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original research

Emergency Face-Mask Removal Effectiveness: A Comparison of Traditional and Nontraditional Football Helmet Face-Mask Attachment Systems

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Context: Football helmet face-mask attachment design changes might affect the effectiveness of face-mask removal.

Objective: To compare the efficiency of face-mask removal between newly designed and traditional football helmets.

Design: Controlled laboratory study.

Setting: Applied biomechanics laboratory.

Participants: Twenty-five certified athletic trainers.

Intervention(s): The independent variable was face-mask attachment system on 5 levels: (1) Revolution IQ with Quick Release (QR), (2) Revolution IQ with Quick Release hardware altered (QRAlt), (3) traditional (Trad), (4) traditional with hardware altered (TradAlt), and (5) ION 4D (ION). Participants removed face masks using a cordless screwdriver with a backup cutting tool or only the cutting tool for the ION. Investigators altered face-mask hardware to unexpectedly challenge participants during removal for traditional and Revolution IQ helmets. Participants completed each condition twice in random order and were blinded to hardware alteration.

Main Outcome Measure(s): Removal success, removal time, helmet motion, and rating of perceived exertion (RPE). Time and 3-dimensional helmet motion were recorded. If the face mask remained attached at 3 minutes, the trial was categorized as unsuccessful. Participants rated each trial for level of difficulty (RPE). We used repeated-measures analyses of variance (α = .05) with follow-up comparisons to test for differences.

Results: Removal success was 100% (48 of 48) for QR, Trad, and ION; 97.9% (47 of 48) for TradAlt; and 72.9% (35 of 48) for QRAlt. Differences in time for face-mask removal were detected ($F_{4,20}$ = 48.87, P = .001), with times ranging from 33.96 ± 14.14 seconds for QR to 99.22 ± 20.53 seconds for QRAlt. Differences were found in range of motion during face-mask removal ($F_{4,20}$ = 16.25, P = .001), with range of motion from 10.10° ± 3.07° for QR to 16.91° ± 5.36° for TradAlt. Differences also were detected in RPE during face-mask removal ($F_{4,20}$ = 43.20, P = .001), with participants reporting average perceived difficulty ranging from 1.44 ± 1.19 for QR to 3.68 ± 1.70 for TradAlt.

Conclusions: The QR and Trad trials resulted in superior results. When trials required cutting loop straps, results deteriorated.

Key Words: spine injuries, protective equipment, emergency management

Key Points

- Quick Release face-mask attachments optimized the efficiency of face-mask removal.
- Cutting loop straps induced more motion, took more time, and increased difficulty of face-mask removal.

Because of concerns surrounding the maintenance of spinal alignment in football players with suspected spine injuries, researchers[1,2] have recommended that the face mask, rather than the helmet, be removed to allow airway access. Techniques of face-mask removal, including cutting the loop straps with various tools and removing the loop straps with a cordless screwdriver, have been investigated.[3–8] A cordless screwdriver has been reported to perform more efficiently than cutting tools on multiple styles of face-mask attachment loop straps.[9,10] However, concerns about the inability to remove damaged or defective face-mask attachment hardware[11–13] with the cordless screwdriver have resulted in a recommendation to use a combined-tool approach for face-mask removal. The combined-tool technique incorporates using a cordless screwdriver with an appropriately matched backup cutting tool and is an efficient, reliable technique for managing football helmet and face-mask attachment systems.[13,14]

In addition to differences associated with tools used, the design of the helmet, face mask, and associated face-mask attachment hardware (ie, screws, loop straps, T-nuts) has affected the efficiency of face-mask removal, based on assessment of head movement, removal time, ease of use, and removal success rates.[8,11–13] In 2008, 2 helmet manufacturers made design changes in face-mask attachment systems. The Revolution IQ (Riddell Inc, Elyria, OH) helmet incorporates the Quick Release system at the side loop-strap locations. Inserting an appropriately sized tool to depress the button on the Quick Release mechanism pin releases it from the connector on the inside of the helmet's shell. The ION 4D (Schutt Sports Inc, Litchfield, IL) face-mask design has only 1 secured attachment of the face mask to the helmet (at the top), with face-mask projections that insert into channels incorporated into the shell of the helmet. This reduces the attachment points a rescuer must manipulate to

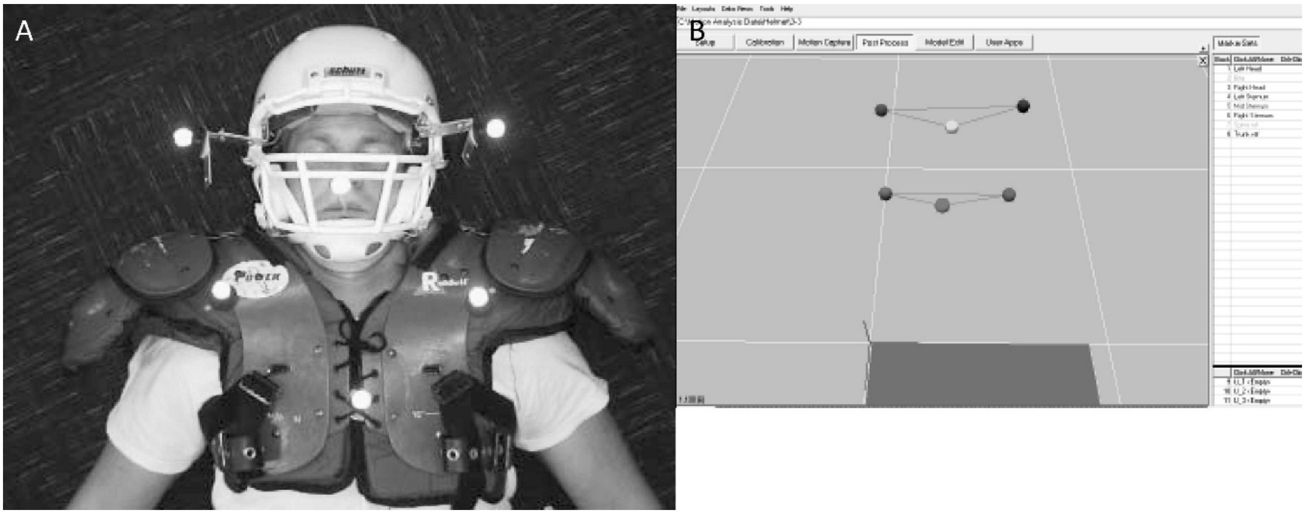

Figure 1. A, Representation of marker set, and B, marker set depicted in motion software.

remove the face mask from 4 in a traditional helmet to only 2.

