Microsoft Corporation, Redmond, WA). We completed the remaining statistical tests with IBM SPSS Statistics (version 19; IBM Corporation, Armonk, NY). We used a 3-way factorial multivariate analysis of variance to analyze the effects of helmet type, removal method, and sex on the dependent variables (FMR time, ease of use). We further explored findings that were different using analyses of variance (ANOVAs) and post hoc Tukey tests when more than 2 groups existed (ie, helmet type and removal method). We used an ANOVA to determine if grip strength differed between the sexes and used the Pearson product moment correlation to examine the relationship between FMR time and grip strength overall and for each removal method. We set the α level a priori at equal to or less than .05.

RESULTS

We gathered data on 254 trials (3 to 4 removal methods on 5 different helmets with 14 participants) in this study. Eighteen attempts to remove facemasks were considered failures, giving us a failure rate of 7.0% (95% CI = 3.8%, 10.4%). One failed attempt occurred because a foreign object was lodged into a screw head of a new helmet that had not been used in previous data collection. The other 17 failed attempts occurred because participants exceeded the 8-minute time limit or quit the attempt. A description of the failed trials is provided in Table 2. In addition, we could not obtain replacement loop straps and screws for the Venom helmet. The company released a new helmet after we purchased our supplies but before we started data collection and stopped producing loop straps for the Venom. Therefore, 3 participants did not complete trials

Table 3. Facemask Removal Times (s) and Reported Ease of Use (6-Point Likert Scale) Based on Removal Method[a] and Helmet Type[b]

Helmet Type	Removal Method				
	Face Mask Extractor 2	Trainer's Angel	Cordless Screwdriver	Pruner	Total
Triumph XP					
Facemask removal time	79.95 ± 31.33	132.00 ± 113.05	25.15 ± 7.88	67.33 ± 48.24	72.89 ± 70.17
Ease of use	3.17 ± 0.94	2.82 ± 1.17	4.86 ± 0.53	4.25 ± 0.97	3.84 ± 1.21
Riddell Revolution					
Facemask removal time	121.45 ± 106.34	115.74 ± 120.98	37.11 ± 10.58	76.25 ± 65.74	85.37 ± 88.62
Ease of use	3.23 ± 1.09	3.09 ± 1.45	5.00 ± 0.00	4.43 ± 0.65	4.00 ± 1.20
CPX					
Facemask removal time	88.68 ± 61.46	130.47 ± 120.15	27.00 ± 4.18	54.24 ± 25.05	72.75 ± 74.67
Ease of use	2.69 ± 1.32	2.83 ± 1.27	4.93 ± 0.27	4.00 ± 1.04	3.66 ± 1.37
Venom					
Facemask removal time	189.64 ± 144.19	118.89 ± 126.99	42.10 ± 14.64	51.86 ± 20.25	100.62 ± 111.03
Ease of use	2.55 ± 1.44	3.55 ± 1.37	5.00 ± 0.00	4.55 ± 0.69	3.91 ± 1.39
Pro7					
Facemask removal time	158.68 ± 103.91	243.82 ± 163.83	NA	88.24 ± 83.48	159.57 ± 132.30[f,g]
Ease of use	3.29 ± 1.14	2.92 ± 1.31	NA	4.36 ± 0.63	3.55 ± 1.20
Total					
Facemask removal time	126.96 ± 101.87	149.55 ± 135.41	32.32 ± 11.70[c]	68.32 ± 55.46[e]	95.28 ± 99.84
Ease of use	3.00 ± 1.19	3.04 ± 1.30	4.94 ± 0.30[c,d]	4.31 ± 0.81[c]	3.72 ± 1.34

Abbreviation: NA, not applicable.

[a] Removal methods consisted of the Face Mask Extractor 2 (Sports Medicine Concepts, Inc, Livonia, NY), the Trainer's Angel (Trainer's Angel, Riverside, CA), the cordless screwdriver (model HP41LK; Ryobi Technologies, Inc, Anderson, SC), and a pruner (model 61106966J; Fiskars Brands, Inc, Madison, WI).

