Original article

Association between feels-like temperatures and injury risk during international outdoor athletic championships: A prospective cohort study on 29,579 athlete starts during 10 championships

Pascal Edouard[1,2,3], Pierre-Eddy Dandrieux[1,4,5], Milan Klöwer[6], Astrid Junge[5], Sébastien Racinais[7,8], Pedro Branco[3], Karsten Hollander[5], Laurent Navarro[4]

Affiliations:

[1] Université Jean Monnet, Lyon 1, Université Savoie Mont-Blanc, Inter-university Laboratory of Human Movement Biology, EA 7424, F-42023, Saint-Etienne, France

[2] Department of Clinical and Exercise Physiology, Sports Medicine Unit, University Hospital of Saint-Etienne, Faculty of Medicine, Saint-Etienne, France

[3] European Athletics Medical & Anti-Doping Commission, European Athletics Association (EAA), Lausanne, Switzerland

[4] Mines Saint-Etienne, Univ Lyon, Univ Jean Monnet, INSERM, U 1059 Sainbiose, Centre CIS, F-42023 Saint-Etienne France

[5] Institute of Interdisciplinary Exercise Science and Sports Medicine, MSH Medical School Hamburg, Hamburg, Germany

[6] Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge MA, USA

[7] CREPS Montpellier – Font Romeu, Environmental stress unit, Montpellier, France

[8] DMEM, Univ Montpellier, INRAE, Montpellier, France

Correspondence to

Pascal Edouard, MD PhD, Department of Clinical and Exercise Physiology, Sports Medicine Unit, IRMIS, Campus Santé Innovations, University Hospital of Saint-Etienne, 42 055 Saint-Etienne cedex 2, France. Tel.: +33 674 574 691; Fax numbers: +33 477 127 229; E-mail: Pascal.Edouard@univ-st-etienne.fr

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ABSTRACT

Objective: To analyse associations between feels-like temperatures measured with the universal thermal climate index (UTCI) and injury rates during international athletics championships.

Methods: During 10 international outdoor athletics championships from 2007-2022, in-competition injuries were collected by medical teams and local organising committees. UTCI was extracted hourly from a global reanalysis of observed atmospheric conditions during each championship. We performed Poisson regressions with incidence rates (number of injuries per 1,000 athlete starts) as outcomes and UTCI as a predictive variable adjusted for sex, for all and time-loss injuries, for different injured tissue types (i.e., muscle, tendon, ligament, articular, bone, and skin) and specific discipline (i.e., sprints, hurdles, jumps, throws, middle distance, long distance, marathon, and race walking).

Results: A total of 1,203 in-competition injuries were reported for 29,579 athlete starts. For all in-competition injuries (i.e., all injured tissue types and all disciplines), higher UTCI was associated with lower incidence rates for time-loss injuries (IRR=0.98, 95%CI: 0.97-0.98) but not for all injuries (IRR=1.00, 95%CI: 1.00-1.01). Based on injured tissue type with all disciplines included, higher UTCI was associated with lower incidence rates for all (IRR=0.97, 95%CI: 0.97-0.98) and time-loss (IRR=0.96, 95%CI: 0.96-0.96) muscle injuries. Based on the specific discipline, higher UTCI was associated with lower incidence rates for all and time-loss muscle injuries for sprints (IRR=0.95, 95%CI: 0.95-0.96, and IRR=0.94, 95%CI: 0.93-0.94, respectively), hurdles (IRR=0.97, 95%CI: 0.96-97, and IRR=0.95, 95%CI: 0.94-0.96, respectively), and throws (IRR=0.97, 95%CI: 0.97-0.98).

Conclusions: Higher feels-like temperatures were associated with a decreased risk of time-loss and muscle injuries, particularly in sprints, hurdles, and throws. Although the precise mechanism for lower injury rates with higher feels-like temperatures requires further

investigation, adapting preparations such as warm-up or clothing to forecasted weather conditions may be of benefit.

Keywords: Sports injury; epidemiology; track and field; climate; weather.

KEY MESSAGES / SUMMARY BOX

What is already known on this topic?

- While some intrinsic risk factors are associated with higher injury risk during international athletics championships, no environmental risk factors (such as heat or cold stress) have been analysed in this context.
- We hypothesised that lower feels-like temperatures might increase the risk of musculoskeletal (e.g., muscle and tendon) injuries.

What this study adds?

- During international athletics championships, lower feels-like temperatures were associated with a higher risk of time-loss injuries, and specifically all and time-loss muscle injuries.
- For all injury types and all disciplines, for every 10°C decrease in feels-like temperature (in the interval of 1.1°C to 38.9°C), the risk of time-loss injury increased by about 20%, and the risk of all or time-loss muscle injury by 30-40%.
- In sprints, hurdles and throws, for every 10°C decrease (in the interval of 1.1°C to 38.9°C), the risk of injury or muscle injury increased by 20-60%.

How this study might affect research, practice or policy?

- This study may inform injury risk reduction strategies at athletics competitions. Athletes, coaches, medical teams, and championship organisers may consider i) warmer clothing to limit muscle temperature loss in cold outdoor environments, ii) active and passive methods to increase muscle temperature, and iii) adapting the timing of events to limit environmental cold stress.

INTRODUCTION

Participating in international athletics championships is associated with a risk of sustaining an injury with consequences on health and performance.[1,2] This supports the need for injury risk reduction strategies, which should be based on the understanding of mechanisms and risk factors.[3] While some intrinsic risk factors have been reported to be associated with a higher injury risk during international athletics championships (e.g., previous injury,[4,5] male sex,[6] higher age,[7,8] illness symptom causing anxiety,[5] or type of event/discipline[1,5]), no environmental risk factor has been analysed in this context. Environmental heat or cold stress could be an environmental risk factor for injury.

Experimental animal studies showed that 1) an increase in muscle temperature due to warm-up leads to an increase in force and length of stretch needed to tear a muscle,[9] 2) an increase in tendon temperature leads to an increase in force and length of stretch to rupture the tendon,[10,11] and 3) reduced temperatures lead to decreases in nerve conduction velocities,[12,13] which can affect the neuromuscular control. Experimental human studies also reported extreme (i.e., cold and heat) tissue temperatures lead to alteration of neuromuscular electrophysiology,[14,15] and proprioception and balance.[16,17] Based on these laboratory studies, we hypothesised that a decrease in tissue temperature associated with colder outdoor environments would increase the risk of musculoskeletal injuries.

Few studies analysed the relationships between environmental temperature and sports injuries. In football, injury incidence was higher in teams from northern compared to more southern European countries.[18,19] In Australian Football League, ligament injuries were generally more likely in teams playing in warmer climate zones, and tendon injuries in teams playing in cooler zones.[20] In the United States of America (USA) National Football League, an

increased risk for concussion and ankle injuries during matches played at colder temperatures was reported.[21] In athletics, lower rates of hamstring injuries were reported when temperatures were above 25°C, and higher rates when temperatures were between 10-14.9°C.[22] Based on these epidemiological field studies, we hypothesised that a decrease in environmental temperature would increase the risk of musculoskeletal injuries.

In this context, we hypothesised that lower environmental temperatures would increase the injury risk in athletics championships. Therefore, we aimed to analyse the associations between feels-like temperatures and injury rates during international athletics championships. Feels-like temperatures describe air temperatures adjusted with wind speed, solar and terrestrial radiation, and humidity to quantify physiologically more relevant temperatures. An improved understanding of the potential association between environmental temperatures and injuries is of great interest to reduce their risk. In the context of global warming, it is of additional interest to know if future weather conditions might impact injury risk in athletics competitions and more generally outdoor sports.

METHODS

Study design and overall procedure

In this total population study, we analysed the associations between feels-like temperatures measured with the Universal Thermal Climate Index (UTCI),[23,24] and the incidence rate of in-competition injuries among elite athletes participating in at least one of the 10 following international athletics championships: Olympic Games 2012;[25] World Outdoor Championships 2007,[26] 2009,[27] 2011,[28] and 2013;[29] and European Outdoor Championships 2012,[7] 2014, 2016, 2018, and 2022 (Supplementary Table 1).

Before each championship, athletes were informed about the study and that they could refuse the use of their data.[1,6,30,31] All injuries reported to the database were pseudo-anonymous. The study protocol was reviewed and approved by the Saint-Etienne University Hospital Ethics Committee (Institutional Review Board: IORG0007394; IRBN742020/CHUSTE).

Patient and public involvement

There was no patient or public involvement.

Equity, diversity, and inclusion statement

All athletes registered at the international athletics championships were included in this study without any restriction based on sex, race/ethnicity/culture, socioeconomic level, or representation from marginalised groups. Apart from sex and discipline, no other sociodemographic data were considered in the analysis and interpretation of results.

The research team included two sexes, one junior researcher, one senior physician and six senior researchers, from a variety of disciplines (sports medicine, sports science, sports epidemiology, physical medicine and rehabilitation, data science, and earth, atmospheric and planetary sciences), and four different countries in Europe (France, Portugal, Germany) and America (USA).

Injury and exposure definition and data collection

All data were collected using the same study design, injury definition and data collection procedures, previously described in detail.[1,6,30,31]

Injuries were collected by the national medical teams (physicians and/or physiotherapists) and/or by the local organising committee physicians (LOC) daily during each championship.[1,6,30,31] Injuries were defined as “all musculoskeletal injuries (traumatic and overuse) and concussion newly incurred during competition or training regardless of the

consequences with respect to the athlete's absence from competition or training".[1,6,30,32] We included in the present study only injuries occurring during competitions (injuries during warm-up were considered as in-competition injuries; training injuries were excluded). For each recorded injury, we knew the event and competition round and/or the date (and sometimes also the time) during which the injury occurred. We analysed all in-competition injuries and in-competition time-loss injuries, as well as these two categories according to the type of tissue injured: muscle, tendon, ligament, articular, bone, and skin.[1]

For each event, we extracted from the results list of World Athletics (https://worldathletics.org/competition/calendar-results) or European Athletics (https://www.european-athletics.com) the number of athletes taking part in the event as exposure measurement (i.e., athlete starts of each round and event) and the date and time of the event, which was used to match with the recorded injuries and the hourly feels-like temperatures.

Disciplines were grouped in eight categories (sprints, hurdles, jumps, throws, middle distance, long distance, marathon and race walking) as in previous studies.[1,6,32] In the present study, each event of the discipline "combined events" was included in the corresponding discipline category (e.g., 100 metres included in sprints, long jump in jumps, shot put in throws). Although "combined events" is a specific discipline, it includes different events from the disciplines of running, jumping and throwing. They all have different durations and the influence of temperature on injury risk could differ between them, as for the other eight athletics discipline categories.

Feels-like temperature data collection

Different indices are used to quantify how temperatures physiologically feel like, the so-called feels-like temperatures.[33] One of these is the UTCI,[23,24,33–36] which provides a unitary

estimate of the physiological experience of temperature,[23,24,34,35] to determine feels-like temperatures. UTCI can be calculated directly from weather forecasts and past weather data from global weather models. To calculate the Wet-Bulb Globe Temperature (WBGT), this requires to have on-site (or nearby) measurements. On-site weather measurements are not necessarily available, neither would they allow to investigate past injury data for which no weather measurements were taken. Furthermore, if on-site measurements were taken, they are not necessarily comparable across events in various stadiums on several continents over a decade (e.g., measurements might be taken in the sun or under an umbrella, on bare ground or over moist grass, or exposed to or sheltered from wind). In addition, WBGT does not actually quantify the heat stress on the human. Technically, it assumes a human to be a small black sphere (globe) that wears soaking wet clothes (wet bulb). We thus decided to use a single consistent global weather data set that circumvents these problems and use the UTCI as proposed by Hollander et al.[36] investigating its impact on heat illnesses.

In the present study, we used UTCI data from Di Napoli et al.[35] who combined the meteorological variables air temperature, humidity, wind speed and solar radiation as provided in the ERA5-HEAT dataset.[37] ERA5-HEAT quantifies UTCI globally at 25km and hourly resolution and is based on the ERA5 reanalysis, which is a best estimate for the local weather globally over the last decades combining both observational data and model calculations. The closest point to the respective stadium for every championship was chosen, and available data in surrounding points was used to estimate the uncertainty of the UTCI calculation. Hourly UTCI during the period of each championship (Figure 1) was matched with the time of each competition event.

Data analysis

We performed a descriptive analysis and presented the data using frequency with percentage

for categorical data and mean with standard deviation for continuous variables.

For each event of the 10 international championships, the number of injuries, the number of athlete start and the UTCI were available. We calculated several *incidence rates,* i.e., number of injuries per 1000 athlete starts (with 95% confidence intervals, 95%CI), for all in-competition injuries and in-competition time-loss injuries, and according to the injured tissue type (i.e., muscle, tendon, ligament, articular, bone and skin), and according to the disciplines (i.e., sprints, hurdles, jumps, throws, middle distance, long distance, marathon and race walking). The 95% confidence intervals for the incidence rates were calculated using the exact Poisson confidence intervals with the following equations:

$$95\%\ CI\ lower\ limit = \frac{\chi^2_{2Y,\alpha/2}}{2T}$$

$$95\%\ CI\ upper\ limit = \frac{\chi^2_{2(Y+1),1-\alpha/2}}{2T}$$

with Y = number of injuries, T = number of athlete starts, $\alpha = 0.05$

We then performed Poisson regressions with incidence rates as outcome and UTCI as predictive variable, adjusted for sex. More precisely, we first performed a Poisson regression with incidence rate of all in-competition injuries as outcome and UTCI as predictive variable adjusted for sex, and then a Poisson regression with incidence rate of in-competition time-loss injuries as outcome and UTCI as predictive variable adjusted for sex. Since the influence of the temperature on each tissue can differ, we then performed Poisson regressions for each injured tissue type (i.e., muscle, tendon, ligament, articular, bone and skin) with incidence rate of all in-competition injuries and in-competition time-loss injuries as outcome and UTCI as predictive variable, adjusted for sex. Finally, since each athletics discipline has different physiological and biomechanical requirements and constraints and that the influence of the

temperature on each discipline can differ, we performed Poisson regressions for each discipline with incidence rates of all in-competition injuries and in-competition time-loss injuries and for each injury type as outcome and UTCI as predictive variable adjusted for sex. For each Poisson regression, we presented the association between the variables using the Incidence Rate Ratio (IRR) with 95% CI and the p-value. We also presented the regressions in figures with their confidence intervals (in gray in the figures), which were calculated using a "non-parametric" bootstrap method. For each regression and figure, 500 regressions were carried out, taking for each point a random UTCI value in surrounding points to estimate the uncertainty of the UTCI calculation, and a random incidence rate in the 95% confidence interval. The confidence intervals of the regressions in the figure corresponds to the 2.5 and 97.5 percentiles extracted from this bootstrap.

The significance level was set at $P < 0.05$. Analyses were performed using Python (version 3.9.12, © Python Software Foundation, https://www.python.org/) and the statsmodels library (version 0.14.1, © 2024, https://www.statsmodels.org/).

RESULTS

Population and feels-like temperatures

A total of 13,817 starts of female and 15,762 starts of male athletes were registered during the total 75 competition days of the 10 international athletics championships. On average, 90.7% of the national medical teams, covering 83.1% of the registered athletes, participated in the injury surveillance project and returned 91.6% of the report forms. No athlete refused the use of their data for scientific research.

The UTCI during the period of the 10 international athletics championships is presented in Figure 1.

In-competition injuries

During the 10 championships, a total of 1,203 in-competition injuries were reported, 483 in female and 720 in male athletes (Supplementary Table 2), corresponding to 35.0 (95%CI: 31.9 to 38.2) injuries per 1000 starts in female and 45.7 (95%CI: 42.4 to 49.1) injuries per 1000 starts in male athletes (Supplementary Table 3). Muscle injuries represented 41.1% of all in-competition injuries, 23.7% were injuries of the skin, 11.9% of ligaments, 11.4% of tendons, 3.9% of bones and 3.1% of articular (4.4% others and for 0.5% information was missing) (Supplementary Table 2).

Association between feels-like temperatures and in-competition injuries

Injury incidence rates of the total injuries in relation to feels-like temperatures measured as UTCI according to the 8 disciplines are presented in Figure 2 for all in-competition injuries and in Figure 3 for in-competition time-loss injuries. The results of the Poisson regressions with IRR and 95%CI are presented in Table 1, and the number of values of incidence rates different than 0 are presented in Supplementary Table 4, allowing to better interpret the results of the regressions.

Overall, for all in-competition injuries with all disciplines included, the Poisson regressions showed that higher UTCI was associated with lower incidence rates for time-loss injuries (IRR=0.98, 95%CI: 0.97 to 0.98), but not for all injuries (IRR=1.00, 95%CI: 1.00-1.01) (Figure 3 and Table 1). By injured tissue types with all disciplines included, the Poisson regressions showed that higher UTCI was associated with lower incidence rates for all in-competition (IRR=0.97, 95%CI: 0.97 to 0.98) and in-competition time-loss (IRR=0.96, 95%CI: 0.96 to 0.96) muscle injuries, in-competition time-loss skin injuries (IRR=0.98, 95%CI: 0.97 to 0.98) and all in-competition articular injuries (IRR=0.98, 95%CI: 0.97 to 0.98) (Table 1).

For sprints, higher UTCI was associated with lower incidence rates for all (IRR=0.97, 95%CI: 0.97 to 0.97; Figure 4) and time-loss (IRR=0.94, 95%CI: 0.94 to 0.95; Figure 5) injuries, and for all (IRR=0.95, 95%CI: 0.95 to 0.96; Figure 4) and time-loss (IRR=0.94, 95%CI: 0.93 to 0.94; Figure 5) muscle injuries (Table 1).

For hurdles, higher UTCI was associated with lower incidence rates for all (IRR=0.98, 95%CI: 0.98 to 0.99) and time-loss (IRR=0.96, 95%CI: 0.96 to 0.97) injuries, and for all (IRR=0.97, 95%CI: 0.96 to 0.97) and time-loss (IRR=0.95, 95%CI: 0.94 to 0.96) muscle injuries (Table 1 and Supplementary Figures).

For jumps, higher UTCI was associated with higher incidence rates for all (IRR=1.01, 95%CI: 1.01 to 1.02) and time-loss (IRR=1.02, 95%CI: 1.02 to 1.03) injuries, and for all (IRR=1.03, 95%CI: 1.02 to 1.03) and time-loss (IRR=1.04, 95%CI: 1.03 to 1.04) muscle injuries (Table 1 and Supplementary Figures).

For throws, higher UTCI was associated with lower incidence rates for all (IRR=0.98, 95%CI: 0.97 to 0.98) and time-loss (IRR=0.97, 95%CI: 0.96 to 0.97) injuries, and for all (IRR=0.97, 95%CI: 0.97 to 0.98) muscle injuries (Table 1 and Supplementary Figures).

For middle distance, higher UTCI was associated with higher incidence rates for time-loss (IRR=1.03, 95%CI: 1.03 to 1.04) injuries (Table 1 and Supplementary Figures).

For long distance, higher UTCI was associated with lower incidence rates for time-loss (IRR=0.98, 95%CI: 0.97 to 0.98) injuries (Table 1 and Supplementary Figures).

Other results of Poisson regressions were in samples of number of incidence rates values different than zero lower than 30, suggesting caution in these results (Table 1, Supplementary Table 4, and Supplementary Figures).

DISCUSSION

The main finding of the present study was that lower feels-like temperatures were associated with a higher risk of time-loss injuries, and especially all and time-loss muscle injuries, incurred during international athletics championships. Although IRR were closed to 1.00, the tight reported IRR 95% confidence intervals support the robustness of the analyses, and give credits to the clinical importance of these results. In clinical perspective, these results can be presented as: for every 10°C decrease in feels-like temperature (in the whole UTCI data range from 1.1°C to 38.9°C), the risk of time-loss injury increased by about 20%, and the risk of muscle injury by 30-40%. Specific analyses of each discipline revealed that this association was also found for sprints, hurdles and throws, where for every 10°C decrease (in the whole UTCI data range from 1.1°C to 38.9°C), the risk of injury or muscle injury increased by 20-60% according to disciplines.

Feels-like temperature and injury risk

These findings partially confirm our hypothesis. The hypothesis was derived from studies in animals,[9–13] healthy humans,[14–17] in team sports[18–21] and in athletics.[22] The IRR and their 95% CI, reported that an association between feels-like temperature and injury risk was found for muscle injuries, and especially for sprints, hurdles, and throws. For other disciplines, there were i) no significant association, ii) inverse association with higher muscle injury risk for higher feels-like temperature (i.e., jumps, marathon and race walking), and/or iii) the association should be taken with caution due to the small number of values (i.e., throws, middle and long distances, marathon and race walking). For specific injury types, the association between feels-like temperatures and injury rates varied between injury types and disciplines without clear consistencies (Table 1 and Supplementary Figures), and given the small number of values of incidence rates different than zero, caution should be taken in the

potential significance of these results (Supplementary Table 4). Thus, only association between feels-like temperatures and muscle injury risk could be considered. This may be explained by either that temperature did not influence the occurrences of other injuries or a lack of statistical power due to the small number of other injury types, or a combination of both. The association was significant for all tissue types combined for time-loss and lower limb time-loss injuries, possibly because about half of the injuries were muscle injuries.

The association between temperature and muscle injury risk is consistent with animal studies[9,10] and with the study from Tokutake et al.[22] in athletics reporting that the incidence of hamstring muscle injuries was significantly lower in the very-high-temperature zone (>25°C), and significantly higher in the lower-middle-temperature zone (10-14.9°C). It is, however, not possible to draw any conclusion about the mechanisms or pathophysiology: is the higher injury risk in lower temperature due to the decrease in mechanical muscle tissue capability (e.g., a decrease of elasticity, contractility), neuromuscular control, or both?

Strengths and limitations

We considered UTCI during the one-hour period during which the event took place and the injuries occurred, and not just the climate zone of the championships location[18–20] or the weather condition or temperature during the day of the injury occurrence.[21,22] The large database including almost 30,000 athlete starts and more than 1,200 injuries allowed for such exploratory analyses. The tight reported IRR 95% confidence intervals support the robustness of the analyses.

In addition to limitations previously discussed regarding injury data collection during international athletics championships,[1,6,8,38] the injuries were diagnosed by medical teams based on history and physical examination and not always imaging, which can lead to uncertainty in the determination of the injury type,[1,6,8,38] and caution should be taken

regarding the determination of estimated time-loss.[39] Further, we have to acknowledge that we considered mean UTCI for one hour periods and related them to the time at the start of the event, while i) some events could have been longer than one hour (e.g., marathon and 50-km race walking events last more than 2 hours), and ii) injury could have occurred before (e.g., during the warm-up) or after the one hour period for which we considered the UTCI. Nevertheless, the temporal variation in UTCI have been minor (Figure 1). More importantly, we also have to acknowledge the spatial variations in UTCI although we use single value representative for the competition area within a radius of 25km given the data limitations and unknown exact whereabouts of the athletes. UTCI can vary substantially within metres particularly when radiation or wind are obstructed. No specific analysis of the discipline of combined events was performed, since for combined events, specifically for this study, each event was included in the corresponding discipline category. This was to limit the potential bias induced by the fact that the events have different durations and the influence of temperature on injury risk could differ between them, as for the other eight athletics discipline categories. Based on the total population study design, we did not formally calculate *a-priori* sample sizes for the analyses. However, it can post-hoc be observed that the sizes of the samples used in the analyses were acceptable due to that the confidence intervals generated can be regarded as sufficiently small. Although the database can be considered as large, some sample could be considered as small, given the small number of values of incidence rates different than zero, and thus underpower the statistical analysis leading to caution in these results (Supplementary Table 4). The relationships between feels-like temperatures and injury incidence rates although significant could not perfectly follow the Poisson distribution and could not be considered as linear. Finally, we also have to acknowledge the limitations inherent to the study design and analysis including unmeasured confounding.