The purpose of our study was to compare the efficiency of face-mask removal (success rates, time, head motion, difficulty) between these newly designed football helmets and a traditional helmet and face-mask attachment system. Based on previous research,[13,14] the combined-tool approach was the face-mask removal method used when allowed by the helmet design. We expected that these 2 face-mask attachment design changes would be better than traditional face-mask attachments for face-mask removal efficiency.

METHODS

Participants

A convenience sample of 25 participants (13 men, 12 women; age = 31.79 ± 10.14 years) was recruited from the local population of certified athletic trainers (ATs; years certified = 9.24 ± 7.18). To confirm eligibility, participants completed a health history questionnaire to ensure that they were free from substantial upper extremity or central nervous system injury. Before participation, the ATs signed an informed consent form, and the study was approved by the University of New Hampshire's Institutional Review Board.

Instrumentation

A 6-camera, high-speed, 3-dimensional (3-D) motion-capture and analysis system (Motion Analysis Corporation, Santa Rosa, CA) recorded motion (120 Hz) of the helmet during face-mask removal trials. We used EVaRT software (version 5.0; Motion Analysis Corporation) to track and edit 3-D trials and Kintrak software (version 6.02; Motion Analysis Corporation) to analyze head motion. A live model wearing appropriately fitted football equipment was outfitted with a 6-point, 2-segment marker set to record and analyze head motion during the face-mask removal trials with the 3-D camera system (Figure 1). Three markers (2.54-cm diameter) were used to create a helmet segment; 3 different markers were used to create a segment representing the model's torso. Two of the helmet markers were secured to 2 custom-made steel frame extensions that were attached adjacent to the top loop-strap attachment locations of each individual helmet. The third helmet segment marker was secured to a custom-made bite marker. The bite marker was constructed using a custom-fit mouth guard with a 10-cm wand that extended through the face mask of the helmet. The model's torso segment was created with 2 markers adhered to the shoulder pads over the anterior left and right acromioclavicular joints and one 10-cm wand marker adhered to the shoulder pads over the midsternum. The model was instructed to lie still during each trial.

A digital stopwatch was used to time each face-mask removal trial. The participants used a modified Borg CR-10 scale to rate the difficulty (rating of perceived exertion [RPE]) of each trial. This reliable and valid scale is a category ratio scale using values from 0 (*nothing at all*) to 10 (*impossible*).[8,15] A standard digital camcorder was used to record all trials. Six 3.6-V lithium-ion cordless screwdrivers (model LI3000; Stanley Black & Decker, New Britain, CT), 25 FMxtractors (FMX) (Sports Medicine Concepts Inc, Livonia, NY) face-mask removal tools, and 1 pair of emergency medical technician (EMT) shears (MedSource International, LLC, Mound, MN) were used during data collection (Figures 2 and 3).

The following helmets and helmet accessories were acquired for the study: 8 new Revolution IQ helmets; 25 complete Quick Release face-mask attachment system components; 130 Revolution IQ face-mask loop straps; 130 Revolution top loop straps; 6 new ION 4D helmets; 50 ION 4D face-mask retainer clips; 30 chin straps (Schutt Sports Inc); 8 new VSR-4 (Riddell Inc) helmets; and 200 thin-wire loop-strap, screw, and T-nut face-mask attachment components (Riddell Inc; Figure 4). We also obtained 1200 new stainless steel combination-head screws; 75 stainless steel T-nuts; and 200 Armorguard Elite (Schutt Sports Inc) loop straps (for use during familiarization sessions).

Procedures

Face-Mask Removal Conditions. The independent variable in this project was helmet–face-mask attachment system on 5 levels: (1) Revolution IQ with Quick Release (QR), (2)

Figure 2. Cordless screwdriver (Stanley Black & Decker, New Britain, CT).

Revolution IQ with Quick Release hardware altered (QRAlt), (3) traditional (Trad), (4) traditional with hardware altered (TradAlt), and (5) ION 4D (ION). The VSR-4 helmet was used to represent a traditional-style helmet. In the Trad condition, 4 standard thin-wire loop straps (Riddell Inc) attached the face mask to the helmet using stainless steel screws and T-nuts. The other face-mask attachments systems used in this project are described.

The Revolution IQ helmet incorporates the Quick Release system, which eliminates the need to unscrew the loop-strap attachment (Figure 5). It uses standard Revolution top loop-strap hardware with the traditional screw and T-nut fixation.

The only secured attachment of the tested version of the ION face mask to the helmet is at the top (forehead area) of the helmet via a retainer clip that straddles the top face-mask bar and secures it against the helmet at 2 points with screws and T-nuts (Figure 6). The ION face mask also has 2 projections that insert into integrated channels on each side of the helmet shell. When properly applied, the top chin strap courses through a slot in the face mask, and the top strap must be cut to allow face-mask removal. When the top retainer clip and the top chin strap are cut, the face mask is pulled away from the helmet, and the side face-mask projections can slide out of the helmet channels.

Figure 3. The FMxtractor (Sports Medicine Concepts Inc, Livonia, NY).

Figure 4. Quick Release (Riddell Inc, Elyria, OH) face-mask attachment components. Reprinted with permission from Swartz EE, Boden BP, Courson RW, et al. National Athletic Trainers' Association position statement: acute management of the cervical spine–injured athlete. *J Athl Train*. 2009;44(3):306–331.

To introduce the possibility that damaged helmet hardware (eg, a rusted or shredded screw or a spinning or fused T-nut) might impede the rescuer's ability to unscrew face-mask loop straps,[8,11–14] the 2 remaining test conditions involved investigator-created hardware failures at the top or side loop-strap locations on the traditional and Revolution helmets to occasionally force participants to use the backup cutting tool to remove the face mask (the combined-tool approach). The tested version of the ION face-mask attachment retainer can be removed only with a cutting tool, so no altered hardware scenario was created for this condition. These failure conditions were created to reflect the possibility that screwdriver removal of face-mask attachment hardware in the field might or might not succeed because of damage caused by regular use, maintenance, and environmental factors. All participants encountered 1 altered hardware component at the top and 1 altered hardware component at the side loop-strap locations in each of the TradAlt and QRAlt conditions.

