

Supplementary Materials

Rule changes (2011-2019) to enhance player safety

Listed below are the changes in rules the NFL has adopted prior to every season (2011-2019)¹ and the parts of the body the rule change protects, shown in red. See <https://operations.nfl.com/football-ops/nfl-ops-honoring-the-game/health-safety-rules-changes/>. Specifically

- Statements regarding rule changes impacting player safety and health provided by the NFL prior to a given season, and are shown in black.
- Putative impact of rule change on different body parts (legs, back, arms, head) are shown in red and are provided by the authors.

2019

The blindside block is eliminated, expanding protection of defenseless players. It is now prohibited for a blocker to initiate forcible contact with his head, shoulder or forearm when his path is toward or parallel to his own end line. **Protects mainly arms and head**

It is a foul for running forward and leaping across the line of scrimmage in an obvious attempt to block a field goal or Try Kick, or apparent kick. **Protects all parts of body**

2018

- Makes permanent the playing rule that changes the spot of the next snap after a touchback resulting from a free kick to the 25-yard line. **Protects all parts of body**

- It is a foul if a player lowers his head to initiate and make contact with his helmet against an opponent. It is a penalty that will result in the loss of 15 yards. If the foul is by the defense, it is also an automatic first down. The player may be disqualified. **Protects head**
- New kickoff rules instituted, including no running start, setup zone creation, no blocking in setup zone, banning two-man wedges and all wedges altogether, evened spacing on each side of the ball². **Protects mainly head but all other parts of body as well.**

2017

- Prohibits the “leaper” block attempt on field goal and extra point plays **Protects legs (see ³)**
- Extends the rule changing the spot of the next snap after a touchback resulting from a free kick to the 25-yard line for another year. **Protects all parts of body (but may have the opposite effect – see ⁴)**
- Gives a receiver running a pass route defenseless player protection. **Protects all parts of body**
- Prohibits crackback blocks by a backfield player who is in motion, even if he is not more than two yards outside the tackle when the ball is snapped. **Protects all parts of body**
- Reduces the length of overtime in the preseason and regular season to 10 minutes **Protects all parts of body, because less playing time means reduced scope for injury**

2016

- All chop blocks are prohibited. **Protects legs⁵**
- The horse collar tackle rule is expanded to include when a defender grabs the jersey at the name plate or above and pulls a runner toward the ground. **Protects legs**

- In an effort to increase touchbacks, the spot of the next snap after a touchback resulting from a kickoff is moved from the 20- to the 25-yard line. **Protects all parts of body**

2015

- Rules prohibiting illegal “peel back” blocks are extended to cover all offensive players. **Protects legs**
- Offensive backs are prohibited from chopping a defensive player engaged above the waist by another offensive player outside the tackle box. **Protects legs**
- Defenseless player protections are expanded to cover the intended receiver of a pass in the immediate continuing action following an interception. **Protects all – legs, arms, head, miscellaneous (but head already covered)**
- When a team presents a punt, field-goal or try kick formation, defenders are prohibited from pushing teammates on the line of scrimmage. **Protects all**

2014

- Clipping and unnecessary roughness penalties are expanded to prohibit blockers from rolling up on the side of a defender’s leg. **Protects legs**

2013

- Players are required to wear protective knee and thigh pads. **Protects legs**
- It is illegal for a runner or tackler to initiate forcible contact by delivering a blow with the top or crown of his helmet against an opponent when both players are clearly outside the tackle box. **Protects head**

- “Peel back” blocks below the waist are illegal inside the tackle box. **Protects legs**
- The list of “defenseless players” is expanded to include long snappers on field goals and PATs (point after touchdowns). **Protects all parts of body**
- The “bunch” formation is eliminated on field goals and PATs. No more than six defenders may be on the line of scrimmage on either side of the snapper at the snap for these plays. **Protects all parts of body**

2012

- The list of “defenseless players” is expanded to include defensive players on crackback blocks, making it illegal to hit them in the head or neck area. **Protects head**

2011

- The restraining line for the kicking team is moved from the 30- to the 35-yard line in an effort to increase touchbacks. **See response to next bullet below.**
- All kicking team players other than the kicker must be lined up no more than five yards behind their restraining line, eliminating the 15- to 20-yard running “head start” that had become customary for many players. **Could lead to more touchbacks or more injuries to the returner, so hard to say. Helmet to helmet protected so could lead to more injuries affecting legs, arms, back. Makes game more exciting though.**
- The list of “defenseless players” is expanded to include: a kicker/punter during the kick or during the return; a quarterback at any time after a change of possession; and a player who receives a “blindside” block when the blocker is moving toward his own endline and approaches the opponent from behind or from the side. Previously, these players were protected against blows to

the head, but not against blows delivered by an opponent with the top/crown or forehead/“hairline” parts of the helmet against other parts of the body. **Protects other parts of body, i.e. arms, back, and legs**

- A receiver who has completed a catch is a “defenseless player” until he has had time to protect himself or has clearly become a runner. A receiver/runner is no longer defenseless if he is able to avoid or ward off the impending contact of an opponent. Previously, the receiver who had completed a catch was protected against an opponent who launched and delivered a blow to the receiver’s head. **Protects other parts of body, i.e. arms, back, and legs.**

The number of rule changes that were adopted to protect each major body part (leg/arm/head/ miscellaneous or remaining) is summarized in the table below.

- **Suppl. Table 1**

	2011	2012	2013	2014	2015	2016	2017	2018	2019
Legs	√√		√√√√	√	√√√√	√√√	√√√√√	√√	√
Back	√√		√√		√√	√	√√√√	√√	√
Arms	√√		√√		√√	√	√√√√	√√	√√
Head		√	√√√		√		√√√√	√√√	√√

Time series modeling of injury data

We fit the data on the number of players with major injuries and injury severity with two competing models – i) a linear regression model and ii) a step function model from a family with variable step location. Here, we compared the two models to see if the more complicated step function model was a better fit of the data over the linear regression model. We performed separately the same analysis for data on leg, arm, and head injuries.

The linear regression model had two parameters – the slope and intercept of the line – and eight (=10-2) degrees of freedom. For the step function fit $h(t) = \begin{cases} \alpha, & \text{if } t \geq \text{season} \\ \beta, & \text{if } t < \text{season} \end{cases}$, we varied the location of the step (*season* in the equation above; α and β are the values that correspond to the least sum-of-square errors for their respective intervals), compared the residual sum-of-square errors across all the step functions from the same family, and chose the one that yielded the minimum residual (SS_{step}). Thus, the final step function model chosen for comparison with the simpler linear regression model was from a family of step functions, and as such, had three parameters – the location of the step, and the constant values α and β of the two disjoint sub-intervals – and consequently seven (=10-3) degrees of freedom. We compared the two models using an F ratio test. The F ratio quantifies the relationship between the relative increase in sum-of-squares and the relative increase in degrees of freedom (df) with the linear fit. Specifically, $F(df_{linear} - df_{step}, df_{step}) = \frac{(SS_{linear} - SS_{step}) / (df_{linear} - df_{step})}{SS_{step} / df_{step}}$. If the simpler linear regression model is correct, an F ratio near 1.0 is expected. If the ratio is $\gg 1.0$, then either the more complicated step function model is correct, or the simpler model is correct, but random scatter led the more complicated model to fit better. The p -value distinguishes between the two possibilities, with a low p -value indicating the more complicated model is the better fit.

Suppl. Fig. 1a shows the number of players who missed at least one game of the regular season due to an injury to the leg with the linear regression (dotted line) and optimal step function (dashed line) model fits superimposed. As Suppl. Fig. 1A illustrates, the step function model and the linear regression model were statistically indistinguishable fits of the data ($F(1,7) = 1.298$, $p = .292$; $SS_{linear} = 15540$, $SS_{step} = 13109$). Suppl. Fig. 1B shows the number of games the injured player missed on average, and the step function and the linear regression models were

statistically similar fits of the data as well ($F(1,7) = 2.362$, $p = .168$; $SS_{linear} = 2.902$, $SS_{step} = 2.170$). The results were similar as regards to injuries of the back: The step function model and the linear regression model were statistically indistinguishable fits of trends on both the number of players with injuries of the back ($F(1,7) = 1.330$, $p = .287$; $SS_{linear} = 116.6$, $SS_{step} = 98.0$; Suppl. Fig. 2A) and number of games players that had injuries to the back missed ($F(1,7) = 0.844$, $p = .389$; $SS_{linear} = 4.845$, $SS_{step} = 4.324$; Suppl. Fig. 2B). Suppl. Fig. 3A shows the number of players who missed at least one week due to an injury to the arm. Again, the step function model was not a significantly better fit of the data than the linear regression model ($F(1,7) = 0.514$, $p = 0.497$; $SS_{linear} = 497.2$, $SS_{step} = 463.2$). Suppl. Fig. 3B shows that the step function, as compared with the linear model, was not a significantly better fit of the number of games missed on average because of injury to the arm, but the result did trend towards significance ($F(1,7) = 3.985$, $p = 0.086$; $SS_{linear} = 3.832$, $SS_{step} = 2.442$). Suppl. Fig. 4A shows the number of players who missed at least one game of the season due to head injury. The step function model was not a significantly better fit ($F(1,7) = 3.120$, $p = .121$; $SS_{linear} = 2520.6$, $SS_{step} = 1743.6$). Suppl. Fig. 4B shows that the step function was not a significantly better fit of the number of games missed because of head injury, although the effect trended towards significance ($F(1,7) = 4.523$, $p = 0.071$; $SS_{linear} = 0.890$, $SS_{step} = 0.541$). Overall, the step function did not better account for injury data as compared to the simpler linear model.