[b] Helmet types consisted of Triumph XP (Brine, Warren, MI), Riddell Revolution (Onyx Lacrosse, East Hanover, NJ), CPX (Cascade, Liverpool, NY), Venom (Warrior, Warren, MI), and Pro7 (Cascade).

[c] Different from Face Mask Extractor 2 and Trainer's Angel ($P < .001$).

[d] Different from pruner ($P = .004$).

[e] Different from Face Mask Extractor 2 and Trainer's Angel ($P \leq .001$).

[f] Different from CPX, Riddell Revolution, and Triumph XP ($P < .001$).

[g] Different from Venom ($P = .02$).

with the Venom, which accounted for 12 trials. We removed failed attempts from data analysis; however, failure rates should be considered in conjunction with the results for FMR time.

The results of FMR time, reported ease-of-use scores, and post hoc tests are reported in Table 3 for all participants, in Table 4 for women, and in Table 5 for men. We did not find interactions among helmet type, removal method, and sex (multivariate $F_{22,398} = 0.56$, $P = .95$, $\eta^2 = 0.06$, $1 - \beta = 0.46$). We did not find an interaction between helmet type and removal method (multivariate $F_{22,398} = 1.10$, $P = .34$, $\eta^2 = 0.11$, $1 - \beta = 0.84$) or between helmet type and sex (multivariate $F_{8,398} = 1.13$, $P = .34$, $\eta^2 = 0.04$, $1 - \beta = 0.53$). We found an interaction between removal method and sex for the combined dependent variables (multivariate $F_{6,398} = 2.72$, $P = .01$, $\eta^2 = 0.08$, $1 - \beta = 0.87$). Follow-up ANOVAs revealed differences for the ease-of-use scores ($F_{3,246} = 4.67$, $P = .01$, $\omega^2 = 0.02$, $1 - \beta = 0.89$), with women registering lower preference scores (3.78 ± 1.36) than men (3.82 ± 1.20), but did not reveal differences for FMR time ($F_{3,230} = 2.54$, $P = .06$, $\omega^2 = 0.01$, $1 - \beta = 0.62$).

Facemask Removal Method

We found a main effect for method of removal (multivariate $F_{6,398} = 24.00$, $P < .001$, $\eta^2 = 0.46$, $1 - \beta = 1.00$). Follow-up ANOVAs revealed differences for time ($F_{3,200} = 19.41$, $P < .001$, $\omega^2 = 0.20$, $1 - \beta = 1.00$) and ease-of-use scores ($F_{3,200} = 53.78$, $P < .001$, $\omega^2 = 0.40$, $1 - \beta = 1.00$). Post hoc Tukey tests for FMR time between the removal methods revealed differences between CSD (32.32 ± 11.70 seconds) and FMX (126.96 ± 101.87 seconds; $P < .001$), CSD and TA (149.55 ± 135.41 seconds; $P < .001$), pruner (68.32 ± 55.46 seconds) and FMX ($P = .001$), and pruner and TA ($P < .001$). When we calculated post hoc Tukey tests for the ease-of-use scores between the removal methods, we found differences between CSD (4.94 ± 0.30) and FMX (3.00 ± 1.19; $P < .001$), CSD and pruner (4.31 ± 0.81; $P = .004$), CSD and TA (3.04 ± 1.30; $P < .001$), pruner and FMX ($P < .001$), and pruner and TA ($P < .001$).