Practical implications

The present results may inform injury risk reduction strategies at athletics competitions. Muscle injuries are the predominant injury type in athletics, especially during international athletics championships.[1,8,38] Efforts are needed to try to reduce their risk, and a multifactorial approach is recommended.[38,40] Although the precise mechanism for higher muscle injury rates with lower feels-like temperatures requires further investigation, the present results provide an additional opportunity for risk reduction strategies. Since lower feels-like temperatures were associated with a higher risk of muscle injuries, we can suggest improving the strategies to manage with lower feels-like temperatures, by for instance i) adapting clothing by wearing warmer clothing in cold outdoor environments with the aim of limiting muscle temperature decrease, ii) active and/or passive methods with the aim of increasing muscle temperature (e.g., improving and increasing warm-up quality and duration, using devices to heat the body),[41] and/or iii) adapting the timing of the event to the weather conditions or by anticipating preparation according to the weather conditions to avoid/limit environmental heat or cold stress conditions. The weather conditions, and especially the feels-like temperatures (i.e., UTCI) can be forecasted.[33] Thus, we can suggest to athletes, coaches, medical teams, and championship organisers to take into consideration the forecasted weather conditions in order to anticipate the preparation of the competition.

Regarding the performance in sprints, Haida et al.[42] reported that the best performance in sprints was achieved at temperatures of 23 ± 3°C. Our results showed that muscle injury risk in sprints decreases with higher temperature (Table 1 and Figures 4 and 5). This suggests that increased temperatures can reduce injuries as well as enhance performance in sprints. Regarding long-duration endurance events, Mantzios et al.[43] reported that the optimal WBGT was 7.5°C for marathon and between 12.5 and 15°C for race walking. Although results were not significant and should be taken with caution, the incidence rate ratio showed increased

muscle injury risk with increased temperature for marathon and race walking (Table 1 and Supplementary Figures). Our findings seem to support that lower temperatures were associated with lower muscle injury risk and higher performances in these two disciplines.

CONCLUSIONS

During international athletics championships, muscle injury risk was associated with temperature, especially for sprints, hurdles and throws. For all disciplines, for every 10°C decrease in feels-like temperature (in the whole UTCI data range from 1.1°C to 38.9°C), the risk of muscle injury increased by 30-40%, for sprints by 50-60%, for hurdles by 30-50%, and for throws by 30%. This suggests that increasing muscle temperature (e.g., warm-up), limiting muscle temperature decrease (e.g., clothes), or adapting preparation to forecasted weather conditions could be of benefit.

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Table 1: Results of the Poisson regressions (Incidence Rate Ratio (IRR) (95% confidence intervals (95% CI)), p-value) with incidence rates as outcome and universal thermal climate index (UTCI) as predictive variable, adjusted for sex, for all disciplines and for each of the 8 disciplines (i.e., sprints, hurdles, jumps, throws, middle distances, long distances, marathon and race walking), for all in-competition injuries and in-competition time-loss injuries, and for each injury type (i.e., muscle, skin, ligament, tendon, bone, and articular) during the 10 international outdoor athletics championships. Results in italic and grey correspond to regressions with number of values of incidence rates lower than 30, suggesting caution in the results of the regressions.

	All injuries	Muscle	Skin	Ligament	Tendon	Bone	Articular not ligament
All disciplines							
All injuries	1.00 (1.00 to 1.01); p=0.004	0.97 (0.97 to 0.98); p<0.0001	1.00 (1.00 to 1.01); p=0.004	1.00 (0.99 to 1.00); p=0.077	1.00 (1.00 to 1.01); p=0.601	1.00 (0.99 to 1.00); p=0.300	0.98 (0.97 to 0.98); p<0.0001
Time-loss injuries	0.98 (0.97 to 0.98); p<0.0001	0.96 (0.96 to 0.96); p<0.0001	0.98 (0.97 to 0.98); p<0.0001	1.01 (1.00 to 1.01); p=0.034	1.00 (0.99 to 1.00); p=0.567	1.00 (0.99 to 1.01); p=0.934	*0.97 (0.96 to 0.98); p<0.0001*
Sprints							
All injuries	0.97 (0.97 to 0.97); p<0.0001	0.95 (0.95 to 0.96); p<0.0001	*0.98 (0.97 to 0.99); p<0.0001*	*0.96 (0.95 to 0.97); p<0.0001*	*1.01 (1.00 to 1.02); p=0.044*	*1.02 (1.00 to 1.03); p=0.042*	*1.00 (0.98 to 1.02); p=0.849*
Time-loss injuries	0.94 (0.94 to 0.95); p<0.0001	0.94 (0.93 to 0.94); p<0.0001	*0.93 (0.91 to 0.94); p<0.0001*	*0.98 (0.97 to 1.00); p=0.094*	*0.96 (0.95 to 0.97); p<0.0001*	*1.23 (1.18 to 1.27); p<0.0001*	*0.94 (0.92 to 0.97); p<0.0001*
Hurdles							
All injuries	0.98 (0.98 to 0.99); p<0.0001	0.97 (0.96 to 0.97); p<0.0001	*1.01 (1.00 to 1.02); p=0.005*	*0.96 (0.95 to 0.97); p<0.0001*	*1.08 (1.07 to 1.10); p<0.0001*	*1.01 (0.99 to 1.03); p=0.429*	*1.19 (1.19 to 1.19); p<0.0001*
Time-loss injuries	0.96 (0.96 to 0.97); p<0.0001	0.95 (0.94 to 0.96); p<0.0001	*0.92 (0.91 to 0.94); p<0.0001*	*0.94 (0.92 to 0.95); p<0.0001*	*1.07 (1.05 to 1.08); p<0.0001*	*1.01 (0.99 to 1.03); p=0.429*	*1.19 (1.19 to 1.19); p<0.0001*
Jumps							
All injuries	1.01 (1.01 to 1.02); p<0.0001	1.03 (1.02 to 1.03); p<0.0001	1.00 (0.99 to 1.01); p=0.529	1.02 (1.01 to 1.03); p<0.0001	*1.00 (0.99 to 1.01); p=0.857*	*0.96 (0.94 to 0.98); p<0.0001*	*0.97 (0.96 to 0.98); p<0.0001*
Time-loss injuries	1.02 (1.02 to 1.03); p<0.0001	1.04 (1.03 to 1.04); p<0.0001	*0.96 (0.95 to 0.98); p<0.0001*	*1.03 (1.03 to 1.04); p<0.0001*	*1.00 (0.99 to 1.02); p=0.399*	*0.96 (0.94 to 0.98); p<0.0001*	*0.97 (0.97 to 0.97); p<0.0001*
Throws							
All injuries	0.98 (0.97 to 0.98); p<0.0001	0.97 (0.97 to 0.98); p<0.0001	*1.00 (0.99 to 1.02); p=0.636*	*0.92 (0.91 to 0.92); p<0.0001*	*1.07 (1.06 to 1.09); p<0.0001*	*1.17 (1.10 to 1.23); p<0.0001*	*1.09 (1.06 to 1.13); p<0.0001*
Time-loss injuries	0.97 (0.96 to 0.97); p<0.0001	*1.00 (0.98 to 1.01); p=0.342*	*0.96 (0.94 to 0.98); p<0.0001*	*0.93 (0.92 to 0.94); p<0.0001*	*0.97 (0.94 to 1.00); p=0.041*	*1.17 (1.10 to 1.23); p<0.0001*	*1.09 (1.06 to 1.13); p<0.0001*
Middle distance							
All injuries	1.00 (1.00 to 1.01); p=0.364	*0.98 (0.97 to 0.99); p<0.0001*	*1.01 (1.00 to 1.01); p=0.010*	*1.03 (1.01 to 1.05); p<0.0001*	*0.93 (0.92 to 0.94); p<0.0001*	*1.12 (1.10 to 1.14); p<0.0001*	*0.91 (0.87 to 0.95); p<0.0001*
Time-loss injuries	1.03 (1.03 to 1.04); p<0.0001	*1.00 (0.99 to 1.01); p=0.517*	*1.05 (1.03 to 1.07); p<0.0001*	*1.01 (0.99 to 1.03); p=0.604*	*1.16 (1.14 to 1.19); p<0.0001*	*1.10 (1.08 to 1.13); p<0.0001*	-
Long distance							
All injuries	1.00 (1.00 to 1.01); p=0.406	*0.97 (0.96 to 0.98); p<0.0001*	*1.03 (1.02 to 1.03); p<0.0001*	*1.11 (1.10 to 1.13); p<0.0001*	*0.94 (0.93 to 0.95); p<0.0001*	*0.97 (0.96 to 0.98); p<0.0001*	*0.87 (0.86 to 0.89); p<0.0001*
Time-loss injuries	0.98 (0.97 to 0.98); p<0.0001	*0.95 (0.95 to 0.96); p<0.0001*	*0.99 (0.98 to 1.00); p=0.006*	*1.15 (1.13 to 1.17); p<0.0001*	*0.94 (0.93 to 0.96); p<0.0001*	*0.94 (0.93 to 0.96); p<0.0001*	*0.88 (0.86 to 0.90); p<0.0001*
Marathon							
All injuries	*1.03 (1.02 to 1.04); p<0.0001*	*1.03 (1.01 to 1.04); p=0.004*	*1.15 (1.12 to 1.19); p<0.0001*	*1.10 (1.06 to 1.14); p<0.0001*	*0.95 (0.92 to 0.98); p=0.001*	*0.78 (0.73 to 0.82); p<0.0001*	*0.94 (0.86 to 1.03); p=0.186*
Time-loss injuries	*1.06 (1.04 to 1.07); p<0.0001*	*1.11 (1.08 to 1.14); p<0.0001*	*1.21 (1.16 to 1.27); p<0.0001*	*1.11 (1.03 to 1.19); p=0.007*	*0.86 (0.82 to 0.90); p<0.0001*	*0.81 (0.76 to 0.85); p<0.0001*	*0.91 (0.81 to 1.01); p=0.088*
Race walking							
All injuries	*1.04 (1.03 to 1.04); p<0.0001*	*1.05 (1.04 to 1.06); p<0.0001*	*1.14 (1.11 to 1.17); p<0.0001*	*0.97 (0.95 to 1.00); p=0.022*	*0.96 (0.94 to 0.98); p<0.0001*	-	-
Time-loss injuries	*1.00 (0.99 to 1.01); p=0.599*	*0.99 (0.97 to 1.00); p=0.164*	*1.15 (1.10 to 1.19); p<0.0001*	*0.95 (0.93 to 0.97); p<0.0001*	*0.95 (0.92 to 0.97); p<0.0001*	-	-

Figures:

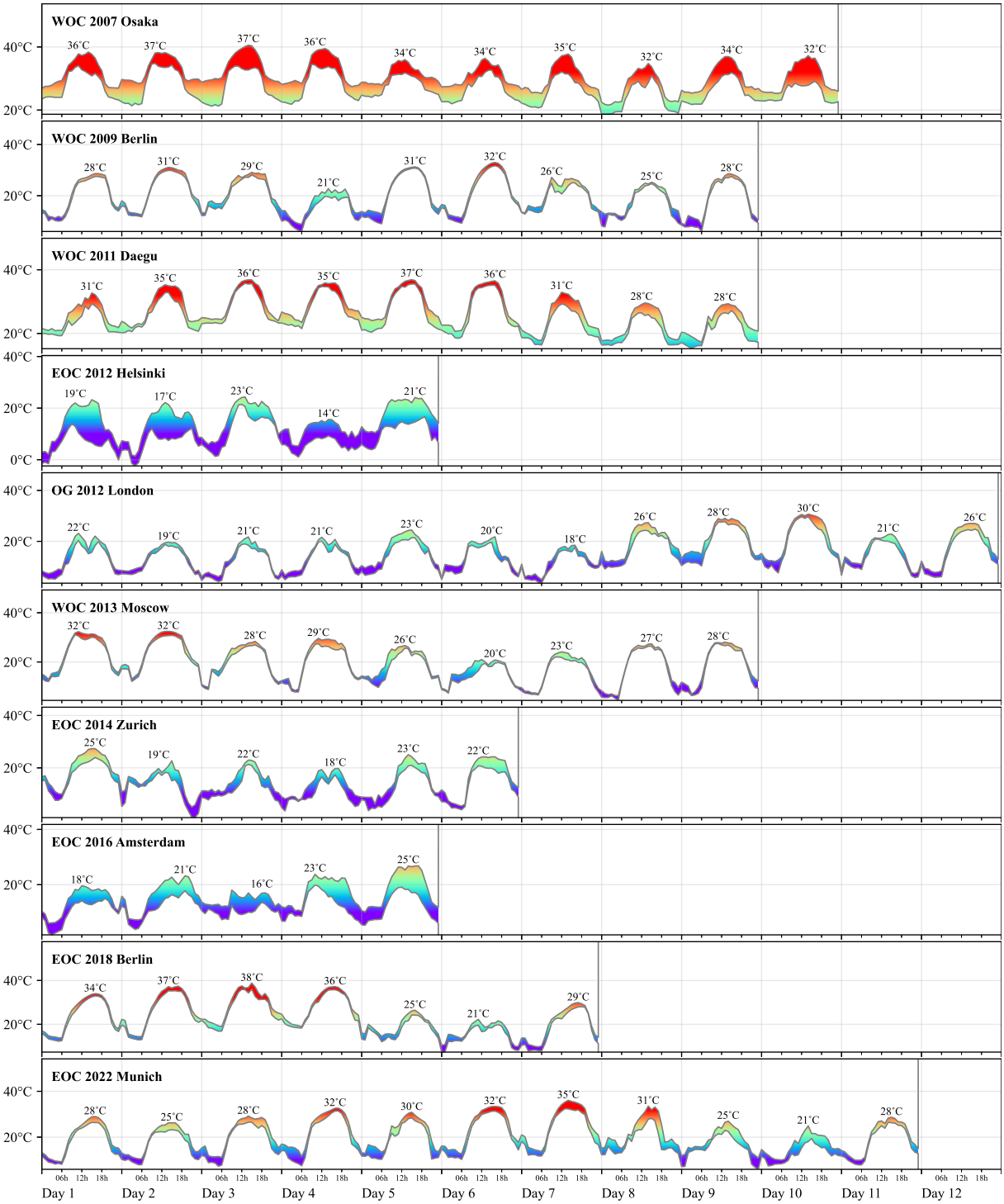
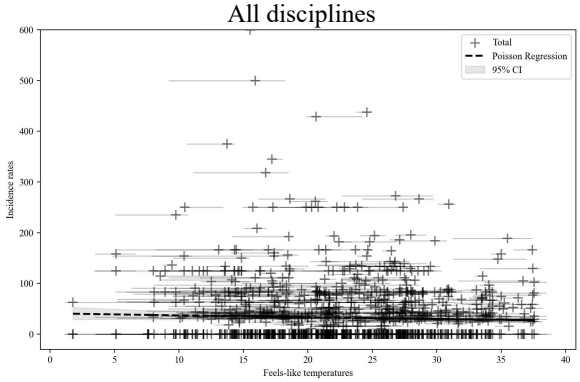


Figure 1: Feels-like temperatures measured as universal thermal climate index (UTCI) for all championship days of different World (WOC) and European (EOC) Outdoor Athletics Championships, as reported by Hollander et al.[36] Colour shading from violet (<10°C) to red

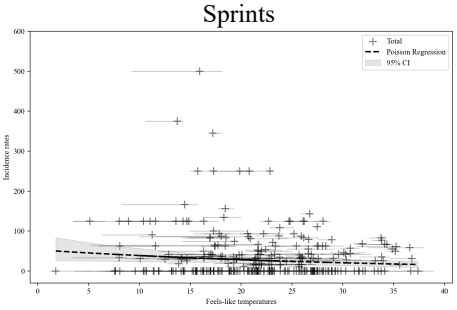
(>32°C) reflects UTCI. Width of the shading represents the minimum-maximum range of UTCI within 50 km from the respective stadium. Daily maximum UTCI temperatures are labelled.

All injuries

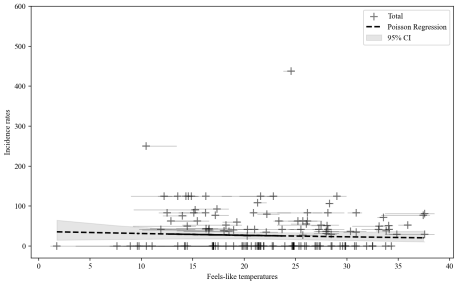
All disciplines



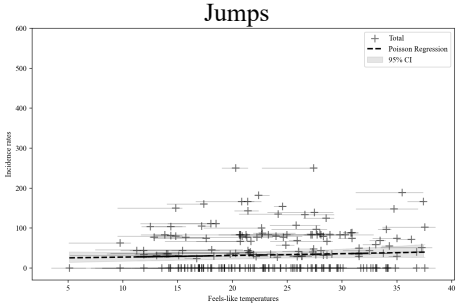
Sprints



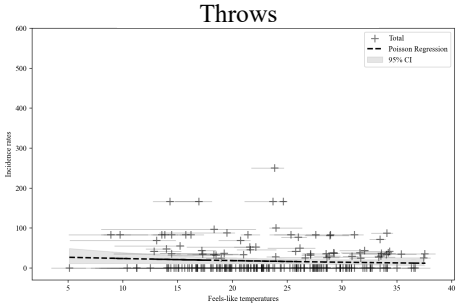
Hurdles



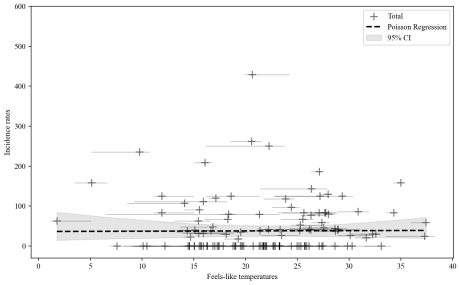
Jumps



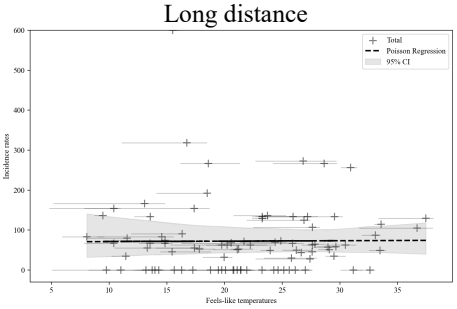
Throws



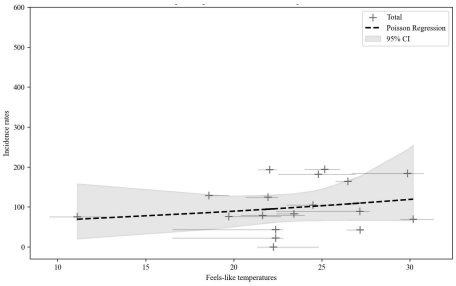
Middle distance



Long distance



Marathon



Race walking

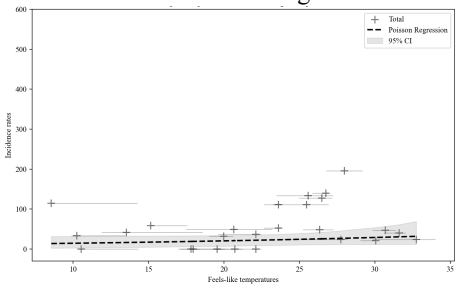
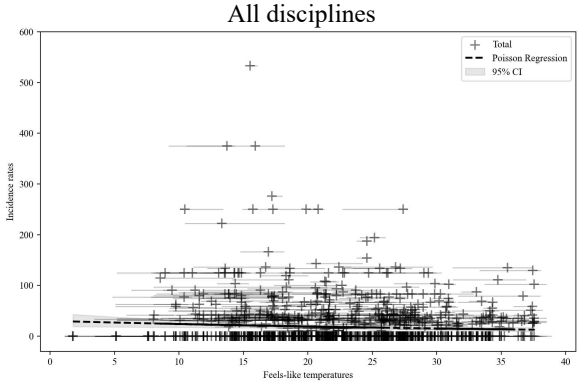


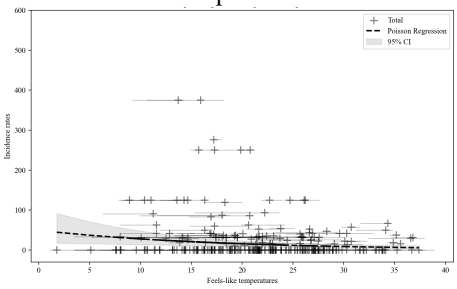
Figure 2: Incidence rates (number of in-competition injuries per 1000 athlete starts) of all injuries in relation to feels-like temperatures measured as universal thermal climate index for the total of injuries, for all disciplines and according to each of the different disciplines during the 10 international outdoor athletics championships, with the Poisson regressions presented as dotted lines with units of incidence rate per ˚C UTCI. The confidence intervals of the regressions (in gray) correspond to the 2.5 and 97.5 percentiles extracted from the bootstrap. The confidence intervals of the UTCI presented on each dot correspond to the minimal and maximal UTCI values available in a radius of about 25 km around the closest point to the respective stadium for every championship.