Suppl. Table 1: Leg injuries (number of injured players according to position of player)

Position\Season	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
C	5	6	6	5	7	2	8	2	10	1
CB	20	29	31	18	28	19	35	15	39	31
DE	15	16	24	10	18	18	12	7	20	1
DT	12	8	20	16	18	21	11	13	22	3
G	12	11	16	7	15	15	12	8	10	1
K	0	0	0	0	0	1	0	0	2	1
KR	0	0	0	0	0	0	0	0	0	0
LB	30	33	36	26	58	46	36	33	42	24
LS	0	0	0	1	0	0	0	0	0	0
OL	0	0	0	0	0	0	0	0	0	44
P	0	0	0	0	0	0	1	0	1	0
QB	2	2	0	7	4	5	3	3	2	3
RB	23	26	28	24	25	24	23	7	28	17
S	26	9	23	19	17	28	15	10	17	15
T	15	15	17	14	12	13	17	10	10	1
TE	12	9	11	16	15	13	26	11	21	12
WR	17	25	25	17	17	31	19	19	46	28
FB	0	0	0	0	0	0	0	0	0	1

C – center; CB – cornerback; DE – defensive end; DT – defensive tackle; G – guard; K – kicker; KR – kick returner; LB – linebacker; LS – long snapper; OL – offensive lineman; P – punter; QB – quarterback; RB – running back; S – safety; T – tackle; TE – tight end; WR – wide receiver; FB - fullback

Suppl. Table 2: Back injuries (number of injured players according to position of player)

Position\Season	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CB	1	1	1	1	0	0	2	0	1	1
DE	0	0	0	0	1	2	2	2	0	0
DT	0	1	2	1	1	1	1	1	2	0
G	2	0	1	2	5	0	0	2	3	0
K	0	0	0	0	0	0	0	0	0	0
KR	0	0	0	0	0	0	0	0	0	0
LB	1	1	0	0	1	2	1	0	0	0
LS	0	0	0	0	0	0	0	0	0	0
OL	0	0	0	0	0	0	0	0	0	1
P	0	0	0	0	0	0	0	0	0	0
QB	0	1	0	1	1	1	1	0	1	0
RB	0	1	0	1	0	1	1	1	1	0
S	2	1	1	0	2	0	0	0	0	1
T	2	4	2	1	1	0	5	0	0	0
TE	1	0	0	0	0	2	3	2	1	1
WR	0	0	1	1	1	1	0	1	0	2
FB	0	0	0	0	0	0	0	0	0	0

Suppl. Table 3: Arm injuries (number of injured players according to position of player)

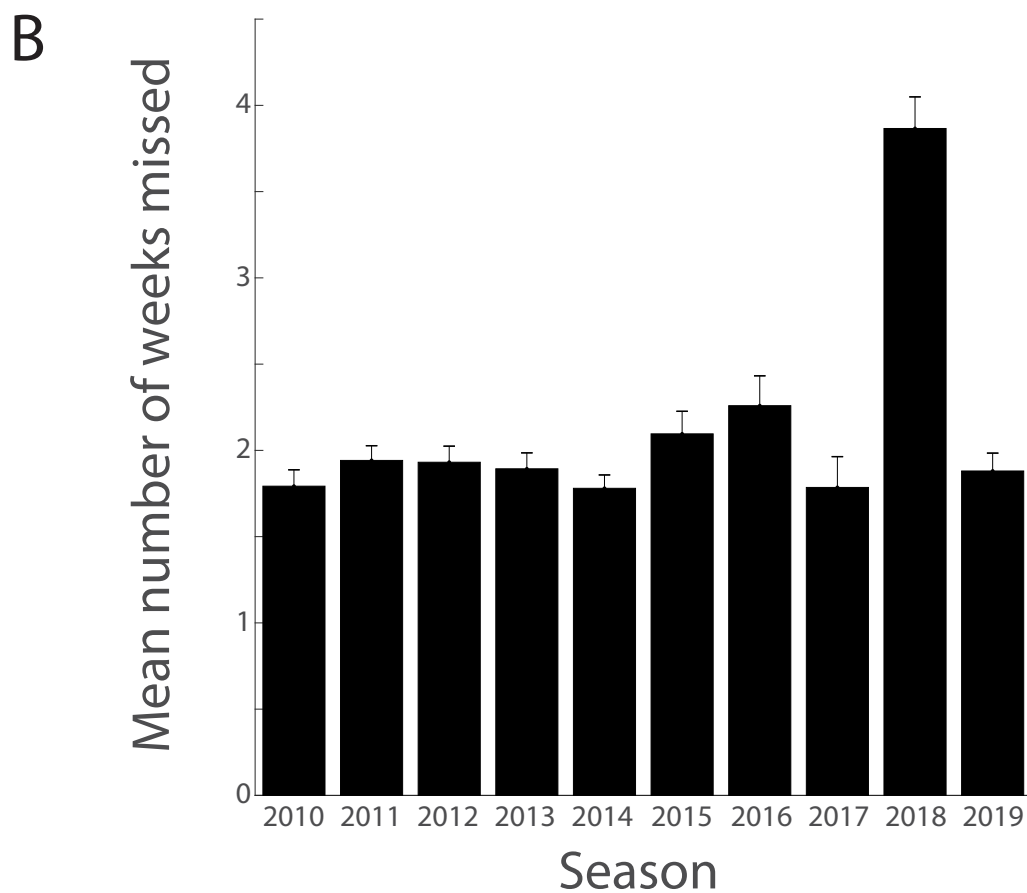
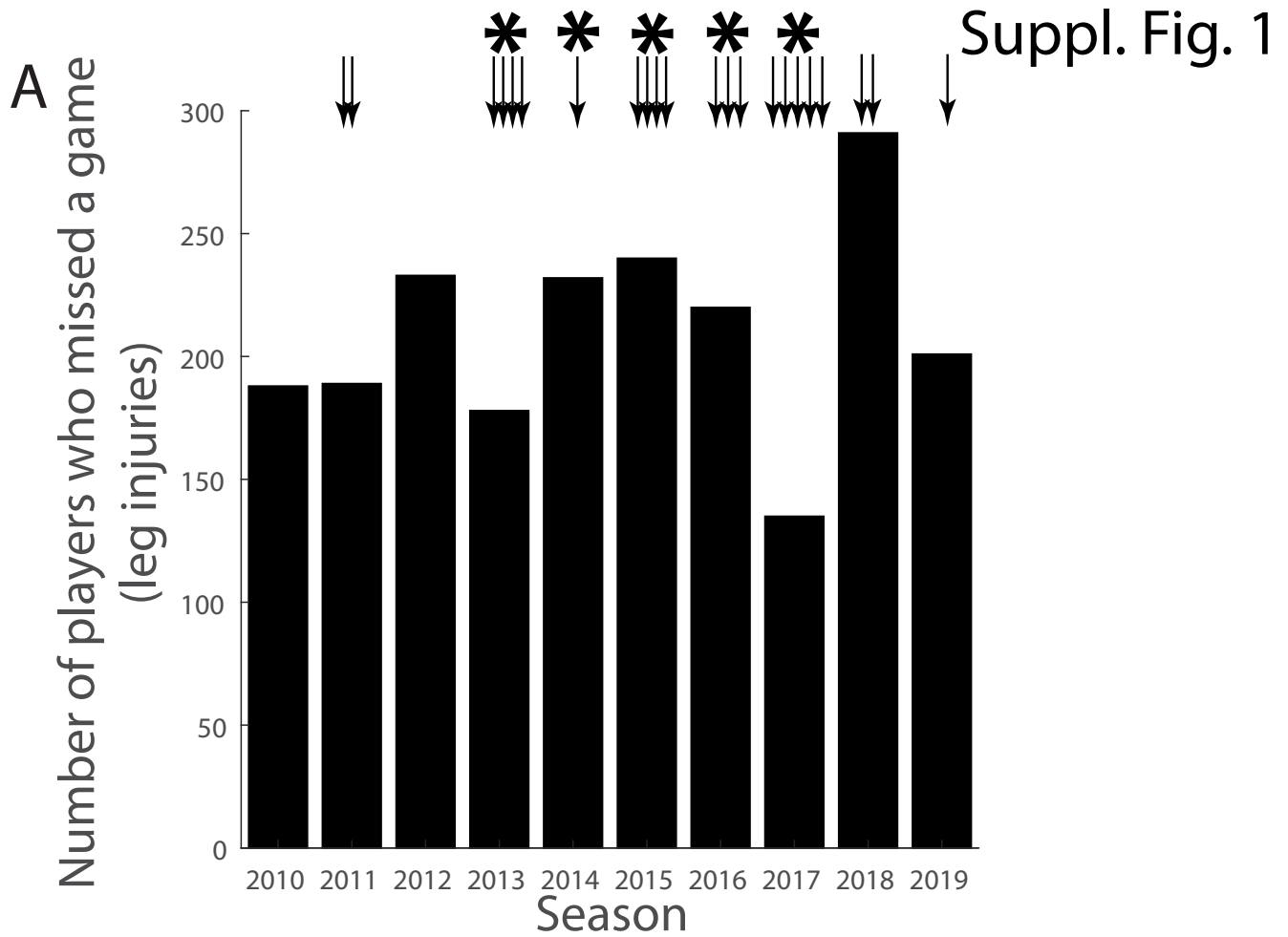
Position\Season	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
C	0	0	0	1	0	2	1	0	0	0
CB	2	3	6	2	4	3	3	0	11	6
DE	2	3	0	4	2	5	3	3	4	1
DT	1	1	0	1	3	1	5	1	1	0
G	1	1	2	1	3	2	1	2	1	0
K	0	1	0	0	0	0	0	0	0	0
KR	1	0	0	0	0	0	0	0	0	0
LB	8	6	4	3	4	5	4	2	4	6
LS	0	0	0	0	0	0	0	0	0	0
OL	0	0	0	0	0	0	0	0	0	2
P	0	0	0	0	1	0	0	0	0	0
QB	0	0	0	0	0	3	3	1	3	1
RB	1	1	3	2	2	3	2	3	4	4
S	2	3	2	4	3	3	4	4	5	4
T	0	4	0	1	1	3	2	1	2	0
TE	0	0	3	1	0	3	3	3	3	0
WR	1	4	2	4	2	4	6	3	8	4
FB	0	0	0	0	0	0	0	0	0	0

Suppl. Table 4: Head injuries (number of injured players according to position of player)