Helmet Type

We noted a main effect for helmet type (multivariate $F_{8,398} = 4.47$, $P < .001$, $\eta^2 = 0.16$, $1 - \beta = 0.99$). The follow-up ANOVAs disclosed differences for FMR time ($F_{4,200} = 5.34$, $P < .001$, $\omega^2 = 0.08$, $1 - \beta = 0.97$) but not for ease-of-use scores ($F_{4,200} = 0.87$, $P = .48$, $\omega^2 = 0.008$, $1 - \beta = 0.28$). We discovered differences between CPX (72.75 ± 74.67 seconds) and Pro7 (159.57 ± 132.30 seconds; $P < .001$), Revolution (85.37 ± 88.62 seconds) and Pro7 ($P = .001$), Venom (100.62 ± 111.03 seconds) and Pro7 ($P = .02$), and Triumph (72.89 ± 70.17 seconds) and Pro7 ($P < .001$) when we calculated post hoc Tukey tests for the effects of helmet type on FMR time.

Table 4. Facemask Removal Times (s) and Reported Ease of Use (6-Point Likert Scale) Based on Removal Method[a] and Helmet Type[b] for Female Participants

Helmet Type	Removal Method				
	Face Mask Extractor 2	Trainer's Angel	Cordless Screwdriver	Pruner	Total
Triumph XP					
Facemask removal time	75.30 ± 26.31	174.86 ± 158.69	26.69 ± 5.97	73.27 ± 65.58	81.35 ± 91.17
Ease of use	3.33 ± 1.21	2.40 ± 1.34	5.00 ± 0.00	4.33 ± 0.82	3.87 ± 1.33
Riddell Revolution					
Facemask removal time	154.75 ± 136.58	133.12 ± 136.26	34.77 ± 10.76	70.89 ± 20.54	91.69 ± 95.24
Ease of use	3.17 ± 1.33	2.75 ± 1.50	5.00 ± 0.00	4.43 ± 0.53	4.00 ± 1.25
CPX					
Facemask removal time	100.32 ± 86.01	152.33 ± 99.93	27.63 ± 4.66	64.77 ± 28.28	83.17 ± 76.49
Ease of use	3.00 ± 1.55	2.33 ± 1.21	5.00 ± 0.00	4.57 ± 0.53	3.81 ± 1.44
Venom					
Facemask removal time	264.97 ± 132.62	177.52 ± 151.60	43.40 ± 13.83	60.53 ± 20.65	136.60 ± 132.15
Ease of use	2.00 ± 1.10	3.00 ± 1.55	5.00 ± 0.00	4.83 ± 0.41	3.71 ± 1.57
Pro7					
Facemask removal time	218.26 ± 100.98	303.02 ± 61.80	Not applicable	125.40 ± 108.09	206.35 ± 115.51
Ease of use	3.28 ± 1.25	2.40 ± 0.55	Not applicable	4.29 ± 0.76	3.42 ± 1.17
Total					
Facemask removal time	164.51 ± 120.64	188.50 ± 130.21	32.74 ± 11.00[c]	79.70 ± 61.30[c]	115.51 ± 110.80
Ease of use	32.97 ± 1.30	2.58 ± 1.21	5.00 ± 0.00	4.48 ± 0.62	3.78 ± 1.36

[a] Removal methods consisted of the Face Mask Extractor 2 (Sports Medicine Concepts, Inc, Livonia, NY), the Trainer's Angel (Trainer's Angel, Riverside, CA), the cordless screwdriver (model HP41LK; Ryobi Technologies, Inc, Anderson, SC), and a pruner (model 61106966J; Fiskars Brands, Inc, Madison, WI).
[b] Helmet types consisted of Triumph XP (Brine, Warren, MI), Riddell Revolution (Onyx Lacrosse, East Hanover, NJ), CPX (Cascade, Liverpool, NY), Venom (Warrior, Warren, MI), and Pro7 (Cascade).
[c] Different from Face Mask Extractor 2 and Trainer's Angel ($P \leq .001$).