Time loss injuries

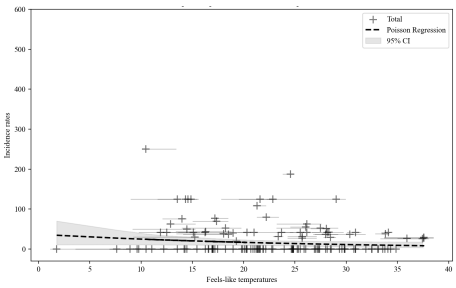
All disciplines



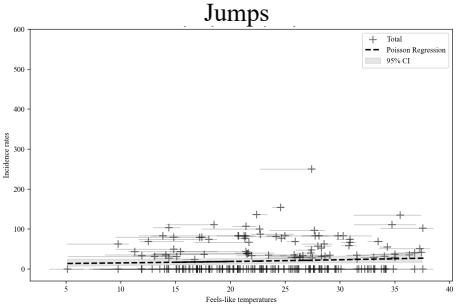
Sprints



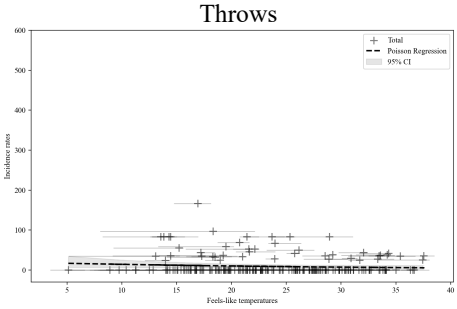
Hurdles



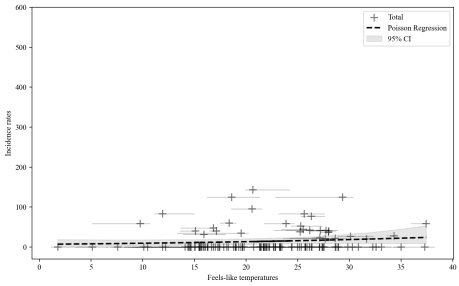
Jumps



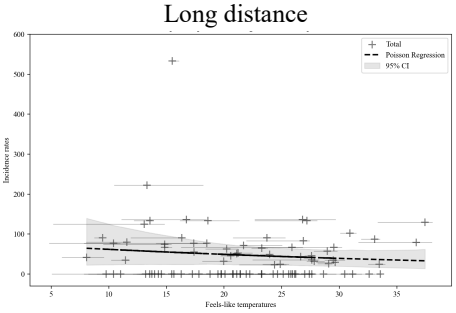
Throws



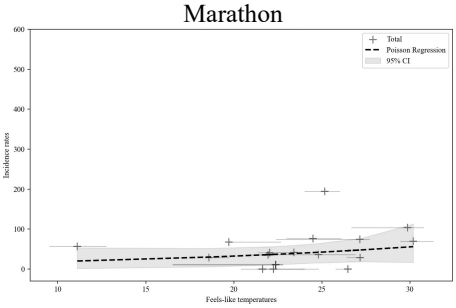
Middle distance



Long distance



Marathon



Race walking

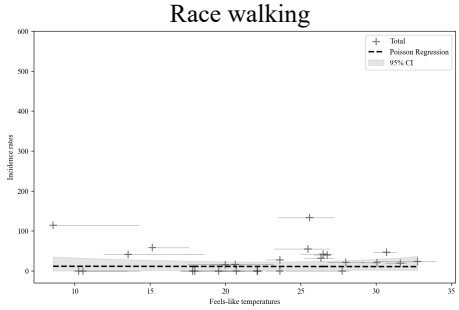
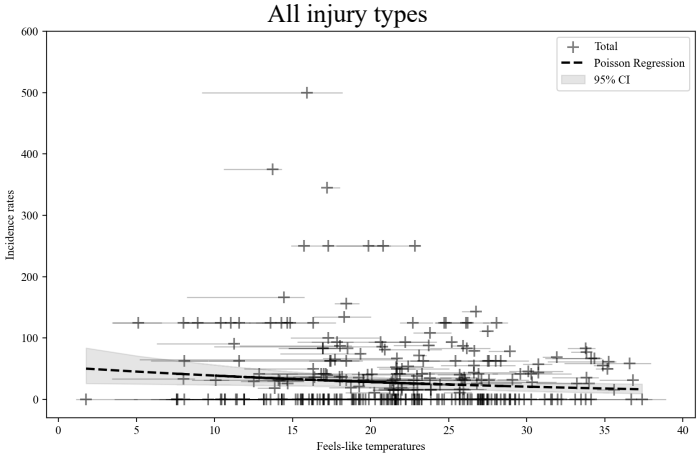


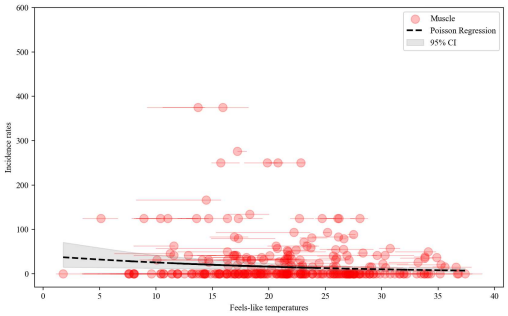
Figure 3: Incidence rates (number of in-competition injuries per 1000 athlete starts) of time-loss injuries in relation to feels-like temperatures measured as universal thermal climate index for the total of injuries, for all disciplines and according to each of the different disciplines during the 10 international outdoor athletics championships, with the Poisson regressions presented as dotted lines with units of incidence rate per ˚C UTCI. The confidence intervals of the regressions (in gray) correspond to the 2.5 and 97.5 percentiles extracted from the bootstrap. The confidence intervals of the UTCI presented on each dot correspond to the minimal and maximal UTCI values available in a radius of about 25 km around the closest point to the respective stadium for every championship.

Sprints - All injuries

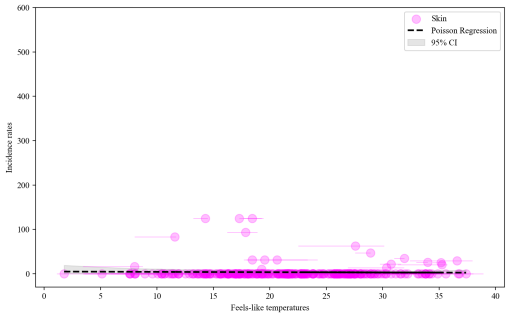
All injury types



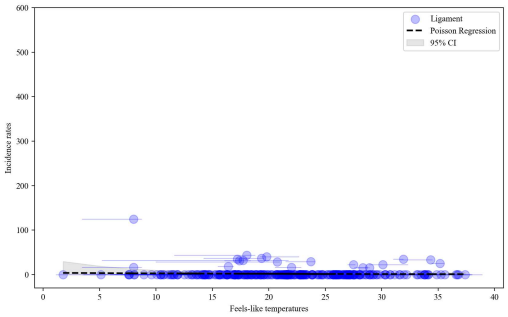
Muscle



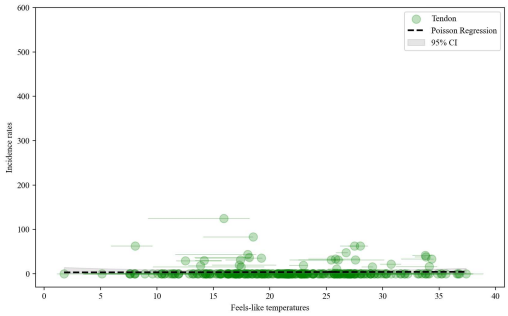
Skin



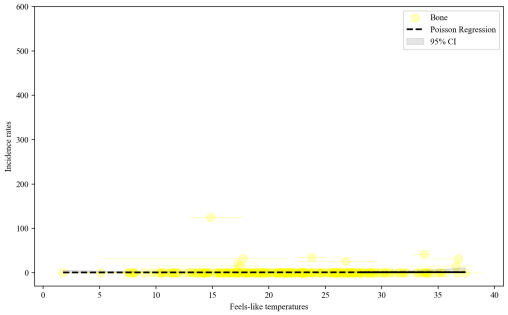
Ligament



Tendon



Bone



Articular not ligament

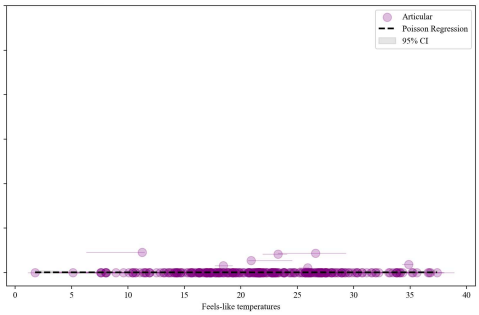
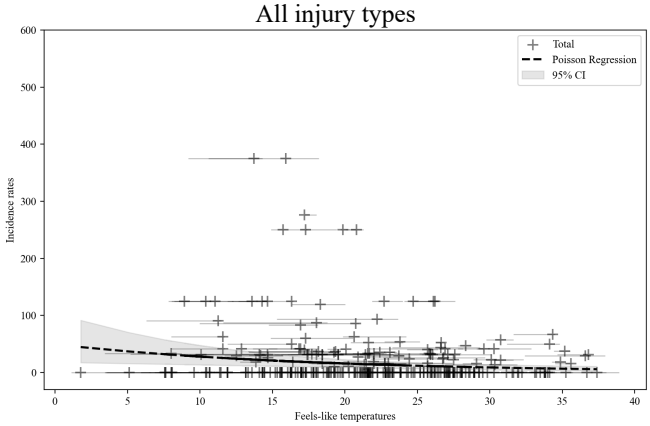


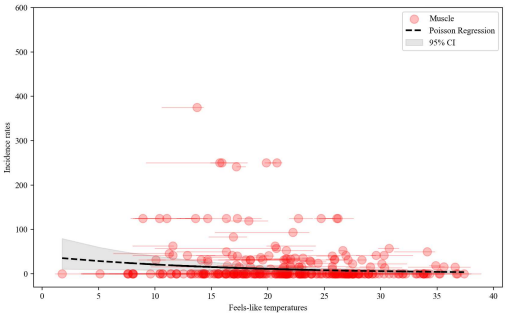
Figure 4: Incidence rates (number of in-competition injuries per 1000 athlete starts) of all injuries in relation to feels-like temperatures measured as universal thermal climate index for the total of injuries (all types of injuries) and the different injury types (i.e., muscle, tendon, ligament, articular, bone, and skin) in sprints during the 10 international outdoor athletics championships, with the Poisson regressions presented as dotted lines with units of incidence rate per ˚C UTCI. The confidence intervals of the regressions (in gray) correspond to the 2.5 and 97.5 percentiles extracted from the bootstrap. The confidence intervals of the UTCI presented on each dot correspond to the minimal and maximal UTCI values available in a radius of about 25 km around the closest point to the respective stadium for every championship.

Sprints – Time loss injuries

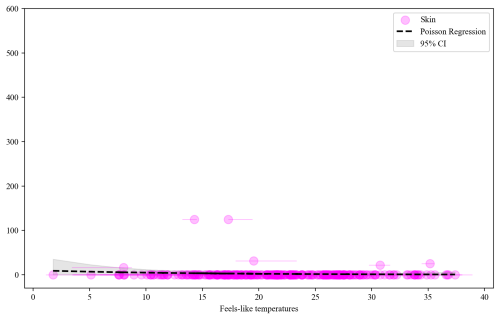
All injury types



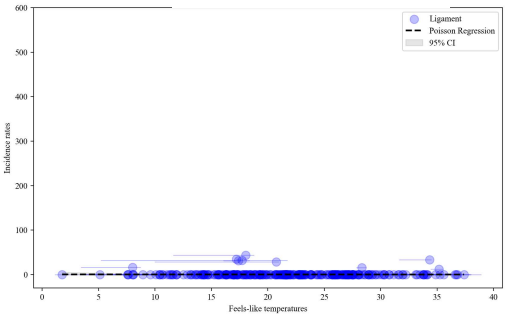
Muscle



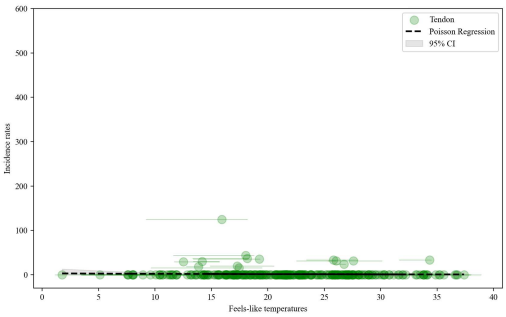
Skin



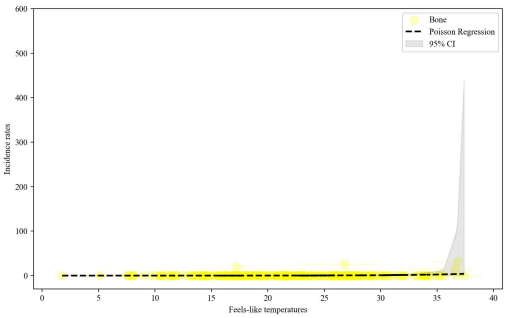
Ligament



Tendon



Bone



Articular not ligament

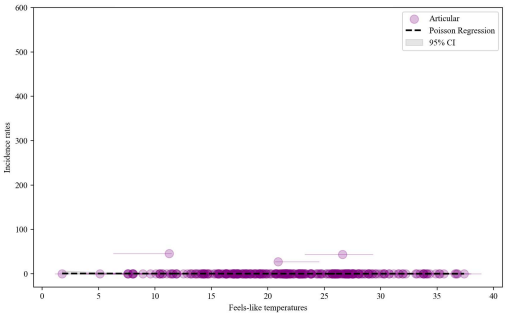


Figure 5: Incidence rates (number of in-competition injuries per 1000 athlete starts) of time-loss injuries in relation to feels-like temperatures measured as universal thermal climate index for the total of injuries (all types of injuries) and the different injury types (i.e., muscle, tendon, ligament, articular, bone, and skin) in sprints during the 10 international outdoor athletics championships, with the Poisson regressions presented as dotted lines with units of incidence rate per ˚C UTCI. The confidence intervals of the regressions (in gray) correspond to the 2.5 and 97.5 percentiles extracted from the bootstrap. The confidence intervals of the UTCI presented on each dot correspond to the minimal and maximal UTCI values available in a radius of about 25 km around the closest point to the respective stadium for every championship.

Supplementary material:

Association between feels-like temperatures and injury risk during international outdoor athletic championships: A prospective cohort study on 29,579 athlete starts during 10 championships

Supplementary Table 1: Characteristics of the 10 outdoor Athletics championships and climate classification of the respective locations presented using the Koeppen and Geiger climate classification (https://koppen.earth/).

Type of championships	Championship	Dates	Location (city, country, continent)	Koeppen climate classification
World	WOC 2007	2007, Aug 25-Sep 2	Osaka, Japan, Asia	Humid subtropical, climate (Cfa)
World	WOC 2009	2009, Aug 15-23	Berlin, Germany, Europe	Oceanic climate (Cfb)
World	WOC 2011	2011, Aug 27-Sep 4	Daegu, South Korea, Asia	Humid subtropical climate (Cwa)
European	EOC 2012	2012, Jun 27-Jul 1	Helsinki, Finland, Europe	Warm humid continental climate (Dfb)
Olympic Games	OG 2012	2012, Aug 3-12	London, UK, Europe	Oceanic temperate climate (Cfb)
World	WOC 2013	2013, Aug 10-18	Moscow, Russia, Europe	Warm humid continental climate (Dfb)
European	EOC 2014	2014, Aug 12-17	Zürich, Switzerland, Europe	Oceanic climate, warm summer (Cfb)
European	EOC 2016	2016, Jul 6-10	Amsterdam, Netherlands, Europe	Oceanic climate, warm summer (Cfb)
European	EOC 2018	2018, Aug 6-12	Berlin, Germany, Europe	Oceanic climate (Cfb)
European	EOC 2022	2022, Aug 15-21	Munich, Germany, Europe	Oceanic climate (Cfb)

WOC: World Outdoor Championships; OG: Olympic Games; EOC: European Outdoor Championships.

Supplementary Table 2: Number of athlete starts and of injuries, for all injuries and time loss injuries, according to sex and discipline, and according to the injured tissue type (i.e., muscle, skin, ligament, tendon, bone, articular, and others) during the 10 international outdoor athletics championships.

	Total	**Female athletes**									**Male athletes**								
		Total	**Sprints**	**Hurdles**	**Jumps**	**Throws**	**Middle distance**	**Long distance**	**Marathon**	**Race walking**	**Total**	**Sprints**	**Hurdles**	**Jumps**	**Throws**	**Middle distance**	**Long distance**	**Marathon**	**Race walking**
Total number of athlete starts	**29579**	**13817 (100.0)**	**4482 (32.4)**	**1515 (11.0)**	**2181 (15.8)**	**2187 (15.8)**	**1422 (10.3)**	**997 (7.2)**	**647 (4.7)**	**386 (2.8)**	**15762 (100.0)**	**5000 (31.7)**	**1538 (9.8)**	**2586 (16.4)**	**2515 (16.0)**	**1549 (9.8)**	**1116 (7.1)**	**740 (4.7)**	**718 (4.6)**
All injuries																			
Total	1203 (100.0)	483 (100.0)	109 (100.0)	50 (100.0)	76 (100.0)	39 (100.0)	69 (100.0)	71 (100.0)	60 (100.0)	9 (100.0)	720 (100.0)	184 (100.0)	66 (100.0)	125 (100.0)	46 (100.0)	78 (100.0)	85 (100.0)	81 (100.0)	55 (100.0)
Muscle	495 (41.1)	163 (33.7)	57 (52.3)	13 (26.0)	23 (30.3)	8 (20.5)	22 (31.9)	15 (21.1)	24 (40.0)	1 (11.1)	332 (46.1)	125 (67.9)	36 (54.5)	47 (37.6)	19 (41.3)	11 (14.1)	18 (21.1)	43 (53.1)	33 (60.0)
Skin	285 (23.7)	118 (24.4)	12 (11.0)	16 (32.0)	13 (17.1)	1 (2.6)	28 (40.6)	32 (45.1)	12 (20.0)	4 (44.4)	167 (23.2)	17 (9.2)	16 (24.2)	21 (16.8)	6 (13.0)	45 (57.7)	41 (48.2)	14 (17.3)	7 (12.7)
Ligament	143 (11.9)	69 (14.3)	7 (6.4)	10 (20.0)	20 (26.3)	15 (38.5)	2 (2.9)	7 (9.9)	8 (13.3)	0 (0.0)	74 (10.3)	13 (7.1)	4 (6.1)	23 (18.4)	12 (26.1)	7 (9.0)	7 (8.2)	1 (1.1)	7 (12.7)
Tendon	137 (11.4)	62 (12.8)	17 (15.6)	6 (12.0	10 (13.2)	8 (20.5)	8 (11.6)	4 (5.6)	8 (13.3)	1 (11.1)	75 (10.4)	12 (6.5)	6 (9.1)	15 (12.0)	6 (13.0)	7 (9.0)	11 (12.9)	12 (14.8)	6 (10.9)
Bone	47 (3.9)	27 (5.6)	5 (4.6)	3 (6.0)	4 (5.3)	1 (2.6)	5 (7.2	7 (9.9)	2 (3.3)	0 (0.0)	20 (2.8)	4 (2.2)	1 (1.5)	2 (1.6)	0 (0.0)	4 (5.1)	3 (3.5)	6 (7.4)	0 (0.0)
Articular	37 (3.1)	11 (2.3)	3 (2.8)	0 (0.0)	2 (2.6)	1 (2.6)	0 (0.0)	3 (4.2)	1 (1.7)	1 (11.1)	26 (3.6)	4 (2.2)	1 (1.5)	13 (10.4)	2 (4.3)	1 (1.3)	3 (3.5)	2 (2.5)	0 (0.0)
Others	53 (4.4)	30 (6.2)	8 (7.3)	2 (4.0)	4 (5.3)	5 (12.8)	2 (2.9)	3 (4.2)	5 (8.3)	1 (11.1)	23 (3.2)	7 (3.8)	1 (1.5)	4 (3.2)	1 (2.2)	3 (3.8)	2 (2.4)	3 (3.7)	2 (3.6)
Missing	*6 (0.5)*	*3 (0.6)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*2 (2.9)*	*0 (0.0)*	*0 (0.0)*	*1 (11.1)*	*3 (0.4)*	*2 (1.1)*	*1 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*
Time loss injuries																			
Total	633 (100.0)	255 (100.0)	53 (100.0)	28 (100.0)	49 (100.0)	21 (100.0)	24 (100.0)	49 (100.0)	26 (100.0)	5 (100.0)	378 (100.0)	107 (100.0)	40 (100.0	72 (100.0)	31 (100.0)	17 (100.0)	42 (100.0)	42 (100.0)	27 (100.0)
Muscle	310 (49.0)	101 (39.6)	34 (64.2)	9 (32.1)	17 (34.7)	5 (23.8)	10 (41.7)	14 (28.6)	11 (42.3)	1 (20.0)	209 55.3)	87 (81.3)	27 (67.5)	28 (38.9)	15 (48.4)	7 (41.2)	12 (28.6)	20 (47.6)	13 (48.1)
Skin	91 (14.4)	49 (19.2)	6 (11.3)	5 (17.9)	6 (12.2)	0 (0.0)	4 (16.7)	18 (36.7)	8 (30.8)	2 (40.0)	42 (11.1)	1 (0.9)	4 (10.0)	8 (11.1)	3 (9.7)	3 (17.6)	12 (28.6)	7 (16.7)	4 (14.8)
Ligament	90 (14.2)	38 (14.9)	2 (3.8)	6 (21.4)	13 (26.5)	9 (42.9)	1 (4.2)	5 (10.2)	2 (7.7)	0 (0.0)	52 (13.8)	7 (6.5)	2 (5.0)	17 (23.6)	10 (32.3)	3 (17.6)	6 (14.3)	1 (2..4)	6 (22.2)

Tendon	72 (11.4)	32 (12.5)	8 (15.1)	3 (10.7)	8 (16.3)	2 (9.5)	6 (25.0)	2 (4.1	2 (7.7)	1 (20.0)	40 (10.6)	6 (5.6)	5 (12.5)	9 (12.5)	1 (3.2)	1 (5.9)	6 (14.3)	8 (19.0)	4 (14.8)
Bone	35 (5.5)	20 (7.8)	2 (3.8)	3 (10.7)	4 (8.2)	1 (4.8)	3 (12.5	5 (10.2)	2 (7.7)	0 (0.0)	15 (4.0)	2 (1.9)	1 (2.5)	2 (2.8)	0 (0.0)	3 (17.6)	3 (7.1)	4 (9.5)	0 (0.0)
Articular	18 (2.8)	5 (2.0)	1 (1.9)	0 (0.0)	0 (0.0)	1 (4.8)	0 (0.0)	2 (4.1)	1 (3.8)	0 (0.0)	13 (3.4)	2 (1.9)	1 (2.5)	6 (8.3)	2 (6.5)	0 (0.0)	2 (4.8)	0 (0.0)	0 (0.0)
Others	17 (2.7)	10 (3.9)	0 (0.0)	2 (7.1)	1 (2.0)	3 (14.3)	0 (0.0)	3 (6.1)	0 (0.0)	1 (20.0)	7 (1.9)	2 (1.9)	0 (0.0)	2 (2.8)	0 (0.0)	0 (0.0)	1 (2.4)	2 (4.8)	0 (0.0)
Missing	*1 (0.2)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*1 (0.3)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*0 (0.0)*	*1 (2.4)*	*0 (0.0)*

Supplementary Table 3: Incidence rates, i.e., number of injuries per 1000 athlete starts (with 95% confidence intervals, 95%CI), for all injuries and time loss injuries, according to sex and discipline, and according to the injured tissue type (i.e., muscle, skin, ligament, tendon, bone, articular, and others) during the 10 international outdoor athletics championships.