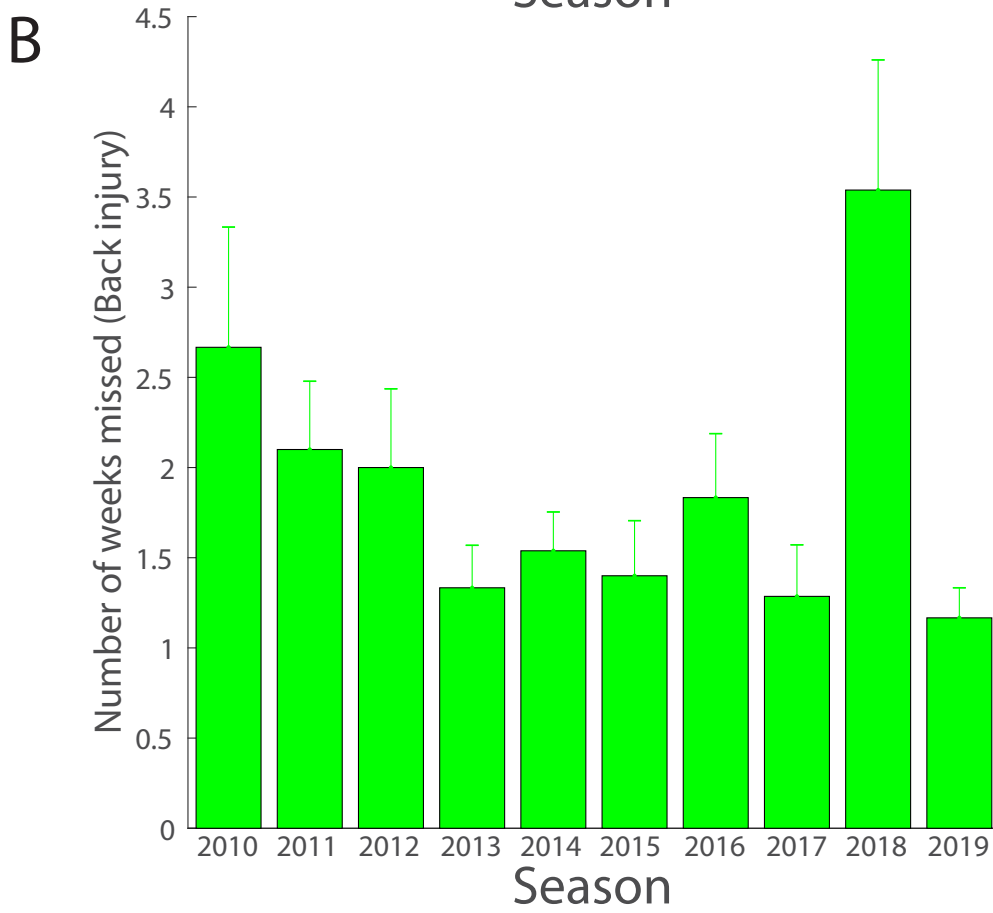
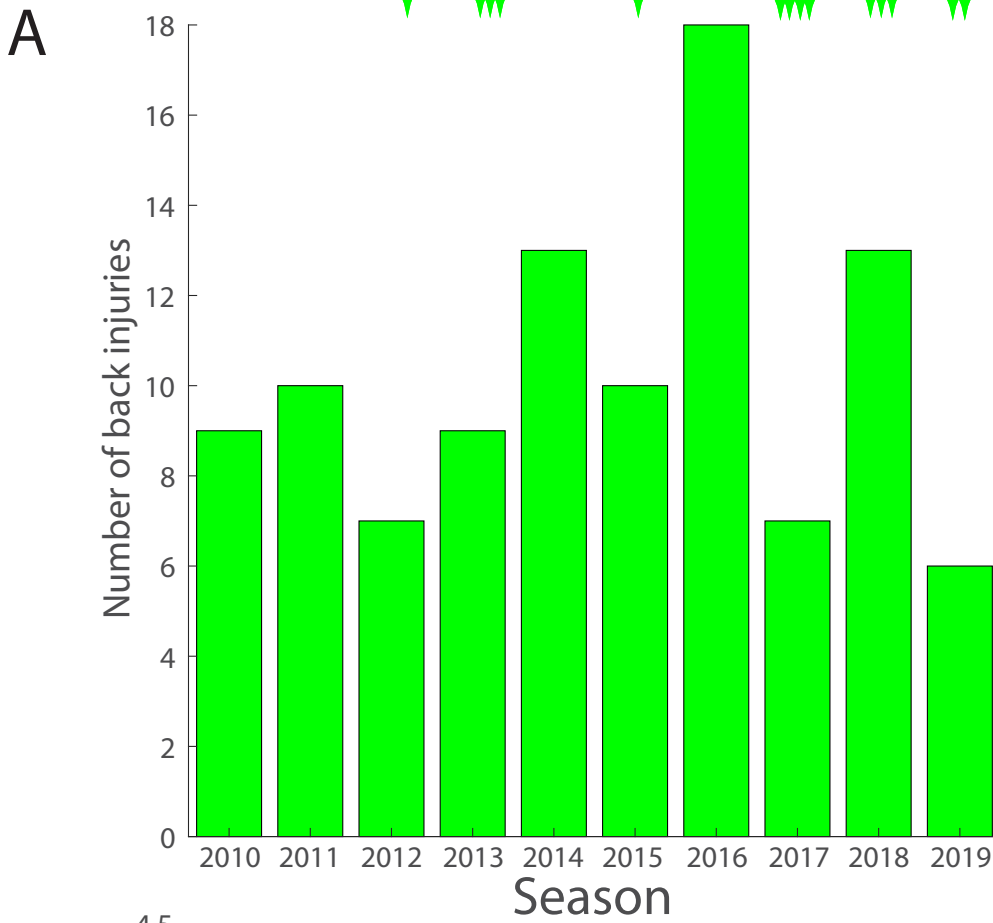
Position\Season	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
C	0	0	0	2	0	1	2	3	1	0
CB	6	3	10	3	7	12	10	6	10	4
DE	3	4	3	2	1	5	3	3	2	0
DT	1	4	1	1	1	1	0	1	0	0
G	0	4	4	2	1	3	8	1	2	1
K	0	0	0	0	0	0	0	0	0	0
KR	0	0	0	0	0	0	0	0	0	0
LB	6	5	5	2	2	12	12	6	7	6
LS	0	0	0	0	0	0	0	0	0	0
OL	0	0	0	0	0	0	0	0	0	11
P	0	0	0	0	0	0	0	0	0	0
QB	4	1	3	5	1	5	4	2	1	1
RB	1	3	7	6	5	10	5	3	0	3
S	8	4	3	3	4	5	9	5	5	3
T	2	4	0	3	2	12	8	5	2	2
TE	5	4	6	8	2	9	11	6	7	9
WR	9	4	11	7	3	9	7	5	2	11
FB	0	0	0	0	0	0	0	0	0	0