Table 5. Facemask Removal Times (s) and Reported Ease of Use (6-Point Likert Scale) Based on Removal Method[a] and Helmet Type[b] for Male Participants

Helmet Type	Removal Method				
	Face Mask Extractor 2	Trainer's Angel	Cordless Screwdriver	Pruner	Total
Triumph XP					
Facemask removal time	84.60 ± 37.62	96.28 ± 45.24	23.61 ± 9.66	61.38 ± 27.10	64.76 ± 41.72
Ease of use	3.00 ± 0.63	3.17 ± 0.98	4.71 ± 0.76	4.17 ± 1.17	3.80 ± 1.12
Riddell Revolution					
Facemask removal time	92.90 ± 70.78	105.80 ± 121.63	39.46 ± 10.67	81.61 ± 94.21	79.94 ± 83.91
Ease of use	3.29 ± 0.95	3.29 ± 1.50	5.00 ± 0.00	4.43 ± 0.79	4.00 ± 1.19
CPX					
Facemask removal time	78.70 ± 33.76	108.60 ± 143.62	26.37 ± 3.91	43.71 ± 17.36	62.71 ± 72.87
Ease of use	2.43 ± 1.14	3.33 ± 1.21	4.86 ± 0.38	3.43 ± 1.14	3.52 ± 1.31
Venom					
Facemask removal time	99.24 ± 106.14	48.54 ± 15.60	40.54 ± 17.06	41.46 ± 15.64	57.44 ± 56.20
Ease of use	3.20 ± 1.64	4.20 ± 0.84	5.00 ± 0.00	4.20 ± 0.83	4.15 ± 1.14
Pro7					
Facemask removal time	158.68 ± 103.91	243.82 ± 163.83	Not applicable	88.24 ± 83.48	159.57 ± 132.30
Ease of use	3.29 ± 1.11	3.29 ± 1.60	Not applicable	4.43 ± 0.53	3.67 ± 1.24
Total					
Facemask removal time	90.58 ± 62.39	116.88 ± 132.96	31.88 ± 12.60[c,d]	56.58 ± 46.80[e]	75.71 ± 83.87
Ease of use	3.03 ± 1.09	3.42 ± 1.26	4.88 ± 0.43	4.12 ± 0.94	3.82 ± 1.20

[a] Removal methods consisted of the Face Mask Extractor 2 (Sports Medicine Concepts, Inc, Livonia, NY), the Trainer's Angel (Trainer's Angel, Riverside, CA), the cordless screwdriver (model HP41LK; Ryobi Technologies, Inc, Anderson, SC), and a pruner (model 61106966J; Fiskars Brands, Inc, Madison, WI).
[b] Helmet types consisted of Triumph XP (Brine, Warren, MI), Riddell Revolution (Onyx Lacrosse, East Hanover, NJ), CPX (Cascade, Liverpool, NY), Venom (Warrior, Warren, MI), and Pro7 (Cascade).
[c] Different from Trainer's Angel ($P < .001$).
[d] Different from Face Mask Extractor 2 ($P < .05$).
[e] Different from Trainer's Angel ($P < .05$).

