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A prospective cohort study on the acute:chronic workload ratio in relation to injuries in high level eventing horses: A comprehensive 3-year study

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ABSTRACT

In human sport science, the acute:chronic workload (ACWR) ratio is used to monitor an athlete's preparedness for competition and to assess injury risks. The aim of this study was to investigate whether acute and chronic workload calculations for external and internal loads (e.g. high-speed work distance and associated exertional effort) were associated with injury risk in elite eventing horses and to identify workloads performed by horses competing in different competition and at different fitness levels.

Training load and injury data were collected from 58 international eventing horses (CCI2*–CCI5* level) over 1–3 years. A total of 94 individual competition seasons were monitored. During this period, heart rate (HR; beat/min) and GPS data were collected of all their conditional training sessions and competitions. External load was determined as the distance (m) covered at high speed (HS[1] ; velocity between 6.6 and 9.5 m/s), and sprint speed (SS[2] ; velocity > 9.5 m/s). Internal load was calculated for HS and SS, using individualized training impulses (TRIMP[3] ;AU). For internal and external workload HS and SS the acute (1-week) and chronic (4-week) workloads were calculated and ACWR[4] determined. The injury data in relation to ACWR was modelled with a multilevel logistic regression. Akaike's information criterion was used for model reduction.

Sixty-four soft tissue injuries were registered from a total of 2300 training sessions and competitions. External and internal workload at HS and SS were significantly affected by the year and fitness level of horses. Competition level and year significantly affected the distances covered at SS. The ACWR of high-speed distance of the present week (OR; 0.133, 95 % CI; 0.032, 0.484) and the previous week (OR 3.951, 95 % CI; 1.390, 12.498) were significantly associated with injury risk. Competition level and chronic workload had no significant effect on injuries.

In agreement with findings in human athletes, acute spikes of workload in eventing horses increased the risk of injury. Evaluation of horses' workload can be used to design and effectively monitor training programs and can help to improve equine welfare by reducing injury risk.

1. Introduction

In human sports daily monitoring of training load is a well-recognised aspect of the training process for athletes, coaches and sport scientists and that enables planning and optimization of their training process (Blanch and Gabbett, 2016; Borressen and Lambert, 2009; Bucheit, 2017). The International Olympic Committee (IOC) has developed a consensus statement on load in sport and risk of injury

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[1] High speed = HS, velocity between 6.6 m/s and 9.5 m/s
[2] Sprint speed = SS, velocity above 9.5 m/s
[3] Training impulses; TRIMP (represented in AU)
[4] Acute:chronic workload ratio: ACWR

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(Soligard et al., 2016). This paper defines guidelines for monitoring workload and factors influencing workload. When the recovery time between the applied training loads is inadequate or when the training or competition load surpass the current loadbearing capacity, this may lead to a non-functional overreaching status, increasing the risk at redundant microdamage and injuries (Soligard et al., 2016). More and more studies show that injuries are not caused by solely a high workload, but that the rate of change in workload is the essential factor (Soligard et al., 2016). Therefore, the load history of an athlete representing its fitness level, or chronic workload, has to be taken into account (Blanch and Gabbett, 2016).

Workload can be described as external load and/or internal load. Evaluating external and internal load simultaneously reveals also how an athlete has experienced the specific training session in terms of biological stress (Saw et al., 2015; Vanrenteghem et al., 2017; Mujika, 2017). It has been shown that no or wrong workload management is a main risk factor for injury in many human sporting disciplines (Bowen et al., 2017; Carey et al., 2017; Gabbett et al., 2016; Hulin et al., 2016; Soligard et al., 2016; Akubat et al., 2014; Weaving et al., 2017; Stevens et al., 2017; Sanders et al., 2017). This raises the possibility that the association between workload and the risk of injury might also apply to equine athletes.

Training in equine sports is largely based on experience and intuition and there is a clear need for a more scientific evidence based approach to equestrian training (McLean and McGreevy, 2010). In 2007 an attempt was made to define workload definitions in horses as they were not consistent throughout literature (Rogers et al., 2007). External workload has been described as race distance, duration and frequency, as well as a cumulative workload index per week (Murray et al., 2010; Parkin, 2008; Rogers et al., 2007). Dekker et al. (2007) and Munsters et al. (2013) evaluated the relative workload of horses in training, using heart rate (HR), frequency and duration as a measure for internal workload. However, these calculations were not based on the individual HR-lactate (LA) characteristics to calculate the internal workload. In addition, in none of the studies, the rate of change in workload, or the load history (chronic workload) was taken into account.

Musculoskeletal injuries cause over 33 % of all training day losses and wastage of sport horses, in all kind of equestrian disciplines (Rogers et al., 2012; O'Brien et al., 2005; Murray et al., 2010; Sloet van Oldruitenborgh-Oosterbaan et al., 2010; Munsters et al., 2013). In eventing, wastage figures are high ranging from 28.1 % in lower level event horses (Caston and Burzette, 2018) to 45 % of the elite eventing horses (Munsters et al., 2013). Several studies investigating the relation between workload and injuries have been performed (Egenvall et al., 2013; Murray et al., 2010; Munsters et al., 2013; Vallance et al., 2013; Verheyen and Wood, 2004). However, data about the actual workload of sport horses and measures to determine these are limited.

