Male flat jockeys do not display deteriorations in bone density or resting metabolic rate in accordance with race riding experience: implications for RED-S

George Wilson[1], Dan Martin[1], James P Morton[1] and Graeme L Close[1]

[1]Research Institute for Sport and Exercise Sciences
Liverpool John Moores University
Liverpool, UK
L3 3AF

Address for correspondence:
Professor Graeme L. Close
Research Institute for Sport and Exercise Sciences
Liverpool John Moores University
Liverpool, UK
L3 3AF
g.l.close@ljmu.ac.uk
0151 904 6266

Abstract

Despite consistent reports of poor bone health in male jockeys, it is not yet known if this is a consequence of low energy availability or lack of an osteogenic stimulus. Given the rationale that low energy availability is a contributing factor in low bone health, we tested the hypothesis that both hip and lumbar bone mineral density (BMD) should progressively worsen in accordance with the years of riding. In a cross-sectional design, male apprentice (n=17) and senior (n=14) jockeys (matched for body mass and fat free mass) were assessed for hip and lumbar spine BMD as well as both measured and predicted resting metabolic rate (RMR). Despite differences ($P<0.05$) in years of race riding (3.4 ± 2 v 16.3 ± 6.8), no differences were apparent ($P>0.05$) in hip (-0.9 ± 1.1 v -0.8 ± 0.7) and lumbar Z-scores (-1.3 ± 1.4 v -1.5 ± 1) or measured RMR (1459 ± 160 v 1500 ± 165 $kcal.d^{-1}$) between apprentices and senior jockeys, respectively. Additionally, years of race riding did not demonstrate any significant correlations ($P>0.05$) with either hip or lumbar spine BMD. Measured RMR was also not different ($P>0.05$) from predicted RMR in either apprentice (1520 ± 44 $kcal.d^{-1}$) or senior jockeys (1505 ± 70 $kcal.d^{-1}$). When considered with previously published data examining under-reporting of energy intake and direct assessments of energy expenditure, we suggest that low BMD in jockeys is not due to low energy availability *per se*, but rather, the lack of an osteogenic stimulus associated with riding.

Keywords: energy availability, metabolic rate, jockeys

Introduction

The relative energy deficiency in sport syndrome (RED-S) was recently developed in recognition that male athletes display evidence of impaired physiological function that may be related to low energy availability (Mountjoy et al., 2014). Jockeys are unique amongst professional athletes in that they have to make weight daily and to do so they commonly undertake periods of food deprivation (Wilson et al. 2014). In this regard, we (Wilson et al., 2013; Wilson, Prtichard, et al., 2015; Wilson, Hill, et al., 2015) and others (Dolan et al., 2012; Greene et al, 2013; Jackson et al., 2017; Leydon & Wall, 2002; Poon, et al., 2017; Waldron-Lynch et al., 2010; Warrington et al., 2009) have consistently reported that male flat jockeys present with low bone mineral density (BMD), with Z-scores often lower than -1. Such low bone densities are often considered to be due to a combination of nutritional factors including low energy availability and sub-optimal micronutrient intake (Dolan et al., 2011; Greene, Naughton, Jander, & Cullen, 2013; Martin, Wilson, Morton, Close, & Murphy, 2017; Wilson, Drust, Morton, & Close, 2014; Wilson, Fraser, et al., 2013) as well as a potential loss of calcium (Barry et al., 2011) due to the forced daily sweating that is often utilised as a technique to achieve daily riding weight (Warrington et al., 2009; Wilson et al., 2014). As such, low BMD is a continual cause of concern for jockey athlete-welfare considering the increased risk of fracture in the event of a fall (Dolan et al., 2012; Jackson et al., 2017; Wilson et al., 2012; Wilson, Pritchard, et al., 2015).