Sex Differences

We observed a main effect for sex (multivariate $F_{2,199} = 9.32$, $P < .001$, $\eta^2 = 0.09$, $1 - \beta = 0.98$). Follow-up ANOVAs showed differences for time ($F_{1,200} = 17.57$, $P < .001$, $\omega^2 = 0.04$, $1 - \beta = 0.99$), with slower FMR times for women (115.51 ± 110.80 seconds) than men (75.71 ± 83.87 seconds). When we compared FMR time for the removal methods between sexes, we only found differences when using the FMX ($F_{1,61} = 9.42$, $P = .003$, $\omega^2 = 0.12$, $1 - \beta = 0.86$) and the TA ($F_{1,55} = 4.18$, $P = .05$, $\omega^2 = 0.05$, $1 - \beta = 0.52$), with slower FMR times for women (164.51 ± 120.64 and 188.50 ± 130.21 seconds, respectively) than men (90.58 ± 62.39 and 116.88 ± 132.96 seconds, respectively). No differences were found when comparing FMR times for women and men with the CSD ($F_{1,51} = 0.07$, $P = .80$, $\omega^2 = 0.02$, $1 - \beta = 0.06$) or the pruner ($F_{1,63} = 2.91$, $P = .09$, $\omega^2 = 0.03$, $1 - \beta = 0.39$). Within each sex, we found differences in FMR times between removal methods for women ($F_{3,113} = 16.85$, $P < .001$, $\omega^2 = 0.29$, $1 - \beta = 1.00$) and men ($F_{3,117} = 6.54$, $P < .001$, $\omega^2 = 0.12$, $1 - \beta = 0.97$). Post hoc Tukey tests revealed faster FMR times for women when using the CSD than when using the FMX ($P < .001$) or the TA ($P < .001$) and when using the pruner than when using the FMX ($P = .001$) or TA ($P < .001$). For men, post hoc Tukey tests revealed faster FMR times when using the CSD than when using the FMX ($P = .03$) or TA ($P < .001$) and when using the pruner than when using the TA ($P = .02$). We did not find a difference between sexes for the ease-of-use scores ($F_{1,200} = 1.06$, $P = .31$, $\omega^2 = 0.001$, $1 - \beta = 0.18$) when we calculated a follow-up ANOVA.

Grip Strength Correlations

When we analyzed grip strength, we saw a difference between the sexes ($F_{1,265} = 652.55$, $P < .001$, $\omega^2 = 0.71$, $1 - \beta = 1.00$), with women (37.90 ± 3.32 kg) having lower strength scores than men (55.52 ± 7.23 kg). We noted a correlation between FMR time and grip strength ($r = -0.218$, $P = .001$). On further exploration, we found correlations between FMR time and grip strength when using the FMX ($r = -0.40$, $P = .001$), pruner ($r = -0.26$, $P = .04$), and TA ($r = -0.26$, $P = .047$) but not when using the CSD ($r = -0.07$, $P = .61$).

DISCUSSION

Our results are similar to the results reported by investigators[10–12,19,20] researching football helmets. We discovered differences for FMR time depending on the removal methods and lacrosse helmet style used. We also saw differences for the participant self-reported ease-of-use scores depending on removal method. Finally, we found that sex altered FMR time for lacrosse helmets across different removal methods and found a strong correlation between grip strength and FMR time for cutting methods but not removal methods.

Facemask Removal Method

The CSD has been found to be the fastest[10,19,20] and easiest[10] method for football helmet FMR. Contrary to these findings, some researchers have reported no differences in removal time[13,15] between manual or cordless screwdrivers and other methods. Although the FMR times for the CSD and the pruner were not different in our study, our participants reported that the CSD was easier to use. Although removal time between the CSD and the pruner was not different, it may be clinically important. Facemask removal using the CSD took approximately 32 seconds to complete, whereas FMR using the pruners took approximately 68 seconds. The CSD FMR times were less than the 60 seconds suggested for FMR of the helmeted athlete.[9] The FMR times when participants used the pruner exceeded the 60-second recommendation, indicating that the CSD would be a more appropriate tool based solely on time.

We believe the CSD registered the fastest times and was rated the easiest to use because this method simplified the FMR process. For 60% of the helmets (CPX, Revolution, and Triumph), the use of the CSD decreased the number of steps from a minimum of 5 to a minimum of 3 by allowing removal of the chin guard with the facemask. Using a cutting method does not allow for removal of the chin guard, requiring 2 additional loop straps attaching the facemask to the chin guard to be cut.