Eventing is an Olympic discipline, which is physical and mentally challenging for both rider and horse. During a three-day event, horse-rider combinations have to perform three separate tests: dressage, cross-country, and show jumping. Eventing is performed at national (grassroot) and international level and both with ponies (age of the rider ≤18 years) and horses (age of the rider ≥12 years). International competitions in horses range from Introductory level (CCI*; meaning Concours Complet International level 1) to CCI5* (Concours complet international level 5), which is the highest level, including the Olympic Games. In ponies CCIP** is the highest level, meaning CCI level 2 for ponies. At the highest level, eventing horses have to perform a cross-country test with a distance of up to 6270 m with 40 jumping efforts at 9.5 m/s. During this part of the competition HRs between 171–207 beats/min and plasma LA concentrations of 8.5–38.5 mmol/L are frequently achieved (Amory et al., 1993; Marlin et al., 1995; White et al., 1995a, 1995b; Muñoz et al., 1999; Serrano et al., 2002). The dressage test demands different technical skills from rider and horse for around 6 min and is performed at a lower intensity; HRs seldom exceed 150 bpm/min (Clayton, 1991). During the 1-min lasting show jumping test, horses jump at velocities between 5–7.5 m/s with HRs ranging from 150 beats/min to 190–200 beats/min (Art et al., 1990a, 1990b; Sloet van Oldruitenborgh-Oosterbaan et al., 2006).

Simple measures of distance covered during training were not associated to injuries in eventing horses (Caston and Burzette, 2018). In racehorses, several studies investigated the accumulated workload in a certain time frame. Higher intensity of recent exercise seemed to increase the risk for developing failure of the suspensory apparatus (Hill et al., 2004) and racehorses which covered large total high-speed distances or increased their total amount of high speed work in a fast manner within a 2-month period had an increased risk of getting a fatal skeletal injury or catastrophic musculoskeletal injury (Estberg et al., 1996, 1998). However, findings were not always consistent between different regions (Cohen et al., 2000; Hitchens et al., 2019). In eventing horses there are no studies available regarding workload and change in workload in relation to the development of injuries.

Therefore, the aim of this study was to calculate the internal and external acute and chronic workloads and the acute:chronic workload ratios (ACWRs) in relation to injury occurrence in elite event horses during a period of 1–3 years. The second aim was to provide more insight into training programs of horses of different competition and fitness levels.

2. Materials and methods

2.1. Study design

This prospective cohort study evaluates the external and internal workload, the ACWR and the injury incidence of elite eventing horses in the Netherlands during the competition seasons of 2015 – 2017. Compliance with STROBE-VET is documented in supplementary material. As each horse is followed over a longer period of time from one up to three competition years, a multilevel logistic regression was used to deal with the repeated measures within an animal or group. Since a multilevel logistic regression was used in the present study, power calculations are difficult or impossible; to calculate sample size, the usual rate of injury had to be known. In this manner, the number of variables planned can be included and then the required number of participants can be calculated. As injury rates (training-days lost) in eventing are not available, a general rule of thumb ($N \geq 104 + m$, whereas m is the number of independent variables) was used to calculated the required number of participants (Green, 1991; Tabachnick and Fidell, 2013). In addition, authors were restricted to the eligibility criteria, horses had to be qualified and performing at international level in eventing and riders and horse owners willing to participate in the study. In total 58 horses met the eligibility criteria and were enrolled in the study.

2.2. Study subjects

Data were collected from privately owned, high level international event horses (n = 58) competing under the rules of the Federation Equestrian International (FEI); 7 horses competing at CCI5*, 14 at CCI4*, 14 at CCI3*, 18 at CCI2*, 5 at CCIP**). Whereas the highest level is at CCI5* (5-star) and the lowest level in our study was CCI2* (2-star). The average age the horses was 12.1 ± 2.7 years. Data was collected in the years 2015, 2016 and 2017. In total 94 individual competition seasons were assessed (in 2015; 28 horses participated in the study, in 2016 28 horses and in 2017 38). These horses participated for one (n = 35), two (n = 10) or three years (n = 13) (see supplementary Table 1). During this period, several horses participated at Senior or Youth European Championships (n = 28) or Olympic Games (n = 4) (see supplementary Table 2). Throughout the competition season, all animals were ridden by their usual rider and housed in individual stables, provided with water *ad libitum*, and fed an individual diet.

The Animal Ethics Committee of Utrecht University concluded that

Table 1
Type of injuries reported in 58 elite eventing horses in the Netherlands during competition seasons 2015–2017.

Type of injury	Number of times occurred (n)
Lameness	Total: 57
Swollen limb	5
Fetlock/knee	4
Lost shoe	1
Undiagnosed	28
Tendon injury	18
Shoulder injury	1
Tying up (myopathy)	6
Euthanasia *(broken limb in cross country)*	1
Total	64

the proposed study did not need ethical approval, as it did not qualify as an animal experiment under Dutch law; individual owner's consent was obtained for all horses participating in this study.