Despite the well-documented reports of low BMD, it remains questionable if jockeys are athletes who truly exhibit symptoms of RED-S. Indeed, measured RMR does not differ from predicted RMR (as predicted from Cunningham, 1980) either before (Wilson, Pritchard, et al., 2015; Wilson, Hill, et al., 2015) or after dietary interventions (Wilson, Pritchard, et al., 2015). Furthermore, when considering the potential impact of low energy availability on endocrine function, it is noteworthy that male flat jockeys display testosterone, insulin-like growth factor 1 and sex hormone binding globulin values all within normal ranges (Wilson, Prtichard, et al., 2015). Previous reports of low energy availability have also been largely ascertained from analysis of self-reported food diaries (Dolan et al., 2011; Leydon & Wall, 2002; Wilson, Fraser, et al., 2013; Wilson, Sparks, Drust, Morton, & Close, 2013), a method often critiqued for their reliability (Braakhuis, Meredith, Cox, Hopkins, & Burke, 2003; Dhurandhar et al., 2015) and under-reporting (Poslusna, Ruprich, de Vries, Jakubikova, & van't Veer, 2009). Moreover, energy intakes of jockeys are significantly higher when food intake has been monitored via a wearable camera as opposed to the traditional food diary approach (O'Loughlin et al., 2013). Further evidence for likely under-reporting of energy intake is also provided by our recent assessment of energy expenditure (via doubly labelled water) of male flat jockeys. Indeed, although self-reporting of energy intake was estimated at approximately 1500 kcal.d^{-1}, energy expenditure was calculated as 2500 kcals.d^{-1} but yet body mass did not significantly change during a four month data collection period (Wilson et al., 2017).

When taken together, it is therefore difficult to ascertain if the low BMD consistently observed in jockeys is in fact due to low energy availability and/or the lack of a consistent osteogenic stimulus arising from years of non-weight bearing activity due to riding. Regardless of the precise contribution of each of the aforementioned factors, it could therefore be hypothesised that symptoms of RED-S should progressively worsen in accordance with the years of race riding. With this in mind, the aim of the present study was to assess both measured and predicted RMR as well as hip and lumbar spine BMD in a cohort of apprentice and senior professional male flat jockeys.

Methods

Subjects

Thirty-one male professional flat jockeys currently race riding in Great Britain (GB) provided informed written consent to participate in this study. Apprentice jockeys (n=17) were classified as those jockeys who were race riding at the time of the study with a ‘claim-weight-allowance’ of 3, 5 or 7 lb. This ‘claim’ is a reduction of weight from the allocated competition race weight for newly licensed professional riders who had not ridden a specified number of race winners, in order to incentivise racehorse trainers with a more favourable racing weight (lower), thus providing more chances for these riders. The senior jockey group (n=14) consisted of those jockeys who had reached a specified total of winners negating their ‘claim’. This group did include a 21-year-old jockey who had been successful in a comparably short race riding career and had therefore reached the senior categorisation in a relatively short time span. At the time of the study, none of the jockeys were taking any prescribed medication or nutritional supplements though three jockeys (all senior jockeys) were smokers. The study received ethical approval from the National Research Ethics Service. A comparison of age, race riding experience and anthropometrical characteristics are shown in Table 1.

Design

In a cross-sectional design, both apprentice and senior jockeys (matched for body mass, fat mass and fat free mass) were assessed for both resting metabolic rate (RMR) and hip and lumbar spine BMD.

