An investigation into the validation of pedometers to detect foreleg steps in horses (*Equus caballus*) at walk and trot.

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Author's Signed Declaration

I declare that:

At no time during the registration for the research degree has the author been registered for any other University award, without prior agreement of the Graduate Sub-Committee,

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Abstract

An investigation into the validation of pedometers to detect foreleg steps in horses (*Equus caballus*) at walk and trot.

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Background: Current research, surrounding motor laterality at a population level in horses, indicates that in order to stand with the left forelimb in advance of the other, it is achieved by taking a greater amount of steps with the left foreleg than the right foreleg (McGreevy & Thomson 2006; McGreevy *et al.* 2007); suggesting that pedometers could effectively estimate asymmetry of forelimb locomotion in grazing horses. This novel method of detecting forelimb preference also reduces the likelihood of operator influence and provides an inexpensive objective measure of vertical movement which has the advantage of scoring large sample sizes, avoids single-day anomalies by recording over multiple days and overcomes logistical challenges (Vincent & Sidman 2003; Chan *et al.* 2005; Silva *et al.* 2010; Warren-Smith & McGreevy 2010). However in order to determine the reliability and validity of this novel measure the relationship between pedometer data and those derived from direct observation will first need to be assessed (Warren-Smith and McGreevy 2010).

Objectives: To determine: (1) if pedometers accurately record equine steps at walk and trot, when compared to video analysis, (2) if alternative positioning of these pedometers affected the accuracy of step detection when compared to video analysis.

Method: Five horses each wearing a Yamax Digiwalk SW-200 (spring lever arm pedometer) and a Yamax Power Walker PW-610/611 (piezoelectric pedometer) positioned on the left foreleg (LF), left scapular (LS), chest (C), right scapular (RS) and right foreleg (RF) walked and trotted on a 20m circle 10 times on each rein to yield 100 results for each gait. Video recorded by GoPro Hero 3 Black edition camera positioned on the girth facing the forefeet using the following settings: 180 degree field of view, 720p, 120fps. Both visual and audio data were captured and recorded.

Results: Kruskal-Wallis Test on the deviation from actual number of steps per unit for each type of pedometer and the position of the pedometer compared to the actual number of steps taken by both forelegs determined that there is a significant difference (H_1= 340.31; P<0.0001) between readings in walk and also in trot (H_1 = 483.49; P<0.0001). A further Kruskal-Wallis Test on the deviation from actual number of steps per unit for each type of pedometer and the position of the pedometer compared to the actual number of steps taken by individual forelegs determined that there is a significant difference (H = 403.36; p<0.0001) at walk and also at trot (H = 477.10; p<0.0001).

Conclusion: In summary, the analysis of the pedometer data compared to video analysis indicate that pedometers are not useful for scoring forelimb movements in horses at walk and trot, regardless of positioning.

Key words: *equine, motor laterality, piezoelectric, spring lever arm, pedometers.*

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Introduction

The subject of laterality is complex and multifaceted due to the number of potential genetic and environmental impacts and influences which surround our understanding (Mercola & Levin 2001). Once thought to be a uniquely human feature, left-right asymmetries in brain and behaviour have now been demonstrated in many vertebrate and invertebrate species (Clapham *et al.*1995; Laska & Tutsch 2000; Rogers & Andrews 2002; Wells 2003; Hopkins 2006; Tucker *et al.* 2009; Wells & Millsopp 2009; McGreevy *et al.* 2010; Zucca *et al.* 2011[a]). Laterality refers to the preference shown by humans and animals to use one side of their body over the other, such as, left or right-handedness, left or right footedness and language dominance (Weber *et al.* 2005; Williams & Norris 2007). This observable side-bias in behavioural patterns is a reflection of underlying lateralised functional activity of the cerebral hemisphere (Rogers & Andrew 2002; Rogers 2002). The left hemisphere is associated with the manipulation of objects through controlled motor dexterity and is also used for decision making e.g. foraging and prey capture; whereas the right hemisphere expresses intense emotions (most notably fear and aggression), processes complex auditory tones, manages rapid reactions i.e. responses to novel stimuli/potential predators and controls spatial processing such as topographical information (Rogers 2002; Rogers & Andrew 2002; Jansen *et al.* 2006). Typically a specialism of the left hemisphere is often apparent as a right-sided response (contra-lateralisation) and *vice versa* (Rogers 2002; Weber *et al.* 2005).

On an individual level it has been suggested that lateralised animals have increased biological fitness leading to several advantages (Rogers *et al.* 2004; Vallortigara *et al.* 2011) such as; enhanced cognitive abilities by avoiding the unnecessary duplication of neural functions between the two brain hemispheres, parallel processing of information and by allowing one hemisphere to have control over responses it prevents incompatible signals from being simultaneously initiated and causing interference between functions (Rogers 2002; Ghirlanda *et al.* 2009). Although computational advantages exist for lateralised individuals, the individual efficiency theory does not explain neither the alignment of lateralisation at a population level nor why a minority of individuals continue to exhibit preference in the alternate direction (Vallortigara 2000 & 2006; Ghirlanda *et al.* 2009). In the context of predator-prey interactions, Ghirlanda and Vallortigara (2004) suggest that influences from the equilibrium between competitive and cooperative exchanges can explain the phylogenies of lateralisation as an evolutionary stable strategy. Whilst the origins of laterality and its role are still debated, our understanding of these side preferences are constantly evolving as new hypotheses are scrutinised and as technological advances are made, however what is clear is that “functional preferences in the use of right/left forelimbs are not exclusively present in humans but have been widely documented in a variety of vertebrate and invertebrate species” (Versace & Vallortigara 2015).

As well as exhibiting functional lateralisation of the brain when compared to humans, some non-human species also demonstrate asymmetric use of a thoracic appendage during manipulation of objects (Weir *et al.* 2004) or for tasks such as grooming, climbing and foraging (McGreevy *et al.* 2007). Motor laterality is evident in rodent species which show bias towards turning a particular direction in a maze (Alonso *et al.* 1991; Schwarting & Borta 2005), snakes exhibit a predisposition to coil in a favoured direction and humpback whales (*Megaptera novaeangliae)* show evidence of directional bias during flippering behaviour (Clapham *et al.* 1995). Research by Wells and Millsopp (2009) indicate that there is a relationship between paw preference and task complexity in cats (*Felis silvestris catus).*

However it has been argued that true motor laterality should be reflected by consistent use of limb across all tasks (McGrew & Marchant 1997). Therefore this consideration is especially important in animal studies as often each species is limited by their own appendages and tasks should form part of the species already existing behavioural repertoire so as not to introduce additional error through learned/taught behaviour. One such study is by Humle and Matsuzawa (2008) who assessed data on five measures (age and sex class effects, influence of task motor, cognitive and haptic demands) of hand use across four tool-use skills among the wild chimpanzees (*Pan troglodytes)* of Bossou, Guinea, West Africa. The behaviours assessed for laterality include; ant-dipping, algae-scooping, pestle-pounding and nut- cracking, which are all part of the species behavioural repertoire. The results indicate that the most cognitively complex tasks such as nut-cracking, which requires complementary coordination of both hands, yielded the greatest strength of lateralised hand use and the least lateralised behaviour was pestle-pounding, which required bimanual coordination, but also imposed constraints owing to fatigue. It emerged that only the most hazardous tool use, i.e. ant-dipping, and the sole haptic task, i.e. the extraction by hand of crushed oil-palm heart, were laterally biased and both to the right. However there was not a consistent use of limb or grip patterns in tool-use skills across all tasks at an individual level (Humle & Matsuzawa 2008). According to McGrew and Marchant's (1997) definition, these chimpanzees do not show 'true' motor laterality across these tasks in any one particular direction however further research conducted across another set of tasks could yield different results. This however raises more questions, such as, how many tasks need to be completed showing left/right bias before we can accept that a 'true' motor laterality exists?