2.3. Data collection

All horses were equipped with a HR monitor with a built-in GPS system (Polar Electro, Oy, Oulo, Finland) during all their conditioning training sessions and during their competitions. Only conditioning training sessions were measured as it was impossible to measure every technical low intensity training session (average HR 88 ± 10 bpm and speed < 6.6 m/s).

Each year, at the beginning of the competition season, all horses performed a standardized exercise test (SET); measuring HR, velocity (V; m/s) and plasma lactate concentrations (LA; mmol/L), which were measured using a Lactate Pro 2® (Arkray, Inc., Kyoto, Japan), according to the protocol used by Munsters et al. (2013, 2014). The technology used in this study was previously validated for use in exercising horses (Kingston et al., 2006; Siegers et al., 2018). The SET entailed four incremental steps of 1000 m gallops at velocities aimed at 6.7, 8.3, 10.0, and 11.7 m/s for CCI4* and CCI5* horses (Munsters et al., 2013, 2014). In horses competing at lower levels (< CCI4*) speeds were adjusted according to their competition level. From the SET, calculations were made to determine the relationship of LA to HR as an exponential regression curve. The V_{LA2} and V_{LA4} (V at LA of 2 and 4 mmol/L, respectively) and HR_{LA2} and HR_{LA4} (HR at LA of 2 and 4 mmol/L, respectively) were determined by interpolation. Recovery HRs after 5 and 10 min (HR_{rec5} and HR_{rec10}, respectively) were determined after the last exercise step. Horses were divided into performance groups based on their fitness level assessed during the SET (per competition level; depending on their individual's V_{LA4} and HR recovery values (at 5 and 10 min) were above or below the median V_{LA4} and HR recovery values of all horses of that competition level respectively (Bitschnau et al., 2010; Munsters et al., 2013). In the present study, eventing horses were each year, according to protocol used in Munsters et al. (2013), divided into average or good performers (AP or GP, respectively).

2.4. Quantifying workload

Raw GPS and HR data were exported to determine distance (m), average HR and time (seconds) spent at high speed (HS; velocity between 6.6 m/s and 9.5 m/s) and sprint speed (SS; velocity > 9.5 m/s). The external workload was quantified as the distance covered at HS or SS.

To quantify internal load of HS and SS in horses, individualized training impulses (iTRIMP-HS and iTRIMP-SS, respectively) were used (Manzi et al., 2009; Malone and Collins, 2016). The TRIMP formule is defined as: TRIMP (arbitrary units; AU) = time (min) x ΔHR x y. Where y is a nonlinear coefficient given by the equation; $y = b \times \exp(c \times x)$ where b = 0.64, c = 1.92 (for males) and x is ΔHR (Banister and Calvert, 1980). This y factor replicates the profile of the individual HR-LA response curve. As this relationship in horses is significantly different from humans, in this study individual y factors were defined by calculating the factors b and c, using the plasma LA concentration and fractional elevation of HR (ΔHR) measured during the SET at the beginning of each year. The best-fitted exponential line for the LA -HR curve is reflected by an exponential formula (the weighting factor y) and includes the individual b and c factors for each horse (Banister and Calvert, 1980; Manzi et al., 2009).

To determine the relative HR (ΔHR) of each horse, a resting HR of 30 bpm and a maximal HR of 220 bpm was used. In these elite sport horses it was not possible to obtain maximal HR in an exercise test or to measure correctly resting HR. For each training session or competition iTRIMP was calculated for the HS (iTRIMP-HS) and SS (iTRIMP-SS) part of the session using this formula. Where *b* and *c* are determined in at the SET at the beginning of each competition year for each horse.

Acute (1-week) and chronic (4-weekly) workloads and coupled ACWR (Gabbett et al., 2019) were calculated for the variables using exponentially weighted moving averages (EWMA). When HR or GPS data were missing, measures were estimated using the average HR or distance for a training or competition for that specific horse.

2.5. Injury definition

An injury was defined as one that caused training to be paused or stopped (days lost to training; Egenvall et al., 2013). Injuries that were caused by trauma and were not related to training (for example paddock falls) were excluded from the study. All injuries were assessed by an experienced (team) veterinarian. In addition, when horses were not in training, riders were obligated to report the reason for training absence. Twice a week, researcher (CM) checked whether training sessions were registered online and contacted the riders about missing training sessions. When there was no training registered within three days, riders were obligated to report the reason for training absence. When the reason for training absence was an injury, this was reported. Injuries were reported at the moment of occurrence and 'new' when it happened when a horse was already back in training again (for a least a week). When the training was continued, training sessions were again registered and workload data calculated and included into the analysis.

Table 2
Final logistic regression model of injury data with random horse effect and fixed effects; ACWR-HS, ACWR-HSprev (ACWR-HS of the previous week) of 58 elite eventing horses in the Netherlands during competition seasons 2015–2017. Akaike's Information Criterion was used for model reduction. For the important effects 95 % profile (log-) likelihood confidence intervals were calculated.