Experimental Procedures

After arriving in the laboratory in an overnight fasted state, jockeys were assessed for hydration status, BMD and RMR. Hydration status was assessed from a mid-flow urine sample by measuring urine osmolality (UO) using a handheld refractometer (Atago, USA). Jockeys were then measured for height and weight (Seca, Germany) wearing shorts and underwent a measure of whole body composition, hip bone density and lumbar spine bone density using dual-energy X-ray absorptiometery (DXA) scan (Hologic, USA) for classification of Z-scores, matched for age, sex and ethnicity. Jockeys were firstly asked to lie in a supine position and had their left foot affixed with Velcro to a Perspex triangular platform to invert the head of the left femur for measurement of hip bone density. Secondly, a box was placed under the popliteal crease of both knees of each jockey at a ~90° for assessment of lumbar bone density. Finally, an assessment of full body composition was undertaken in the supine position with inverted feet secured with micropore surgical tape (Nexcare, UK) to allow for greater analysis of the neck of the femur. All measurements were performed within 12 minutes. Jockeys were then required to have resting metabolic rate (RMR) measured in a supine position using indirect calorimetry (Metalyser, USA). Jockeys were required to lie down for an initial 15 minutes before testing to allow for the dissipation of movement from the DXA analysis to the metabolic unit. Data was then collected for a further 30 minutes and using the protocol as previously described by Wilson et al. (2015a,b).

Statistical analysis

All data was analysed using SPSS Statistics for Windows (version 22.0 IBM, USA). Data was checked for normality and independent t-tests were used to compare data between apprentice and senior jockeys as well as for comparing measured RMR versus predicted (Cunningham,

1980) RMR. Correlations between years of race riding and hip / lumbar spine BMD were made using Pearson's correlation coefficient to ascertain the linearity between the two specific variables. All comparison data were reported as means (SD) and statistical significance was set at $P \leq 0.05$ level, with R^2 values reported for correlation coefficient scores.

Results

Overview of baseline characteristics

A comparison of age, racing experience and anthropometric characteristics between apprentice and senior jockeys is shown in Table 1. Apprentice jockeys were significantly younger and had less years of race riding experience than senior jockeys. Although apprentice jockeys were significantly taller than senior jockeys, there were no significant differences in body mass, fat mass (both absolute and percent) and fat free mass between populations. Additionally, urine osmolality was not significantly different between apprentice and senior jockeys.

Resting metabolic rate (RMR)

A comparison of RMR between apprentice and senior jockeys is shown in Figure 1. There was no significant difference ($P=0.48$) in RMR between apprentice (1459 ± 161 kcal.d^{-1}) and senior jockeys (1501 ± 165 kcal.d^{-1}) (see Figure 1A). In addition, measured RMR did not significantly differ from predicted RMR in either apprentice (1459 ± 161 versus 1520 ± 44 kcal.d^{-1}; $P=0.18$) or senior jockeys (1501 ± 165 versus 1505 ± 70 kcal.d^{-1}; $P=0.92$) (see Figure 1 B and C, respectively).

Hip and lumbar spine bone mineral density

There was no significant difference in either hip Z-score (-0.9 ± 1.1 versus -0.8 ± 0.7; P=0.84) or lumbar spine Z-score (-1.3 ± 1.4 versus -1.5 ± 1.0; P=0.70) between apprentice and senior jockeys, respectively (see Figure 2 A and B). Years of race riding did not display any significant correlation with either hip (R^2 = 0.01; P=0.72) or lumbar spine Z-score (R^2 = 0.04; P=0.29) (see Figure 2 C and D).

Discussion

Despite consistent reports of low BMD in male jockeys, it is not yet known if male jockeys exhibit true symptoms of the relative energy deficiency in sport syndrome (RED-S). Given the rationale that low energy availability is a contributing cause to low BMD, the aim of the present study was to test the hypothesis that both hip and lumbar spine BMD should progressively worsen in accordance with the years of riding. Importantly, we demonstrate no differences in hip or lumbar spine Z-score between apprentice and senior jockeys and also observed no associations between years of race riding and BMD. In addition, RMR was not different between jockey cohorts whilst measured RMR was also not different from predicted RMR in either apprentice or senior jockeys.