	Total	**Female athletes**										**Male athletes**							
		Total	**Sprints**	**Hurdles**	**Jumps**	**Throws**	**Middle distance**	**Long distance**	**Marathon**	**Race walking**	**Total**	**Sprints**	**Hurdles**	**Jumps**	**Throws**	**Middle distance**	**Long distance**	**Marathon**	**Race walking**
Total number of athlete starts																			
All injuries																			
Total	40.7 (38.4 to 43.0)	35.0 (31.9 to 38.2)	24.3 (20.0 to 29.3)	33.0 (24.5 to 43.5)	34.8 (27.5 to 43.6)	17.8 (12.7 to 24.4)	48.5 (37.8 to 61.4)	71.2 (55.6 to 89.8)	92.7 (70.8 to 119.4)	23.3 (10.7 to 44.3)	45.7 (42.4 to 49.1)	36.8 (31.7 to 42.5)	42.9 (33.2 to 54.6)	48.3 (40.2 to 57.6)	18.3 (13.4 to 24.4)	50.4 (39.8 to 62.8)	76.2 (60.8 to 94.2)	109.5 (86.9 to 136.0)	76.6 (57.7 to 99.7)
Muscle	16.7 (15.3 to 18.3)	11.8 (10.1 to 13.8)	12.7 (9.6 to 16.5)	8.6 (4.6 to 14.7)	10.5 (6.7 to 15.8)	3.7 (1.6 to 7.2)	15.5 (9.7 to 23.4)	15.0 (8.4 to 24.8)	37.1 (23.8 to 55.2)	2.6 (0.1 to 14.4)	21.1 (18.9 to 23.5)	25.0 (20.8 to 29.8)	23.4 (16.4 to 32.4)	18.2 (13.4 to 24.2)	7.6 (4.5 to 11.8)	7.1 (3.5 to 12.7)	16.1 (9.6 to 25.5)	58.1 (42.1 to 78.3)	46.0 (31.6 to 64.5)
Skin	9.6 (8.5 to 10.8)	8.5 (7.1 to 10.2)	2.7 (1.4 to 4.7)	10.6 (6.0 to 17.2)	6.0 (3.2 to 10.2)	0.5 (0.0 to 2.5)	19.7 (13.1 to 28.5)	32.1 (22.0 to 45.3)	18.5 (9.6 to 32.4)	10.4 (2.8 to 26.5)	10.6 (9.0 to 12.3)	3.4 (2.0 to 5.4)	10.4 (5.9 to 16.9)	8.1 (5.0 to 12.4)	2.4 (0.9 to 5.2)	29.1 (21.2 to 38.9)	36.7 (26.4 to 49.8)	18.9 (10.3 to 31.7)	9.7 (3.9 to 20.1)
Ligament	4.8 (4.1 to 5.7)	5.0 (3.9 to 6.3)	1.6 (0.6 to 3.2)	6.6 (3.2 to 12.1)	9.2 (5.6 to 14.2)	6.9 (3.8 to 11.3)	1.4 (0.2 to 5.1)	7.0 (2.8 to 14.5)	12.4 (5.3 to 24.4)	0.0 (0.0 to 9.6)	4.7 (3.7 to 5.9)	2.6 (1.4 to 4.4)	2.6 (0.7 to 6.7)	8.9 (5.6 to 13.3)	4.8 (2.5 to 8.3)	4.5 (1.8 to 9.3)	6.3 (2.5 to 12.9)	1.4 (0.0 to 7.5)	9.7 (3.9 to 20.1)
Tendon	4.6 (3.9 to 5.5)	4.5 (3.4 to 5.8)	3.8 (2.2 to 6.1)	4.0 (1.5 to 8.6)	4.6 (2.2 to 8.4)	3.7 (1.6 to 7.2)	5.6 (2.4 to 11.1)	4.0 (1.1 to 10.3)	12.4 (5.3 to 24.4)	2.6 (0.1 to 14.4)	4.8 (3.7 to 6.0)	2.4 (1.2 to 4.2)	3.9 (1.4 to 8.5)	5.8 (3.2 to 9.6)	2.4 (0.9 to 5.2)	4.5 (1.8 to 9.3)	9.9 (4.9 to 17.6)	16.2 (8.4 to 28.3)	8.4 (3.1 to 18.2)
Bone	1.6 (1.2 to 2.1)	2.0 (1.3 to 2.8)	1.1 (0.4 to 2.6)	2.0 (0.4 to 5.8)	1.8 (0.5 to 4.7)	0.5 (0.0 to 2.5)	3.5 (1.1 to 8.2)	7.0 (2.8 to 14.5)	3.1 (0.4 to 11.2)	0.0 (0.0 to 9.6)	1.3 (0.8 to 2.0)	0.8 (0.2 to 2.0)	0.7 (0.0 to 3.6)	0.8 (0.1 to 2.8)	0.0 (0.0 to 1.5)	2.6 (0.7 to 6.6)	2.7 (0.6 to 7.9)	8.1 (3.0 to 17.6)	0.0 (0.0 to 5.1)
Articular	1.3 (0.9 to 1.7)	0.8 (0.4 to 1.4)	0.7 (0.1 to 2.0)	0.0 (0.0 to 2.4)	0.9 (0.1 to 3.3)	0.5 (0.0 to 2.5)	0.0 (0.0 to 2.6)	3.0 (0.6 to 8.8)	1.5 (0.0 to 8.6)	2.6 (0.1 to 14.4)	1.6 (1.1 to 2.4)	0.8 (0.2 to 2.0)	0.7 (0.0 to 3.6)	5.0 (2.7 to 8.6)	0.8 (0.1 to 2.9)	0.6 (0.0 to 3.6)	2.7 (0.6 to 7.9)	2.7 (0.3 to 9.8)	0.0 (0.0 to 5.1)
Others	1.8 (1.3 to 2.3)	2.2 (1.5 to 3.1)	1.8 (0.8 to 3.5)	1.3 (0.2 to 4.8)	1.8 (0.5 to 4.7)	2.3 (0.7 to 5.3)	1.4 (0.2 to 5.1)	3.0 (0.6 to 8.8)	7.7 (2.5 to 18.0)	2.6 (0.1 to 14.4)	1.5 (0.9 to 2.2)	1.4 (0.6 to 2.9)	0.7 (0.0 to 3.6)	1.5 (0.4 to 4.0)	0.4 (0.0 to 2.2)	1.9 (0.4 to 5.7)	1.8 (0.2 to 6.5)	4.1 (0.8 to 11.8)	2.8 (0.3 to 10.1)
Missing	0.2 (0.1 to 0.4)	0.2 (0.0 to 0.6)	0.0 (0.0 to 0.8)	0.0 (0.0 to 2.4)	0.0 (0.0 to 1.7)	0.0 (0.0 to 1.7)	1.4 (0.2 to 5.1)	0.0 (0.0 to 3.7)	0.0 (0.0 to 5.7)	2.6 (0.1 to 14.4)	0.2 (0.0 to 0.6)	0.4 (0.0 to 1.4)	0.7 (0.0 to 3.6)	0.0 (0.0 to 1.4)	0.0 (0.0 to 1.5)	0.0 (0.0 to 2.4)	0.0 (0.0 to 3.3)	0.0 (0.0 to 5.0)	0.0 (0.0 to 5.1)
Time loss injuries																			

Total	21.4 (19.8 to 23.1)	18.5 (16.3 to 20.9)	11.8 (8.9 to 15.5)	18.5 (12.3 to 26.7)	22.5 (16.6 to 29.7)	9.6 (5.9 to 14.7)	16.9 (10.8 to 25.1)	49.1 (36.4 to 65.0)	40.2 (26.3 to 58.9)	13.0 (4.2 to 30.2)	24.0 (21.6 to 26.5)	21.4 (17.5 to 25.9)	26.0 (18.6 to 35.4)	27.8 (21.8 to 35.1)	12.3 (8.4 to 17.5)	11.0 (6.4 to 17.6)	37.6 (27.1 to 50.9)	56.8 (40.9 to 76.7)	37.6 (24.8 to 54.7)
Muscle	10.5 (9.3 to 11.7)	7.3 (6.0 to 8.9)	7.6 (5.3 to 10.6)	5.9 (2.7 to 11.3)	7.8 (4.5 to 12.5)	2.3 (0.7 to 5.3)	7.0 (3.4 to 12.9)	14.0 (7.7 to 23.6)	17.0 (8.5 to 30.4)	2.6 (0.1 to 14.4)	13.3 (11.5 to 15.2)	17.4 (13.9 to 21.5)	17.6 (11.6 to 25.5)	10.8 (7.2 to 15.6)	6.0 (3.3 to 9.8)	4.5 (1.8 to 9.3)	10.8 (5.6 to 18.8)	27.0 (16.5 to 41.7)	18.1 (9.6 to 31.0)
Skin	3.1 (2.5 to 3.8)	3.5 (2.6 to 4.7)	1.3 (0.5 to 2.9)	3.3 (1.1 to 7.7)	2.8 (1.0 to 6.0)	0.0 (0.0 to 1.7)	2.8 (0.8 to 7.2)	18.1 (10.7 to 28.5)	12.4 (5.3 to 24.4)	5.2 (0.6 to 18.7)	2.7 (1.9 to 3.6)	0.2 (0.0 to 1.1)	2.6 (0.7 to 6.7)	3.1 (1.3 to 6.1)	1.2 (0.2 to 3.5)	1.9 (0.4 to 5.7)	10.8 (5.6 to 18.8)	9.5 (3.8 to 19.5)	5.6 (1.5 to 14.3)
Ligament	3.0 (2.4 to 3.7)	2.8 (1.9 to 3.8)	0.4 (0.1 to 1.6)	4.0 (1.5 to 8.6)	6.0 (3.2 to 10.2)	4.1 (1.9 to 7.8)	0.7 (0.0 to 3.9)	5.0 (1.6 to 11.7)	3.1 (0.4 to 11.2)	0.0 (0.0 to 9.6)	3.3 (2.5 to 4.3)	1.4 (0.6 to 2.9)	1.3 (0.2 to 4.7)	6.6 (3.8 to 10.5)	4.0 (1.9 to 7.3)	1.9 (0.4 to 5.7)	5.4 (2.0 to 11.7)	1.4 (0.0 to 7.5)	8.4 (3.1 to 18.2)
Tendon	2.4 (1.9 to 3.1)	2.3 (1.6 to 3.3)	1.8 (0.8 to 3.5)	2.0 (0.4 to 5.8)	3.7 (1.6 to 7.2)	0.9 (0.1 to 3.3)	4.2 (1.5 to 9.2)	2.0 (0.2 to 7.2)	3.1 (0.4 to 11.2)	2.6 (0.1 to 14.4)	2.5 (1.8 to 3.5)	1.2 (0.4 to 2.6)	3.3 (1.1 to 7.6)	3.5 (1.6 to 6.6)	0.4 (0.0 to 2.2)	0.6 (0.0 to 3.6)	5.4 (2.0 to 11.7)	10.8 (4.7 to 21.3)	5.6 (1.5 to 14.3)
Bone	1.2 (0.8 to 1.6)	1.4 (0.9 to 2.2)	0.4 (0.1 to 1.6)	2.0 (0.4 to 5.8)	1.8 (0.5 to 4.7)	0.5 (0.0 to 2.5)	2.1 (0.4 to 6.2)	5.0 (1.6 to 11.7)	3.1 (0.4 to 11.2)	0.0 (0.0 to 9.6)	1.0 (0.5 to 1.6)	0.4 (0.0 to 1.4)	0.7 (0.0 to 3.6)	0.8 (0.1 to 2.8)	0.0 (0.0 to 1.5)	1.9 (0.4 to 5.7)	2.7 (0.6 to 7.9)	5.4 (1.5 to 13.8)	0.0 (0.0 to 5.1)
Articular	0.6 (0.4 to 1.0)	0.4 (0.1 to 0.8)	0.2 (0.0 to 1.2)	0.0 (0.0 to 2.4)	0.0 (0.0 to 1.7)	0.5 (0.0 to 2.5)	0.0 (0.0 to 2.6)	2.0 (0.2 to 7.2)	1.5 (0.0 to 8.6)	0.0 (0.0 to 9.6)	0.8 (0.4 to 1.4)	0.4 (0.0 to 1.4)	0.7 (0.0 to 3.6)	2.3 (0.9 to 5.1)	0.8 (0.1 to 2.9)	0.0 (0.0 to 2.4)	1.8 (0.2 to 6.5)	0.0 (0.0 to 5.0)	0.0 (0.0 to 5.1)
Others	0.6 (0.3 to 0.9)	0.7 (0.3 to 1.3)	0.0 (0.0 to 0.8)	1.3 (0.2 to 4.8)	0.5 (0.0 to 2.6)	1.4 (0.3 to 4.0)	0.0 (0.0 to 2.6)	3.0 (0.6 to 8.8)	0.0 (0.0 to 5.7)	2.6 (0.1 to 14.4)	0.4 (0.2 to 0.9)	0.4 (0.0 to 1.4)	0.0 (0.0 to 2.4)	0.8 (0.1 to 2.8)	0.0 (0.0 to 1.5)	0.0 (0.0 to 2.4)	0.9 (0.0 to 5.0)	2.7 (0.3 to 9.8)	0.0 (0.0 to 5.1)
Missing	0.0 (0.0 to 0.2)	0.0 (0.0 to 0.3)	0.0 (0.0 to 0.8)	0.0 (0.0 to 2.4)	0.0 (0.0 to 1.7)	0.0 (0.0 to 1.7)	0.0 (0.0 to 2.6)	0.0 (0.0 to 3.7)	0.0 (0.0 to 5.7)	0.0 (0.0 to 9.6)	0.1 (0.0 to 0.4)	0.0 (0.0 to 0.7)	0.0 (0.0 to 2.4)	0.0 (0.0 to 1.4)	0.0 (0.0 to 1.5)	0.0 (0.0 to 2.4)	0.0 (0.0 to 3.3)	1.4 (0.0 to 7.5)	0.0 (0.0 to 5.1)

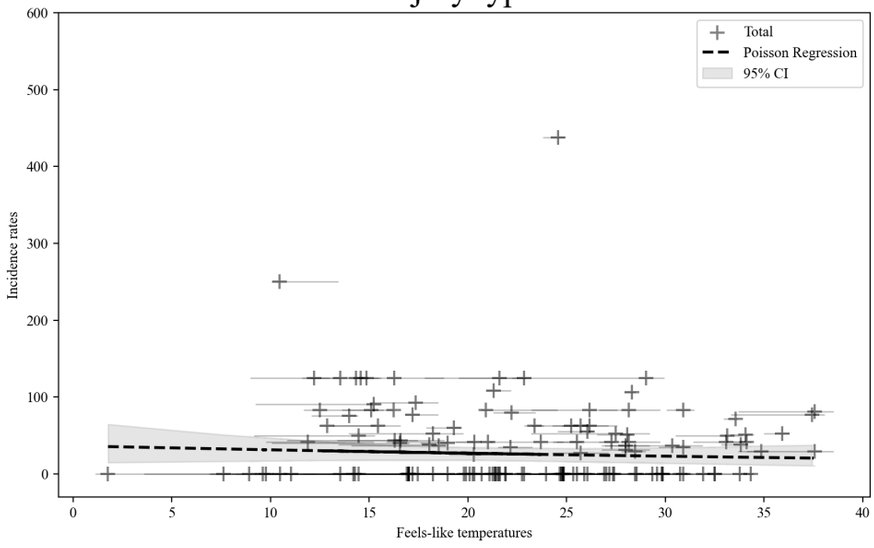
Supplementary Table 4: Total number of events per disciplines during the 10 international outdoor athletics championships, and total number of values of incidence rates (i.e., number of injuries per 1000 athletes' starts) different than 0, for all injuries and time loss injuries, according to discipline and according to the injured tissue type (i.e., muscle, skin, ligament, tendon, bone, articular, and others). Numbers are highlighted in italic when the number of events and/or the number of values of incidence rates were lower than 30, suggesting caution in the results of the linear regressions.

	Total	**Sprints**	**Hurdles**	**Jumps**	**Throws**	**Middle distance**	**Long distance**	**Marathon**	**Race walking**
Total number of events:	1124	302	140	209	210	90	129	*18*	*26*
Total number of values of incidence rates different than 0:									
All injuries	555	150	69	108	64	62	65	*17*	*20*
Muscle	300	109	37	50	*24*	*27*	*27*	*16*	*10*
Skin	173	*19*	*26*	30	*7*	37	35	*12*	*7*
Ligament	120	*19*	*12*	36	*23*	*13*	*8*	*3*	*6*
Tendon	114	*27*	*11*	*22*	*11*	*14*	*12*	*11*	*6*
Bone	44	*9*	*4*	*6*	*1*	*9*	*9*	*6*	*0*
Articular	36	*7*	*1*	*14*	*3*	*6*	*1*	*3*	*1*
Others	46	*12*	*3*	*8*	*5*	*5*	*5*	*5*	*3*
Missing	*6*	*2*	*1*	*0*	*0*	*0*	*2*	*0*	*1*
Time loss injuries	385	105	51	78	44	46	30	*15*	*16*
Muscle	221	82	32	36	*18*	*20*	*16*	*10*	*7*
Skin	67	*6*	*7*	*13*	*3*	*18*	*5*	*10*	*5*
Ligament	81	*9*	*6*	*26*	*18*	*10*	*4*	*3*	*5*
Tendon	67	*14*	*8*	*16*	*3*	*8*	*7*	*7*	*4*
Bone	34	*4*	*4*	*6*	*1*	*7*	*6*	*6*	*0*
Articular	*18*	*3*	*1*	*6*	*3*	*4*	*0*	*1*	*0*
Others	*16*	*2*	*2*	*3*	*2*	*4*	*0*	*2*	*1*
Missing	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*

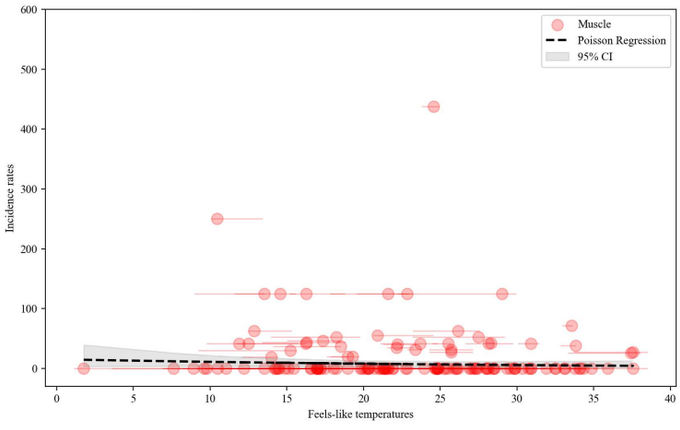
Supplementary Figures: Incidence rates (number of in-competition injuries per 1000 athlete starts) of all in-competition injuries and of in-competition time-loss injuries, in relation to feels-like temperatures measured as universal thermal climate index for the total of injuries (all types of injuries) and the different injury types (i.e., muscle, tendon, ligament, articular, bone, and skin) in hurdles, jumps, throws, middle distance, long distance, marathon and race walking, during the 10 international outdoor athletics championships, with the Poisson regressions presented as dotted lines with units of incidence rate per ˚C UTCI. The confidence intervals of the regressions (in gray) correspond to the 2.5 and 97.5 percentiles extracted from the bootstrap. The confidence intervals of the UTCI presented on each dot correspond to the minimal and maximal UTCI values available in a radius of about 25 km around the closest point to the respective stadium for every championship.