Several reasons exist for potential CSD failure when attempting FMR. The use of a CSD requires regular charging to ensure proper function. In addition, foreign substances lodged in the screw head, stripped screw heads,[16] and T-nut spinning have been reported in several studies,[15,19] especially on used helmets,[16,21,22] as reasons for failure of screw removal. In our study, 1 removal trial failed because a foreign object was lodged in 1 screw head. Given that the helmets were new and had never been worn, we recommend thoroughly inspecting all new helmets for defects when they are received. We also believe comprehensively examining helmets throughout the season for faulty hardware is important to improve the chances of successfully removing facemasks with a CSD. Failure rates for FMR using a CSD have been reported to be as high as 17.6%[21] and 16%[22] on used football helmets. Therefore, helmets used in competition may pose problems for ATs using only CSDs to remove the facemasks. We do not know if a similar failure rate would be found for used lacrosse helmets. We believe studying FMR of used lacrosse helmets is important especially because a CSD is required to remove the top visor screw on most types of helmets used in our study (Pro7, Revolution, Triumph, and Venom). If the screwdriver has been rendered useless in controlled studies with new[13] and used[21,22] helmets, it is realistic to think that also will happen in clinical practice. With this in mind, we agree with previous statements that ATs always should be prepared with a cutting tool in addition to a screwdriver.[13,21,22] Gale et al[16] concluded that using a combination of a CSD and cutting tool (98.6% successful) was more reliable than using only a screwdriver (92.1% successful) for used football helmets.

The pruner was the least expensive tool that we purchased. The cost paired with the shorter time for FMR and high ease-of-use scores compared with the other cutting tools make the pruner an ideal backup tool to the CSD for many ATs. The blade is thin enough to fit into most spaces available for cutting loop straps on lacrosse helmets without compromising durability. The pruner blade is also shorter than the blade on the FMX. This is important when examining the chance of the blade making contact with an athlete's face. On 2 occasions, a participant accidently made contact with the model's face while attempting to remove the facemask with the FMX. In both situations, the participant refused to continue with the trial.

Helmet Type

Researchers have found that helmet construction alters football helmet FMR time and perceived difficulty.[10] In our study, FMR took the most time for the Pro7. This could be attributed to the design of the helmet and the number of steps necessary for proper FMR. The chin guards of the Pro7 helmets in our study were pop riveted to the helmet shell. This construction did not allow for removal of the facemask and chin guard as 1 unit by removing 3 screws with a CSD, which was possible with several other helmets. All of the removal methods for the Pro7 required altering 5 connection points between the facemask and the remainder of the helmet, similar to the cutting methods for the other 4 types of helmets. We believe the facemask of the Pro7 helmet could be removed faster if a CSD could be used to detach the facemask and chin guard from the helmet's shell. Such a design would decrease the need for cutting the 2 loop straps securing the facemask to the chin guard. However, when we examined the Pro7 helmets that our team wears, we noted that the chin guards were attached with screws instead of pop rivets. This construction allows FMR with only a CSD by removing 5 screws. We are unsure why this difference occurred but speculate this construction would produce faster FMR times by allowing only a CSD to be used. When practicing FMR techniques, ATs need to examine whether the chin guard is attached with a screw or pop rivet on the Pro7 to ensure they can promptly remove it when clinically necessary.

Another helmet design factor we believe led to slower FMR times for the Pro7 is the side loop straps and facemask construction. These side loop straps wrap around the facemask and hug the inside and outside of the helmet's shell. When the screw holding the side loop strap is removed, the AT must remove the T-nut that held the screw in place to allow removal of the side loop strap easily without substantial head and neck movement. The side loop straps of the other helmets hugged the facemask but not the helmet shell, improving cutting access and ease of removal. Another recommendation is for the manufacturer to remove the metal ball on each side of the facemask of the Pro7. This ball is designed to keep the side loop straps in place; however, it makes the use of a cutting tool more difficult.

Sex Differences

Our results for sex are similar to the results of researchers[11,12] studying football helmets. These other authors found different FMR times between the sexes for the TA but not for a pruner. We also noted differences between the sexes for the FMX and no differences between sexes for the CSD. The other investigators did not use the FMX or the CSD during data collection.