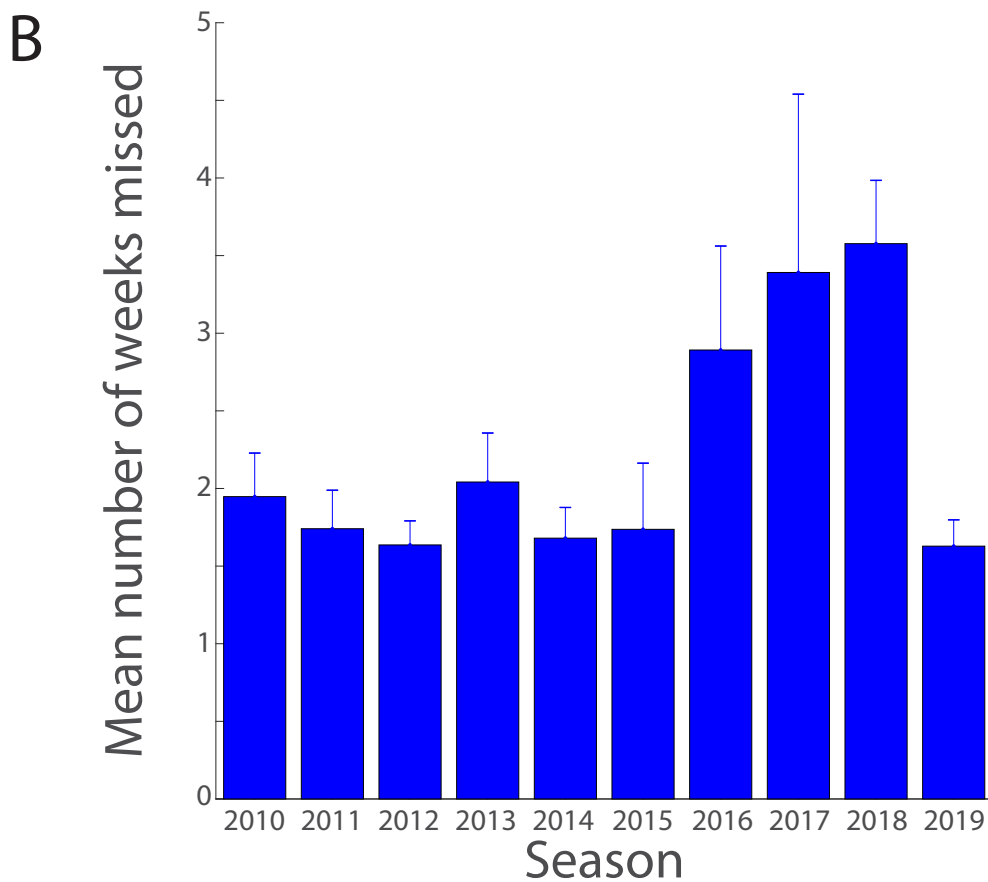
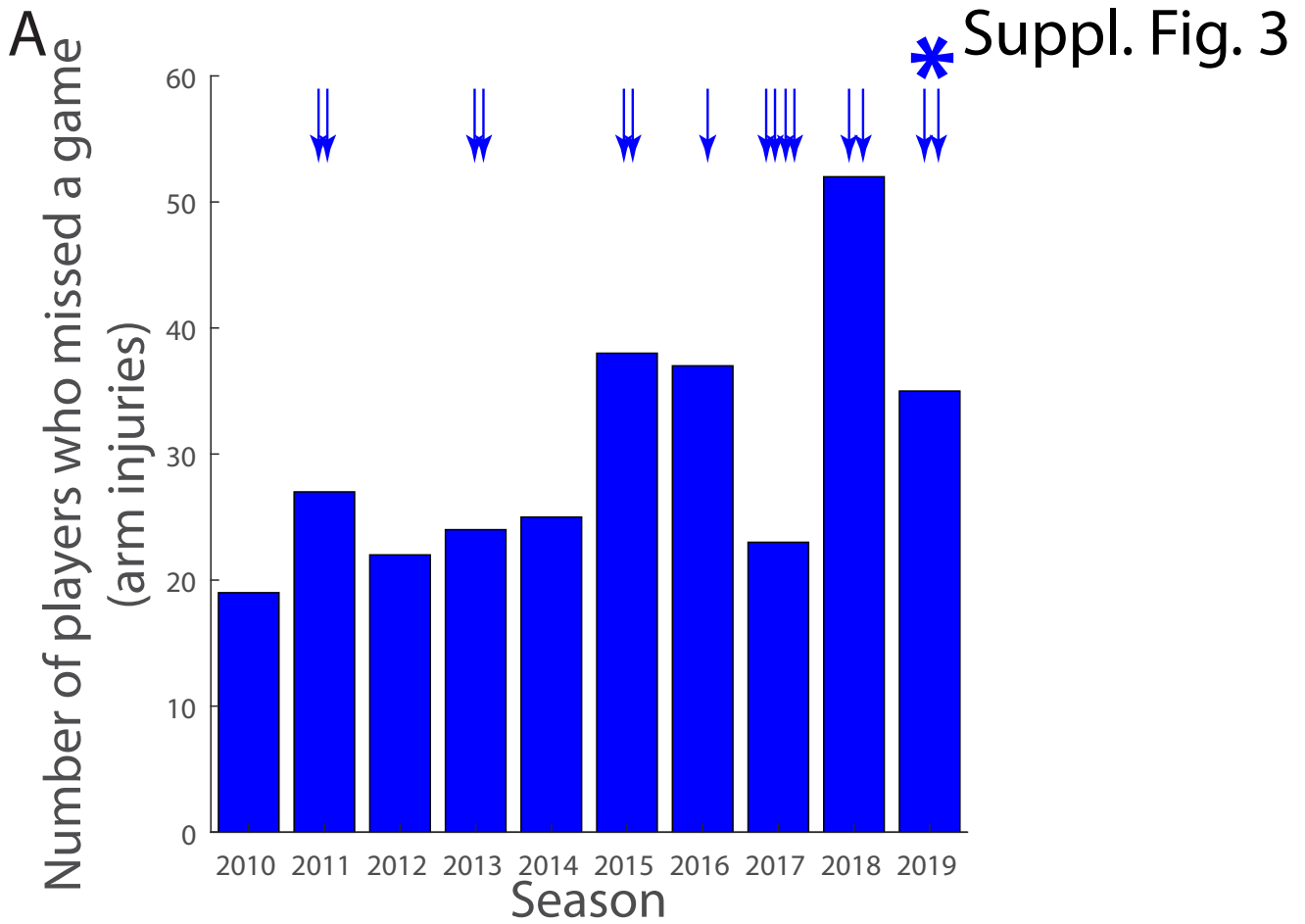
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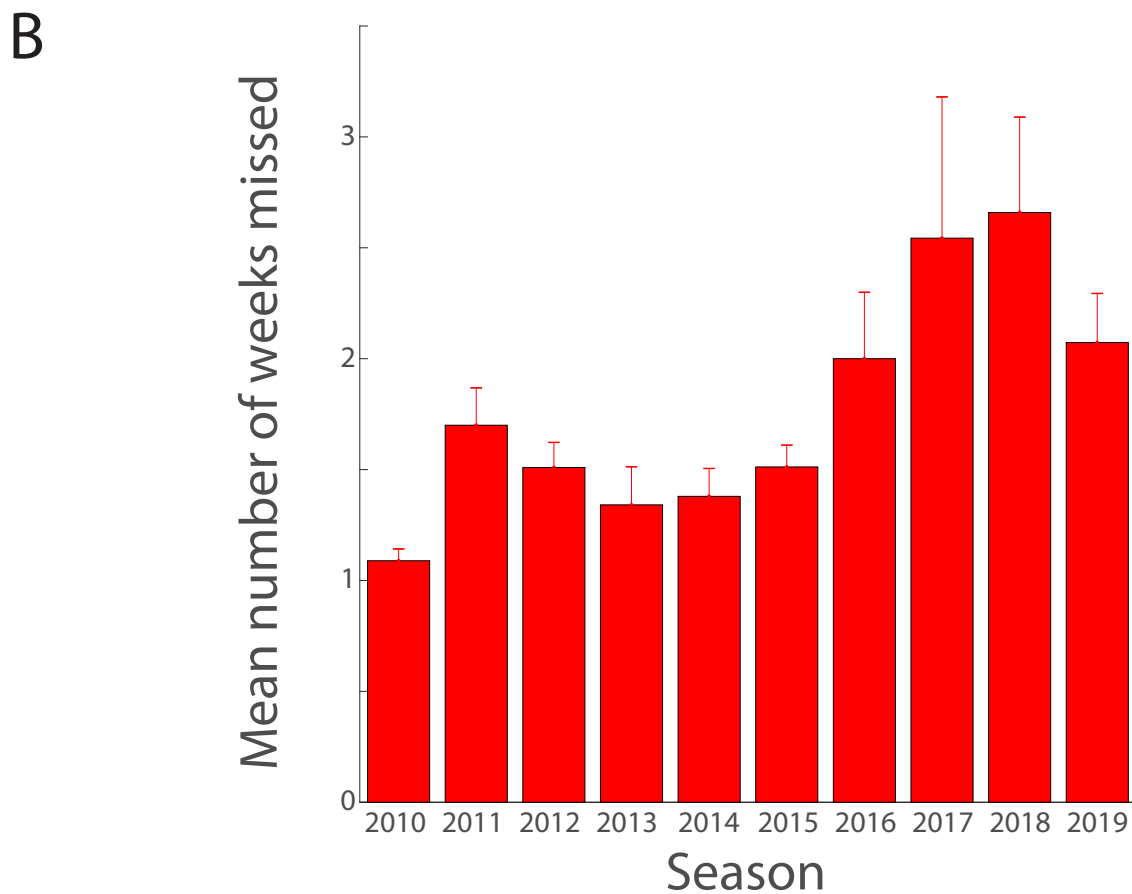
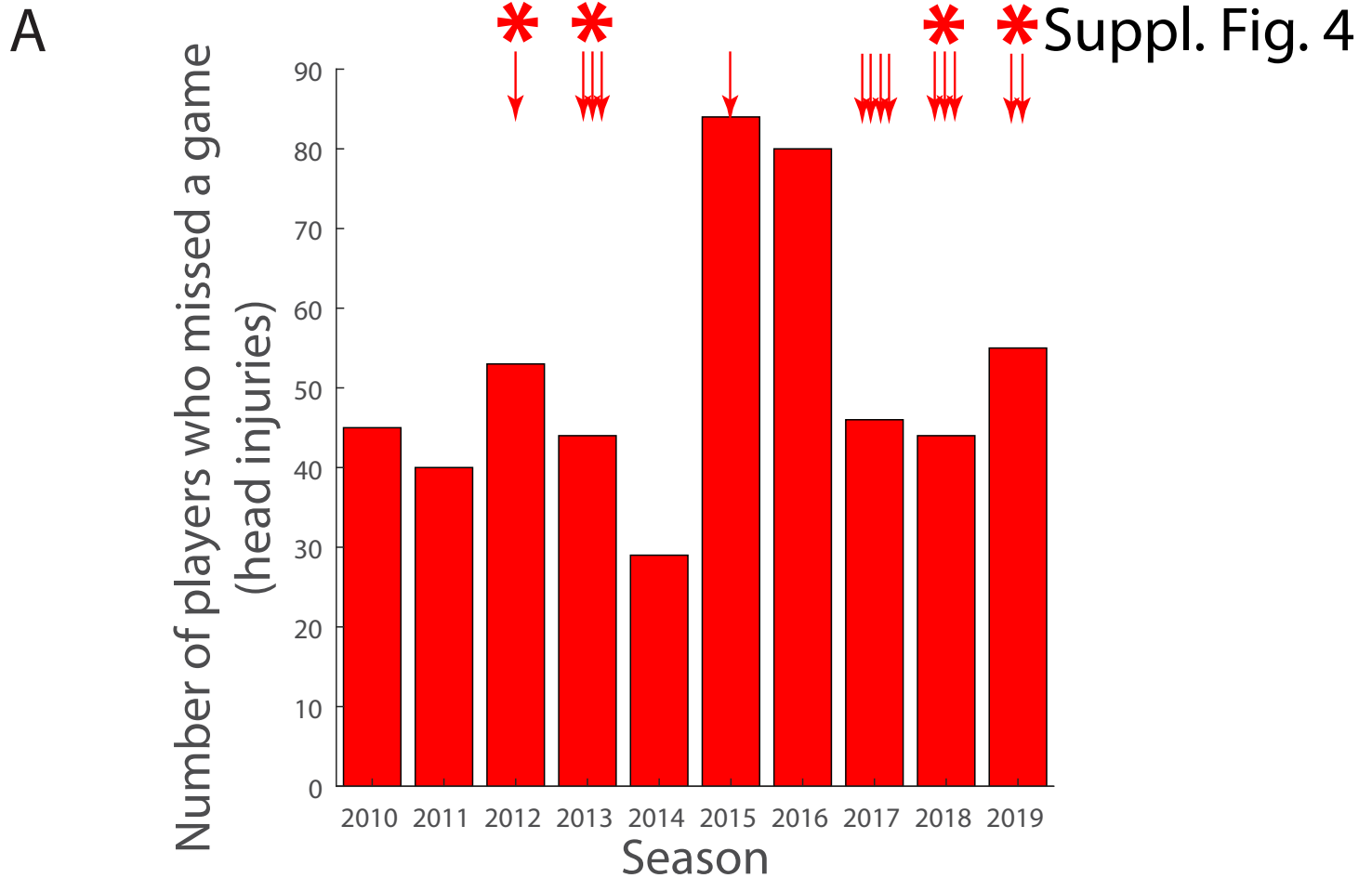
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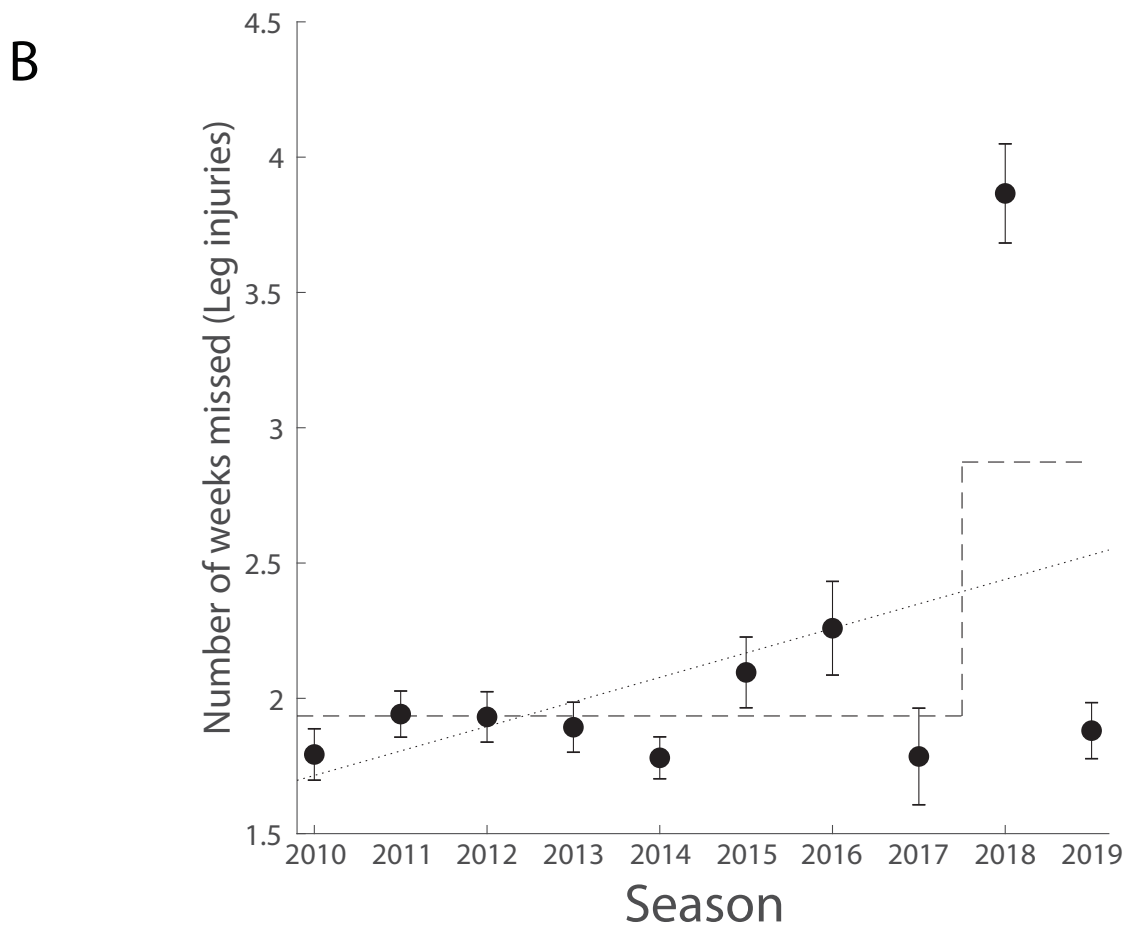
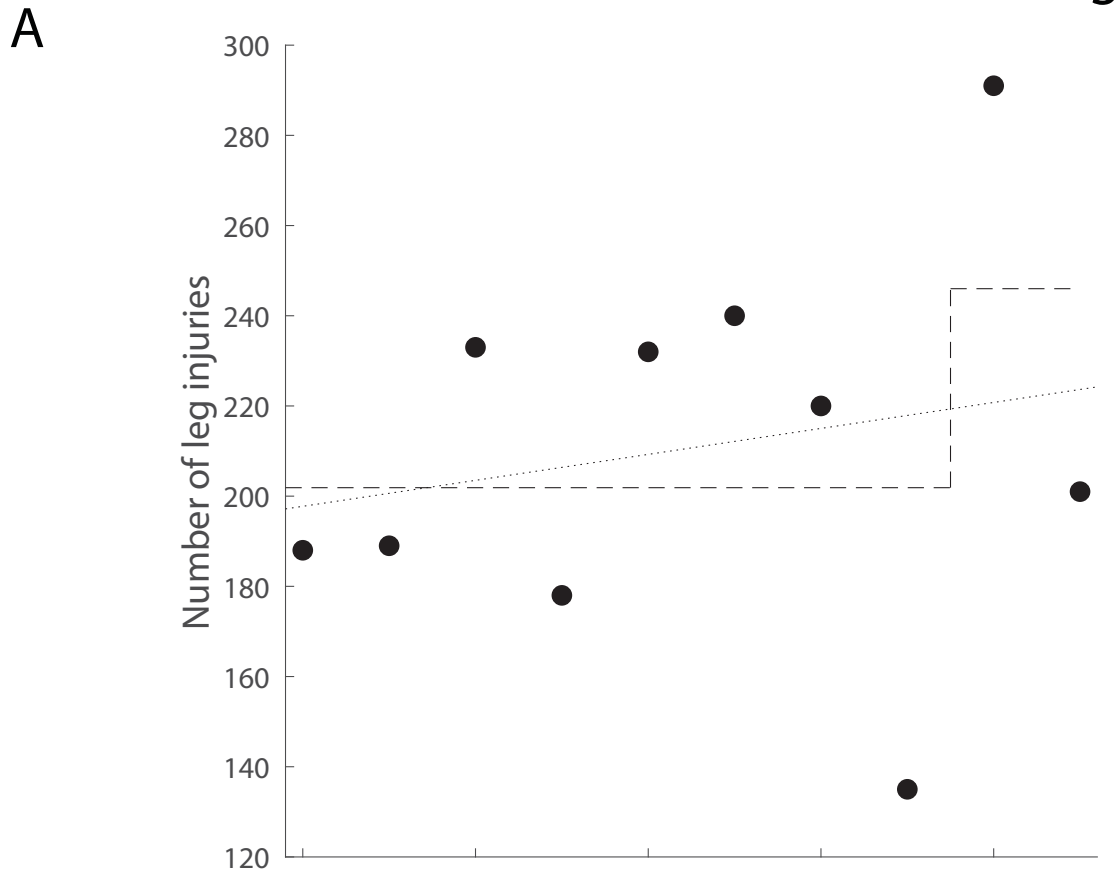
Suppl. Fig. 2