	Estimates of effect (standard error)	95 % confidence intervals	Odds ratio	Akaike's Information Criterion (AIC) for the final model
External ACWR-HS				560.4
Fixed effects				
Intercept	−2.903 (0.389)			
ACWR-HS	−2.014 (0.689)	0.032, 0.484	0.133	
ACWR-HSprev	1.374 (0.559)	1.390, 12.498	3.950	
Random effects				
Horse (intercept) (variance, std. dev.)	0.872 (0.934)			

To calculate and visualize the estimated proportion of injuries versus the ACWR, the fixed effect part of the final model is used, taking various values for the ACWR-HS of the previous week (ACWR-HSprev) on the horizontal axis and using for ACWR-HS the median value. These estimates will represent an average eventing horse, which is an eventing horse with random effect zero.

2.6. Statistics

All data are given as mean ± sd. All data was checked for normality. To check whether or not the normality assumption was reasonable, normal probability plots of the residuals were made. If the normality assumption did not hold, the data were log transformed to obtain a normal distribution. None of the variables used in the data analysis had missing data. For the important effects 95 % profile log-likelihood confidence intervals were calculated.

Horses had a low-intensity training during the ‘off-season’ during which they performed no conditioning training sessions. Since not all horses started the competition season at the same time, the variable ‘training-time’ was created to address each starting week, as week 1 in the analysis.

2.6.1. Factors associated with injury

The injury data in relation to ACWR was modelled with a multilevel logistic regression with random horse effects and with the fixed effects: V_{LA4} (velocity at a plasma lactate concentration of 4 mmol/L), age, training-time, competition level, chronic workload HS, ACWR-HS, ACWR-HSprev (ACWR-HS of the previous week). The variables age and training-time were considered to be potential confounders. Exposures were competition level, chronic workload HS, ACWR-HS and ACWR-HSprev. This model was called the starting model. Akaike’s information criterion (AIC) was used for model reduction. If potential confounders had an effect, these were included in the model (confounder adjustment). The model for which there was no further reduction possible was taken as the final model and remaining factors were considered important (Burnham and Anderson, 2002). To evaluate the sensitivity of all final models, standard errors were judged and effects with large standard errors were considered instable.

As the effect of ACWR-HS in relation to injuries was opposite to the effect of ACWR-HS of the previous week (ACWR-HSprev) on injuries, training-time was included in the model to correct for this early training effect (high ACWR at the beginning of the season). The interaction between ACWR-HS and ACWR-HSprev was assessed, but not included in the final model as it did not improve the fit of the regression model. It was checked whether or not the correlations depended on time, by taking time as a random effect in the model. The same analysis was carried out for external ACWR-SS and internal HS and SS ACWRs.

2.6.2. Factors associated with training regimens

To address the second aim of the study, factors associated with training regimens regarding HS and SS workloads, with length of training, and with competing below classification level were assessed. The internal and external HS and SS workload were modelled with a linear mixed model with random horse effects and with the fixed effects year, competition level and fitness score (average performer or good performer). Number of training weeks were analysed with a linear mixed model with random horse effects and with year and competition level as fixed effects. In both models, AIC were used for model reduction. Number of competitions performed at or below their classified competition level were analysed using a logistic regression with random horse effects and with competition level as a fixed factor. Whether or not there was an influence of competition level was determined with Akaike's information criterion. When there was an important effect, 95 % profile log-likelihood confidence intervals were calculated. All data were analysed with R (R: A Language and Environment for Statistical Computing, Vienna, Austria) and SPSS 25.0 (IBM Corp., Amonk, NY, USA).

3. Results

In total 94 Individual competition seasons were monitored, providing 2300 data sets, 1898 training weeks and 402 competitions. For 37 training sessions, velocity was adjusted and for 33 files the HR data was adjusted.

3.1. Injuries

A total of 64 non-trauma injuries were reported (2.78 % of the 2300 training weeks registered). In 2015, 2016 and 2017 an injury was registered 17, 20 and 27 times respectively. The type of injury is shown in Table 1. On average injuries occurred after 8.5 ± 8.1 weeks of training and caused on average of 5.8 ± 3.8 weeks of training loss. Respectively, 28.1 %, 17.2 % and 54.7 % of the injuries caused less than 2 weeks of training loss, between 2 and 4 weeks or more than four weeks of training loss (or ended the competition season).

3.2. Factors associated with injury

3.2.1. Acute–chronic workload ratio

According to AIC there were no random time effects needed in the final model, only ACWR-HS of the current week and ACWR-HS of the previous week (ACWR-HSprev) were considered important, see Table 2. At the beginning of each competition season ACWR ratios are high due to the off-season, when horses performed no conditioning training sessions. Injuries occur later on (if they occur), when ACWR ratios are already decreased due to training. In addition, injuries occur a week after a spike in workload (when the ACWR is already decreased), which relates to a negative relationship between ACWR of the current week and the injury occurrence (odds ratio for an injury with ACWR-HS of the current week was 0.133, 95 % CI 0.032, 0.484), but a strong positive relationship with ACWR of the previous week (odds ratio for an injury following ACWR-HS of the previous week was 3.95, 95 % CI; 1.390, 12.498), see Fig. 1.