To create hardware failures in the traditional helmet (top and side positions), the head of a screw was intentionally shredded using a high-torque, 12-V cordless driver (DEWALT Industrial Tool Co, Baltimore, MD) and an oversized Phillips-head bit. The top attachment location of the Revolution IQ helmet was treated the same way. For the side Quick Release attachment location of the Revolution IQ helmet, threading was machined into the inside of the connector post of the Quick Release mechanism, and a screw was inserted through the washer on the inside of the helmet. This inserted screw prevented the detachment of the Quick Release pin from the connector on the inside of the helmet, thus preventing removal of the loop strap.

Data-Collection Protocol. Before each data-collection session, a $3 \times 7 \times 3$-m data-capture volume was calibrated using both cube and wand calibration techniques. The 3-D motion-capture system that we used has a marker accuracy within 0.5 mm after cube and wand calibration.[16] A 1-second static trial was recorded on the model lying supine in the volume with the complete marker set in place for each condition before each session. Helmets, removal tools, and associated hardware used in the familiarization session were

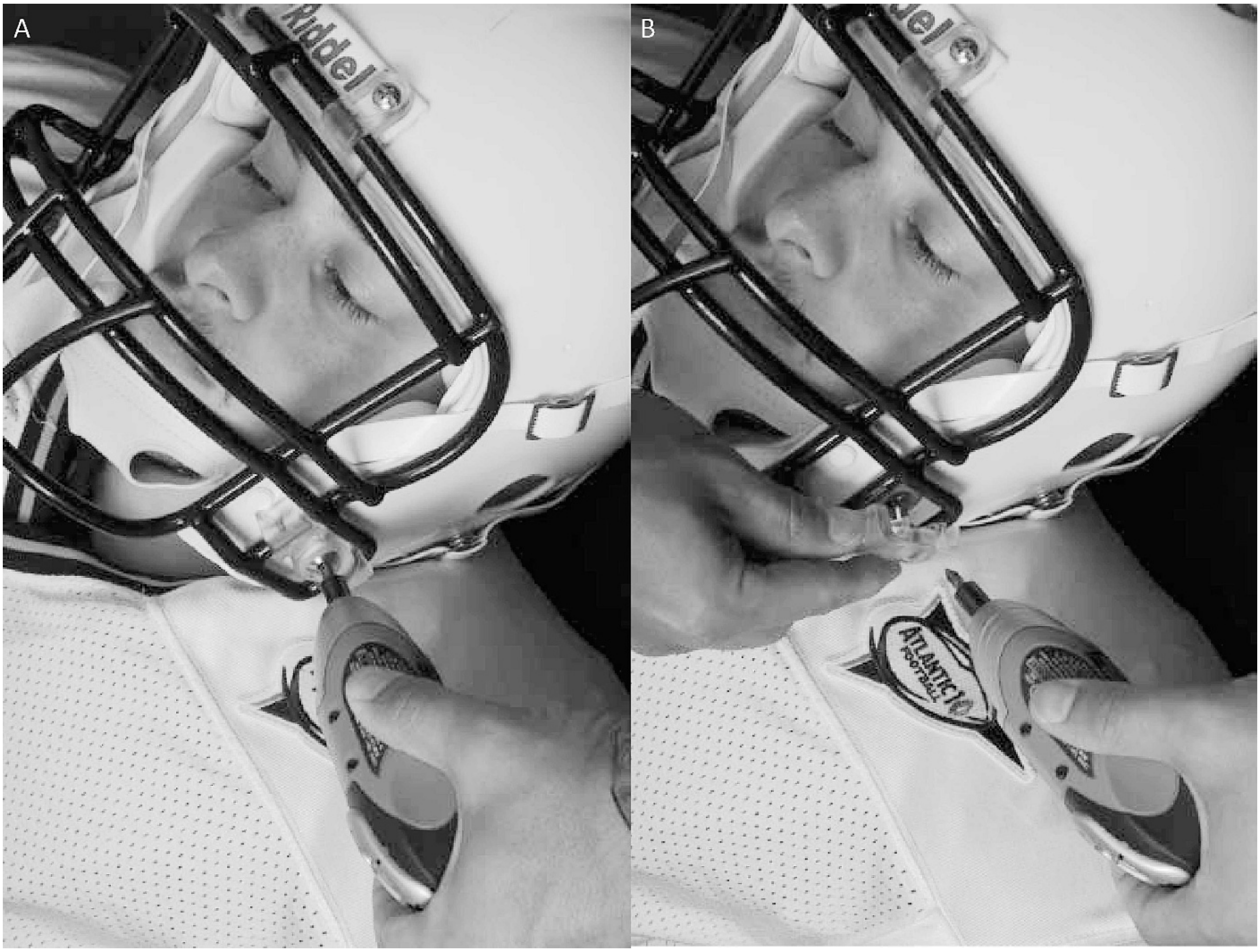

Figure 5. A, Depressing the Quick Release (Riddell Inc, Elyria, OH) button with the point of the cordless screwdriver. B, The pin has been released from the T-nut on the inside of the helmet and the face-mask clip lifts away. Reprinted with permission from Swartz EE, Boden BP, Courson RW, et al. National Athletic Trainers' Association position statement: acute management of the cervical spine–injured athlete. *J Athl Train*. 2009;44(3):306–331.

set up in the laboratory. The 10 data-collection helmets (2 for each of the 5 conditions) were prepared, and data-collection tools were assigned. Each participant started with a new, unused FMX and was assigned a fully charged cordless screwdriver. The 6 screwdrivers used in this project were rotated for each participant to limit wear and tear.