A well-documented negative consequence associated with RED-S is low BMD (Mountjoy et al., 2014). Given that jockeys have to make weight daily, it has therefore been suggested that jockeys are an athletic population especially sensitive to exhibit symptoms of RED-S including impaired BMD (Wilson et al. 2014). Confirming previous data from our group and others (Dolan et al., 2012; Greene et al., 2013; Leydon & Wall, 2002; Poon, O'Reilly, Sheridan, Cai, & Wong, 2017; Waldron-Lynch et al., 2010; Warrington et al., 2009; Wilson, Fraser, et al., 2013; Wilson, Hill, Sale, Morton, & Close, 2015; Wilson, Pritchard, et al., 2015), we also report that the BMD of the jockeys studied here was significantly lower than clinical norms. Indeed, we report that 20 of the 31 jockeys demonstrated low bone mass (Z-score <-1) (Barrack, Fredericson, Tenforde, & Nattiv, 2017) in the lumbar region (10 apprentice and 10 senior) with 13 jockeys also presenting with low bone mass at the hip (6 apprentice and 7 senior).

Nonetheless, despite the consistent reports of low BMD in jockeys, it is not yet certain whether such data are true symptoms associated with RED-S. Indeed, we observed no differences in hip or lumbar spine Z-scores between apprentice and senior jockeys as well as reporting no positive association between years of race riding and BMD (see Figure 2). The latter point is especially important considering that in some cases, senior jockeys presented with 20-30 years of race riding experience. For example, when comparing jockeys who had ridden for the longest periods (i.e. >20 years) with the least experienced jockeys (i.e. <1 year), it is clear that such individuals display similarly low BMD at both the hip and lumbar spine. In consideration of other symptoms of RED-S, we also observed no differences in RMR between apprentices or senior jockeys as well as no differences in measured versus predicted RMR in either cohort (see Figure 1). When such findings are considered with previous data highlighting marked evidence of under-reporting of energy intake (O'Loughlin et al., 2013) as well as direct assessments of energy expenditure (Wilson et al., 2017), it remains questionable if male jockeys truly exhibit low energy availability. Indeed, despite the potential impact of low energy availability on endocrine function, we also previously reported that male flat jockeys display testosterone, insulin-like growth factor 1 and sex hormone binding globulin values all within a clinically normal range (Wilson, Pritchard, et al., 2015). Given the cross-sectional nature of the study, and the lack of a control group (given that there is no appropriate control group for jockeys) we cannot exclude the possibility however that the jockeys experienced an initial reduction in BMD during their adolescent years and this state has persisted without further significant reductions. Future studies may now wish to assess BMD in adolescent jockeys prior to them commencing significant amounts of horse riding.

When taken together, it is therefore possible that the low BMD reported in jockeys is, in fact, predominantly due to the lack of an osteogenic stimulus associated with years of non-weight bearing activity due to riding activities (Olmedillas, Gonzalez-Aguero, Moreno, Casajus, & Vicente-Rodriguez, 2012), as opposed to low energy availability *per se*. Whilst we acknowledge that the apprentice jockeys presented with considerably less race riding experience than their senior counterparts, it is noteworthy that apprentice jockeys are likely to be from “horse-racing families” and hence, may have spent much of their adolescence engaged in riding activities (Greene et al., 2013) and potentially inadequate intake of key micronutrients important in bone development such as vitamin D and calcium (Wilson, Fraser, et al., 2013). Such loading patterns are particularly important given that peak bone mass occurs at the end of the second decade of life (Baxter-Jones, Faulkner, Forwood, Mirwald, & Bailey, 2011). Further studies are now required to accurately quantify the physical loading patterns, energy availability and progression of bone mass of prospective senior jockeys throughout their childhood and adolescence and assess if any of these variables correlate with poor bone health.