When in a week the ACWR-HS ratio of a horse is 1.0 then there is a proportion of 0.01 (1%) of injuries in the following week. When the ACWR-HS ratio was 2.5 there was a proportion of 0.06 (6%), meaning 6

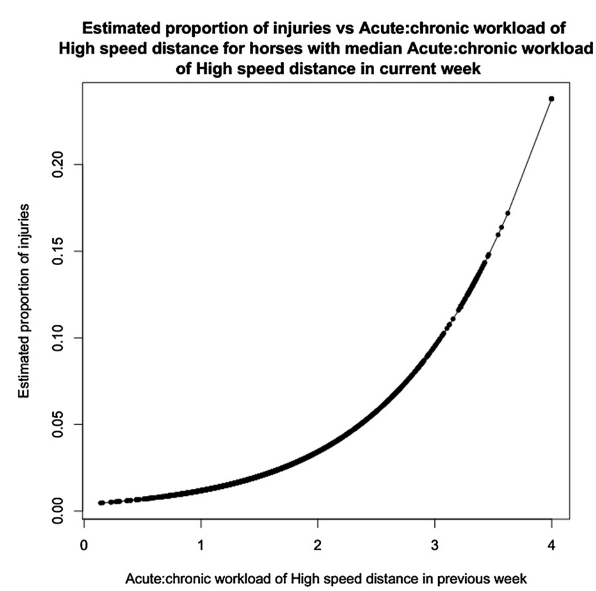

Fig. 1. Estimated proportion of injuries of 58 elite eventing horses in the Netherlands during competition seasons 2015–2017 versus the acute:chronic workload of high speed distance for horses with median acute:chronic workload of high speed distance in current week.

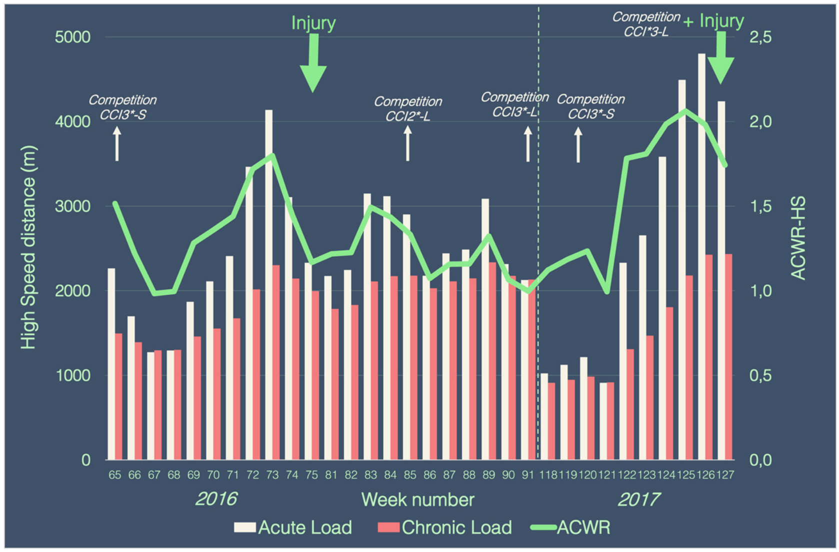

Fig. 2. Acute and chronic workloads and ACWR of a CCI3* level eventing horse in the Netherlands during the competition season of 2016 and 2017. Competition data and level, and when the horse got injured are indicated with an arrow. When ACWR peaks above 1.5 injury risk increases significantly.

times more chance on having an injury in the following week than when ACWR-HS was 1.0. Competition level, age, training-time, V_{LA4} and chronic workload had no significant effect on injuries.

ACWR-SS, iTRIMP ACWR-HS and iTRIMP ACWR-SS (and of previous weeks) had no association with injuries. There was also no effect of the external or internal chronic workload on injuries. Fig. 2 shows an example of the ACWR-HS, the acute and chronic workloads of a horse during the two competition years and its injury occurrence.

3.3. Factors associated with training regimens

3.3.1. Training and competition data

SET data showed on average a V_{LA4} of 9.7 ± 0.7 m/s, LA_{10min} of 2.4 ± 1.5 mmol/L and an iTRIMP *b* and *c* value of respectively 1.53 ± 0.42 and 0.01 ± 0.04 AU. Fitness scores were established based on the individual exercise tests results, whereas 25 horses were classified as good performers (GP) at the beginning of that competition year and 69 horses were classified as average performers (AP). On average, horses trained for 28.1 ± 10.5 training weeks per competition season and this did not differ per year. However this time did differ significantly with performance level; CCI2* horses trained less weeks per year than CCI4* horses (average of log training weeks was -10.508 with 95 % CI; -15.738, -5.288) and they significantly performed the most competitions at the classified competition level compared to other horses, see Table 3.

3.3.2. External and internal workloads

An average training session or competition lasted 62.9 ± 29.4 min, with an average HR of 114 ± 13 bpm, covering a total distance of 13,963.8 ± 4,057.2 m. On average horses spent 2,970.4 ± 1,769.1 m at HS and 1,443.1 ± 1,337.6 m at SS. Internal workload for an average training session or competition was 6.4 ± 13.5 AU, with 11.9 ± 17.1 AU at iTRIMP-HS and 8.0 ± 13.6 AU at iTRIMP-SS.