Participants reported to the Applied Biomechanics Laboratory for 1 data-collection session. After they completed health history questionnaires and informed consent forms, we provided exact instructions regarding the purpose of the study and the protocol they were to follow. A familiarization session included a review of the combined-tool technique and a demonstration and practice of the specific face-mask removal protocol for this study. An investigator demonstrated how to use the Quick Release system on the side loop straps. The investigator also demonstrated how to use the screwdriver and FMX for removal of the top loop straps on the Quick Release helmet and all loop straps on the traditional helmet according to the combined-tool face-mask removal technique. Participants were permitted to practice the techniques and become familiar with the function of the screwdriver and FMX but on a different style of loop strap (Armorguard Elite) than the styles used in the data-collection trials. Although we wanted participants to practice cutting the actual hardware used in the research, we had to use this methodologic adaptation because of the limited availability of the ION retainer. Previous researchers[8,13] have demonstrated the difficulty of the loop-strap cutting task, and we believed it was imperative to allow participants to practice cutting to achieve valid study results. Participants were instructed on how to remove the Quick Release loop-strap system with the FMX in the event the release mechanism malfunctioned, but they were not permitted to practice cutting the loop straps. Participants were not informed that we had altered hardware to force the use of the backup cutting tool. They were instructed on how to remove the ION helmet face-mask retainer using the FMX and where to cut the chin strap using EMT shears, but they were not permitted to practice cutting the retainer. Participants were permitted to practice pulling the ION face mask out of the helmet.

When participants were comfortable with the protocol, they were required to rest for 5 minutes before initiation of data collection. Three live models served as simulated injured football players on an alternating basis, but the model remained the same for each participant. The model was positioned lying supine in the data-collection volume.

Figure 6. The ION 4D (Schutt Sports Inc, Litchfield, IL) helmet. The black arrows point to the locations on the face-mask retainer clip that need to be cut. The white arrow indicates the approximate location where the chin strap needs to be cut on both sides. The face mask inserts into the channels on each side of the helmet (white circle) and slides out when the chin straps and retainer clip are cut.

Models wore eye-protection goggles that were covered with tape to obstruct their view and reduce involuntary movement (flinching) in response to removal activities. Participants were instructed to position themselves kneeling behind the head of the model and were encouraged to stabilize the head with their knees and hands whenever possible. Next, the removal tools, which included a screwdriver and an FMX (QR, QRAlt, Trad, and TradAlt conditions) or EMT shears and an FMX (ION condition), were placed on the floor on the participant's dominant-hand side, and instructions were read. The participant was directed to first attempt removal of the face mask on each helmet using the screwdriver (except for the ION condition). For the QR, QRAlt, Trad, and TradAlt conditions, participants were instructed to remove the screw or Quick Release loop straps on the side of the helmet starting on their dominant side; proceed to their nondominant side; then remove the loop strap at the top of the helmet, again starting on their dominant side. Participants were advised that if they encountered a loop strap that could not be removed, they should continue attempting to remove the rest of the loop straps in the order described with the primary tool (screwdriver) before using the backup tool. After all loop straps that could be removed from the helmet with the screwdriver had been removed successfully, participants could use the backup FMX cutting tool to cut the remaining loop strap or straps. For the ION condition, participants were instructed to cut through the 2 sides of the retainer clip on the top of the helmet, starting with the dominant-side location. Before each trial, participants were reminded to remove the face mask from the helmet as quickly and with as little movement as possible. Participants were directed to lift the face mask away from the helmet when all loop straps were removed.

Participants encountered each condition twice in random order and were blinded to hardware status for the QR, QRAlt, Trad, and TradAlt conditions. Unannounced hardware failures occurred for each participant once in a side and once in a top face-mask attachment location in both the TradAlt and QRAlt equipment conditions. The unannounced hardware failure, whether at the side or top loop-strap location, always occurred on the participant's nondominant side.

We used a stopwatch to measure the time required to fully remove the face mask and used a 3-D motion-capture system to record helmet motion during the entire trial. Data collection for each trial began when the participant picked up the face-mask removal tool and ceased when he or she demonstrated separation of the face mask from the helmet or when the trial time reached 3 minutes. If the face mask remained attached at 3 minutes, the trial was stopped. The participant was instructed to use the modified Borg CR10 RPE scale to rate the difficulty associated with completing the task. Time and RPE data were recorded. The 10 data-collection helmets then were prepared for the next participant. Screws were replaced for the VSR-4 helmets and at the top Revolution IQ loop-strap locations. The ION retainers were replaced. The VSR-4 thin-wire loop straps, Revolution top loop straps, and Revolution IQ side face-mask clips and T-nuts were replaced when necessary, as determined by visual and functional inspection.

Data Reduction and Statistical Analysis

A power analysis was performed a priori to determine appropriate sample size. Effect sizes were calculated specifically for related variables of head motion from selected literature with methods closest to the proposed methods of this project.[5–8,10] Effect sizes in the literature were calculated to be in the range of 0.04 to 0.28. The estimated sample size was calculated based on moderate to large effect statistics (according to the method described by Cohen[17]) with an α level of .05 and power of 0.8. For a large effect, the sample size for the proposed project was determined to be 23 participants.

The dependent variables were face-mask removal success, removal time (seconds), 3-D head range of motion (ROM) (degrees), and RPE. If the trial was completed successfully in less than 3 minutes, it was categorized as *successful*. If the participant could not fully remove the face mask in the required time, the trial was recorded as *unsuccessful*. A 3-minute cutoff was chosen to better reflect a real-life scenario; an AT would unlikely continue to attempt face-mask removal beyond 3 minutes, especially if the athlete had a respiratory emergency. Cutoff times have been used in face-mask removal studies.[8,13,14] Unsuccessful trials were assigned a total removal time of 3 minutes.