Hurdles – All injuries

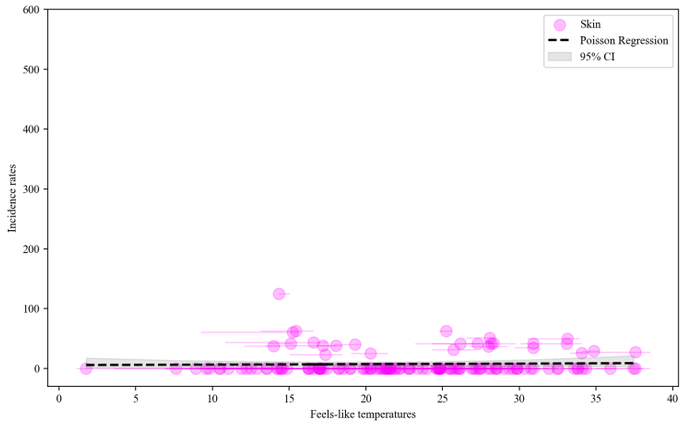
All injury types



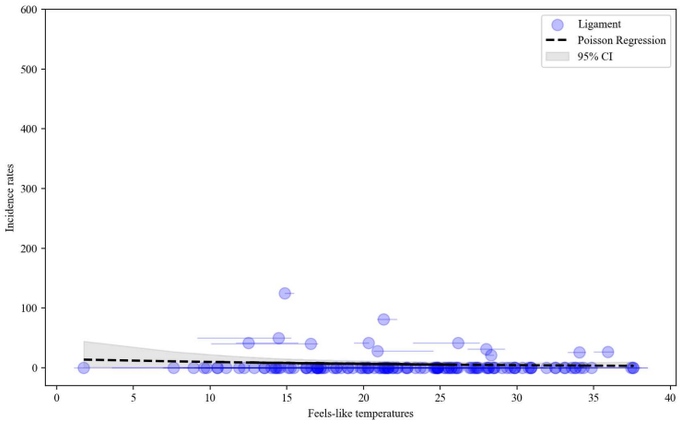
Muscle



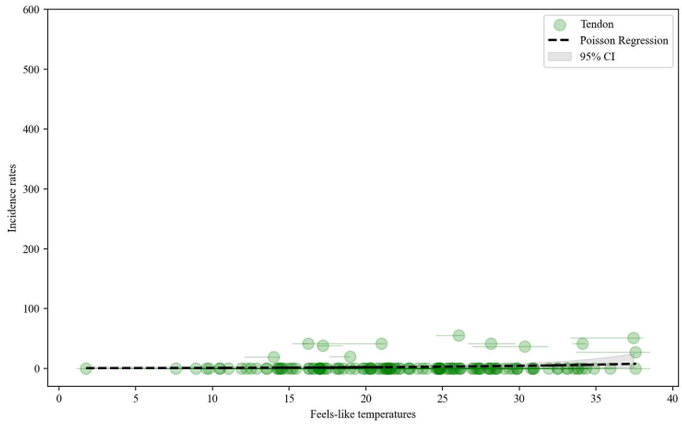
Skin



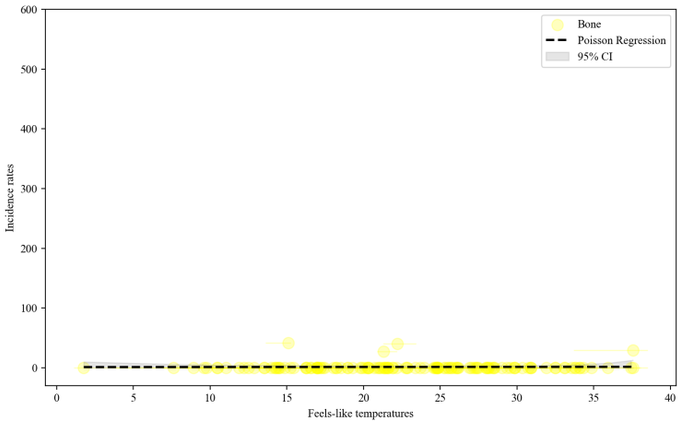
Ligament



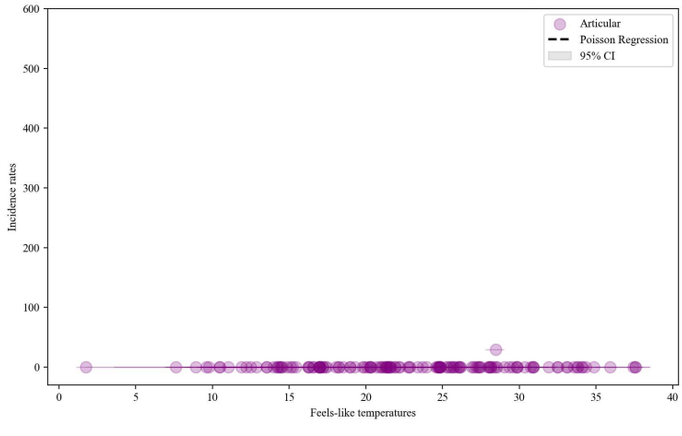
Tendon



Bone

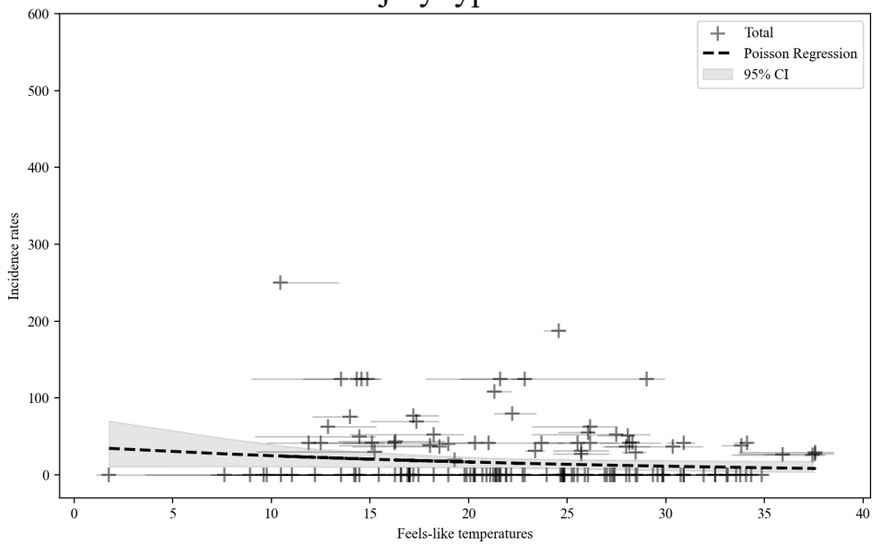


Articular not ligament

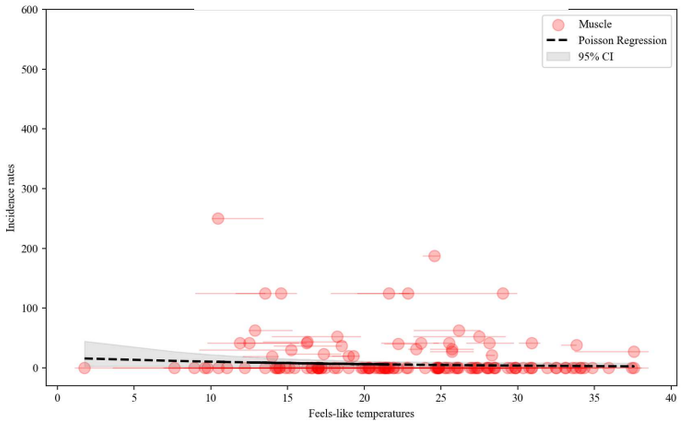


Hurdles – Time loss injuries

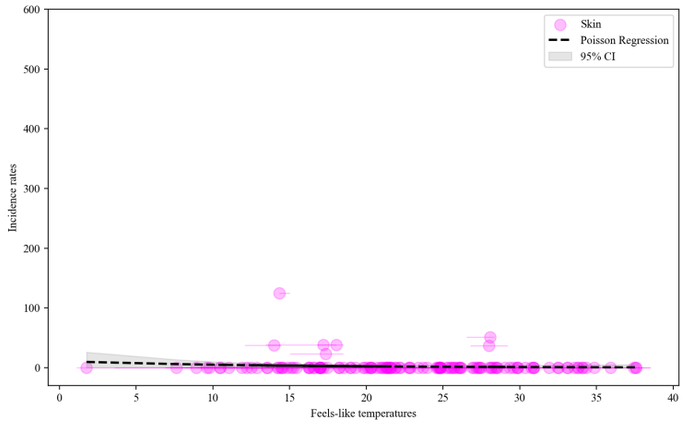
All injury types



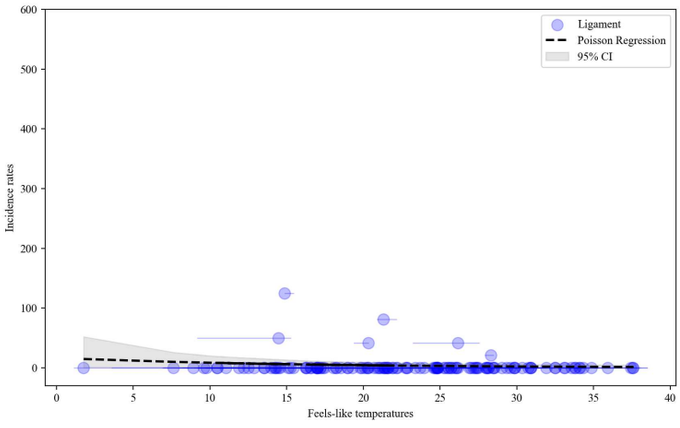
Muscle



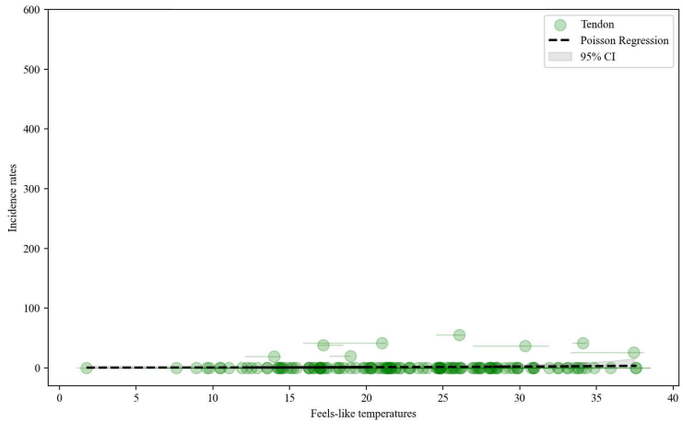
Skin



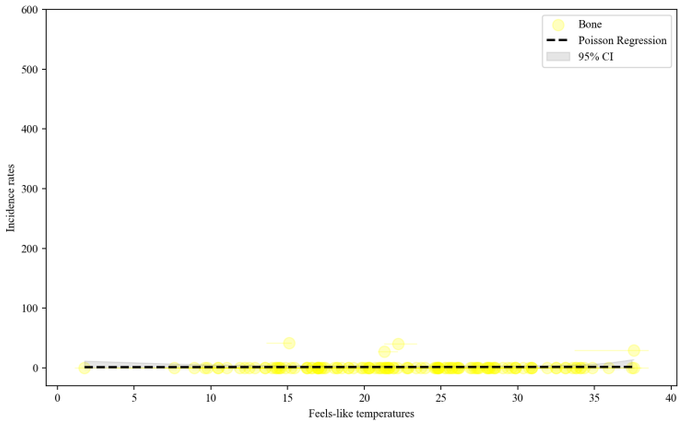
Ligament



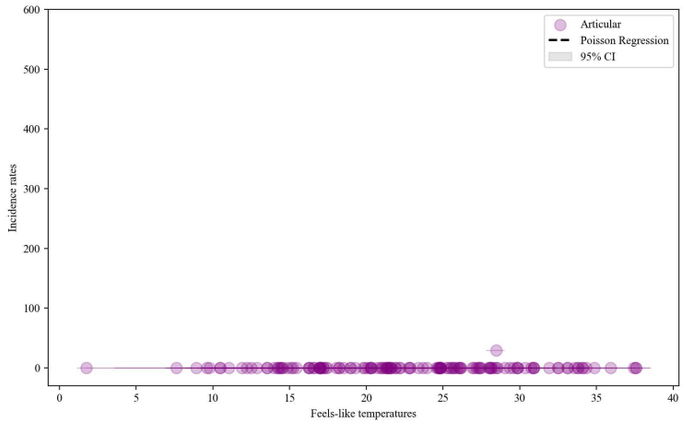
Tendon



Bone

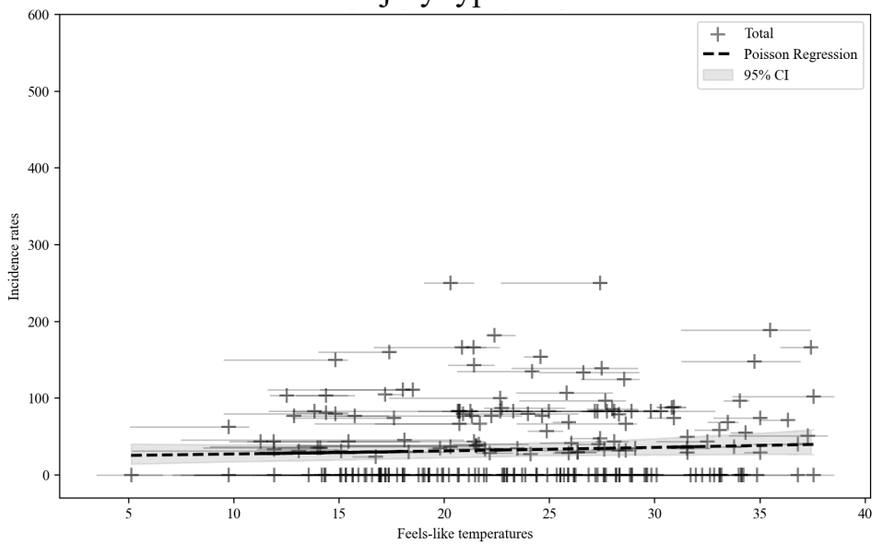


Articular not ligament

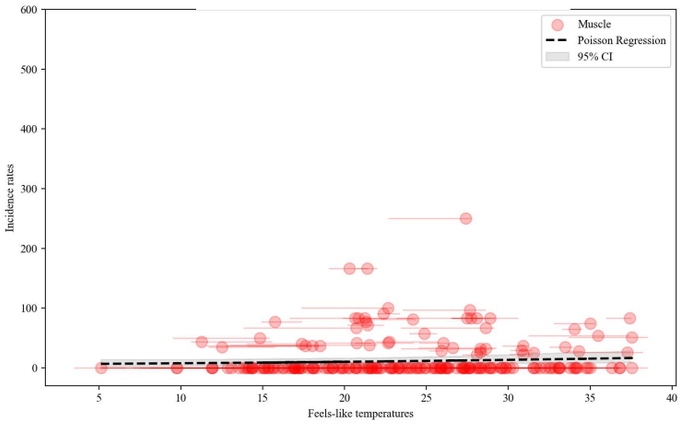


Jumps – All injuries

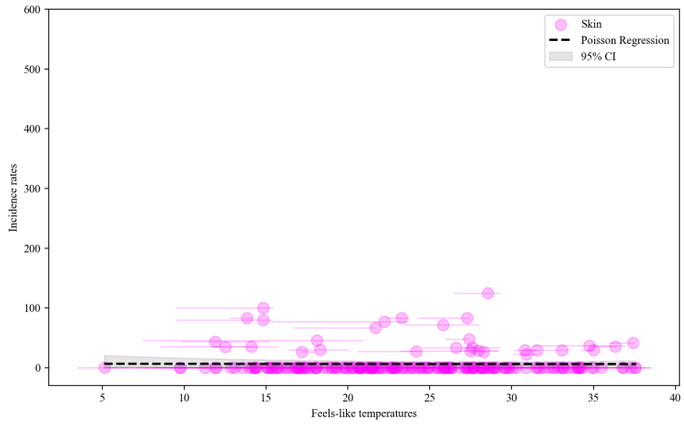
All injury types



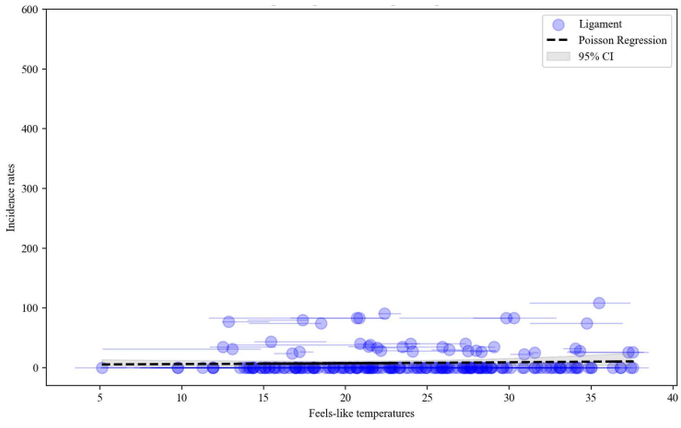
Muscle



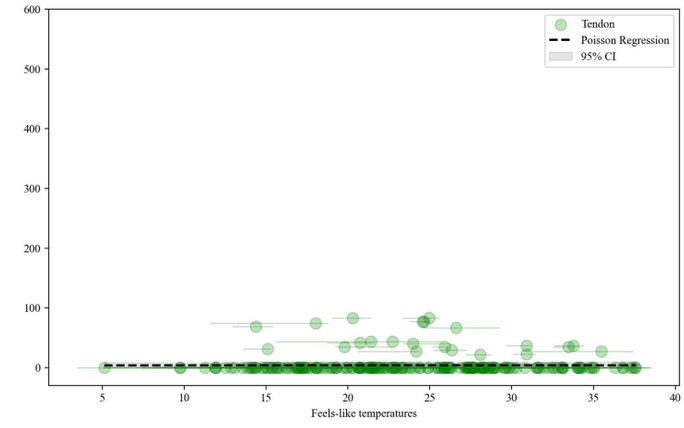
Skin



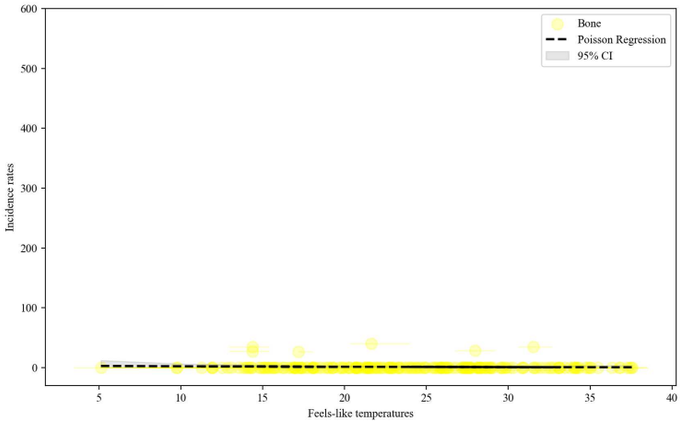
Ligament



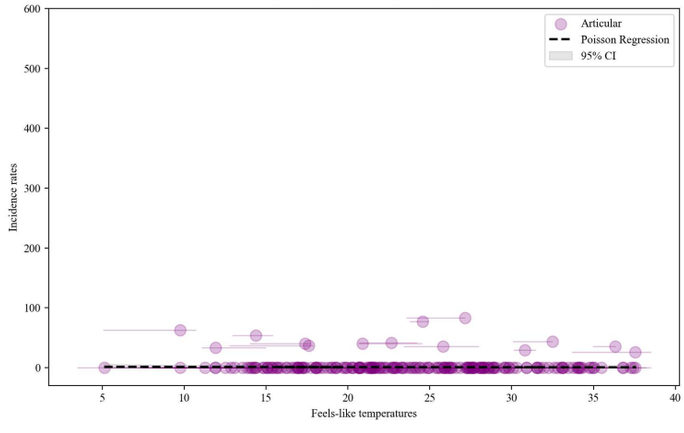
Tendon



Bone

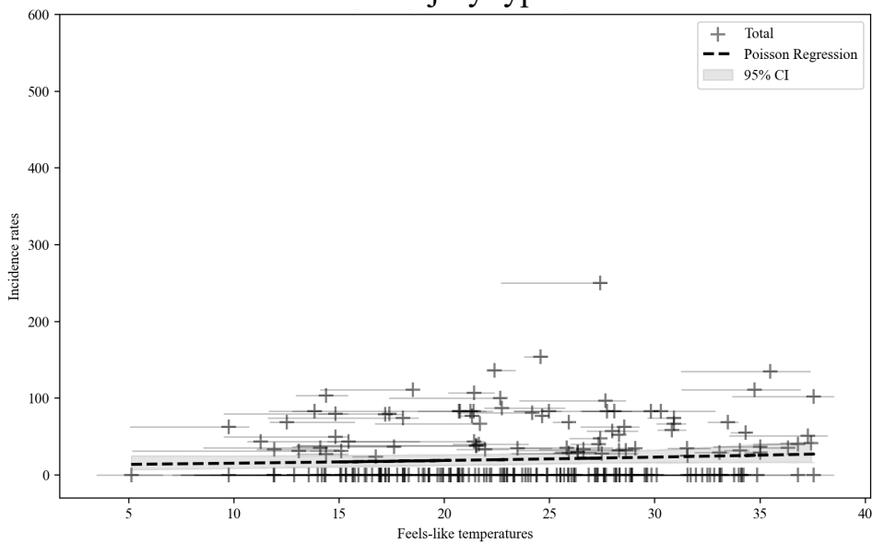


Articular not ligament

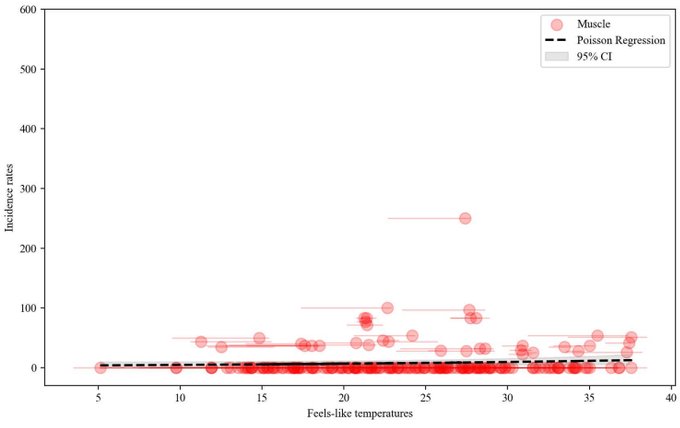


Jumps – Time loss injuries

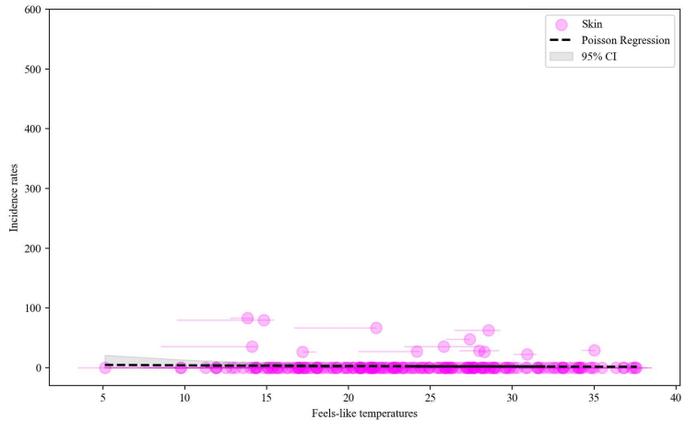
All injury types



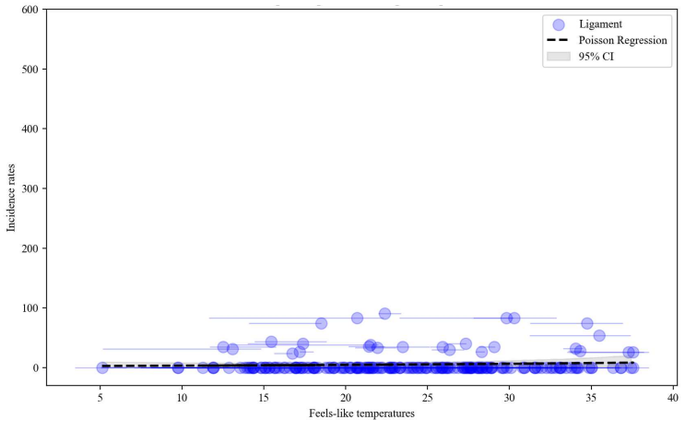
Muscle



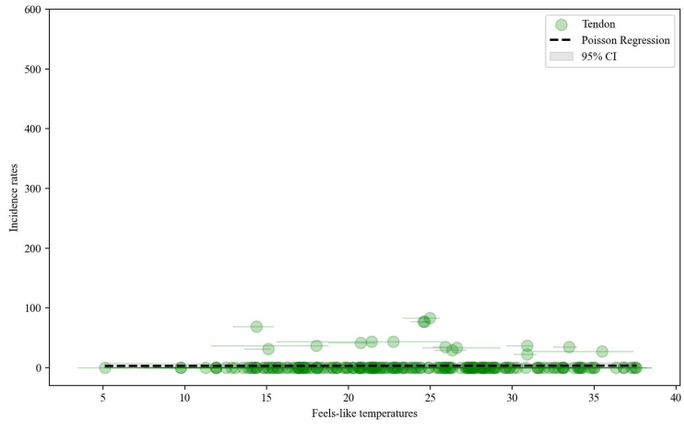
Skin