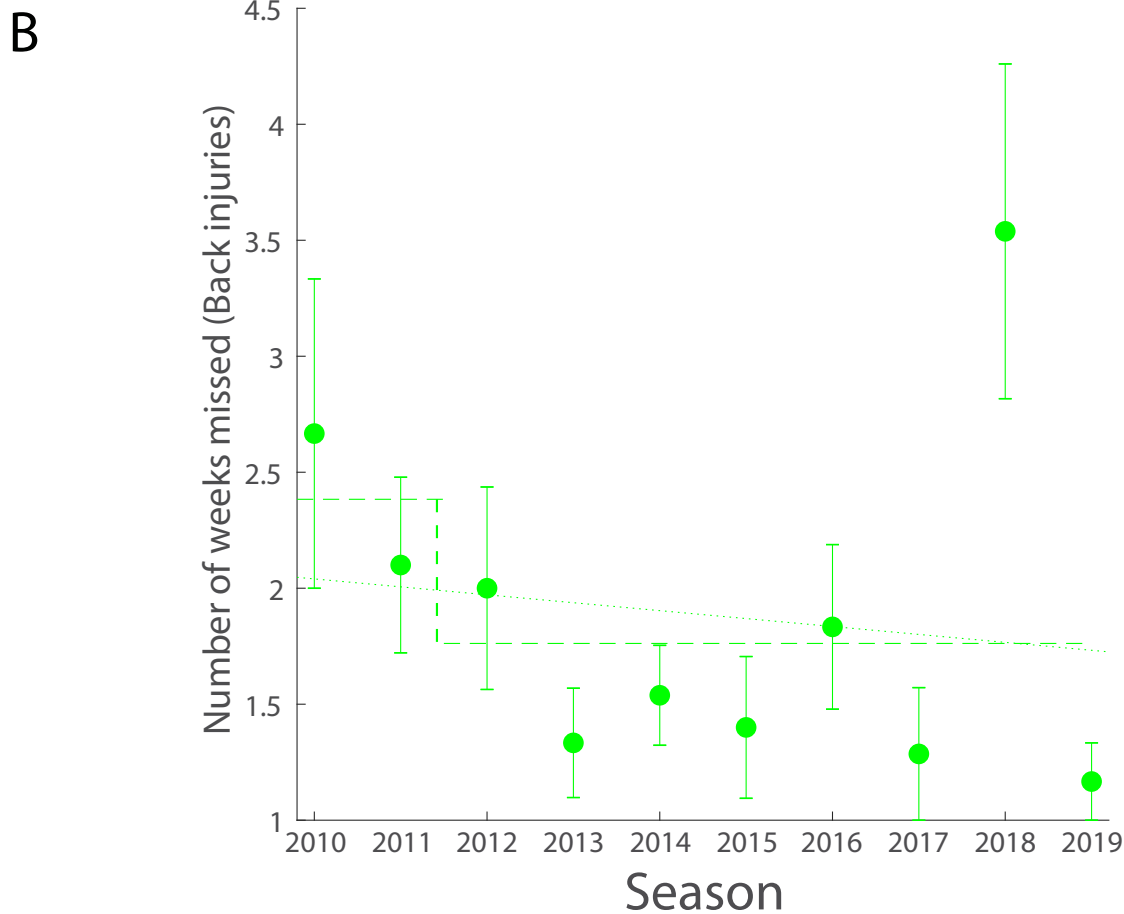
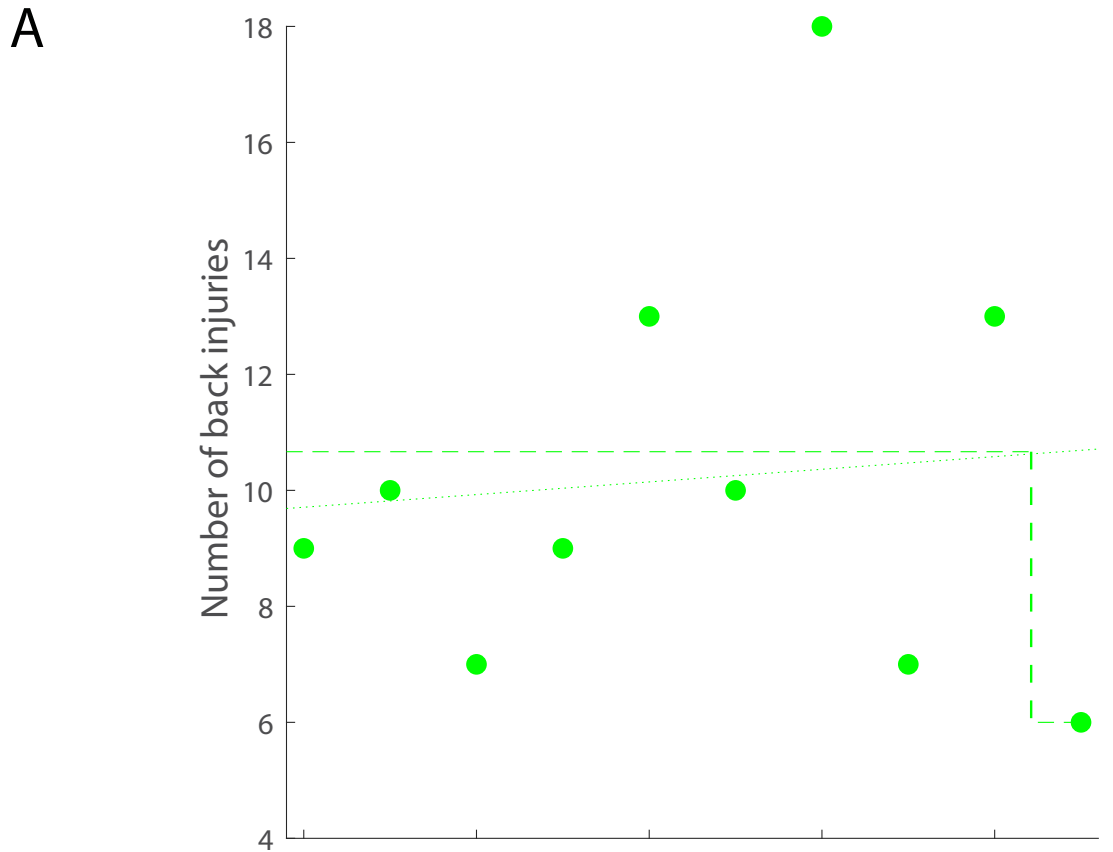