Support for a lack of an osteogenic stimulus is also provided by the observation that one of the apprentice jockeys studied here presented with a hip and lumbar Z-score of 2.2 and 1.8, respectively (see Figure 2). Indeed, this athlete was a former amateur boxer of international status and hence had a training history of high load bearing activity such as daily running, circuit based and resistance-based training. Interestingly, despite potential low energy availability in boxers (Morton, Robertson, Sutton, & MacLaren, 2010) it is noteworthy that amateur boxers exhibit greater bone mineral density in hip and lumbar regions (in a hierarchical manner) when compared with age matched recreationally active individuals and a cohort of professional jockeys, respectively (Dolan et al. 2012). It is therefore possible that the negative effects of transient periods of weight cycling (i.e. multiple training camps per year) on markers of bone turnover in combat athletes (Prouteau et al. 2006) may be offset by the high osteogenic stimulus of habitual training activities (e.g. both amateur and professional boxers may run 5-10 km on 5-6 days per week) as well as the return to normal body mass within 7-10 days post-contest. Furthermore, in a review of studies looking at the influences of participation in ball sports on bone health development in young athletes, Teneforde and colleagues concluded that activities within these sports primarily jumping and multi-directional movements may serve as a pre-rehabilitation strategy for future stress fractures, including for running and swimming sports, which generally are devoid of such activities (Tenforde, Sainani, Carter Sayres, Milgrom, & Fredericson, 2015). From a clinical application perspective, it may therefore be suggested that practitioners who advise aspiring jockeys on injury prevention should also include such activities within their training modalities.

In contrast, an alternative explanation for the anomalies identified in the bone health of jockeys is that jockeys are an 'atypical' population given they are significantly smaller in size and stature than the average western European male (Kidy et al., 2017). An interesting fact here is that the jockeys in this study who were 'smokers' were all senior, yet when compared to the non-smoking apprentice cohort there appears no notable differences in Z-scores, even with newly licensed apprentice jockeys. Given the well-established link between smoking and impaired bone health, this observation may strengthen the 'atypical population' explanation. Clearly, further studies are now warranted utilising much larger cohorts of age and weight matched athletic and non-athletic control subjects. In addition, histochemical analysis of bone fragments (as collected following any break or fracture) would also allow for definitive classification of osteoporosis and osteomalacia.

In summary, we report that purported symptoms of RED-S (e.g. hip / lumbar spine BMD and RMR) display no differences between apprentice and senior male flat jockeys and that such parameters do not progressively worsen with years of race riding. This therefore suggests that there is no clear association between long-term participation as a jockey and impaired skeletal health. When considered with previously published data examining under-reporting of energy intake and direct assessments of energy expenditure, we suggest that poor bone health in jockeys is not due to low energy availability *per se* but rather, the lack of an osteogenic stimulus associated with riding. Further studies are now required to directly test this hypothesis using a large cohort of age and weight matched athletic and non-athletic control subjects. Additionally, future studies should also attempt to longitudinally track the physical loading patterns, energy availability and progression of bone mass of prospective senior jockeys throughout their childhood and adolescence.

References

Barrack, M., Fredericson, M., Tenforde, A., & Nattiv, A. (2017). Evidence of a cummulative effect for risk factors predicting low bone mass among male adolescent athletes. *British Journal of Sports Medicine, 51*, 200-205.

Barry, D. W., Hansen, K. C., van Pelt, R. E., Witten, M., Wolfe, P., & Kohrt, W. M. (2011). Acute calcium ingestion attenuates exercise-induced disruption of calcium homeostasis. *Med Sci Sports Exerc, 43*(4), 617-623. doi:10.1249/MSS.0b013e3181f79fa8

Baxter-Jones, A. D., Faulkner, R. A., Forwood, M. R., Mirwald, R. L., & Bailey, D. A. (2011). Bone mineral accrual from 8 to 30 years of age: an estimation of peak bone mass. *J Bone Miner Res, 26*(8), 1729-1739. doi:10.1002/jbmr.412

Braakhuis, A. J., Meredith, K., Cox, G. R., Hopkins, W. G., & Burke, L. M. (2003). Variability in estimation of self-reported dietary intake data from elite athletes resulting from coding by different sports dietitians. *Int J Sport Nutr Exerc Metab, 13*(2), 152-165.