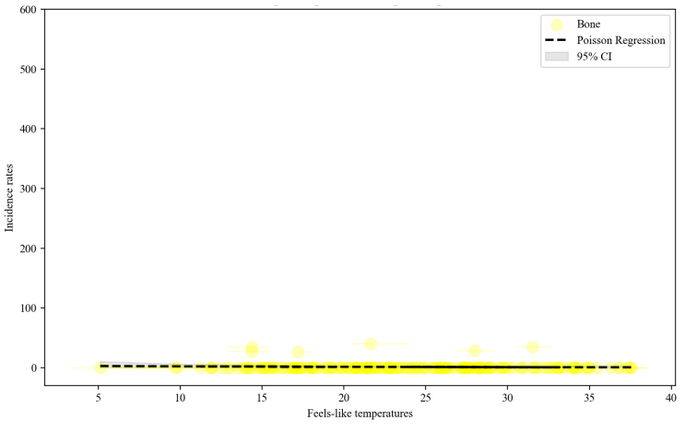
Ligament



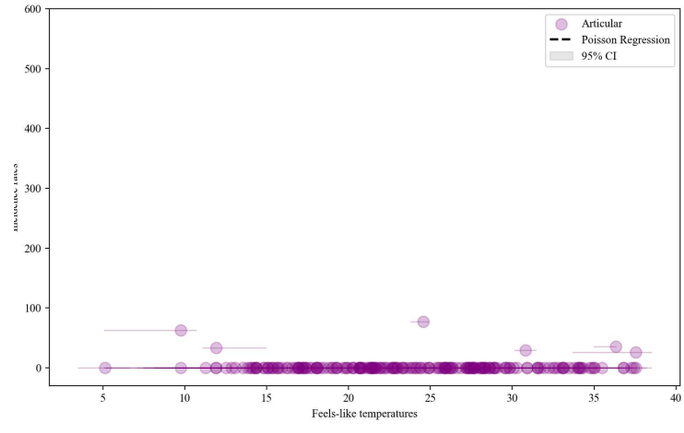
Tendon



Bone

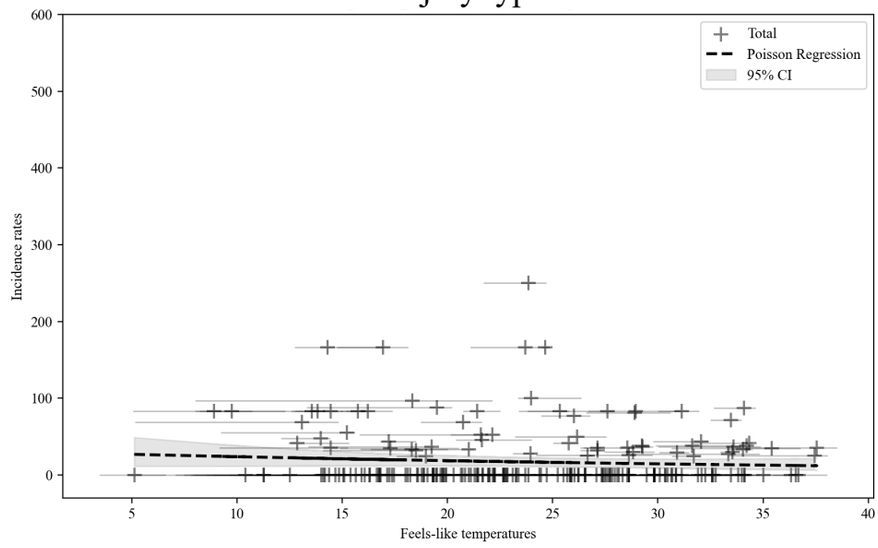


Articular not ligament

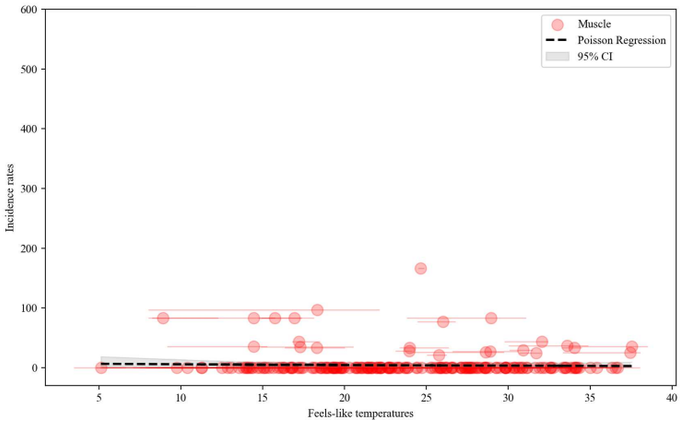


Throws – All injuries

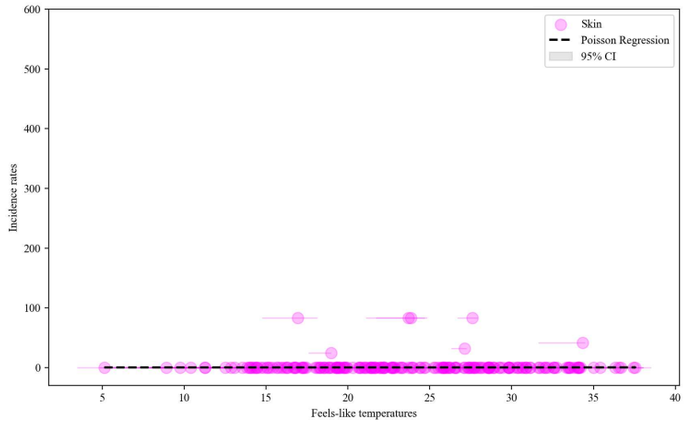
All injury types



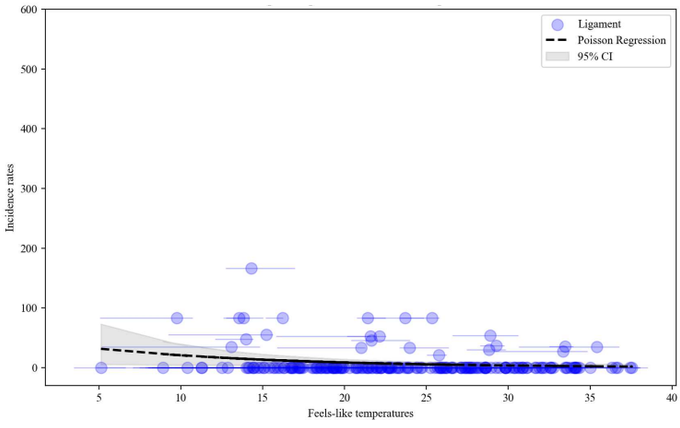
Muscle



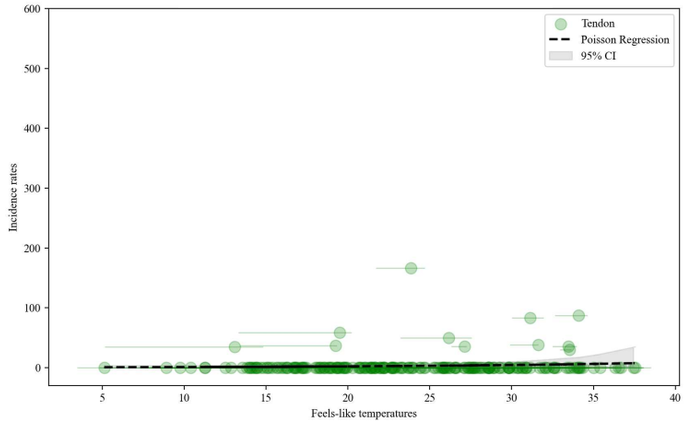
Skin



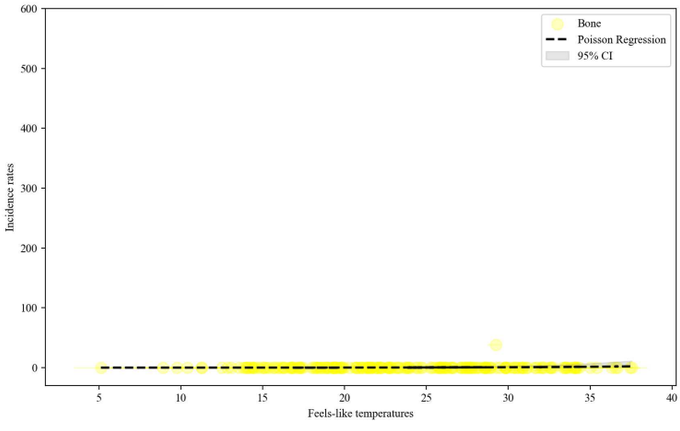
Ligament



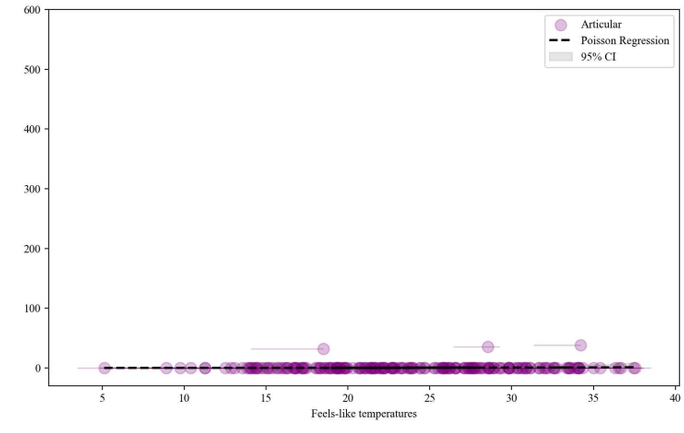
Tendon



Bone

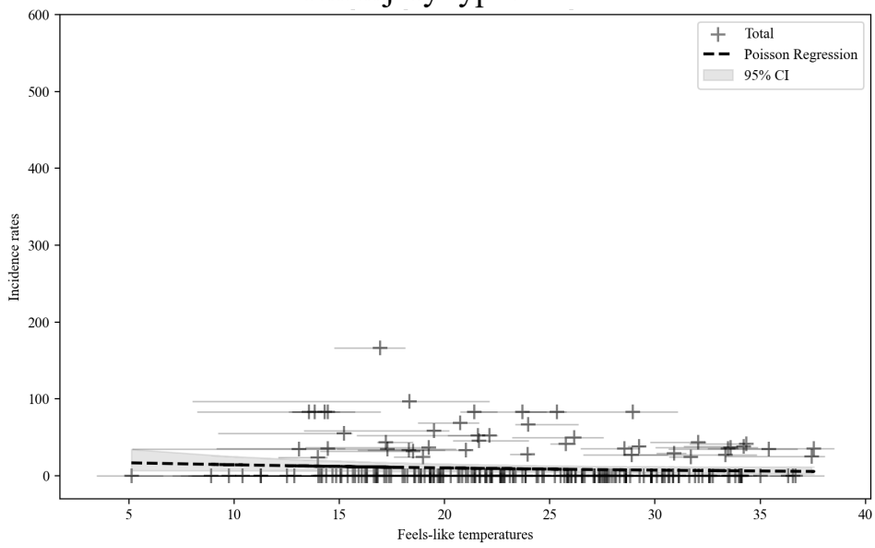


Articular not ligament

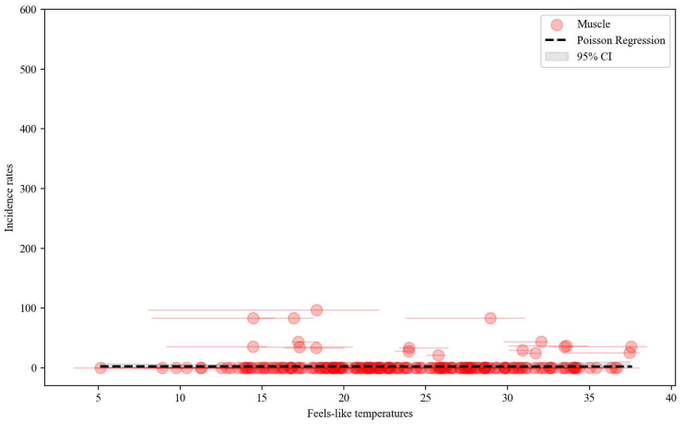


Throws – Time loss injuries

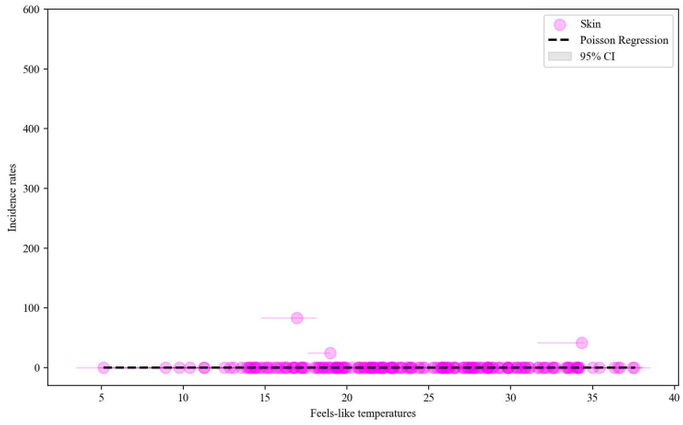
All injury types



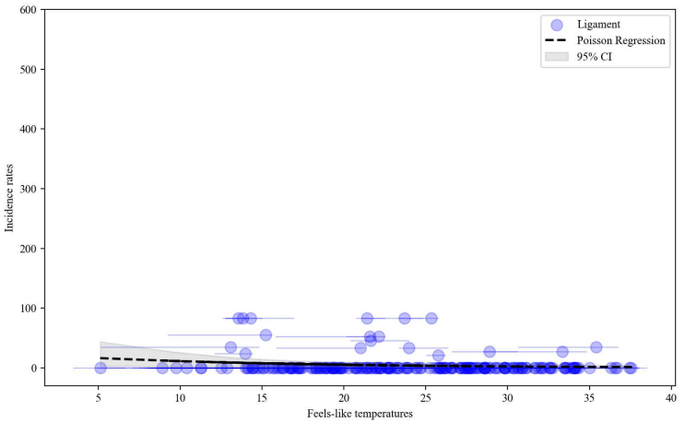
Muscle



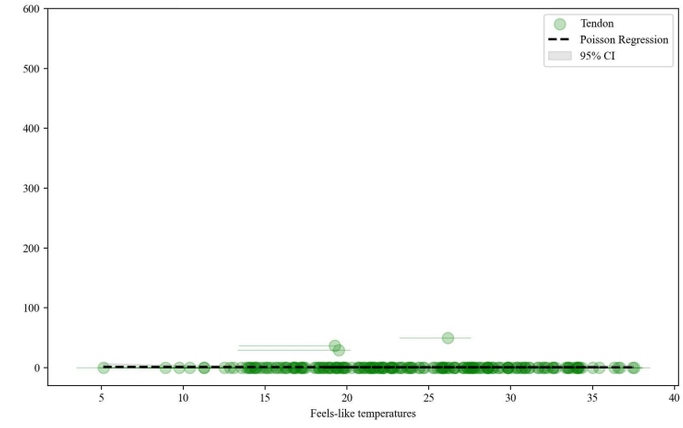
Skin



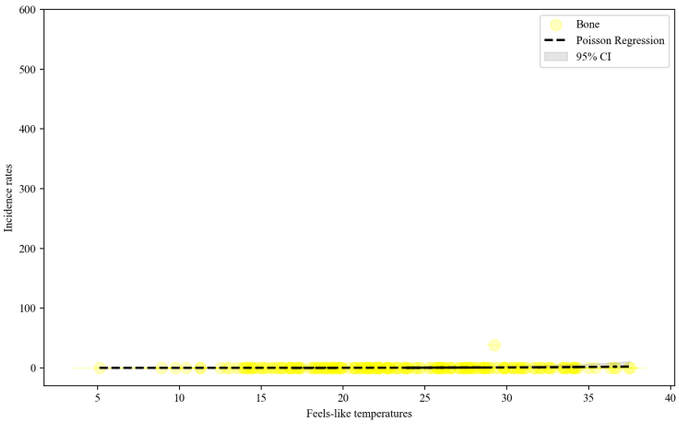
Ligament



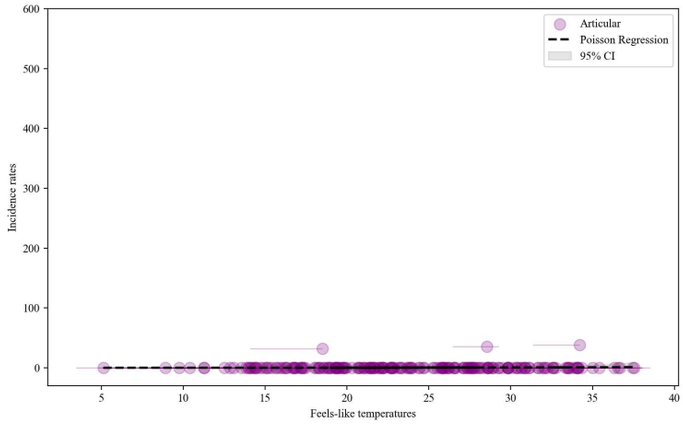
Tendon



Bone

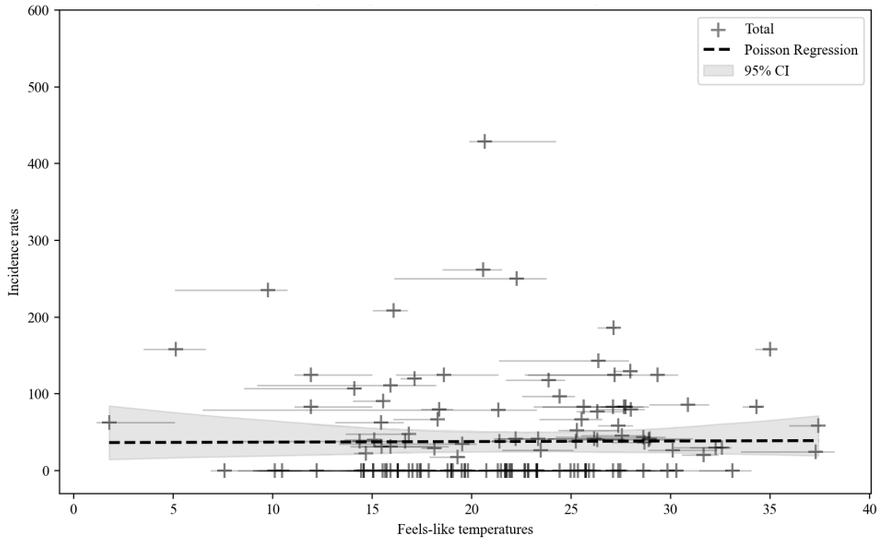


Articular not ligament

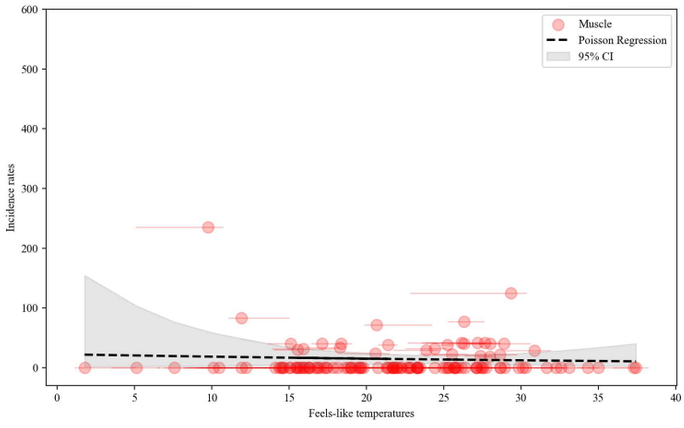


Middle distance – All injuries

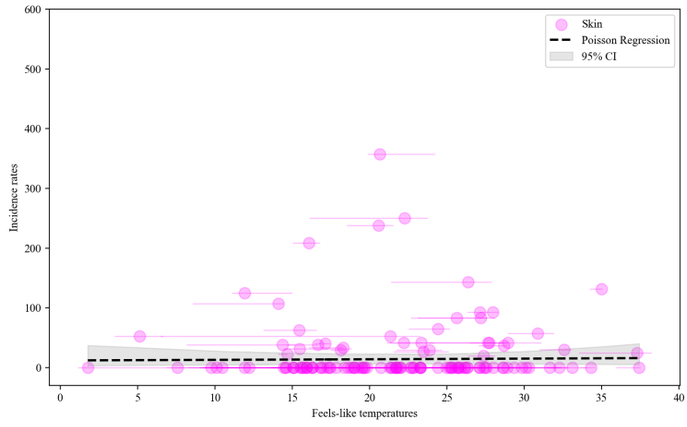
All injury types



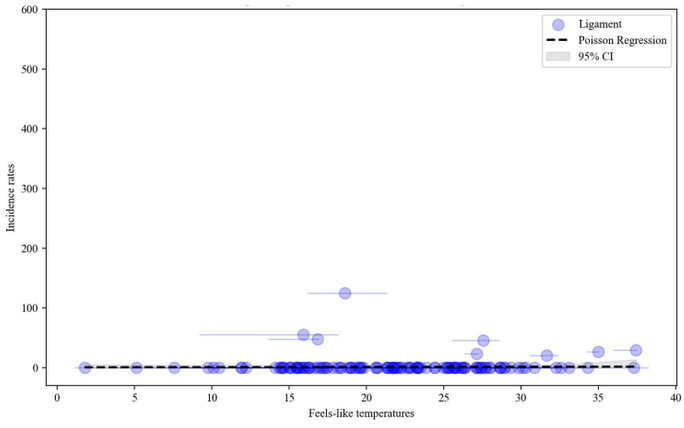
Muscle



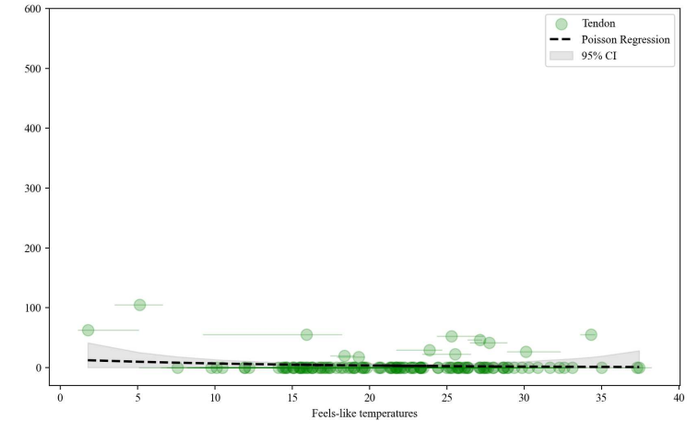
Skin



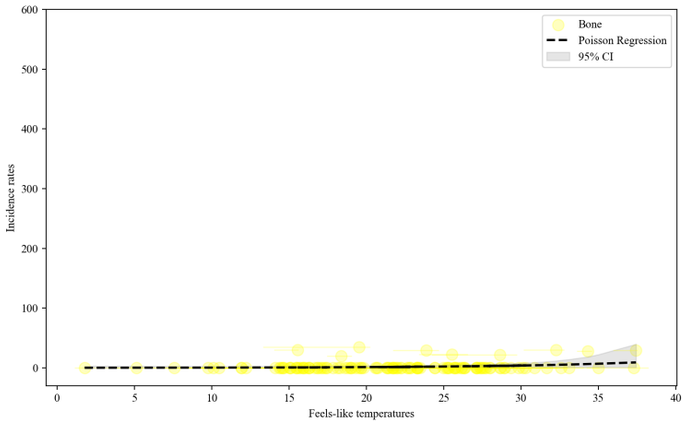
Ligament



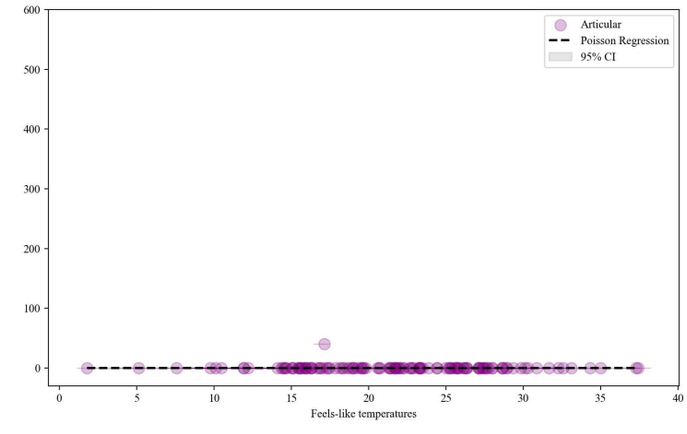
Tendon



Bone

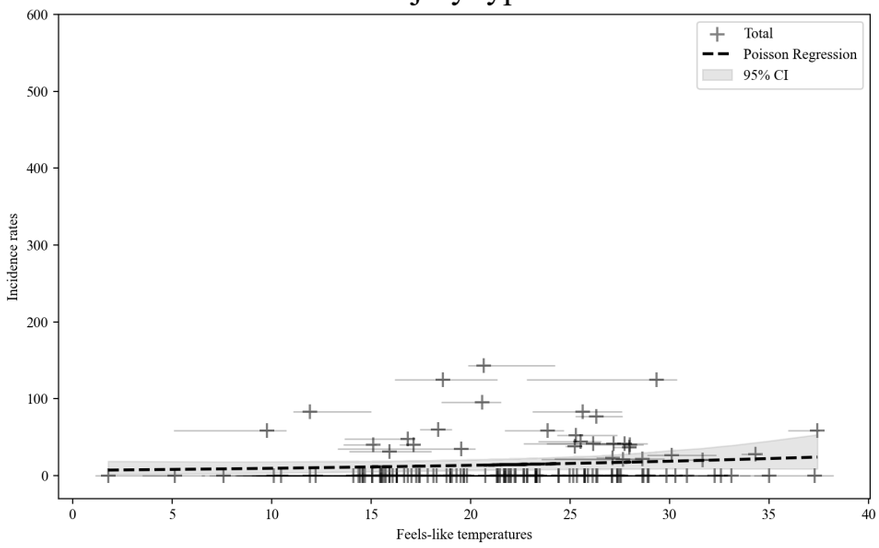


Articular not ligament