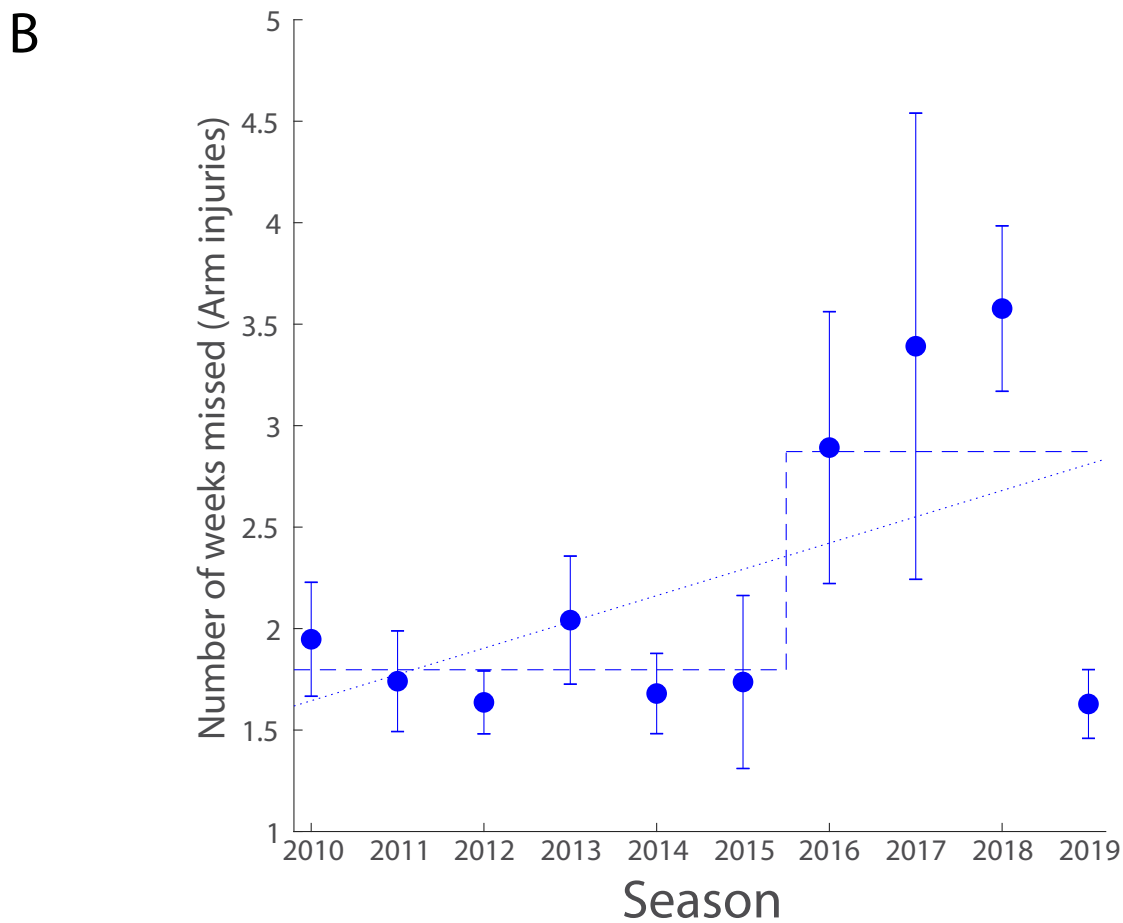
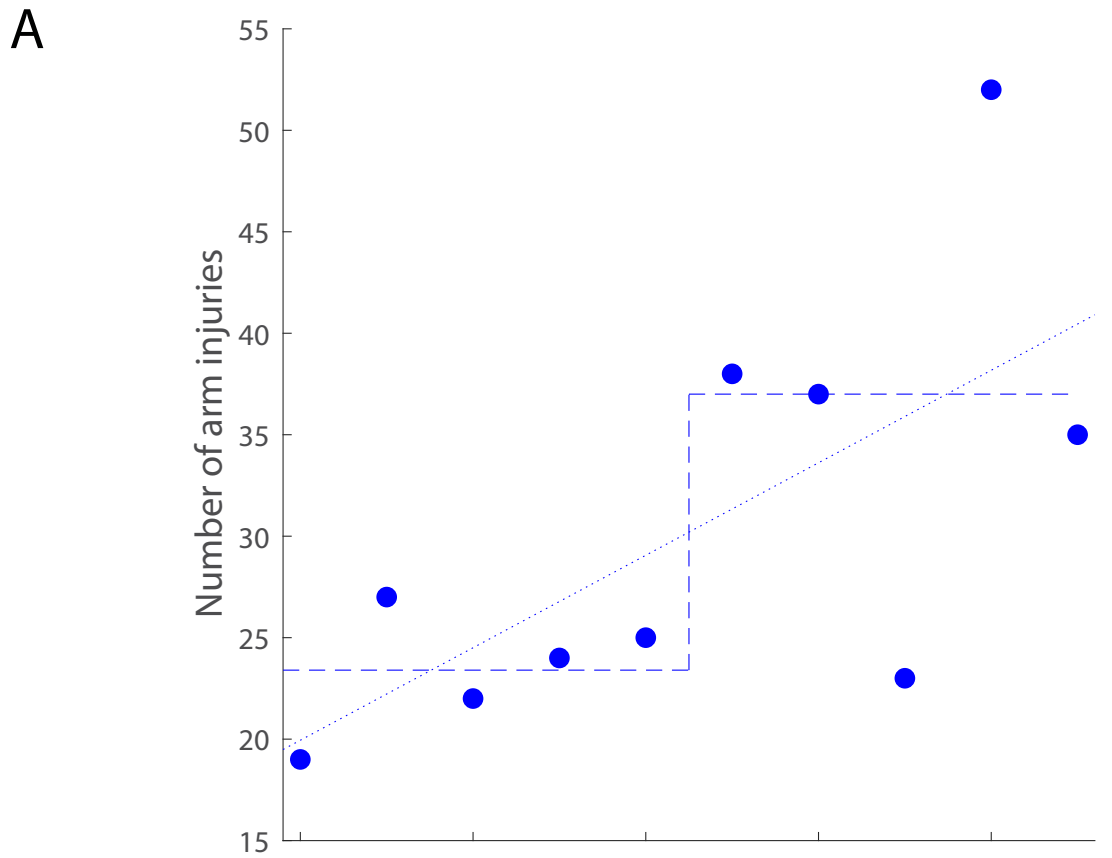
Suppl. Fig. 5