Side preference can be exhibited by multiple sensory organs; fish preferentially use the right side of a mechanosensory organ when navigating novel objects, however once familiarisation occurs no preference is shown (Burt de Perera & Braithwaite 2005). The use of novel objects in assessing laterality in other species is prevalent however the emotional valence of the stimulus needs consideration (De Boyer Des Roches *et al.* 2008; Farmer *et al.* 2010). Bias of auditory processing and vocalisation is evident; birds exhibit preference for the bronchus through which they sing (Suthers *et* *al.* 2004) and horses (*Equus caballus)* demonstrate auditory laterality when processing conspecific whinnies, although this is dependent on the social value of communications (Basile *et al.* 2009). These are all examples of specific behaviours that are lateralised, however there can be a multitude of factors that influence the development and degree of side bias.

Development of laterality in humans is associated with many different factors; biological influences such as the presence of the Leucine-rich repeat transmembrane neuronal 1 (LRRTM1) gene (Francks *et al.* 2007), developmental factors e.g. brain damage resulting from physiological stress during birth and/or a surge of foetal testosterone level during pregnancy (Samlaska 1989) and social factors i.e. cultural/religious beliefs, however in the animal kingdom seldom are all of these factors applicable.

Opportunities for movement have been shown to influence the activity levels and behaviour patterns in horses (Rose-Meierhöfer *et al.* 2010). Space availability as an environmental constraint has been shown to decrease lateralised behaviour in donkeys (*Equus asinus*) in both occurrence and strength. In the context of the study, the disappearance of forelimb preference could be the result of increased right-hemisphere involvement to deal with the acutely aversive situation i.e. confinement; subsequent contra-lateralisation may have produced increased left motor responses therefore masking any right-forelimb bias usually present at population level (Zucca *et al.* 2011a). Surprisingly, this right-forelimb population bias is similar to results found in lions (*Panthera leo)* but in contrast to those displayed by horses (McGreevy & Rogers 2005; Zucca *et al.* 2011b).

Illness has been highlighted as a source of variance of laterality in large captive felids, where the strength of bias is significantly different between clinically healthy and sick lions (Zucca *et al.* 2011b). In response to stressors, and the associated increase in corticosterone levels, rats have shown preference for left turning behaviour and left paw usage, may influence laterality (McGreevy & Thomson 2006). Optimum health and free from lameness should be born in mind when selecting specimens for study where inference of motor laterality is the objective of the experiment.

Wells and Millsopp (2009) found that age was unrelated to either strength or direction of preferred paw use in felines; this is further supported by recent studies in canines (McGreevy *et al.* 2010). However in horses the motor bias has been shown to strengthen with increasing age (Table 1.), suggesting an influence of maturation or training (McGreevy & Rogers 2005).

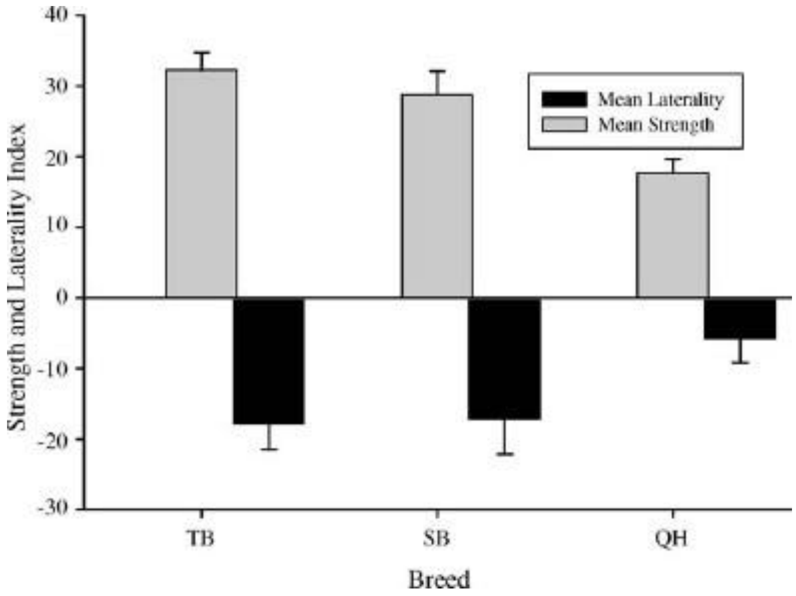
Table 1. The distribution of horses stood with the left foreleg advanced significantly more than the right (FL), the right significantly more than the left (FR) and those with no significant foreleg preference (i.e. ambidextrous FA) in (1) all standing observations in first 2h of recording and (2) the first 50 standing observations

	FL	FA	FR
All standing observations	52 (49%)	41 (39%)	13 (12%)
First 50 standing observations	43 (41%)	53 (50%)	10 (9%)
Under 2 years old	4 (20%)	15 (75%)	1 (5%)
Two-year-old	7 (27%)	16 (62%)	3 (11%)
Over 2 years old	32 (53%)	22 (37%)	6 (10%)

The distribution of FL, FR and FA in the first 50 standing observations within three age groups of horse (*n* = 106) is also shown.

Source: McGreevy & Rogers (2005), p.344

Locomotion and functionality are influenced by an individual's conformation (van Weeren & Crevier-Denoix 2006); in equines, upright pasterns reduce stride length (de Souza *et al.* 2004), asymmetric hooves reduce competitive longevity (Ducro *et al.* 2009; van Heel 2006), longer stride length is associated with an intermediate hock angle (Gnagey *et al.* 2006) and elite performance horses tend to have sloped scapulars (Holmström *et al.* 1990). Husbandry methods, such as farriery, may impact these asymmetries; right-handed farriers tend to excessively trim the medial left and lateral right forefeet leading to the right forelimb bearing more loading and therefore becoming the support limb, whereas the reverse is true of left-handed farriers (Ronchetti *et al.* 2011). Poor training can also affect behavioural patterns, orthopaedic health and gait biomechanics. It has been suggested that asymmetrical loading through a given limb (McGreevy *et al.* 2011) is a manifestation of lameness originating in the horses back (Landmann *et al.* 2004); therefore it is of paramount importance to ensure that all subjects are free from lameness and injury (McGreevy & Rogers 2005; Murphy *et al.* 2005; McGreevy & Thomson 2006).