Three-dimensional data were tracked and smoothed using a recursive, fourth-order, low-pass Butterworth filter (10 Hz). Digitized x, y, and z coordinates for the dynamic and static trials were imported to the Kintrak software program. Joint centers were calculated based on a static trial for the model using an embedded right-hand Cartesian segment coordinate system. Joint kinematics were created using standard Euler angle calculations, whereby the flexion-extension motion of the head segment was identified as the first rotation occurring about the medial-lateral axis and the second motion (right and left lateral flexion) occurring in the frontal

Table 1. Time for Face-Mask Removal, s

Condition	Mean ± SD	95% Confidence Interval
Revolution IQ with Quick Release[a,b]	33.96 ± 14.14	27.99, 39.93
Revolution IQ with Quick Release hardware altered[a,c]	99.22 ± 20.53	90.55, 107.89
Traditional[b,d]	48.47 ± 15.83	41.79, 55.16
Traditional with hardware altered[d,e]	80.43 ± 27.21	68.94, 91.92
ION 4D[f]	86.20 ± 26.37	75.07, 97.34

[a] Riddell Inc, Elyria, OH.
[b] Indicates different from all conditions ($P < .01$)
[c] Indicates different from Revolution IQ with Quick Release, traditional, and traditional with hardware altered conditions ($P < .05$).
[d] VSR-4; Riddell Inc.
[e] Indicates different from Revolution IQ with Quick Release hardware altered condition ($P = .04$).
[f] Schutt Sports Inc, Litchfield, IL.

plane about the anterior-posterior axis. The total head-excursion ROM in each plane was calculated and summed to create the 3-D head motion variable.[7]

Data for each variable from the 2 trials for each of the 5 conditions were recorded for each participant in spreadsheet format. Frequency of successful and unsuccessful trials and mean values for remaining variables were exported to SPSS (version 17.0; SPSS Inc, Chicago, IL). Mean values were created for each variable by using data from both trials in each condition. This was also true for the TradAlt and QRAlt conditions; in these conditions, the mean reflected a value that combined the effects of alteration location (ie, top or side). Descriptive statistics were used to calculate means, ranges, and measures of variance for each variable. Three separate 1 × 5 repeated-measures analyses of variance (ANOVAs) with follow-up pairwise comparisons using Bonferroni correction were performed to test for differences between conditions for time, ROM, and RPE. The α level was set at .05.

RESULTS

Success Rates

All 25 participants performed the expected 2 face-mask removal trials for each of the 5 conditions. One participant had 5 unsuccessful trials during data collection. Because we were concerned that this participant might not have been proficient in face-mask removal compared with the others, we developed success rates for each participant for comparison. This participant's success rate (50.0%) was more than 3 SDs outside of the average success rate for the group (92.1 ± 10.6%) and was deemed an outlier. Therefore, this participant's data were not included in the analysis, and the results are based on a sample size of 24.

This resulted in 240 face-mask removal trials (48 QR, 48 QRAlt, 48 Trad, 48 TradAlt, 48 ION). Fourteen face masks in the 240 face-mask removal trials were not removed completely in less than 3 minutes, yielding a face-mask removal success rate of 94.2% (226 of 240). Thirteen of the 14 unsuccessful trials occurred in the QRAlt condition, for a success rate of 72.9% (35 of 48). All 13 unsuccessful trials in the QRAlt condition occurred during trials in which hardware had been altered in the side Quick Release loop-strap attachments. Only 11 of the 24 (45.8%) QRAlt side trials were completed successfully. Success rates in the other conditions were 100%, except for the TradAlt condition, in which the rate was 97.9% (47 of 48).

Time

The average times for face-mask removal in order of shortest to longest were 33.96 ± 14.14 seconds for QR, 48.47 ± 15.83 seconds for Trad, 80.43 ± 27.21 seconds for TradAlt, 86.20 ± 26.37 seconds for ION, and 99.22 ± 20.53 seconds for QRAlt. The ANOVA revealed differences regarding time for face-mask removal ($F_{4,20} = 48.87$, $P = .001$). Pairwise comparisons revealed multiple differences in time between individual conditions (Table 1). Figure 7 provides the results for each condition.

Movement

The average movements during face-mask removal in order of least to most were 10.10° ± 3.07° for QR, 12.12° ± 3.98° for Trad, 14.61° ± 2.61° for ION, 15.81° ± 4.84° for QRAlt, and 16.91° ± 5.36° for TradAlt. The ANOVA revealed differences regarding movement associated with face-mask removal ($F_{4,20} = 16.25$, $P = .001$). Pairwise comparisons revealed multiple differences in movement

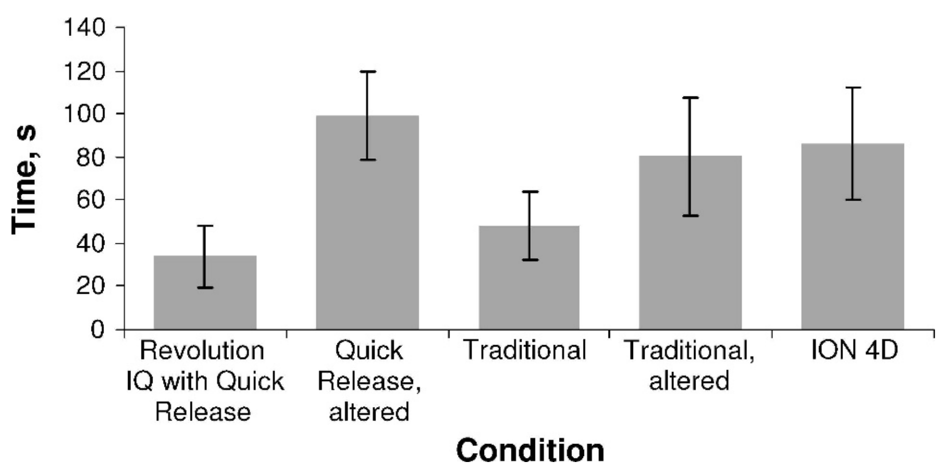

Figure 7. Results for time of face-mask removal for each condition. Quick Release, altered indicates the Revolution IQ with Quick Release (Riddell Inc, Elyria, OH) hardware altered condition.

Table 2. Combined Head Range-of-Motion Excursion During Face-Mask Removal,°

Condition	Mean ± SD	95% Confidence Interval
Revolution IQ with Quick Release[a,b]	10.10 ± 3.07	8.80, 11.40
Revolution IQ with Quick Release hardware altered[a]	15.81 ± 4.84	13.77, 17.86
Traditional[c,d]	12.12 ± 3.98	10.44, 13.80
Traditional with hardware altered[c]	16.91 ± 5.36	14.65, 19.18
ION 4D[e]	14.61 ± 2.61	13.50, 15.71

[a] Riddell Inc, Elyria, OH.
[b] Indicates different from Revolution IQ with Quick Release hardware altered, traditional with hardware altered, and ION 4D conditions ($P <$ .001).
[c] VSR-4; Riddell Inc.
[d] Indicates different from traditional with hardware altered condition ($P <$ .001).
[e] Schutt Sports Inc, Litchfield, IL.

between individual conditions (Table 2). Figure 8 provides the results for each condition.