Suppl. Fig. 6

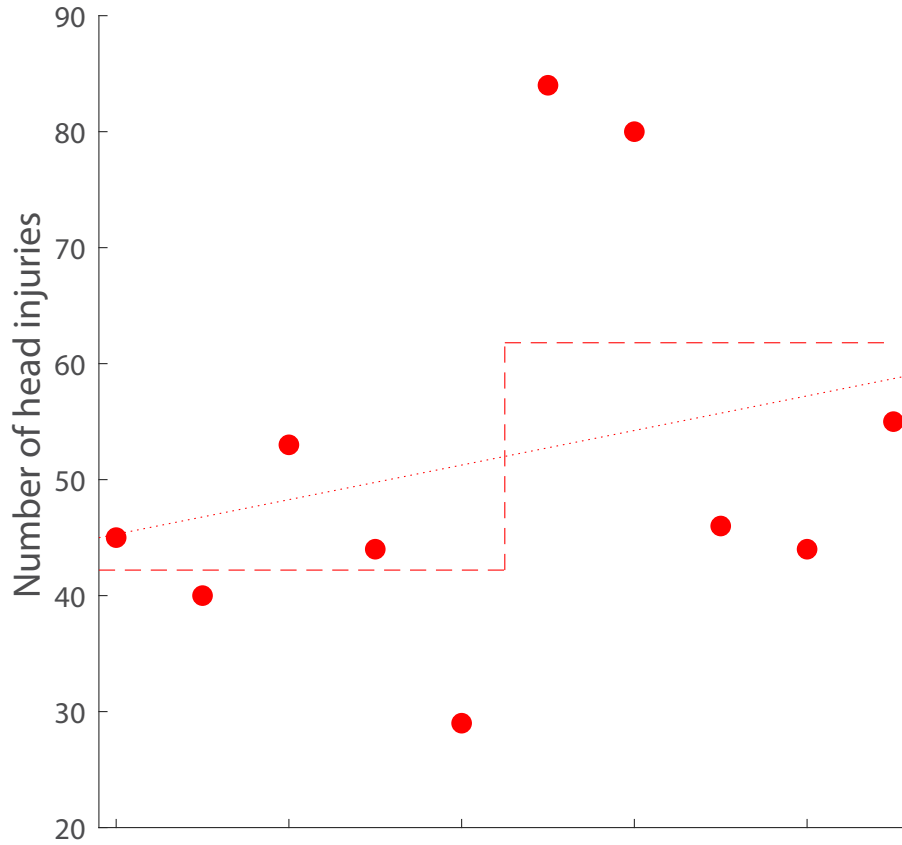


Suppl. Fig. 7

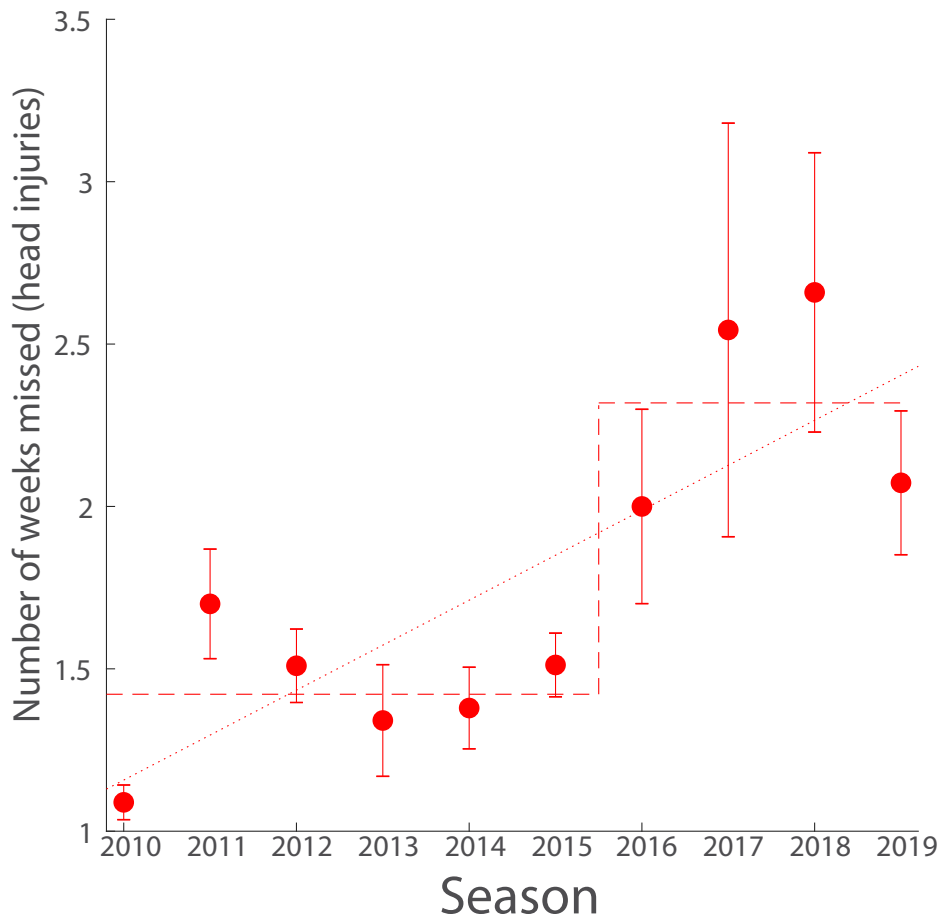


Suppl. Fig. 8

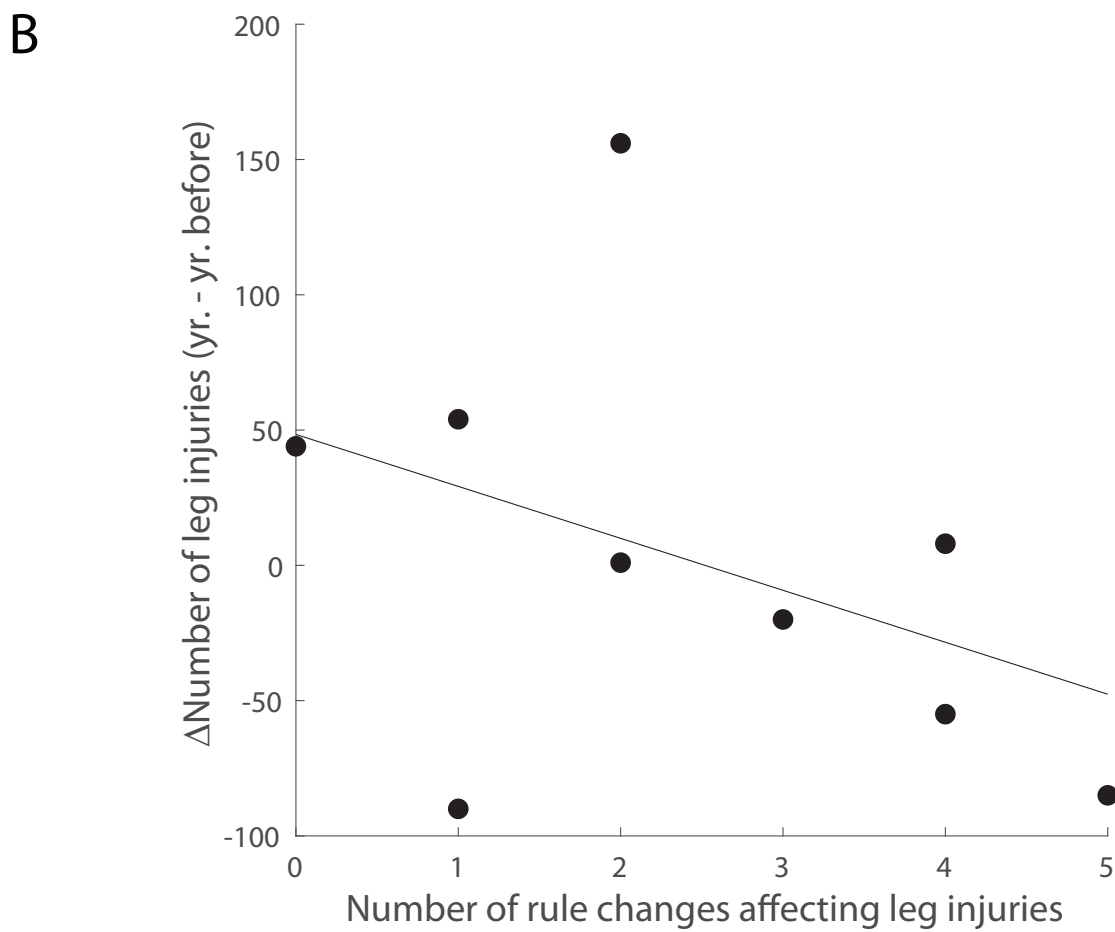
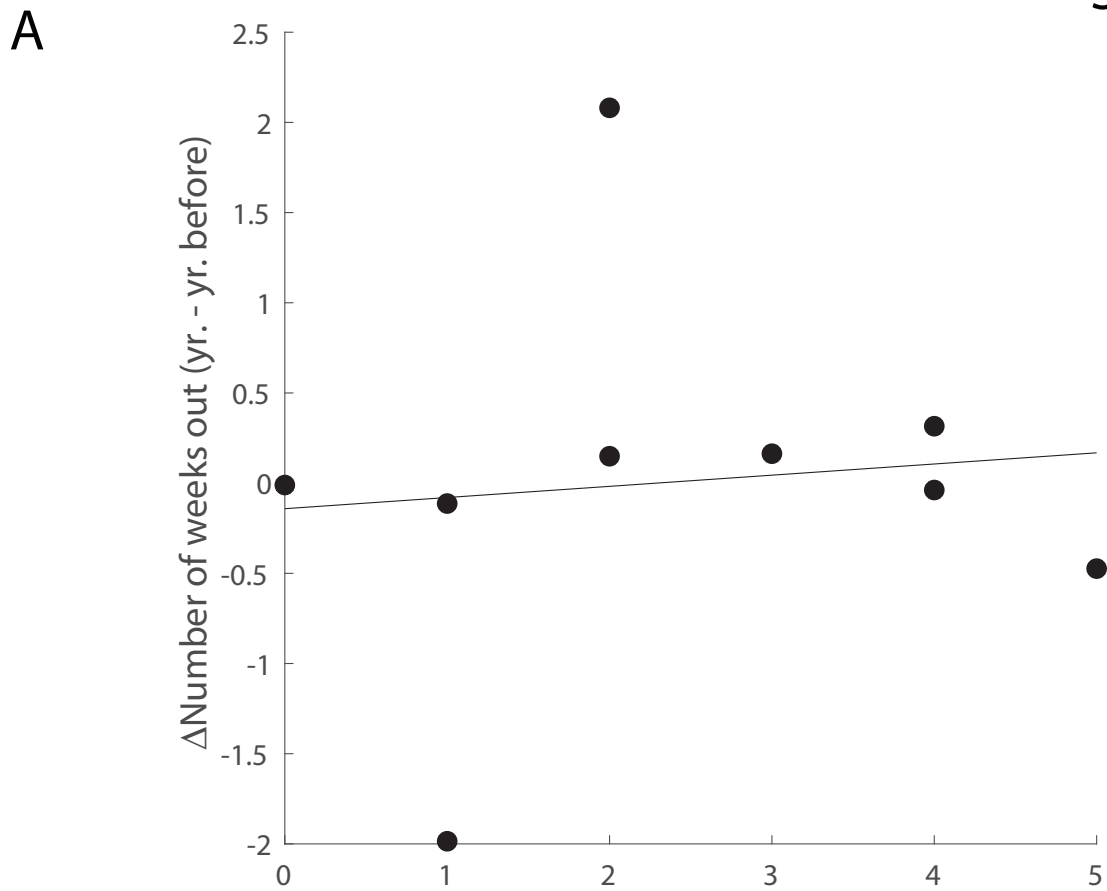
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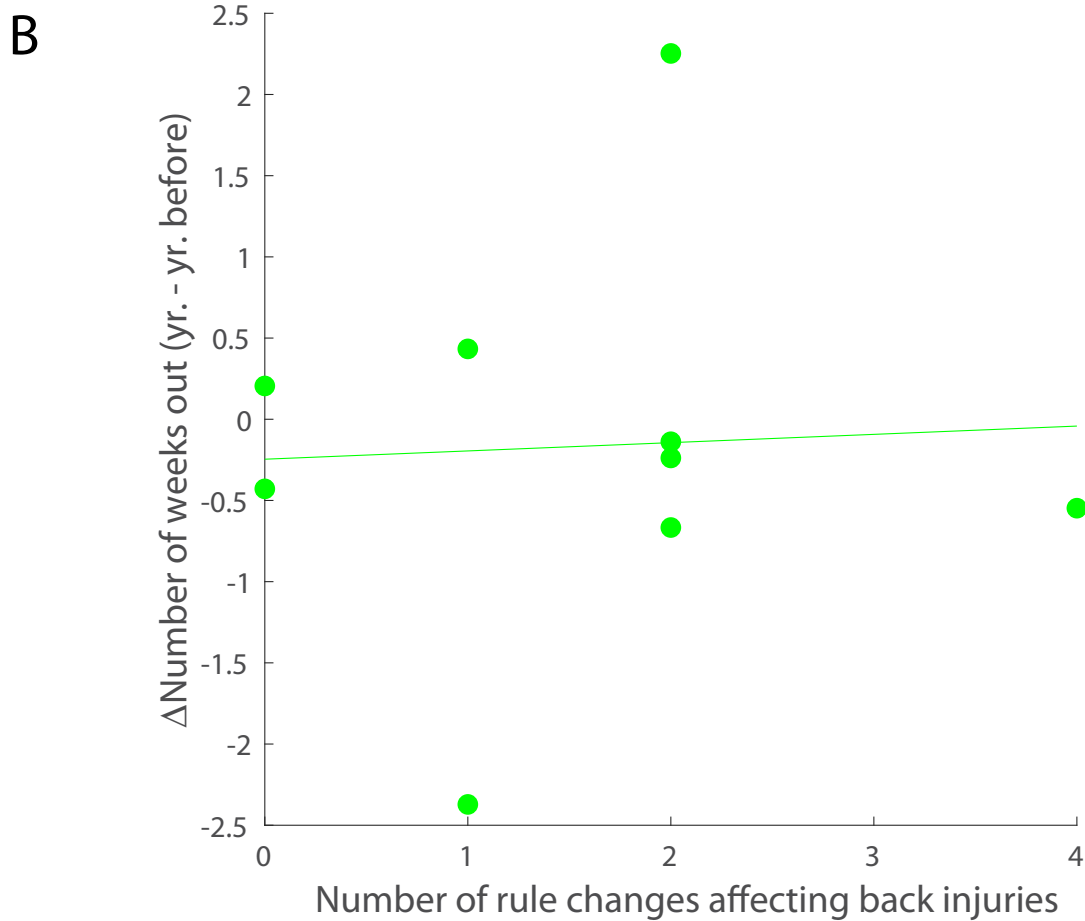