Source: McGreevy & Thomson (2006), p.187

Figure 1. Mean (±S.E.) motor laterality index and strength of laterality in Thoroughbreds (TB, *n* =106), Standardbred (SB, *n* = 40) and Quarter Horses (QH, *n* = 40)

Equines that have an apparent left forelimb preference are more frequently found in those of (racing) Thoroughbred and Standardbred breeding compared to Quarter Horses (Fig.2.); this has been attributed to selective breeding of 'reactive' horses for racing purpose which are right-hemisphere dominant. This inadvertent selection is purposeful in the context of the racetrack however it may have safety implications outside of this environment such as exercising in traffic on public roads (McGreevy & Thomson 2006). This apparent bias occurring in different breeds of horse perhaps indicates that training and/or selection has an influence on motor laterality (McGreevy & Thomson 2006). However, McGreevy *et al.* (2010) found no significant association between different breeds of dog and paw preference.

Racecourse orientation varies between tracks, states and even within countries; courses in the USA and Singapore are primarily counter-clockwise, while Hong Kong, Europe and most of the UK are clockwise (Williams & Norris 2007; McGreevy & Rogers 2005). McGreevy (1996) identified that horses preferred to lead with the right leg when cantering and galloping counter-clockwise; perhaps this goes some way to explain why the left limb is more likely to be involved in fatal injuries on USA racetracks i.e. counter-clockwise tracks (Peloso *et al.* 1996). The relationship between wastage through injury, competitive success and motor bias may be of importance (McGreevy & Rogers 2005).

The influence of behavioural training on motor laterality should not be underestimated; the existence of taught responses may explain the strong preference for dogs (*Canis lupus familiaris)* to use one paw over the other (Wells 2003). Traditionally horses are handled on the left-hand side/'near-side'; this early conditioning may influence forelimb preference in mature horses therefore research from naïve or unhandled animals may be of particular value (Murphy & Arkins 2005; 2008). Uneven horse racing surfaces can cause limb injury and influence musculoskeletal development (Fredricson *et al.* 1975); however, motor lateralisation may not necessarily be the result of training to work in a particular direction as asymmetric forelimbs are evident in untrained 8-month-old Standardbred horses (Drevemo *et al.*1987).

In canine and feline studies both male and females have shown paw preferences at the population level but in opposite directions; females preferentially used the right paw during experimental tasks, whereas males were more inclined to use the left paw (Wells 2003; Wells & Millsopp 2009; McGreevy *et al.* 2010). Horses also demonstrate this gender bias as females' exhibit significantly more right-lateralised responses during foreleg initiation, obstacle avoidance within a passageway and under saddle, compared to males who exhibit significantly left-lateralised responses during obstacle avoidance within a confined space and when rolling; this further supports the need to develop sex-specific training schedules (Murphy *et al.* 2005). All subjects within this study were of a sufficient standard of training so as to allow them to be ridden and therefore the influence of previous human interactions may have predisposed the animals to perform lateralised behavioural patterns (Murphy *et al.* 2005; Murphy & Arkins 2008). In humans, left-handedness has been linked to the steroid hormone testosterone (Samlaska 1989; Wells 2003); perhaps this hormonal difference is partly responsible for the motor bias in animals of opposite sexes. Exploring motor preferences between intact and castrated male animals may shed light on the role of testosterone in lateralisation (Wells 2003; Warren-Smith & McGreevy 2010).

Van Weeren and Crevier-Deniox (2006) identify multiple conformational characteristics that influence sport horse performance, including predisposition to injury which provide clues to the long-term soundness of our elite equine athletes. Whilst this static analysis is important, it is not necessary for top-performance horses to have flawless conformation, but symmetry is key to performance (Van Heel *et al.* 2006). Additionally, the influence of athletic training on equine stride length and therefore motor laterality cannot be underestimated. Ferrari *et al.* (2009) found that whilst stance time stayed consistent throughout the training season in a cohort of National Hunt racing Thoroughbreds, there was a significant increase in stride frequency and subsequent decrease in protraction time were observed after training. However further investigation into whether these findings are exclusive to National Hunt racing or whether these training induced changes to stride parameters exist across other competitive disciplines such as dressage, show jumping and cross country need to be established. Likewise does 'incorrect' training lead to increased limb bias or is conformation more influential?

Related to show jumping performance, a number of kinematic variables, such as elbow flexion, retraction angle of the hind-limb and inclination of the trunk with respect to the horizontal have been identified which can be detected at foal age (Santamaria *et al.* 2002, 2004; Bobbert *et al.* 2005). These anatomical markers enable trainers to identify suitable animals early in life and tailor training regimes accordingly. An inconsistent stride length in equids may indicate the presence of pain; in National Hunt racing Thoroughbreds it has been highlighted that if slight changes of gait could be recognised in the prodromal stages of dorsal metacarpal disease then suitable changes in training management might reduce the effects of the disease (Rogers *et al.* 2005). However, Landmann *et al.* (2004) have suggested that asymmetrical loading through a given limb may be secondary to problems originating in the horses back. Whilst the presence of musculoskeletal pain and associated lameness undoubtedly influences equine motor laterality, the expression of this discomfort in equine stride length and frequency is variable. Peham *et al.* (2001) found that horses with forelimb orthopaedic pain keep stride variability low, potentially because the lame horse employs an optimum compensatory mechanism to reduce the discomfort in the affected limb, and every deviation from this pattern increases pain. Additional studies of both lame horses and cows (*Bos taurus)* indicate that individuals shift the weight from one leg and to another more frequently in an attempt to alleviate discomfort (Ashley *et al.* 2005, Leach *et al.* 2009, Rushen *et al.* 2007), therefore an increase in stride frequency is more likely to be indicative of orthopaedic pain. This observable bias may have practical application in the detection of lameness.

In addition to improved welfare through lameness detection, data gathered from non-human species regarding side preferences at an individual and population level would advance understanding of brain function perhaps leading to advantageous selection of species, breed or type for function (Wells 2003; McGreevy & Thomson 2006). This would have particular application in equestrianism (Williams & Norris 2007) such as; selecting racehorses with heightened reactivity for improved time 'breaking from the starting gate' and choosing appropriate course direction for horses with preference for left or right lead stride patterns.