Rating of Difficulty

The average RPEs during face-mask removal in order of least to most difficult were 1.44 ± 1.19 for QR, 1.96 ± 0.97 for Trad, 3.27 ± 1.71 for ION, 3.68 ± 1.70 for TradAlt, and 4.68 ± 1.62 for QRAlt. The ANOVA revealed differences regarding perceived difficulty of face-mask removal ($F_{4,20} = 43.20$, $P = .001$). Pairwise comparisons revealed multiple differences in RPE between individual conditions (Table 3).

DISCUSSION

The most important results of this study demonstrated that face-mask removal was most efficient in trials that required using only the screwdriver and/or activating the Quick Release mechanism (ie, Trad and QR conditions). Those trials were faster, created less motion, and were perceived to be easier than removal trials that required cutting the loop straps (TradAlt, QRAlt, and ION conditions).

Table 3. Rating of Perceived Exertion During Face-Mask Removal

Condition	Mean ± SD	95% Confidence Interval
Revolution IQ with Quick Release[a,b]	1.44 ± 1.19	0.94, 1.94
Revolution IQ with Quick Release hardware altered[a,c]	4.68 ± 1.62	3.99, 5.36
Traditional[d]	1.96 ± 0.97	1.55, 2.37
Traditional with hardware altered[d]	3.68 ± 1.70	2.96, 4.39
ION 4D[e]	3.27 ± 1.71	2.55, 3.99

[a] Riddell Inc, Elyria, OH.
[b] Indicates different from Revolution IQ with Quick Release hardware altered, traditional with hardware altered, and ION 4D conditions ($P <$ .001).
[c] Indicates different from all other conditions ($P < .02$).
[d] VSR-4; Riddell Inc.
[e] Schutt Sports Inc, Litchfield, IL.

Success Rate

The overall success rate in this study (94.2%) compares favorably with previous studies.[11–14] Only Gale et al[14] have examined the combined-tool technique with occupied (athletes or models versus mounted) helmets; their success rate was 98.6%. Although our result was slightly lower, it is encouraging because our participants encountered difficult removals (altered hardware) at a much higher rate (40%) during data collection than they would likely face in the field. Based on previous reports,[8,11–14] ATs might expect to be unable to remove the face mask in 0% to 17.6% of attempts. Three conditions (QR, Trad, and ION) had success rates of 100%, which is obviously the desired goal in performing face-mask removal. A 100% successful face-mask removal rate has been reported for individual teams within a large sample of helmets[11] and for an entire sample of helmets with face masks being removed using the combined-tool approach.[13]

During the QRAlt condition, participants encountered 1 trial in which, because of the investigator-induced malfunction of the mechanism, they were forced to cut away the loop strap secured with the Quick Release system. Most unsuccessful removal trials in our study occurred in this condition (13 of 14), and all 13 of those trials occurred during attempts to cut the loop strap associated with the manipulated Quick Release system; when the participants

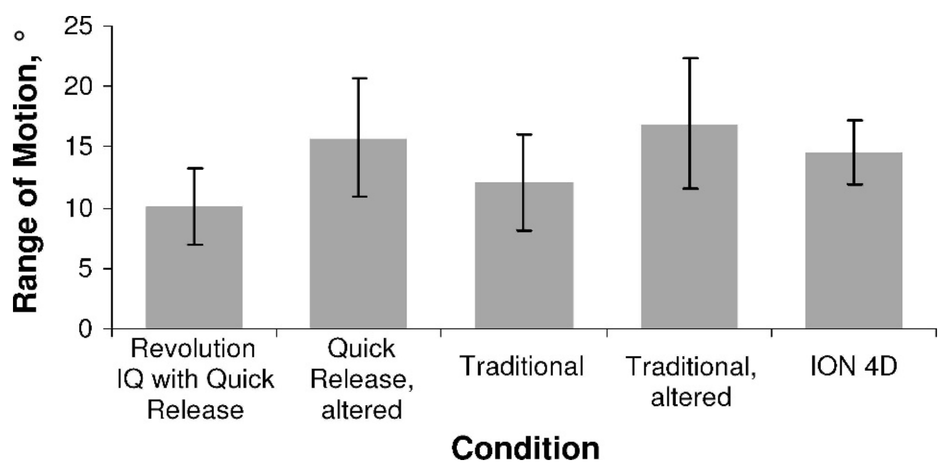

Figure 8. Range of motion during face-mask removal for each condition. Quick Release, altered indicates the Revolution IQ with Quick Release (Riddell Inc, Elyria, OH) hardware altered condition.

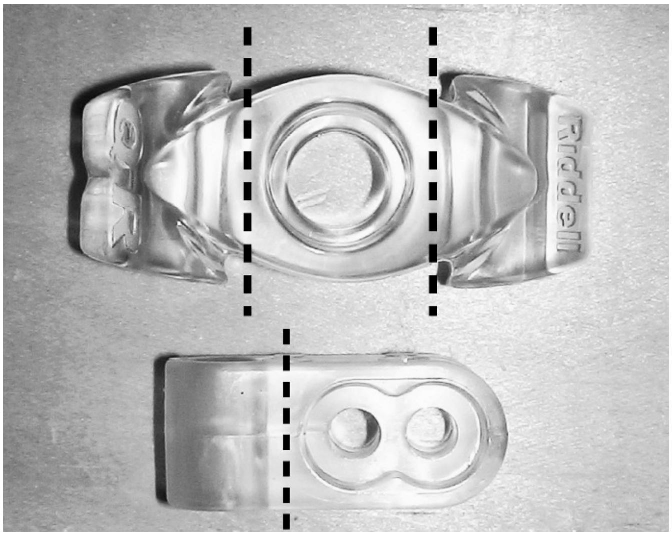

Figure 9. The Quick Release (Riddell Inc, Elyria, OH) loop strap requires 2 cuts, so approximately twice the amount of material needs to be cut compared with a traditional loop strap.

encountered a shredded screw at the top loop-strap locations in this helmet, they successfully cut away the loop strap. The loop strap secured with the Quick Release mechanism in the Revolution IQ helmet is not only thick, but, because it requires 2 cuts to be removed, the amount of material that needs to be cut is approximately twice that of a standard loop strap (Figure 9). This likely contributed to the rate of unsuccessful face-mask removal attempts in this condition. Swartz et al[8] also reported that, in general, loop straps on the side of the helmet, particularly in a Revolution-style helmet, might be more difficult to remove than loop straps located at the top of the helmet. One contributing factor is the proximity of the side loop straps to the shoulder pads, which makes manipulating a tool in the most effective manner more difficult (Figure 10). Another factor that might have caused difficulty in removing the Quick Release loop strap in our study was that the investigator-induced malfunction of the mechanism occurred on the participant's nondominant side. Despite the QRAlt result, the QR condition yielded a 100% success rate for face-mask removal, and, at this time, the probability that an AT will encounter a Quick Release system malfunction is unknown. In the future, researchers should explore the performance durability of the Quick Release system over time and exposure to the football environment.