Cunningham, J. J. (1980). A reanalysis of the factors influencing basal metabolic rate in normal adults. *Am J Clin Nutr, 33*(11), 2372-2374.

Dhurandhar, N. V., Schoeller, D., Brown, A. W., Heymsfield, S. B., Thomas, D., Sorensen, T. I. A., . . . the Energy Balance Measurement Working, G. (2015). Energy balance measurement: when something is not better than nothing. *Int J Obes, 39*(7), 1109-1113. doi:10.1038/ijo.2014.199

Dolan, E., Crabtree, N., McGoldrick, A., Ashley, D. T., McCaffrey, N., & Warrington, G. D. (2012). Weight regulation and bone mass: a comparison between professional jockeys, elite amateur boxers, and age, gender and BMI matched controls. *J Bone Miner Metab, 30*(2), 164-170. doi:10.1007/s00774-011-0297-1

Dolan, E., O'Connor, H., McGoldrick, A., O'Loughlin, G., Lyons, D., & Warrington, G. (2011). Nutritional, lifestyle, and weight control practices of professional jockeys. *J Sports Sci, 29*(8), 791-799. doi:936605285 [pii]

10.1080/02640414.2011.560173

Greene, D. A., Naughton, G. A., Jander, C. B., & Cullen, S. J. (2013). Bone health of apprentice jockeys using peripheral quantitative computed tomography. *Int J Sports Med, 34*(8), 688-694. doi:10.1055/s-0032-1333213

Jackson, K. A., Sanchez-Santos, M. T., MacKinnon, A. L., Turner, A., Kuznik, K., Ellis, S., . . . Newton, J. L. (2017). Bone density and body composition in newly licenced professional jockeys. *Osteoporos Int*. doi:10.1007/s00198-017-4086-0

Kidy, F. F., Dhalwani, N., Harrington, D. M., Gray, L. J., Bodicoat, D. H., Webb, D., . . . Khunti, K. (2017). Associations Between Anthropometric Measurements and Cardiometabolic Risk Factors in White European and South Asian Adults in the United Kingdom. *Mayo Clin Proc, 92*(6), 925-933. doi:10.1016/j.mayocp.2017.02.009

Leydon, M. A., & Wall, C. (2002). New Zealand jockeys' dietary habits and their potential impact on health. *Int J Sport Nutr Exerc Metab, 12*(2), 220-237.

Martin, D., Wilson, G., Morton, J. P., Close, G. L., & Murphy, R. C. (2017). The horseracing industry's perception of nutritional and weight-making practices of professional jockeys. *Qualitative Research in Sport, Exercise and Health, 9*(5), 568-582. doi:10.1080/2159676X.2017.1340330

Morton, J. P., Robertson, C., Sutton, L., & MacLaren, D. P. (2010). Making the weight: a case study from professional boxing. *Int J Sport Nutr Exerc Metab, 20*(1), 80-85.

Mountjoy, M., Sundgot-Borgen, J., Burke, L., Carter, S., Constantini, N., Lebrun, C., . . . Ljungqvist, A. (2014). The IOC consensus statement: beyond the Female Athlete Triad--Relative Energy Deficiency in Sport (RED-S). *Br J Sports Med, 48*(7), 491-497. doi:10.1136/bjsports-2014-093502

O'Loughlin, G., Cullen, S. J., McGoldrick, A., O'Connor, S., Blain, R., O'Malley, S., & Warrington, G. D. (2013). Using a wearable camera to increase the accuracy of dietary analysis. *Am J Prev Med, 44*(3), 297-301. doi:10.1016/j.amepre.2012.11.007

Olmedillas, H., Gonzalez-Aguero, A., Moreno, L. A., Casajus, J. A., & Vicente-Rodriguez, G. (2012). Cycling and bone health: a systematic review. *BMC Med, 10*, 168. doi:10.1186/1741-7015-10-168