Rogers (2010) suggests that successful assessment of animal welfare in varying farming conditions may arise from understanding these behavioural differences caused by underlying hemispheric asymmetries and cognitive functioning; impacting on general consensus of acceptable animal husbandry, i.e. handling protocols (Górecka *et al.* 2006; 2007), housing systems (Rose-Meierhöfer *et al.* 2010) and hoof trimming (Ronchetti *et al.* 2011). Emotionality effects behaviour, such as rate of drinking, eating, defecation and movement; additionally heightened flight or fight responses associated with high levels of right-hemisphere dominance can impact on human/handlers safety during handling procedures e.g. auction rings, farm environments and during transportation (Lanier

2001; Górecka *et al.* 2006; McGreevy and Thomson 2006). According to Visser *et al.* (2003) emotionality (or in their paper nervousness) can profoundly affect an individual's ability to learn, consequently affecting their suitability for particular activities or athletic sports; this characteristic can be detected in early years giving a reliable prediction for life.

Gait asymmetry can compromise physical performance in horses; it is therefore important to detect and assess motor laterality in individuals in order to implement specialised training protocols to allow for optimal athletic development (Drevemo *et al.* 1987; Powers & Harrison 2000; McGreevy & Rogers 2005; Murphy & Arkins 2008). Competitive performance is often closely related to monetary value and therefore of interest to owners, trainers, competitors and breeders alike.

Van Heel *et al.* (2010) found that the relationship between lateralised motor behaviour and asymmetric front hooves continued to increase as the animals aged from foals to young adults. His findings indicate that those sport horses who showed a significant motor bias performed at a suboptimal level when tasked with symmetrically performing trotting, cantering and free jumping tests. According to Sloet van Oldruitenborgh-oosterbaan *et al.* (2010), veterinary reasons for career breaks or even termination of competitive careers in dressage, show jumping, eventing and endurance horses, have been cited as the root cause in between 21.8 and 23.9% of cases. Of these, orthopaedic problems accounted for 63.7%. Lameness has also been identified as a key factor of wastage in racing (Perkins 2005; Parkin 2006). Therefore if lameness and orthopaedic problems are a result of asymmetric musculoskeletal development then the identification of equines with significant motor bias and a subsequent adjustment to their athletic training regime to encourage symmetrical development would potentially reduce industry wastage and prolong the functional competitive life of the equine athlete.

McGreevy *et al.* (2011) identify that poor equitation (musculoskeletal and physiological insults from ridden work, ill-fitting saddlery and inappropriate training paradigms which are not in line with current scientific understanding) can all have a negative influence on equine welfare, affecting behaviour, musculoskeletal health and gait biomechanics. It can also lead to the development of behaviours indicative of conflict that endanger the safety of trainers/riders, veterinarians and the horses themselves, making poor equitation a significant welfare concern. Many of these outcomes are preventable and modifiable, but only through detection and acknowledging a problem can an improved prognosis be made. Therefore having a readily observable bias such as motor laterality could improve equine welfare through early detection and modification of husbandry/training management.

It has been suggested that forelimb preferences might originate from a functional specialisation in the use of hands/paws/forelimbs, such as feeding, tool use or communication; derive from other lateralised functions, for instance dealing with social life, emotions and stress; be a side effect of anatomic asymmetries, developmental or genetic constraints; be produced by a combination of the above options. The choice of which model system choose to test different hypotheses on the origin of forelimb asymmetries is related to the ecology, behavioural habits and phylogeny of the species. There have been a number of methodologies that researchers have employed to identify motor laterality in equids. Like all methods, there are advantages and disadvantages to each one.

A modified irritant removal test has been used to explore forelimb preference in canines. This test involved placing a strip of tape across the bridge of the dog's nose and video recording which forelimb was used to remove the tape. However observations from the tape test were difficult to interpret due to the described frantic behaviour of the dogs in trying to remove the tape, often obscuring the visibility of the head and legs from the camera (Batt *et al.* 2007). Whether a similar test could be implemented to observe forelimb preference in equines is yet untested, what is certainly of paramount importance is the that the camera has a clear view of the animal from multiple angles and that the video should be recorded with adequate frames per second to allow the footage to be slowed down for an operator to accurately record all movements made by the forelegs.

Murphy *et al.* (2005) also utilised direct observation across four distinct tasks; (1) favoured foreleg to initiate forward movement within a 80x35m paddock, (2) obstacle avoidance within a 20x5m passageway, (3) obstacle avoidance within a 20x5m passageway whilst ridden, and (4) assessment of motor preference while rolling in a 6x6m straw filled pen. However whilst *'every effort'* was made to ensure that the horses did not receive any training during the experimental stage, it can be argued that during each and every interaction with subjects we are inadvertently training behavioural responses, therefore this may have predisposed the animals to perform lateralised behavioural patterns. Likewise, although animals with nominal previous human contact were selected for the experiment, part of that experimental design required the animals to be ridden – this indicates that a substantial amount of handling and training had to have taken place to allow for this task to be endured safely by horse and handler.

In general, equine locomotion is marked by the hind limbs generating the energy and net propulsion with one of them engaging more than the other. Functional asymmetry and asymmetric gait have been demonstrated in humans and other primates to cause a skeletal asymmetry more prominent in the non-dominant limb, which acts as power-absorption burst, so called supportive contra-lateral dominance or cross-symmetry pattern. Conformational asymmetry has been demonstrated in horses too, with all the parameters that suggest higher strength of bones being significantly higher in the left side.

Considering that, it could be assumed that in horses the left side, showing greater strength, is best suited as supporting side, meaning that the right side should be considered as the dominant one. Because of this, at each stride the whole animal is pushed toward the supporting side, mainly towards the opposite (diagonal) forelimb: the horse is then 'naturally flexed' on the supporting side. The supporting hindquarter should engage to a greater degree, i.e. to bring the hind foot underneath the horse's body to maintain its balance; this leads the horse to travel with the forelegs and hind-legs on two or more different tracks. This condition will also exacerbate when lunging the horse at a trot, which is a symmetric gait: the animal will be able to perfectly execute a circle in the crookedness direction, thus appearing falling-in. On the contrary, horse's tendency to 'cut the circle' would be due to the horses inability to put the right hind-leg deep in underneath his body, to supply the necessary support for the flexion in the turn to the right. In the light of horse's biomechanics, the different results of other researchers can be better interpreted: the first-step tendencies (or the preferred forelimb stance) used so far as a measure of side-bias, are likely to be strongly affected by postural support requirements.

A methodology that seeks to overcome the influence of training and handling on lateralised motor patterns is the use of derailment analysis at trot in naïve young horses. The observations were aimed at assessing foals' ability to follow their mothers from behind inscribing a perfect circle (falling in) or cutting the circle (derailment), whereby derailment was defined as the occurrence of at least one 'cutting the circle' at each lap of the round pen. Derailment in this context is possibly important as it is proposed that motor laterality in horses is acquired over time and results from this foal study show a higher percentage of ambidextrous animals therefore supporting the hypothesis that motor bias is primarily influenced by training.