3.3.3. Workload between competition levels

According to AIC the interaction between year and competition level had a significant effect on the internal HS workload and on the external SS and internal SS workload horses experienced, see Table 4. There was no effect of competition level on external HS workload. Overall it seems that when the competition level increased, the external HS workload increased in a small amount. This in contrary to the internal HS workload of horses, which seemed to decrease, although not in an equal manner per competition level. Sprint speed workload seemed to increase with increasing competition levels, however this was not in sync with the experienced internal SS workload.

3.3.4. Workload comparison between good and average performers

According to AIC the external and internal HS and SS workload were significantly affected by the fitness score, dependent on the year, see Table 4. Overall, the external HS workload was always lower in GP horses compared to the AP horses, while most of the time this lower workload led to greater exertion in the AP horses. GP horses covered more distance at sprint speed compared to AP horses. Additionally, the rate of change of external and internal SS workload between the groups throughout the years was different; AP horses seemed to continuously decrease the SS workload they performed, however this led to an increase in exertion in these horses, see Table 4.

4. Discussion

This is the first study to examine the relationship between ACWR and injury incidence in horses. We showed that, in equine athletes as in human athletes, a strong workload-injury relationship exists. This is an important finding in respect of the welfare of (sport) horses. It influences the management and training regimes of equine athletes, and injury rates could probably be reduced.

4.1. Workload in sport horses

In horses, a relationship between injuries and external workload has been found (Estberg et al., 1996, 1998; Hill et al., 2004; Murray et al., 2010; Parkin, 2008; Rogers et al., 2007; Verheyen and Wood, 2004). However, these authors used different measurements and definitions for external workload; race distance, duration and frequency and cumulative workload index per week. Additionally measures of internal workload were not used. The relative workload using relative HR, frequency and duration has been used (Dekker et al., 2007; Munsters et al., 2013), but these calculations did not adjust for the individual HR-LA characteristics. Importantly, rate of change of workload has not been previously examined in eventing horses. In this study, both the external and internal workloads and the rate of change were calculated in relation to the injury incidence. As in human literature, the definitions of workload are now better established (Soligard et al., 2016) and the relationship between training loads and injury has subsequently

Table 3
Training weeks, number of competitions and whether they were performed at or below their classified level, of 58 elite eventing horses in the Netherlands during competition seasons 2015–2017. Odds ratio represent the comparison between the odds of competing below classified level in horses of different competition levels.

Classified competition level of horses	Training weeks per competition season (mean ± sd)	Total number of competitions (n)	Total competitions performed at the classified level (n)	Total competitions performed below the classified level (n)	Odd ratio & 95 % CI compared to CCI2* horses (††)
Ponies CCIP**	27.6 ± 6.6	39	16	23†† 21 – CCIP** 2 – preliminary	OR: 14.317 95 % CI: 3.980, 62.936
CCI2*	21.5 ± 9.5	91	77	14 – preliminary	–
CCI3*	27.7 ± 8.1	122	63	59†† 45 – CCI2* 14 – preliminary	OR: 6.120 95 % CI: 2.600, 16.351
> CCI4*	32.1 ± 11.4†	150	84	66 †† 2 - preliminary 18 – CCI2* 46 – CCI3*	OR: 7.873 95 % CI: 3.125, 23.906
Total		402	240	162	

† Number of training weeks differed significantly from CCI2* horses (average of log training weeks was -10.508 with 95 % CI; -15.738, -5.288).
†† Number of competitions performed below the horse's classified level differed significantly from CCI2* horses (OR and 95 % CI, see table).

become comprehensible; equine exercise research can benefit significantly from this knowledge.

4.1.1. External workload and injury

The ACWR-HS of the external workload was significantly associated with injury and this is consistent with findings in human studies (Blanch and Gabbett, 2016; Gabbett et al., 2016; Soligard et al., 2016). When the ACWR ratio increased to 1.5, the likelihood of an injury doubled in the following week. When the rate of change in workload increased still further, the injury risk increased up to 3–6 times. It is therefore essential that the workload of sport horses is accurately evaluated so as to reduce the risk of injury and the days lost due to injury.

The ACWR-HS and the ACWR-HSprev had an opposite effect on injuries. The high ACWR-HS at the beginning of the season (and the relative low injury rates at that moment) causes this negative or seemingly protective effect. This in combination with the fact that when injuries occur a week later after the spike in ACWR-HS, the ACWR-HS of that week has already decreased, giving a negative relationship with injuries. ACWR-HSprev was included in the model to correct for this early training effect.

Although these findings are important and interesting to improve performance and even welfare of sport horses, it had to be noted that the number of participants is a limiting factor. In total 58 horses met the eligibility criteria, showing that this study was probably under-powered to show effects that are not large. Hence in case no relation is observed, this study is cannot claim there truly is no relation between injury and workload change. On the other hand, if a relation is observed, it may not be generalized. However in case a relation is observed, it should provoke further (confirmatory) study. However, due to the novelty and exploratory nature of this study, these findings can definitely be used as a starting point for further research.