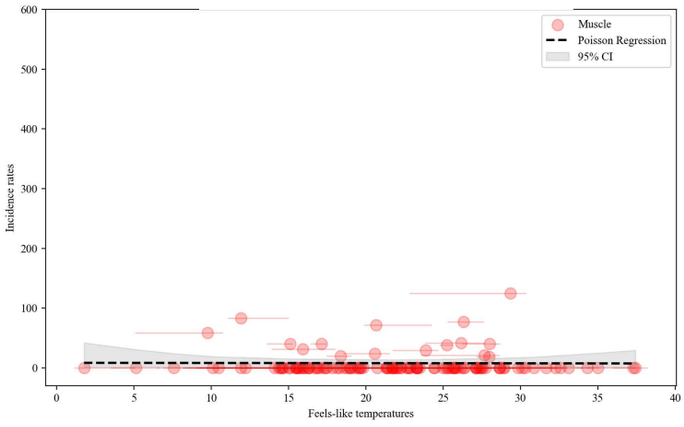


Middle distance – Time loss injuries

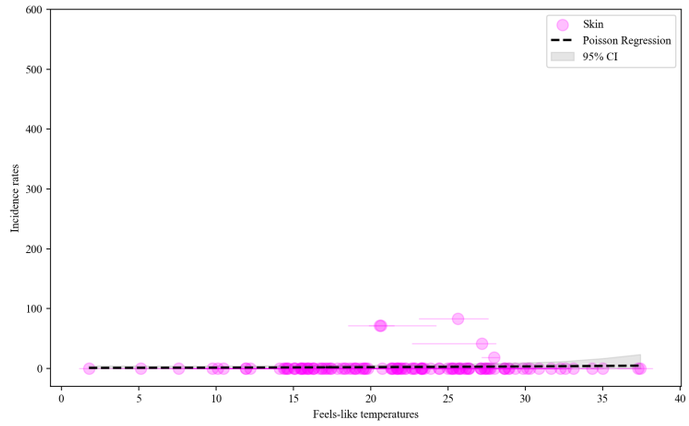
All injury types



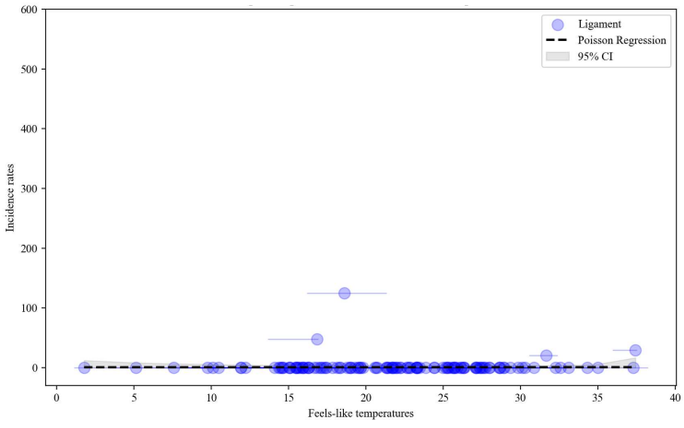
Muscle



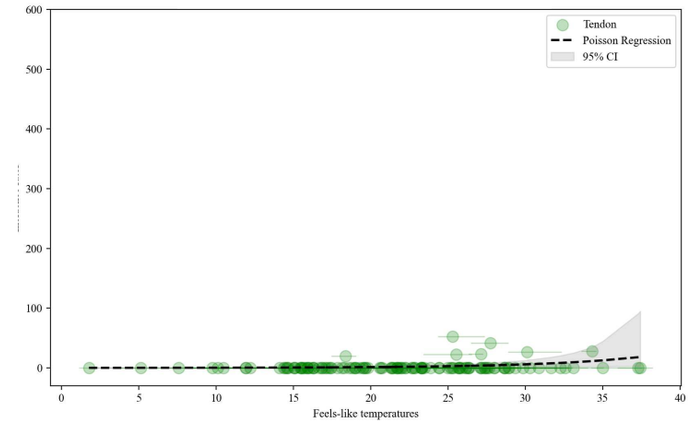
Skin



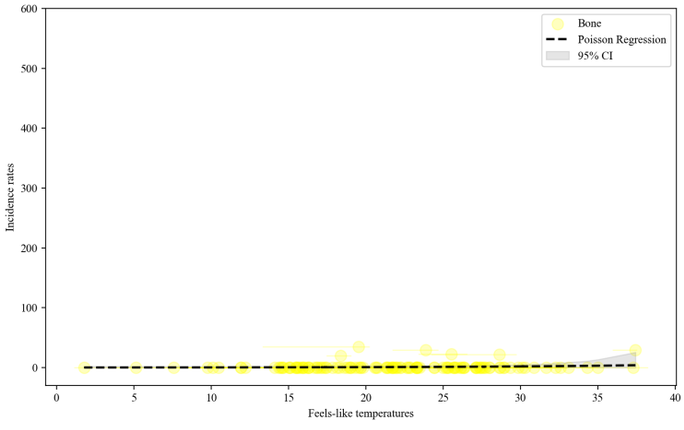
Ligament



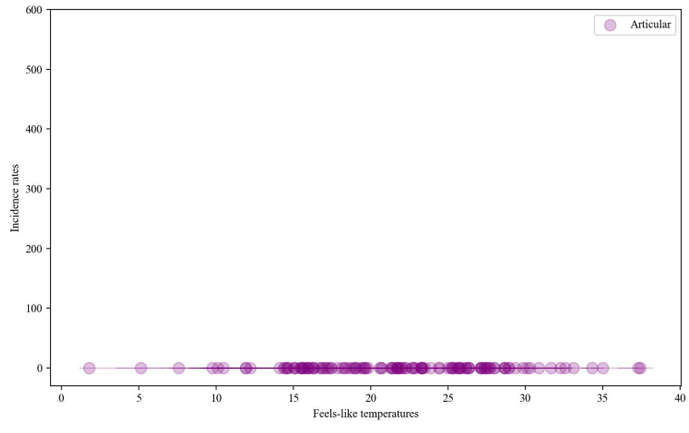
Tendon



Bone

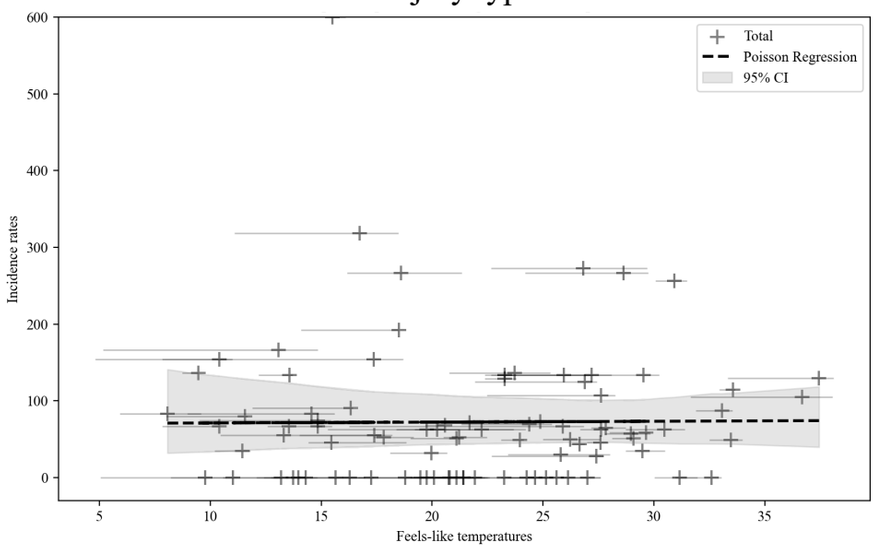


Articular not ligament

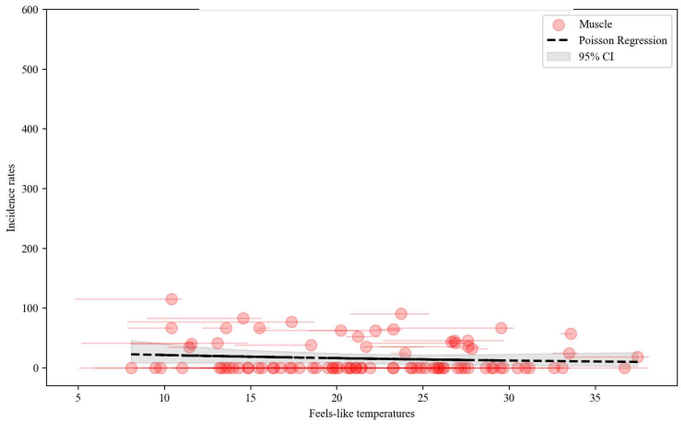


Long distance – All injuries

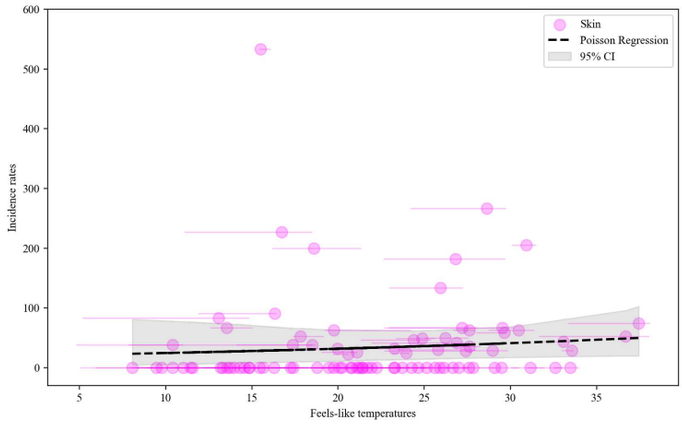
All injury types



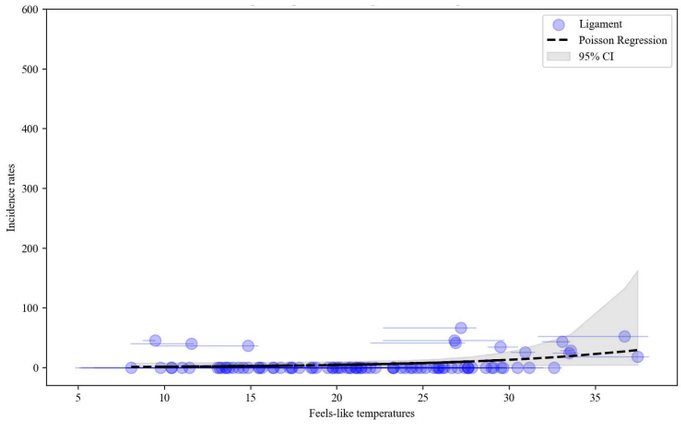
Muscle



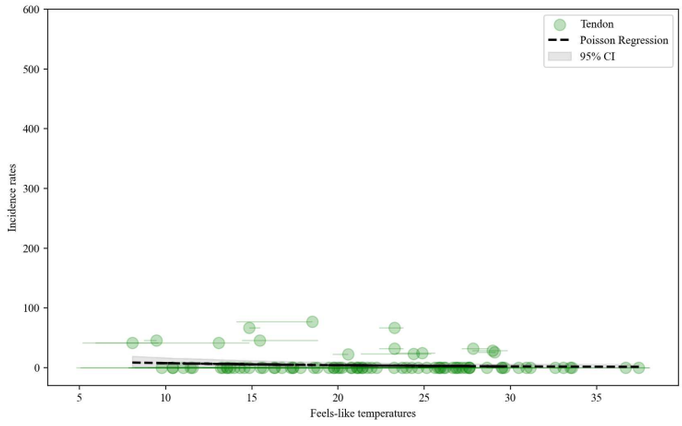
Skin



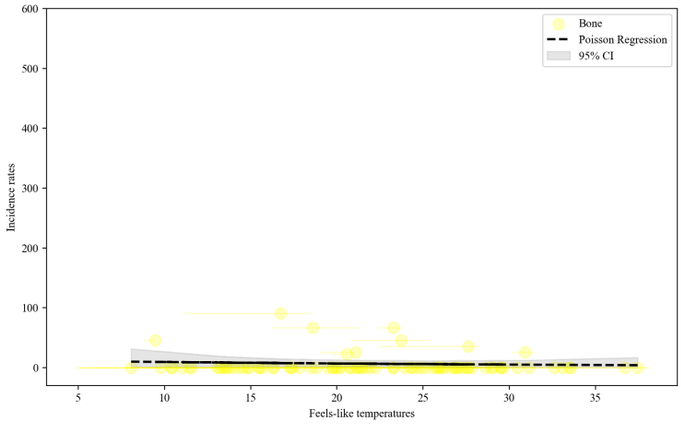
Ligament



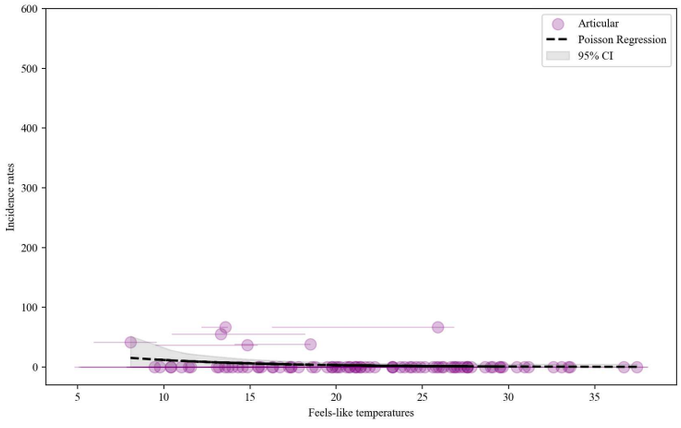
Tendon



Bone

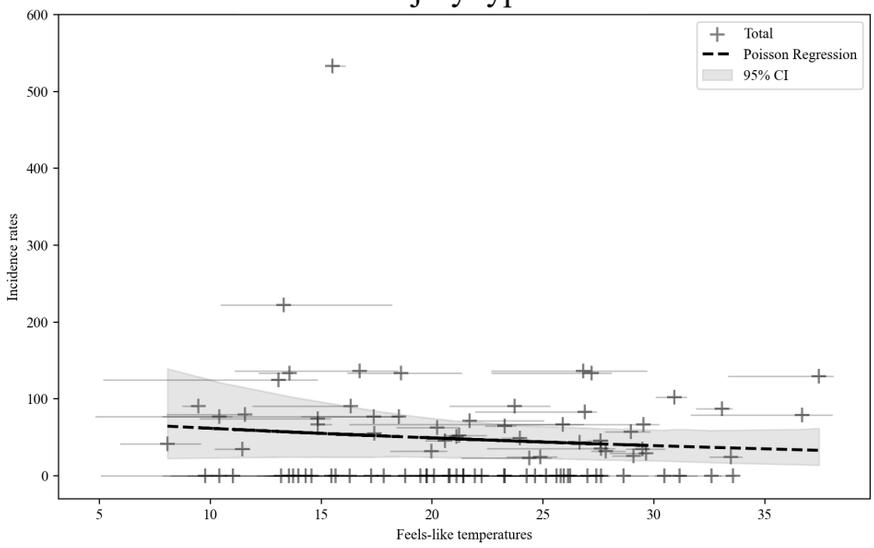


Articular not ligament

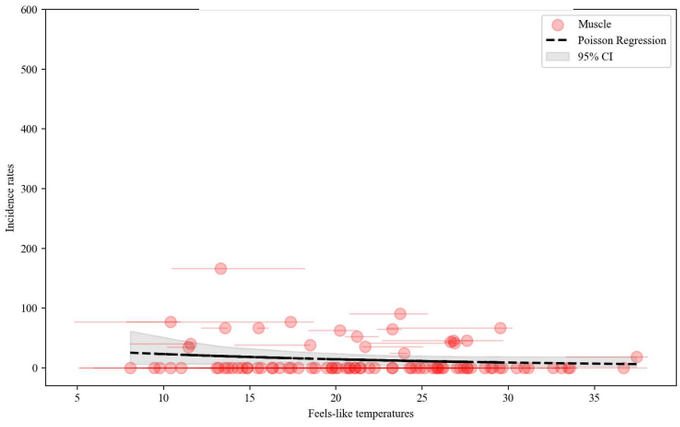


Long distance – Time loss injuries

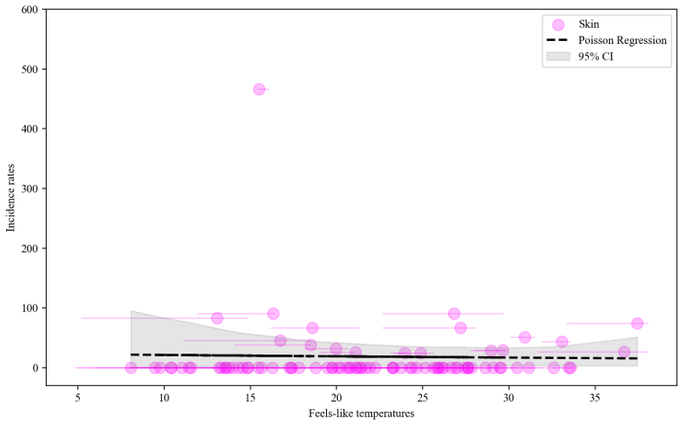
All injury types



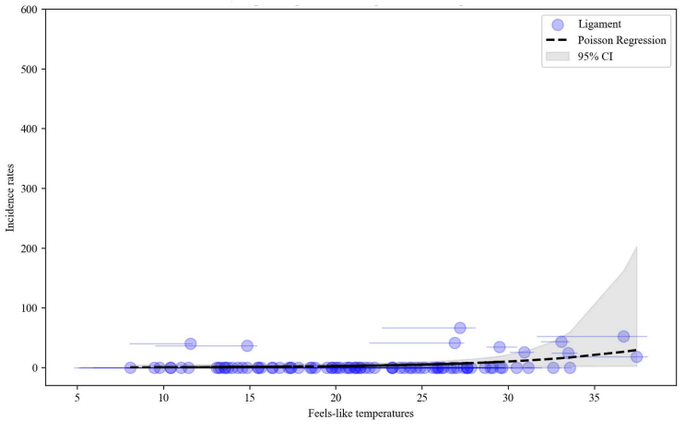
Muscle



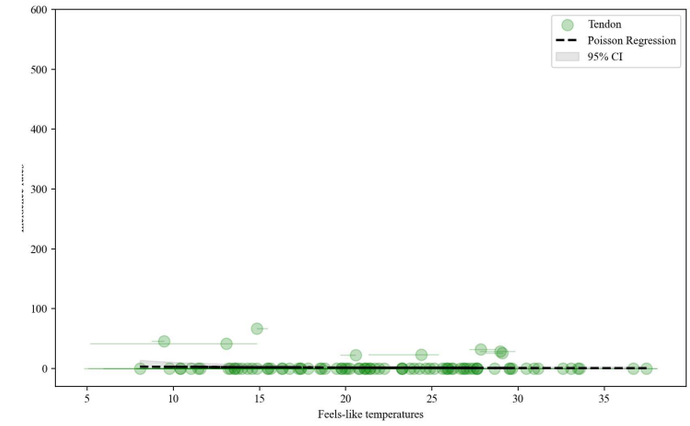
Skin



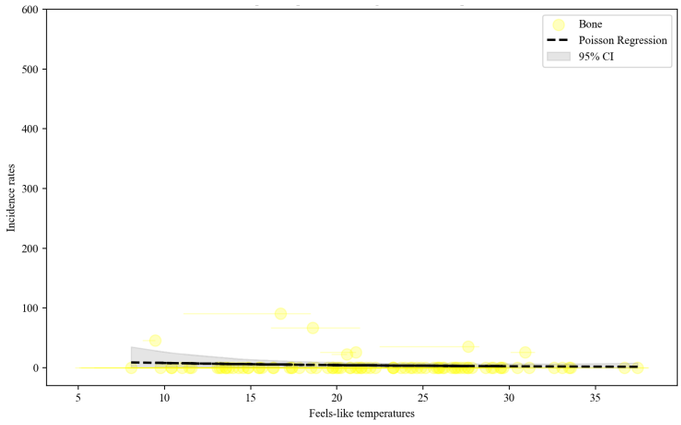
Ligament



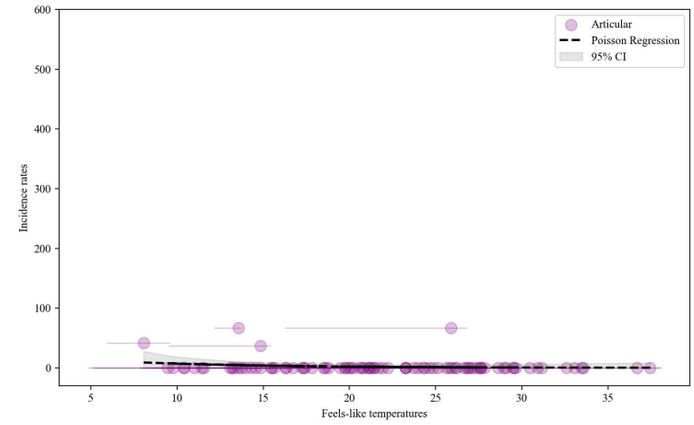
Tendon



Bone

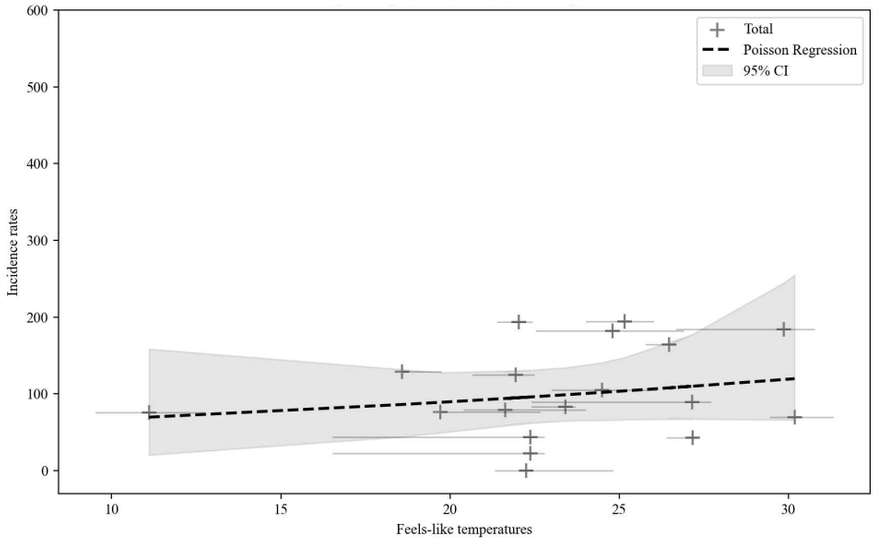


Articular not ligament

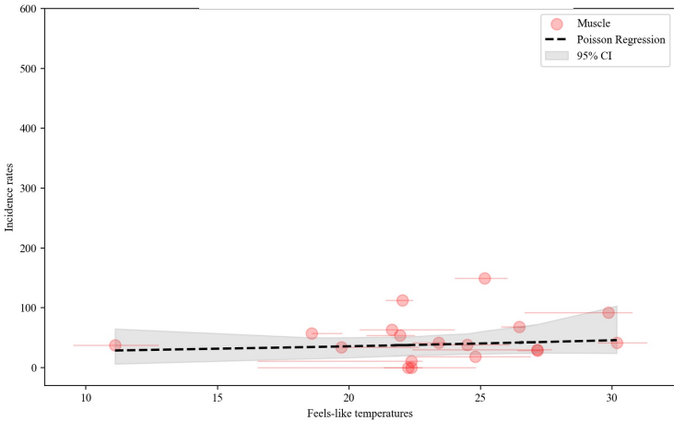


Marathon – All injuries

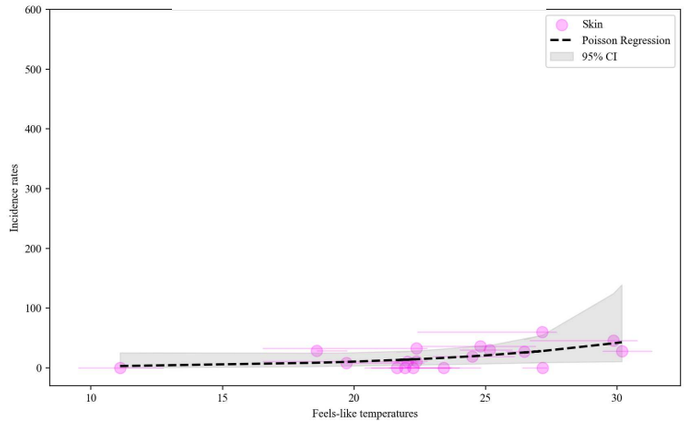
All injury types



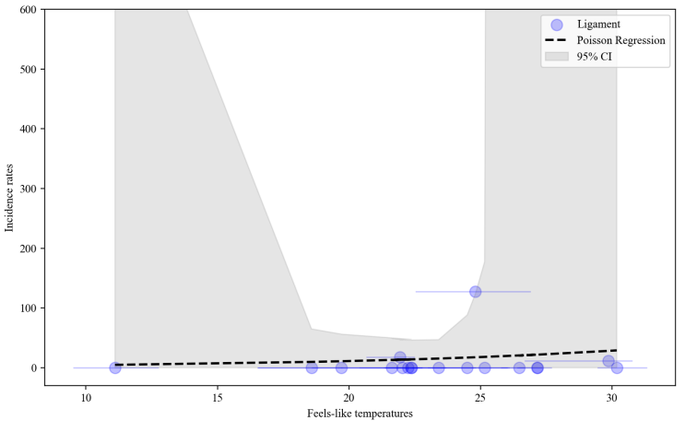