Lucidi *et al.* (2013) also suggest that adult horses could not be adequate candidates for the study of motor laterality, neither ridden or grazing; if the observations take place on ridden horses, riders influence on the horse dynamic could likely bias the results. Similarly, at pasture, adult well-trained horses should not present any bias or, whenever a bias is observed, it can hardly be established to what extent it is ascribable to human influence. Moreover, analyses carried out at pasture do not take into account disruptive environmental elements that the observer cannot control. For example, animals may be motivated to remain in one position that is effective for consuming a preferred type of grass. Further complications may come from the presence of other horses (dominant or not, friendly or not) interacting with the subject under consideration, from the position of the focal animal respect to the fence or from the presence of different substrates; not least the analysis can suffer from an operator's effect. Finally, other environmental disturbances, out of the operators control (such as odorants, pheromones, sounds etc…), could likely lead to confusion between motor and sensory laterality.

When recording motor bias it is of paramount importance to avoid parallax errors (displacement or difference in the apparent position of an object viewed along two different lines of sight, and is measured by the angle or semi-angle of inclination between those two lines) and spherical aberrations (an optical effect observed in an optical device such as a lens or mirror, that occurs due to the increased refraction of light rays when they strike a lens or a reflection of light rays when they strike a mirror near its edge, in comparison with those that strike nearer the centre) that may occur during direct observation (Warren-Smith & McGreevy 2010, Lucidi *et al.* 2013).

A novel method of detecting forelimb preference which reduces the likelihood of operator influence is pedometry; this inexpensive objective measure of vertical movement has the advantage of scoring large sample sizes, avoids single-day anomalies by recording over multiple days and overcomes logistical challenges (Vincent & Sidman 2003; Chan *et al.* 2005; Silva *et al.* 2010; Warren-Smith & McGreevy 2010). Pedometers and accelerometers have been utilised successfully to monitor activity levels in canines (Chan *et al.* 2005), cattle (Ungar *et al.* 2011) and in children (Beets *et al.* 2005; Jago *et al.* 2006). Unlike pedometers, accelerometers are designed to capture a wealth of information such as the duration, intensity and type of physical activity; despite this greater inference, evidence suggests that pedometers agree acceptably with accelerometers (Chan *et al.* 2005). Moreover pedometers are significantly cheaper which makes them more accessible, especially for use in large scale studies and a readily replaceable should damage or loss occur. Recently, digital pedometers and accelerometers have gained acceptance as an effective assessment tool of activity and are become increasingly popular for measuring physical activity in a field setting. They provide an inexpensive, easy to use, objective monitor of daily physical activity and are typically used as the dependent measure in studies on both adults and children (Silva *et al.* 2010, Vincent and Sidman 2011).

Current research, surrounding motor laterality at a population level in horses, indicates that in order to stand with the left forelimb in advance of the other, it is achieved by taking a greater amount of steps with the left foreleg than the right foreleg (McGreevy & Thomson 2006; McGreevy *et al.* 2007); suggesting that pedometers could effectively estimate asymmetry of forelimb locomotion in grazing horses. However in order to determine the reliability and validity of this novel measure the relationship between pedometer data and those derived from direct observation will first need to be assessed (Warren-Smith and McGreevy 2010), this is the basis for this current study.

Pedometers generally come in two difference varieties; spring lever arm and piezoelectric. Spring lever arm pedometers are designed to be worn on the hips by human patients. Its internal sensor mechanism uses a coiled spring-suspended lever arm that moves with each step, the lever arm swinging downward and closing a contact to count a step, then the spring returning it to its original position. Whereas a piezoelectric pedometer which has a horizontal cantilevered beam with a weight on the end that compresses a piezoelectric crystal when subjected to elevation of the hips during walking (acceleration). This generates a voltage proportional to the acceleration. The voltage oscillations are used to record steps if an acceleration is above manufacturer-defined sensitivity thresholds.

Regardless of type of sensor used, the establishment of the error rate of pedometers is vital for maintaining confidence in the data collected (Jago *et al.* 2006); current studies indicate that up to 5% error rate is present in a number of different devices however this variation may be the result of differences in walking patterns among subjects (Welk *et al.* 2000; Vincent & Sidman 2003). Pedometer calibration should be assessed prior to use in order to establish any individual inaccuracies which could be documented and corrected for (Chan *et al.* 2005; Silva *et al.* 2010). Melanson *et al.* (2004) compared the accuracy of piezoelectric and spring lever arm pedometers at slow walking speeds, they found that the accuracy of all pedometers tested exceeded 96% at speeds 3.0 MPH, but decreased at slower walking speeds. In individual humans that naturally ambulate at slower walking speeds (e.g. the elderly), it is recommended that the use of more sensitive piezoelectric pedometers be utilised; this perhaps have implications for the use in equestrian studies as well particularly those focused on free living conditions whereby the rate of movement and grazing speed may be an influence on pedometer sensitivity.

However, when assessing the technical reliability of the Actigraph GT1M accelerometers, Silva *et al.* (2010) indicated that the issue is not necessarily the reliability of the equipment but that the error rate remains consistent after extensive use. This is an especially important consideration when using pedometers in equine studies as they may be subject to a greater variety of movement that they are simply not designed for, as well as additional physical damage to the equipment such as knocks during rolling, bucking and play behaviour of horses. Therefore it is recommended to conduct pre and post-test assessments of the pedometers where accuracy is the key objective of the study.

In fact, as a result of their popularity, best practice guidelines and research recommendations for using pedometers and accelerometers in the physical activity assessment have been produced (Ward *et al.* 2005). These guidelines encourage researchers to store and care for the equipment to the same standards as you would in a laboratory setting.

Whilst the ability to adjust the sensitivity thresholds of some pedometers i.e. piezoelectric pedometers can have the step threshold adjusted for individual wearers prior to using the product, whereas spring lever arms in general can only be used on their factory settings, thus any adjustments to their step threshold can only be done *post hoc*. Systematic error may allow for a correctional factor to be applied to the pedometer units known to over/under-record actual values, however, this would require testing all units before use and thus may not feasible to do in large scale studies (Beets *et al.* 2005).

Additionally, it also introduces other potential errors as well as increasing the volume of manual data handling (Moreau *et al.* 2009). Therefore, it is advantageous to be able to use pedometers on default factory settling for convenience, ease of use and to avoid errors associated with increased manual data manipulation.

The validation of video to record motor laterality has been well documented (Neilsen *et al.* 2010; Ringgenberg *et al.* 2010) and can also be used to identify true positives, false positives and false negatives provided that the footage has been recorded with adequate frames per second (fps). Ringgenberg *et al.* (2010) used 4fps however this is considered to be individual images rather than constant motion. The camera housing is an additional consideration for use in horse studies; it needs to be safe, durable, and resistant to adverse weather/ground conditions. One such product is the GoPro Hero 3 camera series, the Black Edition in particular records both high levels of visual and audio footage, and has robust casing designed for extreme sports so well within the parameters of equestrian sport. GoPro Hero 3 Black Edition specifications: HD 240fps, 720 120fps, play back and real-time features. Additionally, another key feature of this product is its lightweight body and secure housing allowing it to be safely and securely mounted to a variety of surfaces including surfboards, cars, and helmets.