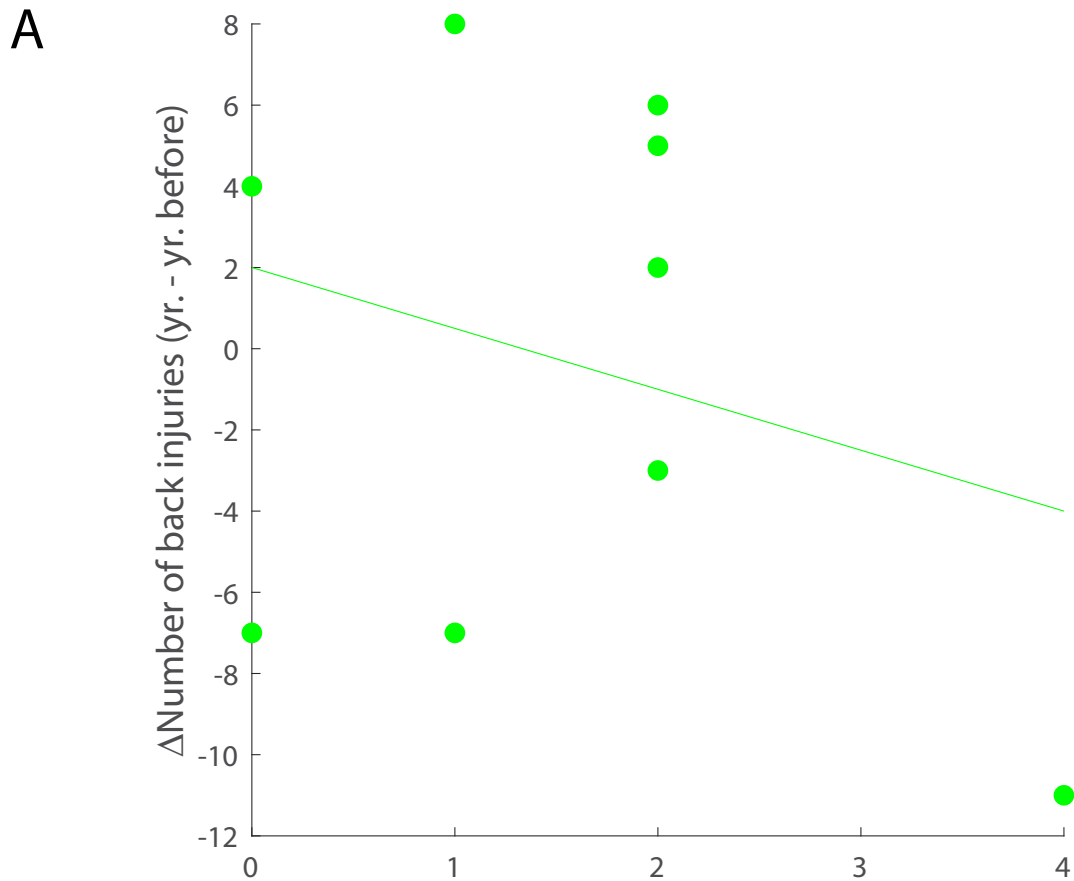
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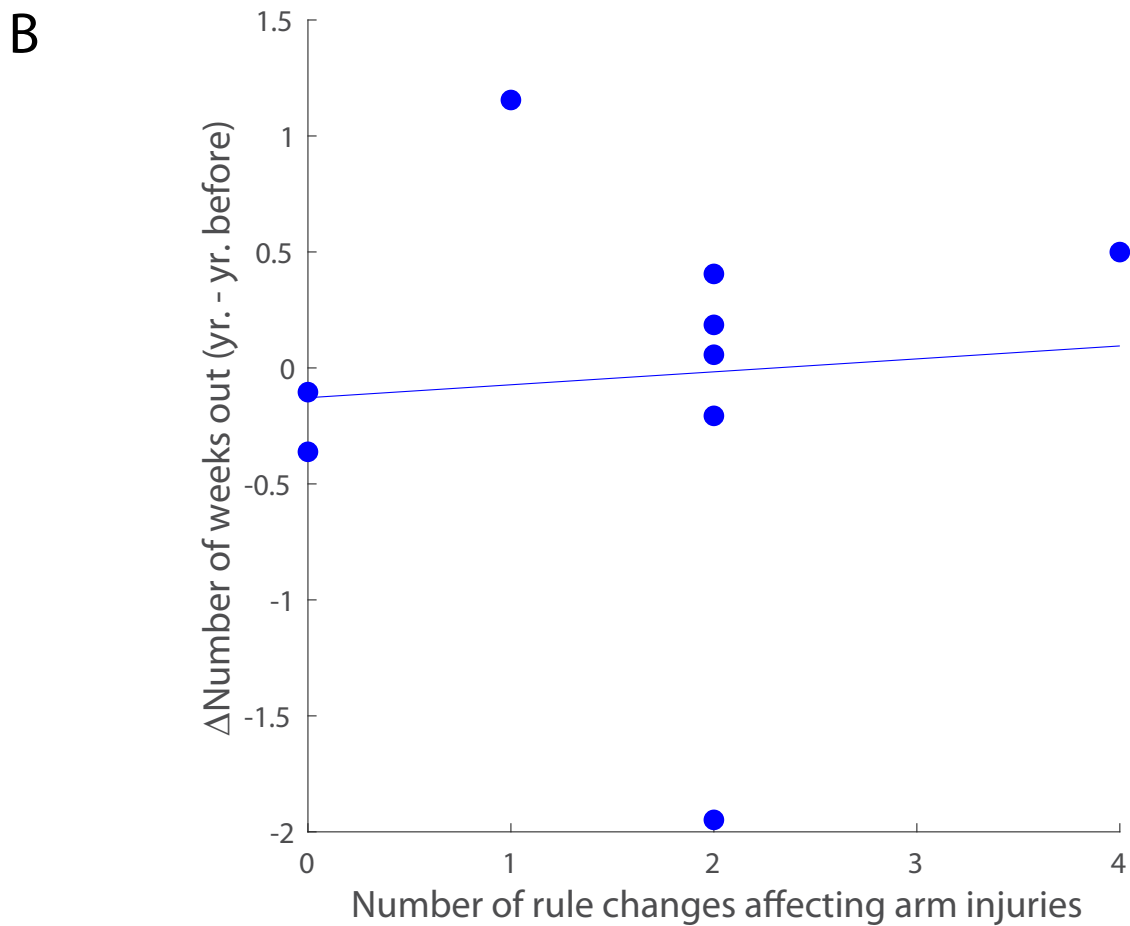
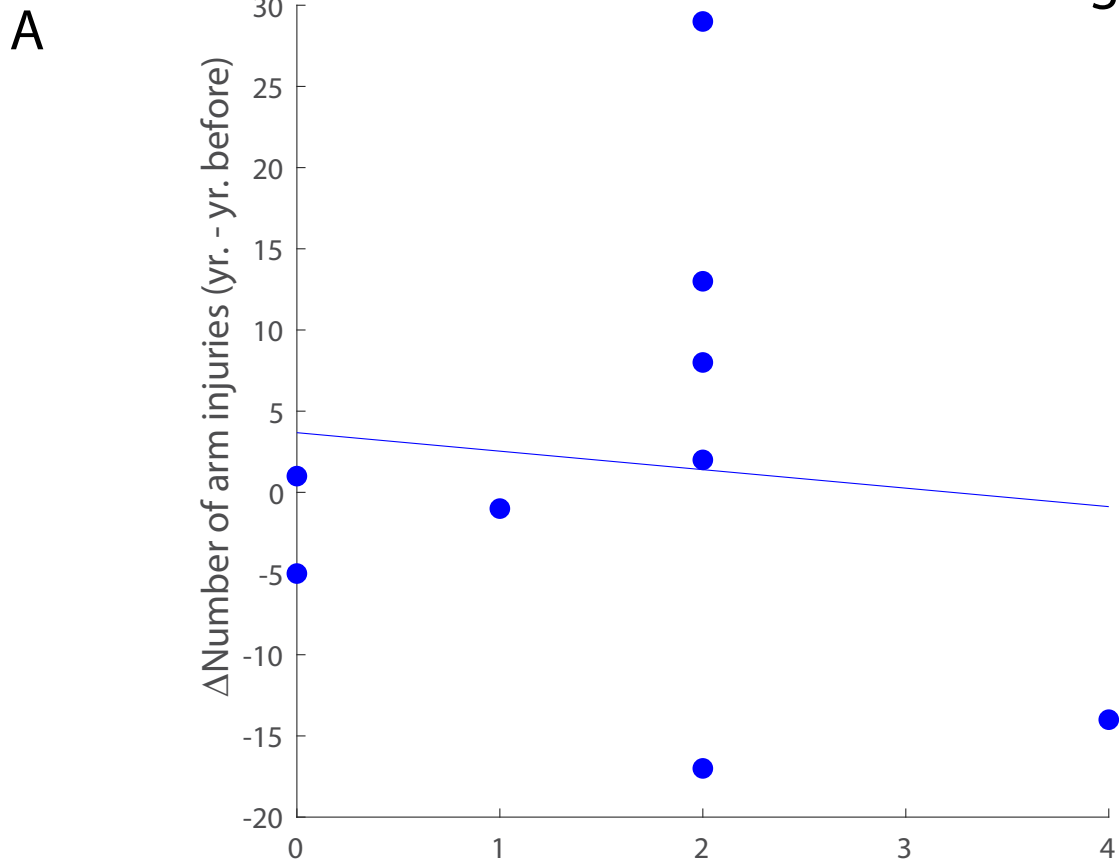
Suppl. Fig. 9



Suppl. Fig. 10



Suppl. Fig. 11



Suppl. Fig. 12