Muscle



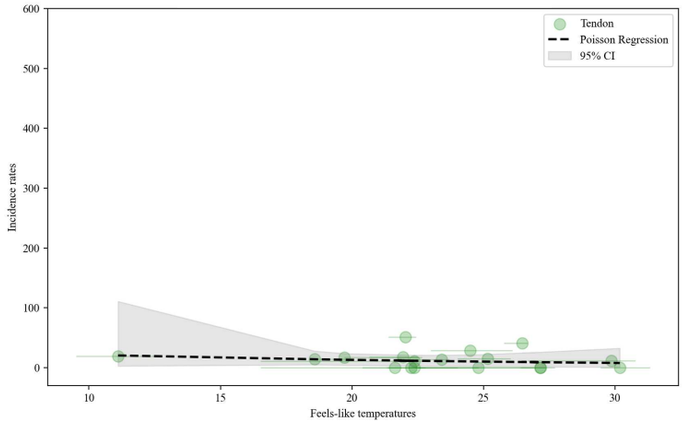
Skin



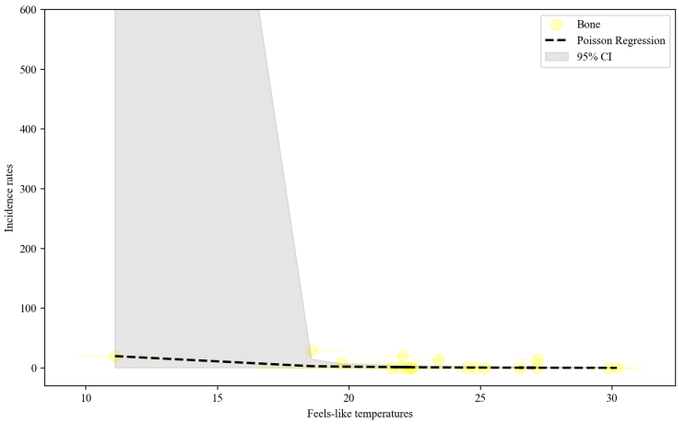
Ligament



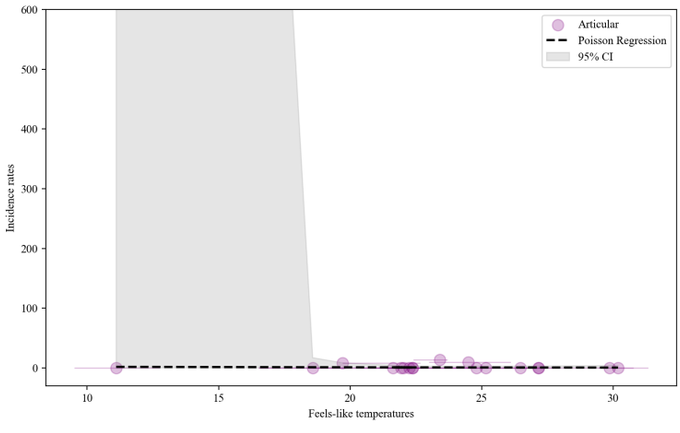
Tendon



Bone

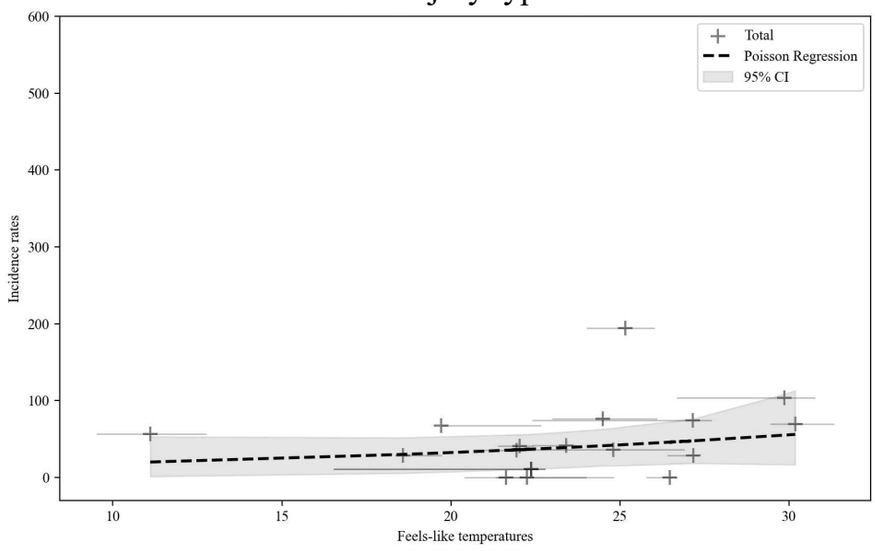


Articular not ligament

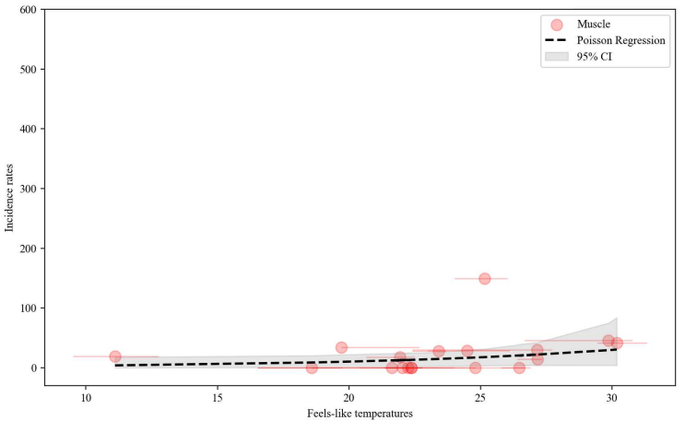


Marathon – Time loss injuries

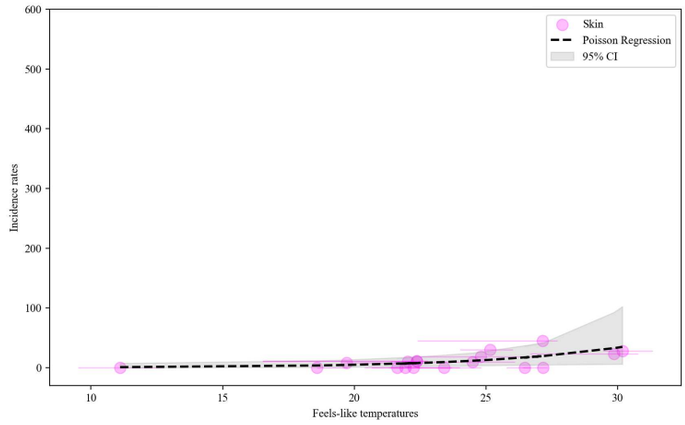
All injury types



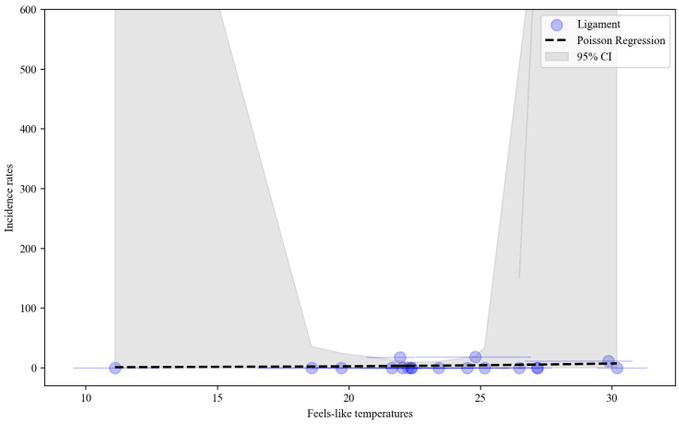
Muscle



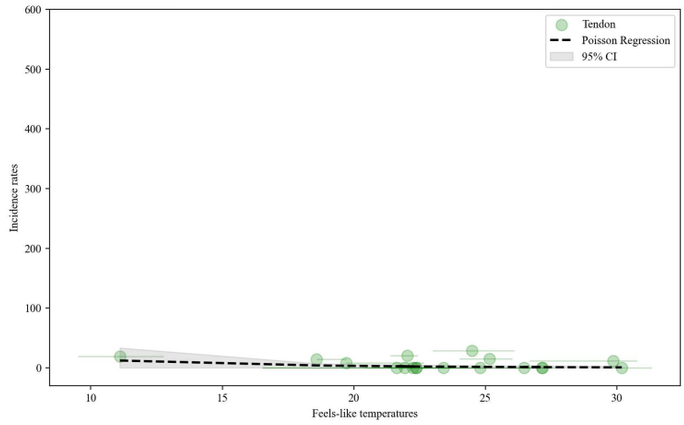
Skin



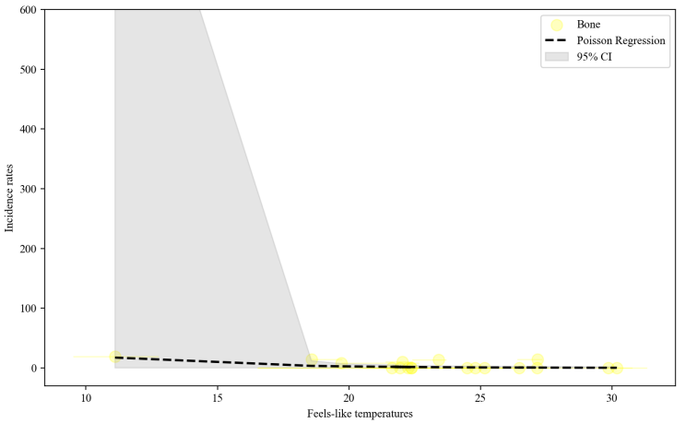
Ligament



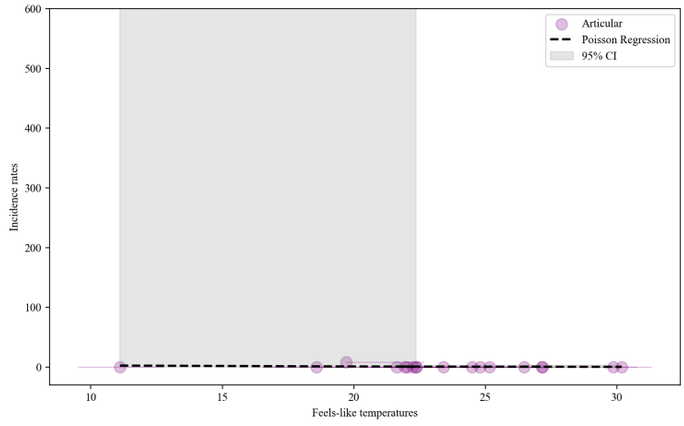
Tendon



Bone

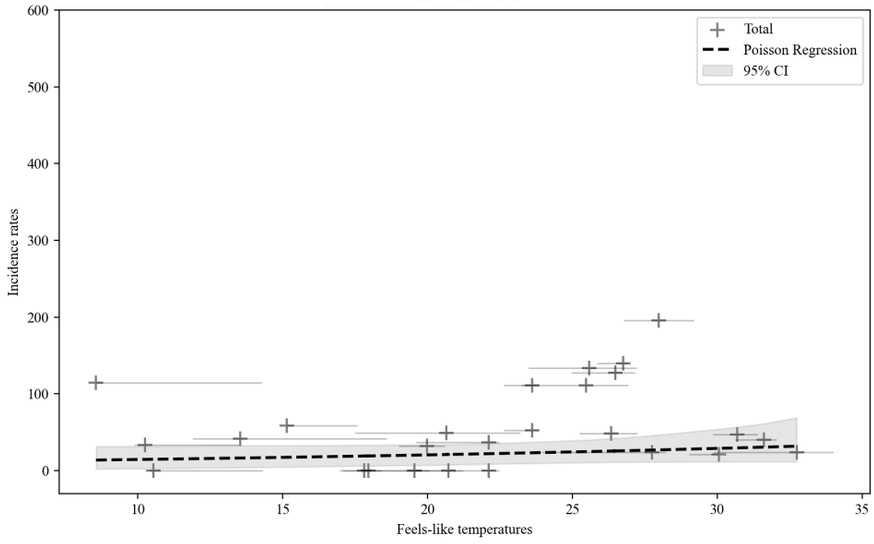


Articular not ligament

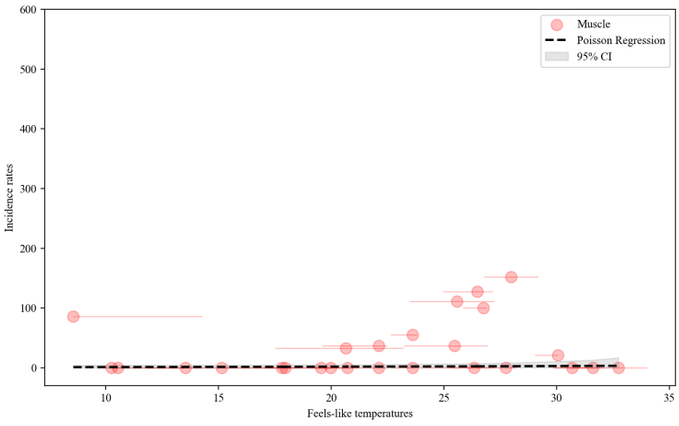


Race walking – All injuries

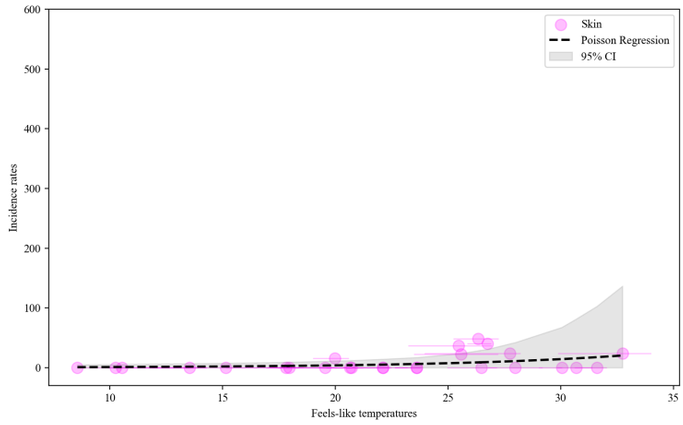
All injury types



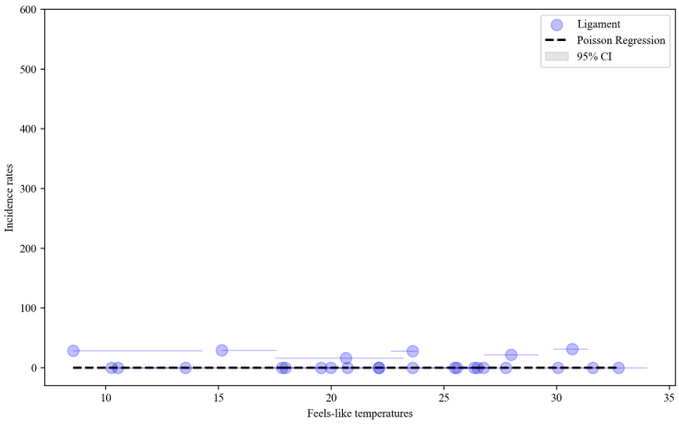
Muscle



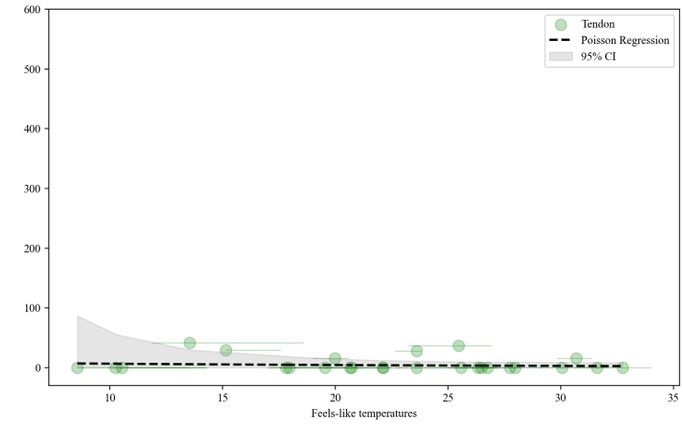
Skin



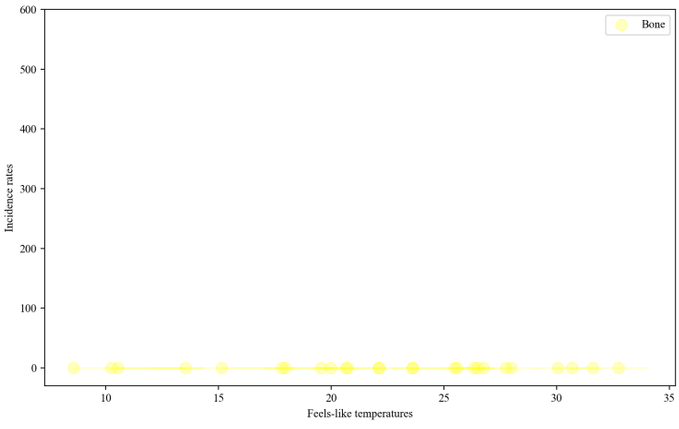
Ligament



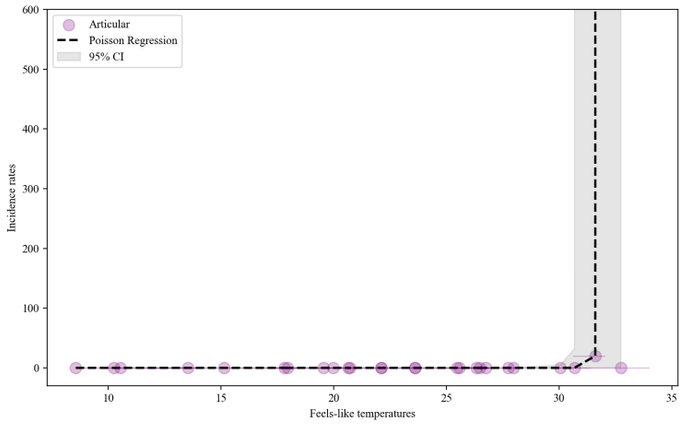
Tendon



Bone

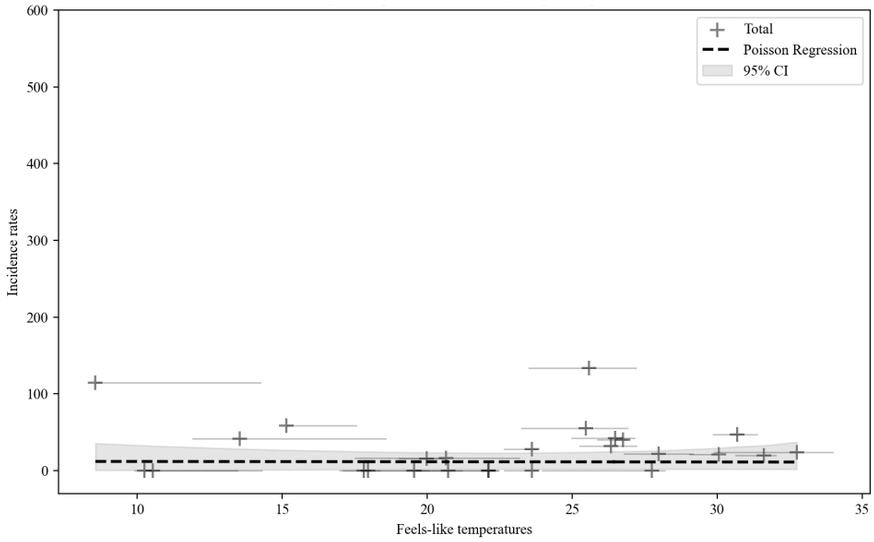


Articular not ligament

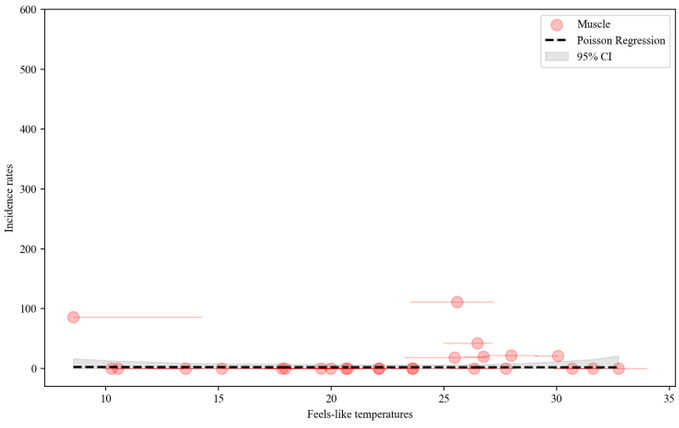


Race walking – Time loss injuries

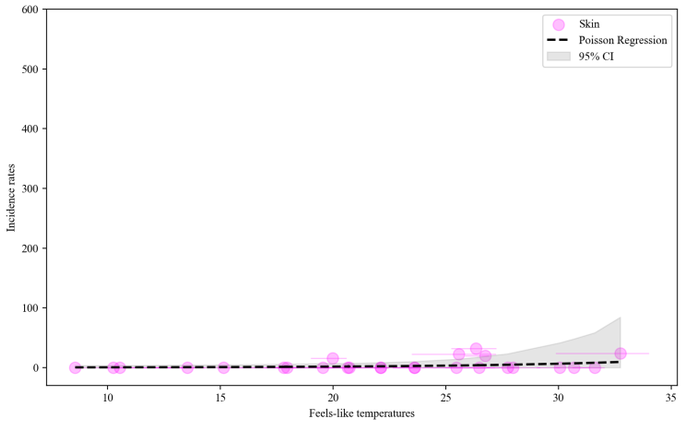
All injury types



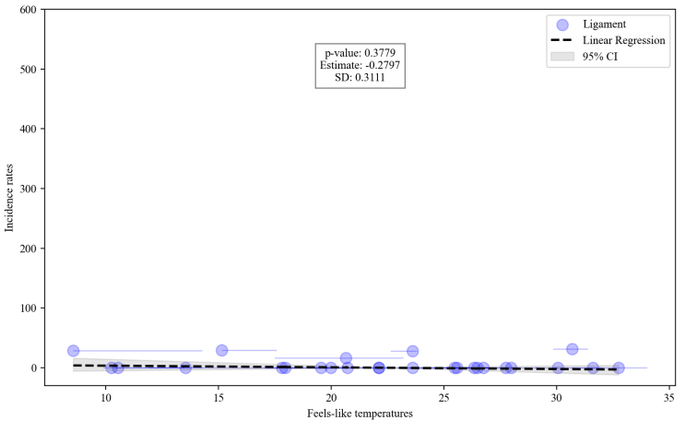
Muscle



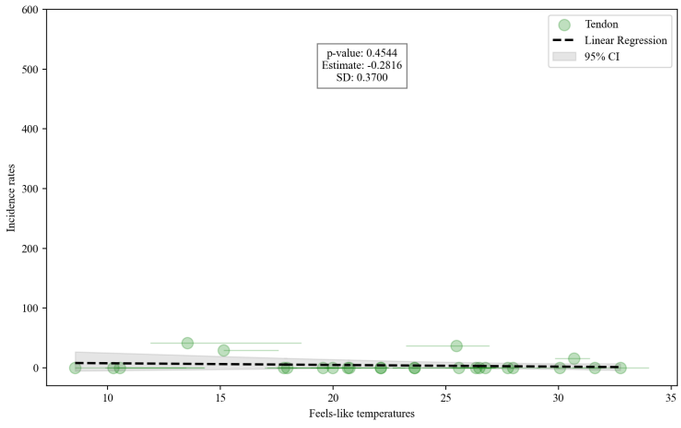
Skin



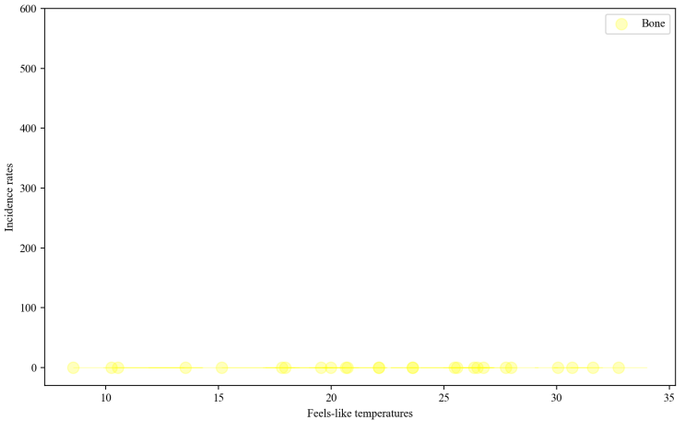
Ligament



Tendon



Bone



Articular not ligament