The positioning of the instruments is of important consideration, as pedometers are designed to estimate the total number of steps taken by a biped however even in human studies, factors such as slow ambulant walking, fat deposits around the waist, hip injuries, and postural/gait abnormality have been shown to influence the accuracy of the pedometers. In general, it is recommended to attach spring lever arm pedometers in a horizontal position on the belt or waistband at the mid-line of the thigh in humans and with piezoelectric pedometers it is recommended to place the pedometer in a pocket for human patients or around the neck, avoiding a 45 degree angle. Animal studies that have utilised sensors to detect and record movement have previously been positioned with success on cow hindlegs (Nadimi *et al.* 2008), attached to the collar or lead of dogs (Chan *et al.* 2005), and on goat collars, harness or chest belt (Moreau *et al.* 2009). It is proposed to use similar harness equipment on horses to provide suitable surfaces upon which to mount the sensors and camera.

The practical application of being able to readily detect motor laterality using sensor technology would enable the user (veterinarian, horse trainer, owner, and breeder) to detect gait anomalies that may be indicative of orthopaedic pain and associated lameness, leading to early treatment of such conditions and therefore an improvement to welfare standards. Significant asymmetry musculoskeletal development can compromise the physical performance of equine athletes (Drevemo *et al.* 1987; Powers & Harrison 2000; McGreevy & Rogers 2005; Murphy & Arkins 2008), therefore as competitive performance is often closely related to monetary value it is of interest to multiple facets of the horse ownership paradigm.

This current study focuses on the potential validation of two different pedometer sensors for use in equine research. The objectives of this study aim to determine: (1) if pedometers accurately record equine steps at walk and trot, when compared to video analysis, (2) if alternative positioning of these pedometers affected the accuracy of step detection when compared to video analysis. This research is thought to be the first of its kind and provides a starting point for which other areas should be investigated.

Materials and methods

Animals, equipment and experimental conditions

Five horses of varying age, breed, sex and height were available from Duchy College, Stoke Climsland, to model the instruments; the horses selected by the college had recently passed a 5-stage vetting by a veterinarian to assess soundness and suitability for use at an equine college, each was considered sound and free from lameness. It is important that the horses were fit for the experimental design so as not to cause harm.

A simple step test, whereby a horse is halted in front of a raised ground pole and then asked to step over it, the first foreleg over the pole is recorded as the preferred foreleg lead, is one task that could have been used to determine a foreleg preference prior to the experimental phase taking place. This was proposed to the college by the researcher, however it was turned down due to health and safety concerns and limited staff availability – the researcher was not covered by the college's insurance to handle the horses without supervision therefore a member of college staff had to be present during all experimental tasks. As it was not possible to conduct a step test and assess whether an individual horse had pre-existing foreleg preferences prior to use in the experiment, the aims of this study were adapted, as was the experimental design to factor in the time and staff availability constraints. Therefore, the objectives of this study were not to infer laterality bias in individual horses but to determine: (1) if pedometers accurately record equine steps at walk and trot, when compared to video analysis, and (2) if alternative positioning of these pedometers affected the accuracy of step detection when compared to video analysis.

Due to the busy college schedule, there were difficulties accessing the horses, staff and facilities. Each session with a single horse was limited by the college to one hour (this included the time it took for the horses to be tacked up and walked down to the indoor arena), and data was collected over two sessions for each horse. The college schedule did not allow for sampling to be completed over a single day but rather sessions had to be fitted into the horse's usual routine as the college's teaching objectives took precedence. This means that there were sometimes days or weeks between sessions, these constraints also lead to additional variables being introduced such as varying time of the day of a session relative to the daily management; the presence or absence of other horses sharing the arena, and how much exercise/handling the horse had received prior to the data sampling taking place. It was not possible to have control over these constraints. The horses themselves regularly participated in additional varied activities as the college has multiple research students and horses are handled daily by persons of mixed ability, they are also used to being worked alongside other horses as well as experiencing solitary handling, so whilst these variables could potentially be confounding issues in a laterality bias study, especially as arousal influences stride parameters, I do not feel that they have any bearing on a mechanical sensor's ability to detect steps.

Due to the time constraints, the experimental design needed to incorporate an already familiar task for the horses to complete but also one where the sensors could be readily and safely attached to the horse without causing hindrance. Lunging on a 20m circle in walk and trot is one such task that did not require any pre-training as the horses were regularly lunged by a variety of handlers in the various arenas at the college, therefore this task was selected as it is a time efficient activity whereby a lot of data could be recorded over a short amount of time. Whilst the sensors themselves would be unfamiliar to the horses, the equipment used to attach the sensors was familiar and required no pre-training or habituation

Each horse was fitted with leg protection (veterinary Gamgee and exercise bandages) for two reasons; firstly, as a precaution to protect against knocks and rubs during the experimental phase, and secondly, it also provided a suitable surface upon which the sensors could be secured to the forelimbs. Each horse was also equipped with a well-fitting lunging roller, short girth, and an English hunting breastplate (Fig. 2). The breastplate provided additional anchoring points for sensor attachment, such as the chest and scapular, and it also provided stability for the lunging roller which is important for the camera image quality. The camera was secured to the middle of the short girth, using a mixture of cable ties and a strong adhesive, in addition to the proprietary mount. The camera was positioned underneath the horse with the viewing angle of 180̊ capturing the full movement of the forelimbs – this was checked in real-time via a phone app which displayed the field of view being recorded by the camera at that precise moment.

Handlers were equipped with gloves, hard hats and suitable industry standard personal protective equipment footwear for safety. Handlers differed between horses and sessions, at times the college staff member was also the horse's owner, at other times they were a college student/apprentice or lecturer, and in general all horses were led on the left-hand side – this was due to the horses being handled predominantly on the left-hand side on a daily basis, it was familiar to them, required no pre-training and yielded greater obedience during tasks.

One half of an enclosed indoor 40x20m arena with mixed fibre substrate and natural light was used to conduct the experiment. The same section of the arena was used during each session – this was another constraint set by the college so as to not interrupt the teaching schedule, however it did ensure that footing was consistent for the sensors and the horses safety, it was also a familiar working area for the horses and there was adequate light for the camera.