Time

The QR condition resulted in the fastest face-mask removal times (33.96 ± 14.14 seconds) among all conditions, approximately 15 seconds faster than the next fastest condition. The QR also yielded the fastest times reported for face-mask removal with live models serving as simulated injured football players.[8,14] Researchers[8] investigating an earlier model of the Revolution helmet without the Quick Release system reported a 53.40-second face-mask removal time when using a cordless screwdriver to remove all 4 loop straps. Although a direct comparison with this older model was not included in our study, the Quick Release system improved face-mask removal time when comparing those results with our results.

However, the trials that involved an investigator-induced malfunction at 1 loop-strap location in the same helmet (QRAlt) were the longest of all 5 conditions. As mentioned, this is likely due to the difficulty associated with cutting the remaining loop strap. Time for face-mask removal was affected negatively in any condition in which cutting loop straps was required. When cutting was necessary, the time to remove the face mask exceeded 60 seconds. The loop straps were cut in the QRAlt and TradAlt conditions and in the ION condition, in which use of a cordless screwdriver was not an option on the model tested. This is consistent with previous reports in which researchers have found the use of a screwdriver to be faster than cutting during face-mask retraction[3,10] or full removal.[8,13]

Motion

Because the extent of spinal instability associated with a given injury cannot be known in the field, the accepted tenet is to minimize motion as much as possible. During face-mask removal, our participants created the least amount of motion with the Trad and QR conditions. The primary difference between these 2 conditions and the others is that the former do not require use of the backup cutting tool to cut loop straps. Therefore, the participant moved the helmet more when using a cutting tool than when only using the screwdriver to depress the Quick Release mechanism or remove the screws. Results from previous studies[3,8,10,13] also have shown that more motion is associated with the cutting than unscrewing of loop straps.

We are the first to analyze motion using a combined-tool technique. Direct comparisons with other studies in which only a portion of the trials was captured[7,8] or a face-mask retraction technique was used[5,6,10] are difficult to make. Swartz et al[8] used methods that were largely similar to our methods and provided the best opportunity for comparison of the motion data. Before making those comparisons, we must identify 2 important methodologic differences in the earlier study: data were collected for only the first 25 seconds of each trial, and the previous generation of the FMX was used when loop-strap cutting was required.[8] In addition, data were reported for each plane rather than combined, but data presented in Tables 3 and 4 in the Swartz et al[8] study can be summed for comparisons. In general, ROM in the earlier study (from 13.5° to 32.2°) was larger than in our study, in which the combined ROM excursion ranged from 10.10° ± 3.07° (QR) to 16.91° ± 5.36° (TradAlt). The 2 studies also included 2 common helmets. The VSR-4 helmet with thin-wire loop straps was included in the earlier study, and the screwdriver-only condition featured in the earlier study is effectively the same as the Trad condition in our project. Interestingly, total ROM excursion created during the previous study (18.4°) and that created in our study (12.12° ± 3.98°) appear to be considerably different. The condition that required all 4 loop straps to be cut from the same helmet in the earlier study (26.6°) created more motion than our TradAlt condition (16.91°). The other reasonable comparison might be made between the previous study's Revolution condition and our study's QR condition. The previous study predated the Quick Release loop strap; therefore, the loop straps at all 4 positions were unscrewed (20°) or cut (31.7°), again with much greater motion than in our study