Contrary to the common belief in eventing trainers and riders, the SS distance was not related to an increased injury risk. The authors consider that this discrepancy is a result of different interpretations of the sprint speed; in race horses the sprint speed is conventionally defined as 16 m/s and slow canter as a speeds below 13.3 m/s (Rogers et al., 2007; Verheyen and Wood, 2004). In practice, an eventing horse almost never canters at speeds around or above 13.3 m/s. As workloads and speeds during eventing training are rarely measured, it is easy to misinterpret which 'sprint' speed is related to injuries (Rogers et al., 2007; Verheyen et al., 2006). Analysing measured speeds across different equine disciplines is therefore necessary to correctly interpret data and injury risks.

In humans, a higher chronic workload seems to work protective against injuries (Gabbett, 2018). This was not shown in the present study, nor was the U-shape of the relationship between injury occurrence and workload. This may indicate that the relation between workload and injuries may be affected differently in eventing horses than in humans.

4.1.2. Internal workload in eventing horses

In humans the relationship between workload and injury seems to be strongest for subjective internal training load (Eckard et al., 2018; Soligard et al., 2016). In horses, internal load was not found to be related to injury risks. As session-rating of perceived exertion (sRPE) could not be used in horses, an alternative had to be found. Individualized TRIMP showed a better correlation with fitness and performance than Bannister's TRIMP (Malone and Collins, 2016; Manzi et al., 2009; Sanders et al., 2017). They can be adjusted to the individual horse as there are huge differences in cardiovascular and respiratory capacities between man and horse (Hodgson and Foreman, 2014). As resting and maximal heart rate had to be estimated, this may have influenced the outcomes. For further research it would be interesting to apply this method to analyse workload in horses where resting and maximal HR can be established.

4.2. Workload, competition level and fitness

There is a lack of evidence for training programs in sport horses, and therefore it is interesting to analyse the workload horses performed at different levels and fitness indices. It seemed that when the competition level increases, the external HS workload seemed also to increase. In addition, good performers (GP) covered less distances at HS and more at SS than average performing horses (AP). It is not clear whether these differences in training results in fitter eventing horses or if fitter eventing horses train like this because they are fit. This needs further investigation.

The highest level eventing horses (CCI4*) horses cover, on average, more distances at HS and SS, but experience them as less intense compared to other horses. They seem to be more able to endure this workload. Notably CCI2* horses train the least number of weeks per competition season, but compete at the highest number of competitions at their classified level. This may explain the variation in HS and SS workloads of CCI2* horses. Higher competition levels do not seem to lead to a higher number of injuries, but the way horses are trained towards that level (their fitness) and the rate of change a heavy training or competition causes, is more important. Consistent training and preventing fast changes, especially increases in workload may be the solution (Gabbett et al., 2016).

Table 4
Results of the final models regarding external and internal high speed (HS) and sprint speed (SS) workload in relation to competition level, year and fitness score (average or good performers) of 58 elite eventing horses in the Netherlands during competition seasons 2015-2017. As a reference values the year 2017, competition level CCI4* and the fitness score 'good performer' were used.

	Estimates of effect (standard error)	95 % confidence intervals	Akaike's Information Criterion (AIC)
External HS workload			998.3
Fixed effects			
Intercept	3.395 (0.028)	3.340, 3.451	
Year			
Fitness score			
Year x fitness score			
2015 x good performers	0.146 (0.051)	0.046, 0.246	
2016 x good performers	0.110 (0.070)	−0.027, 0.247	
Random effects			
Horse	0.021 (0.005)		
Internal HS workload			1815.7
Fixed effects			
Intercept	0.882 (0.054)	0.775, 0.989	
Year			
Competition level			
Fitness score			
Year x competition level			
2015 x CCIP2*	−0.231 (0.136)	−0.162, 0.059	
2015 x CCI2*	0.168 (0.113)	−0.054, 0.390	
2015 x CCI3*	−0.058 (0.083)	−0.221, 0.106	
2015 x CCI4*	–	–	
2016 x CCIP2*	−0.097 (0.136)	−0.364, 0.170	
2016 x CCI2*	0.116 (0.116)	−0.113, 0.344	
2016 x CCI3*	0.171 (0.072)	0.029, 0.313	
2016 x CCI4*	–	–	
Year x fitness score			
2015 x good performers	0.317 (0.071)	0.178, 0.457	
2016 x good performers	−0.148 (0.098)	−0.340, 0.445	
Random effects			
Horse	0.052 (0.120)		
External SS workload			2120.7
Fixed effects			
Intercept	2.881 (0.058)	2.766, 2.997	
Year			
Competition level			
Fitness score			
Year x competition level			
2015 x CCIP2*	0.053 (0.172)	−0.446, 0.041	
2015 x CCI2*	0.270 (0.130)	0.013, 0.528	
2015 x CCI3*	−0.100 (0.105)	−0.310, 0.105	
2015 x CCI4*	–	–	
2016 x CCIP2*	−0.392 (0.182)	−0.749, −0.036	
2016 x CCI2*	−0.392 (0.182)	−0.316, 0.247	
2016 x CCI3*	0.015 (0.093)	−0.169, 0.198	
2016 x CCI4*	–	–	
Year x fitness score			
2015 x good performers	−0.242 (0.089)	−0.417, −0.066	
2016 x good performers	−0.203 (0.124)	−.0446, 0.041	
Random effects			
Horse	0.043 (0.012)		
Internal SS workload			2803.4
Fixed effects			
Intercept	0.492 (0.070)	0.354, 0.630	
Year			
Competition level			
Fitness score			
Year x competition level			
2015 x CCIP2*	−0.092 (0.215)	−0.514, 0.330	
2015 x CCI2*	0.361 (0.159)	0.048, 0.674	
2015 x CCI3*	−0.075 (0.131)	−0.332, 0.183	
2015 x CCI4*	–	–	
2016 x CCIP2*	−0.577 (0.235)	−1.038, −0.116	
2016 x CCI2*	−0.077 (0.172)	−0.417, 0.264	
2016 x CCI3*	0.173 (0.118)	−0.059, 0.405	
2016 x CCI4*	–	–	
Year x fitness score			
2015 x good performers	−0.003 (0.113)	−0.225, 0.218	
2016 x good performers	−0.449 (0.157)	−0.758, −0.141	
Random effects			
Horse	0.0523 (0.015)		