Poon, E. T., O'Reilly, J., Sheridan, S., Cai, M. M., & Wong, S. H. (2017). Markers of Bone Health, Bone-Specific Physical Activities, Nutritional Intake and Quality of Life of Professional Jockeys in Hong Kong. *Int J Sport Nutr Exerc Metab*, 1-25. doi:10.1123/ijsnem.2016-0176

Poslusna, K., Ruprich, J., de Vries, J. H., Jakubikova, M., & van't Veer, P. (2009). Misreporting of energy and micronutrient intake estimated by food records and 24 hour recalls, control and adjustment methods in practice. *Br J Nutr, 101 Suppl 2*, S73-85. doi:10.1017/s0007114509990602

Tenforde, A. S., Sainani, K. L., Carter Sayres, L., Milgrom, C., & Fredericson, M. (2015). Participation in ball sports may represent a prehabilitation strategy to prevent future stress fractures and promote bone health in young athletes. *PM R, 7*(2), 222-225. doi:10.1016/j.pmrj.2014.09.017

Waldron-Lynch, F., Murray, B. F., Brady, J. J., McKenna, M. J., McGoldrick, A., Warrington, G., . . . Barragry, J. M. (2010). High bone turnover in Irish professional jockeys. *Osteoporos Int, 21*(3), 521-525. doi:10.1007/s00198-009-0887-0

Warrington, G., Dolan, E., McGoldrick, A., McEvoy, J., Macmanus, C., Griffin, M., & Lyons, D. (2009). Chronic weight control impacts on physiological function and bone health in elite jockeys. *J Sports Sci, 27*(6), 543-550. doi:910052038 [pii]

10.1080/02640410802702863

Wilson, G., Chester, N., Eubank, M., Crighton, B., Drust, B., Morton, J. P., & Close, G. L. (2012). An alternative dietary strategy to make weight while improving mood, decreasing body fat, and not dehydrating: a case study of a professional jockey. *Int J Sport Nutr Exerc Metab, 22*(3), 225-231.

Wilson, G., Drust, B., Morton, J. P., & Close, G. L. (2014). Weight-making strategies in professional jockeys: implications for physical and mental health and well-being. *Sports Med, 44*(6), 785-796. doi:10.1007/s40279-014-0169-7

Wilson, G., Fraser, W. D., Sharma, A., Eubank, M., Drust, B., Morton, J. P., & Close, G. L. (2013). Markers of bone health, renal function, liver function, anthropometry and perception of mood: a comparison between Flat and National Hunt Jockeys. *Int J Sports Med, 34*(5), 453-459. doi:10.1055/s-0032-1321898

Wilson, G., Hill, J., Sale, C., Morton, J. P., & Close, G. L. (2015). Elite male Flat jockeys display lower bone density and lower resting metabolic rate than their female counterparts: implications for athlete welfare. *Appl Physiol Nutr Metab, 40*(12), 1318-1320. doi:10.1139/apnm-2015-0354

Wilson, G., Lucas, D., Hambly, C., Speakman, J. R., Morton, J. P., & Close, G. L. (2017). Energy expenditure in professional flat jockeys using doubly labelled water during the racing season: Implications for body weight management. *Eur J Sport Sci*, 1-8. doi:10.1080/17461391.2017.1406996

Wilson, G., Pritchard, P. P., Papageorgiou, C., Phillips, S., Kumar, P., Langan-Evans, C., . . . Close, G. L. (2015). Fasted Exercise and Increased Dietary Protein Reduces Body Fat and Improves Strength in Jockeys. *Int J Sports Med, 36*(12), 1008-1014. doi:10.1055/s-0035-1549920

Wilson, G., Sparks, S. A., Drust, B., Morton, J. P., & Close, G. L. (2013). Assessment of energy expenditure in elite jockeys during simulated race riding and a working day: implications for making weight. *Appl Physiol Nutr Metab, 38*(4), 415-420. doi:10.1139/apnm-2012-0269