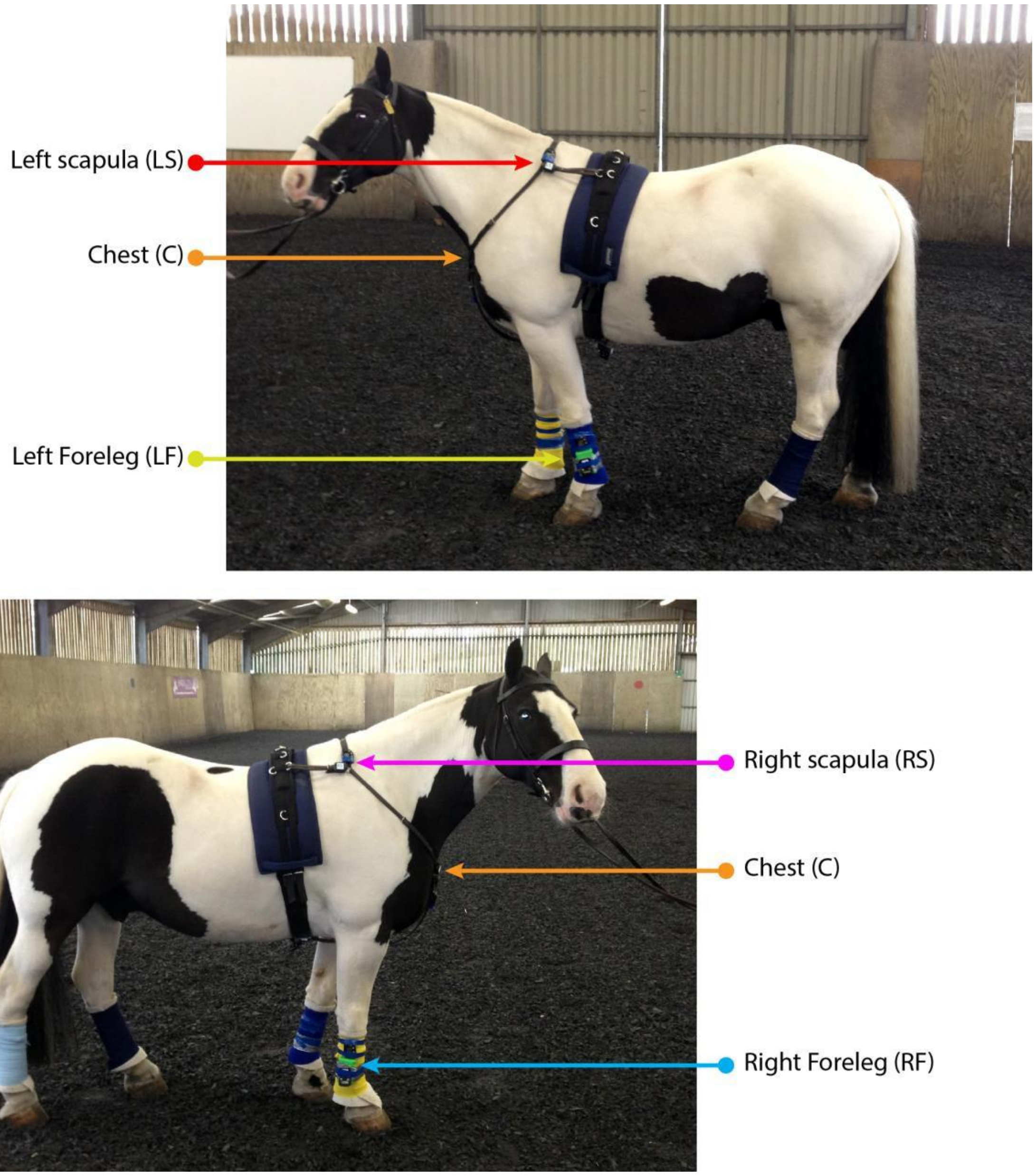


Figure 2. Equipment on horse showing Left Foreleg (LF), Left Scapular (LS), Chest (C), Right Scapular (RS) and Right Foreleg (RF) positions

Instruments : Pedometers

The sensors used were the Yamax Digiwalker SW-200 (Appendix 1; http://www.yamax.co.uk/product.php?product=1) and Yamax Power Walker PW-610/611 (Appendix 2; http://www.yamax.co.uk/product.php?product=8&storecookie=1).

The Yamax Digiwalker SW-200 is a spring lever arm pedometer, which is designed to be worn on the hips by human patients. Its internal sensor mechanism uses a coiled spring-suspended lever arm that moves with each step, the lever arm swinging downward and closing a contact to count a step, then the spring returning it to its original position. The instructions recommend attaching the pedometer in a horizontal position on the belt or waistband at the mid-line of the thigh; this was approximated on the horses by positioning the pedometers parallel to the ground at all sites. The Yamax Digiwalker SW-200 spring lever arm pedometer was chosen as it has been successfully used in free living conditions and is considered to be one the best pedometers with regard to accuracy (mean error score = -0.1 steps, CI = 16.7 to – 16.9; no statistical difference in the percentage of actual steps recorded; ±1% within actual steps) and reliability (ICC = 0.98; Chronbach's α=0.99) for counting steps in adults (Cocker *et al.* 2012). It is considered the criterion pedometer for use in human studies, against which others may be compared (McClain & Tudor-Locke 2009; Vincent & Sidman 2003).

The Yamax Power Walker PW-610/611, is a piezoelectric pedometer which has a horizontal cantilevered beam with a weight on the end that compresses a piezoelectric crystal when subjected to elevation of the hips during walking (acceleration). This generates a voltage proportional to the acceleration. The voltage oscillations are used to record steps if an acceleration is above manufacturer-defined sensitivity thresholds. The instructions recommend placing the pedometer in a pocket for human patients or around the neck, avoiding a 45 degree angle. This was approximated on the horse by securing the pedometer in a perpendicular manner (90 degrees) at all test positions.

The test positions chosen were the central chest (C) as viewed from in front with sensors secured to the breastplate, the top of both scapulars; right scapular (RS), left scapular (LS) with sensors secured to the breastplate, and on the outside of the forelimbs; right forelimb (RF) and left forelimb (LF) set equal distance between the fetlock and knee and secured over the bandages. All pedometers were secured using electrical tape at those sites (Fig 2) and to minimise interference with the horse's natural movement.

The pedometers were prepared by being zeroed. No stride length calibration was altered. All sensors were used on their default factory settings. Whilst stride length could be calibrated, it would not alter the number of steps counted, it would only alter the estimated distance travelled. There was no way to change the default factory settings for 'steps'.

For the purpose of this experiment a 'step' is defined as being an act or movement of putting one leg in front of the other in walking or trotting. Lifting and replacing the forelimb into the same hoof prints as before is not classified as a step in this case as this is considered to be shifting of the weight between forelimbs however if the hoof were lifted and replaced on the ground in front of the previous hoof prints then this was considered a 'step'.

Video recording

The GoPro Hero 3 Black Edition camera (Appendix 3; https://shop.gopro.com/cameras) was selected due to its robust design having been created for the extreme sports industry, it has the capability to record high frames per second footage which enabled the footage to be slowed down by up to four times whilst still maintaining a steady 30 frames per second and it also has the ability to capture footage in low light settings. It is lightweight (76g) so as not to be a hindrance to the horse. The GoPro Camera was positioned on the girth facing the forefeet using the following settings: 180 degree field of view, 720p, 120fps (Appendix 3). Both visual and audio data were captured and recorded. The recordings were replayed on a computer screen and the steps counted by a research assistant (criterion standard step count). The video recording could also be used to identify true positives, false positives and false negatives (Ringgerberg *et al.* 2012).