4.3. Injury occurrence and resting period

In the equestrian industry it is normal to have a clear resting period during winter. In the present study, none of the horses performed conditioning training sessions (with physical work causing training speeds to go above 24 km/h) throughout the winter period (no-competition period). Because of this rest period, a high ACWR occurs at the beginning of the competition season. When the ACWR decreased further down the season, injury risks also decreased. Therefore, riders and trainers should be aware of this effect and start slowly and early enough with their conditioning training sessions in the pre-competition season to avoid peaks in ACWR in the beginning of the season.

4.4. Daily training practise

Authors suggest that the evaluation of load applied to horses is essential to optimise welfare and performance. It is noted that many riders and trainers have a general idea of how long and how fast they went during training, however, there is a discrepancy between these feelings and the objective measurements. This is not an uncommon phenomenon; in human sport science it has been shown that athletes may perform more intense training and/or training sessions with a longer duration, or experience the specific training session more intense than what the trainer or the training program intended (Brink et al., 2014; Foster et al., 2001). In addition, wrongly managed training loads in combination with a dense competition schedule may harm the health of athletes (Soligard et al., 2016). Regarding the welfare of a (sport) horse, it is therefore essential to know the actual applied training load and to optimise load management towards a competition. Monitoring competitions gives the 'golden standard' of what the specific demands are of that horse at that competition level and whether the competition itself caused a spike in workload or not. This is crucial as various studies showed that there were eventing horses competing with lower VLA4 values than the average velocity demanded at their competition level (Amory et al., 1993; Serrano et al., 2001, 2002; Munsters et al., 2013). These horses are unfit to compete at that specific competition level and this increases their risk at excessive fatigue and/or getting injured during competition (Amory et al., 1993; Munsters et al., 2013; Serrano et al., 2002). Being fit is therefore essential for good performance and to reduce injury risks. However, how to accomplish this? The authors think that the evaluation of the actual workload and the change of workload of an eventing horse is a step in the right direction to achieve this, comparable to the racing industry (Estberg et al., 1996, 1998; Hill et al., 2004). To apply this in daily practice, riders and trainers should get used to monitoring their sport horse, and calculations of workload ratios should get automatized. Interpretation of the data needs to be done carefully and clarified that an increased risk does not directly mean that the training should be stopped directly or that the horse is definitely getting injured. It should be used as a practical guideline to objectify and optimise load management of a sport horse, to decrease injury risks, optimise welfare and to work gradually towards a competition.

5. Conclusions

In eventing horses, as in human athletes, spikes of acute workload increased the risk of injury. The ACWR of the external HS workload was strongly related to the incidence of injuries. External workload ratios at sprint speed, internal workload ratios and chronic workload measures were not related to injury incidence. ACWR can be used to monitor training programs of (elite) eventing horses and help to determine whether horses are well prepared for the physical demands of competition. These findings contribute to the understanding of the relationship between workload and injuries in sport horses. Each trainer, rider and coach should asses the workload of their horses and use this as a management tool to reduce injury rates and improve equine welfare.

Collaborators

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Contributors

CCM was responsible for the concept, design and production of this project. Workload data were collected by CCM and BRM. Injury data was collected by CCM. JVB and CCM were responsible for data analysis. MMS revised this manuscript and provided scientific support thorough the process.

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Data statement

Data are available upon reasonable request. Data include individual horse data that underlie the results reported in this study, after deidentification (without competition level, year and data as this may lead back to the individual horse). No other documents will be available. Data will be available beginning 9 months and ending 18 months following article publication. Researchers which provide a methodologically sound proposal and are approved by the researches from this study are allowed to reuse this data. Proposals should be directed to carolien@munsters.nl. To gain access, data requestors will need to sign a data access agreement. Publishable contact details: https://orcid.org/0000-0002-8680-6122.

Competing interests

No conflicts of interest have been declared.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.prevetmed.2020.105010.

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