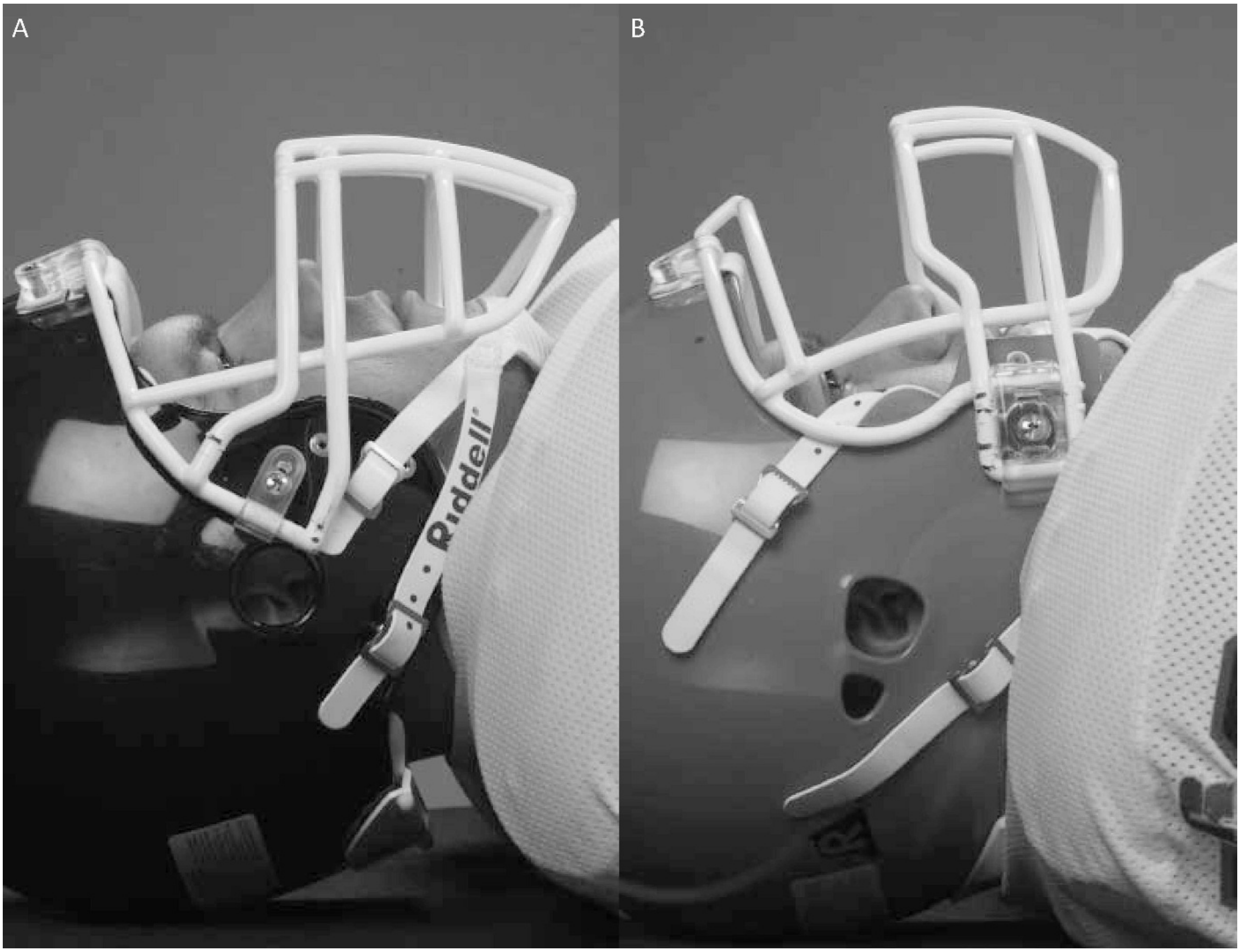

Figure 10. A, traditional-style helmet (VSR-4; Riddell Inc, Elyria, OH) and location of the lateral loop straps relative to the shoulder pads. B, Revolution IQ (Riddell Inc)–style helmet and location of the lateral loop straps relative to the shoulder pads. Reprinted from Swartz EE, Norkus SA, Cappaert T, Decoster LC. Football equipment design affects face mask removal efficiency. *Am J Sports Med.* 2005;33(8):1210–1219. © 2005 The American Orthopaedic Society for Sports Medicine, http://ajs.sagepub.com/content/33/8/1210.full. The final, definitive version of this paper has been published in the *American Journal of Sports Medicine*, Volume 33/Issue 8, August 2005 by SAGE Publications Ltd, Inc. All rights reserved.

(10.10° and 15.81°, respectively). These decreases in motion appear to be due to both the transition from cutting all loop straps to a combined-tool approach and the introduction of the Quick Release face-mask removal technology.

The motion result for the ION condition was the most of the 3 unaltered conditions. The required use of the cutting tool for face-mask removal in this condition likely led to its increase in ROM compared with the Trad and QR conditions. However, compared with previous research[8] in which a cutting tool was used to remove all 4 loop straps on different helmets (range, 23.6° to 32.2°),[a] the results from the ION (14.61°) condition are more favorable. This is similar to the result comparisons noted and might be related to the methodologic variations enumerated, but some evidence also suggests that loop straps at the side locations might be more difficult to remove than top loop straps on any helmet.[8] Therefore, the ION's having only top loop straps might have been an additional factor. This helmet required a chin strap to be cut on each side of the face mask, and the extent to which cutting the chin strap contributed to motion during our trials or affected the stability of the helmet is unknown.

[a]This range was calculated by combining the motion in the individual planes given in Tables 4 and 5 in the study by Swartz et al.[8]

Difficulty

Participants experienced the least amount of difficulty removing face masks during the QR and Trad conditions. These conditions involved simple motor tasks using the cordless screwdriver either to push the Quick Release system button or to remove screws. The use of a cordless screwdriver, either alone or within the combined-tool technique, has been reported[8,13] to be easier than the use of a cutting tool to cut all 4 loop straps for face-mask removal in multiple helmet and loop-strap styles and combinations.

The QRAlt condition resulted in the greatest difficulty associated with removing the face mask compared with the other 4 conditions. Again, this was likely due to the process involved in cutting the Quick Release loop straps, as evidenced by the number of unsuccessful trials and time required to remove the face mask in this condition.

Limitations

Our study had some limitations. First, our participants did not practice cutting the actual loop straps in the TradAlt and QRAlt conditions or cutting the ION retainer used during data collection. Because a large supply of the new ION face-mask retainers was not available, we had to adapt our methods. Our participants' overall performance possibly was poorer because of this circumstance. Although we hope that ATs have practiced face-mask removal on all styles of equipment used at their institutions, an AT might encounter equipment with which he or she is unfamiliar. In this sense, our results might represent a worst-case scenario. That is, if participants had practiced cutting the actual face-mask equipment used in the data-collection portion of the study, they might have performed more efficiently than they did. Second, to ensure external validity, we incorporated the altered hardware conditions into the study design but at a much higher rate than would be expected normally. This also might have led to poorer results but again would represent a worst-case scenario.

Clinical Recommendations

Based on our results, we recommend the use of a combined-tool technique for removing traditional football helmet face-mask attachment designs and the Revolution IQ face-mask attachment system. The combined-tool approach, which reduces the negative effect that cutting loop straps has on time, ROM, and difficulty, has been investigated and recommended over face-mask removal using only cutting.[8,13,14] Evidence[11,14] suggests that 1 loop strap needs to be cut from a 4-point face-mask attachment design because of screw failure only 8% to 11% of the time. Although our participants encountered a much higher rate of failure than would be expected, their overall removal efficiency (time, ROM, RPE) using the combined-tool technique was superior to results[7,8,13] reported in previous studies when participants cut all 4 loop straps. In the ION helmet tested, a combined-tool technique using a screwdriver as the primary tool is not possible because unscrewing the retainer does not release the face mask.

CONCLUSIONS

The Quick Release face-mask attachment system and the screwdriver-only removal of the face mask both resulted in superior face-mask removal efficiency compared with conditions in which cutting loop straps was necessary. Athletic trainers also should be aware that, in our study, cutting the Quick Release loop strap presented a great challenge to our participants. Practicing this skill might address this issue because our participants were not permitted to practice cutting this or any of the other loop straps included in the study.

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