We observed sex differences between the FMX and TA but not for the CSD or pruner. Several possibilities exist for these differences. We believe the CSD produced similar results for both sexes because most ATs regardless of sex are familiar with using this method. The CSD we used is similar to a drill, making it easy to operate, and investigators have found a CSD is the most preferred method for football helmet FMR.[10] The pruner is also a tool with which many ATs may be familiar because it commonly is used for gardening. However, although it is similar in design to the pruner, the FMX produced differences in FMR times between the sexes. The blade on the FMX is much thinner than the blade of the pruner. We believe the difference in blade thickness between the 2 tools may have contributed to the difference in difficulty of cutting the loop straps, especially for women. For it to cut properly, the thin blade of the FMX must not be twisted, potentially making it more difficult to use. The manufacturer's recommendations for the FMX state that the blade should be sharpened after each practice session or after the removal of 15 facemasks. We did not sharpen the pruner throughout data collection, and the participants did not voice concerns when using it to cut loop straps. The TA works differently from the pruner and FMX and is not similar to common household tools, potentially leading to slower times for both sexes.

Grip Strength Correlations

Researchers have reported correlations between grip strength and FMR time when using the TA or a pruner ($r = -0.38$)[11] and when using only a pruner ($r = -0.16$)[12] that are similar to our findings. However, we found a smaller correlation between FMR time and grip strength for the TA ($r = -0.26$) than was found in previous work ($r = -0.66$).[12] The construction of lacrosse helmets appears to reduce the dependency on grip strength for the TA. We speculate this finding is due to the smaller size of the plastic loop straps in lacrosse helmets compared with football helmets.

The sex differences we found are interesting when considering the differences in grip strength between our female and male participants. We found correlations between grip strength and FMR time for the pruner, FMX, and TA. We were not surprised that grip strength was not a factor in the use of the CSD because pulling the trigger to activate the tool takes little effort. We believe the negative correlation between FMR time and grip strength accounted for the variation in time required for FMR between the sexes for the FMX and TA. However, we were surprised that no differences in FMR time existed between the sexes for the pruner although we found a correlation between the pruner and grip strength. In the future, researchers should continue to investigate this finding.

RECOMMENDATIONS AND CLINICAL RELEVANCE

Based on our results, we recommend attempting FMR using a CSD first and having a backup cutting tool in case screw removal fails[13,21,22] regardless of sex or grip strength. Our results support using a pruner as the backup cutting tool. Although the FMR times when using the pruner for both women and men were not different from the times when using the CSD, these times may be clinically important. On average, the pruner took approximately 46.96 seconds longer for women and 24.70 seconds longer for men than FMR with the CSD. We believe the increase in time to cut loop straps could be crucial during a catastrophic injury, further strengthening our recommendation for attempting FMR with the CSD before considering a cutting method.

Ideally, the facemask should be removed in 60 seconds.[9] This requirement and the severity of such circumstances necessitate regular, thorough practice of FMR because repetition has been shown to improve FMR times.[23] We recommend including athletic training students in these practice sessions because they may be required to assist when a catastrophic injury has occurred. In addition, many athletic training students probably learn FMR techniques on football helmets and may not be familiar with lacrosse helmets. Athletic training educators should consider including lacrosse helmets when teaching FMR techniques to athletic training students because lacrosse helmet designs are distinct from football helmet designs. Exposing students to FMR of lacrosse helmets may better prepare them for a career in athletic training after graduation because of the increase in popularity of lacrosse. A CSD and at least one cutting method should be included in all practice and teaching sessions because of the possibility of CSD failure, which has been shown in both new[13] and used[21,22] football helmets for various reasons. We also recommend that ATs carry many types of tools because of the variety of helmets on the market. The opposing team may have a different helmet, and the AT should be prepared to address a catastrophic injury for an athlete on either team.

Recent work may challenge traditional care for a lacrosse athlete with a cervical spine injury. Researchers have found that spine boarding an athlete who is not wearing a helmet alters the alignment of the cervical spine[5] but not the space available for the spinal cord in healthy participants[24] because space did not differ by more than the 1-mm cutoff[25] at any cervical level. Nevertheless, how injury may affect spinal cord space remains unclear. Waninger[4] found that head movement inside a lacrosse helmet is similar to but slightly greater than head movement inside a football helmet. Although these results were not different, the increase in movement may be clinically important. This finding remains controversial because researchers[26] more recently have found that cervical spine motion was limited the most when lacrosse athletes wore no helmet rather than when they wore properly fitted or improperly fitted helmets. The authors concluded that the head can move inside the lacrosse helmet, making cervical spine immobilization of the helmeted lacrosse athlete difficult. Proper fit of the lacrosse helmet is essential for injury prevention[27] and has been identified as a potential area of concern in the sport of men's lacrosse.[28] We are unsure why improperly fitted helmets are tolerated in the sport of men's lacrosse. The prevalence of helmets fitting poorly is unknown, but based on our experience, it appears to be widespread. Given that lacrosse helmets may not fit athletes properly, these recent researchers have supported removing the entire helmet and shoulder pads to immobilize a lacrosse athlete, especially if timely FMR does not occur. However, we agree with Sherbondy et al,[5] who recommended leaving the shoulder pads and helmet in place until they can be removed in a controlled environment. Facemask removal of lacrosse helmets should continue to be an area of research until a consensus can be reached for appropriate care of the helmeted lacrosse athlete with a catastrophic injury.[27]

LIMITATIONS

Our study had some limitations. We used a convenience sample to recruit participants. The abilities of our participants may not represent the abilities of ATs overall, limiting generalizability of our results. Although we gave them time to become familiar with each type of helmet and each removal method along with FMR instructions, many participants performed steps that were unnecessary and repetitive. We believe this may have led to the high variances in the results for FMR time. Perhaps extending the familiarity time or allowing participants 1 full practice trial with feedback would change the results. We believe this gives further credibility to our recommendation of regularly practicing FMR of lacrosse helmets with multiple tools because our participants did not start until they were certain they understood how to complete the trial after being given written and oral directions. We did not attempt to measure cervical motion associated with the different FMR techniques in any way. A decrease in motion when using one method compared with another may outweigh a slight increase in the time required to remove the facemask. Another limitation is the frequency of new types of helmets produced by manufacturers. New helmet types are released approximately every 2 years, decreasing the generalizability of the results. In the future, researchers should evaluate FMR of new helmet types. Our results also can be generalized only to the 4 removal methods we included. Perhaps a different method, such as polyvinylchloride pipe cutters or a device that can cut through the chin guard, would produce faster and easier lacrosse helmet FMR. We also collected data with helmets that had never been used in lacrosse activity. Used helmets may produce different results, especially with the CSD, because screw removal failure has been reported in used football helmets.[16,21,22]

CONCLUSIONS

The use of a CSD was fastest with helmets that do not require a cutting step (32.32 $\pm$ 11.70 seconds) but this time was not statistically different from the removal time recorded with the pruner (68.32 $\pm$ 55.46 seconds). Participants reported the CSD was easier to use for FMR than the FMX, a pruner, and the TA. The facemask of the Pro7 was the most time consuming and difficult to remove for our participants. We found FMR of lacrosse helmets differed between sexes and within sex based on the method used. We also found a strong association between grip strength and FMR times for the 3 techniques using cutting methods but not for the screw removal method. Based on these results, we recommend attempting FMR on lacrosse helmets first with a CSD and second with a pruner to compromise the loop straps if screw removal fails. Athletic trainers should practice regularly, be prepared to perform FMR on various types of helmets, and perform FMR using the tool with which they are most comfortable. Finally, we recommend teaching athletic training students FMR techniques for lacrosse helmets during entry-level education programs.

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