Procedures:

Initially it was intended to lunge the individual horses on a 20m circle, however due to the variance in training and obedience levels of the horses (only discovered at the start of the experimental phase), it was necessary to adapt the lunging into a leading activity – a task that the horses are also familiar with and required no pre-training.

Therefore, each horse was walked in-hand (with the handler on the left-hand side) on a 20m circle and halted once a full circuit was completed, for example, start at the arena marker ‘A’ and walk on a 20m circle and then halt at the same arena marker ‘A’ to manually read and record the pedometer data. At each completed circle (lap) the horse was halted, and the pedometer data were read out aloud by the researcher or handler to an assistant who recorded the information on MS Excel worksheet, the audio (of the team members relaying the results to the assistant) was also recorded by the camera, and could be checked against the recorded MS Excel values at a later date.

Each pedometer was then zeroed before commencing another lap. This was completed 10 times on each rein direction to yield 20 laps. The same procedure was followed to record data for trot.

Generally, all of the walk data was completed in one session and a second session was arranged in order to collect the trot data. For trot sessions it was necessary to allow time at the beginning of the hour session (approximately 10-15 minutes) for an appropriate warm-up and again at the end of the hour slot to cool-down the horse; the warm-up/cool-down time entailed either lunging or walking the horse in-hand for a number of circuits.

If the horse displayed any behaviour such as bucking, cantering, spooking, and rearing and so forth during the lap, then test was restarted, and the pedometers reset to zero.

Analysis

The difference between the number of Actual Steps Taken (AST) by the individual forelegs (as recorded by the camera) and the data recorded by each sensor was calculated by dividing the steps recorded by each pedometer type and position-single forelimb AST by single forelimb AST, giving the deviation per step unit. This was repeated to calculate the difference between number of actual steps taken (AST) by both forelegs (as recorded by the camera) and the data recorded by the sensors (each pedometer type and position-both forelimb AST)/both forelimb AST), giving the deviation per step unit.

Anderson-Darling Normality Test and Grubbs Outliers Tests were utilised to assess the normality of the distribution of steps and the presence of any outliers respectively. This was followed by a more in-depth analysis using Kruskal-Wallis Test and Analysis of Variance on deviation number of steps per unit versus pedometer type, pedometer position and gait.

To determine the overall nature of the data an Anderson-Darling Normality Test was conducted alongside a Grubbs Test for Outliers for walk and trot pedometer data according to pedometer position and pedometer type (Appendix 4, Tables A4.1 & Table A4.2).

Results

Pedometers are designed to estimate the total number of steps taken by a biped, therefore it was initially decided to compare the total number of steps recorded by the pedometers on the horse to the number of actual steps taken by the horse, a quadruped, determined by video recordings. The correlations between the number of steps counted by the pedometer and the actual number of steps taken varied widely (Appendix 5, Tables A5.1 & A5.2). Close inspection of scatterplots (Appendix 5, Figure A5.1-A5.8) show that individual horse, pedometer type, gait and positioning of pedometer all influence the accuracy of pedometers, making them unlikely to be useful in studies requiring a high degree of accuracy.

Analysis of pedometer data at walk compared to actual movement of both forelegs

As the number of actual steps taken per lap varied greatly, the deviation from actual number of steps taken per unit per lap was derived, i.e. (LF-AST Both)/AST Both. A Kruskal-Wallis Test was conducted on pedometer type which shows that regardless of position, there was a significant difference between the number of actual steps and the number recorded by the pedometer (H_{1df} = 26.23, p<0.0001; Appendix 6, Table A6.1).

There was a significant effect on both type of pedometer and where it was positioned on the difference from actual number of step per unit in walk (H_1= 340.31; p<0.001; Figure 3).

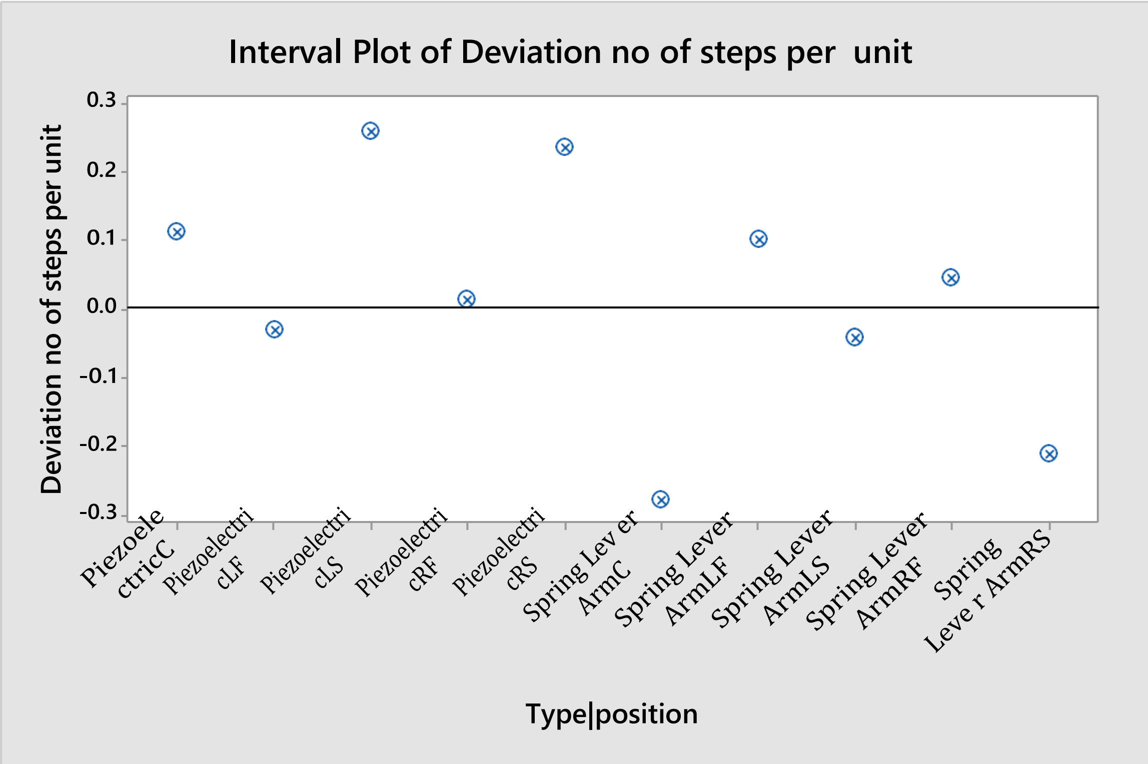


Figure 3. The deviation of number of steps per unit per lap from actual number of steps taken by both forelegs in walk, where pedometer position is; left foreleg (LF), left scapular (LS), chest (C), right scapular (RS) and right foreleg (RF)

Sign Tests (U) were used to further identify differences in the type of pedometer and the positioning of the pedometer, where Ho: there is no significant difference from '0' (i.e. there is no significant difference between the pedometer readings and the number of actual steps taken by both forelegs in walk as recorded by the video) and Ha: is a significant difference from '0' (i.e. there is a significant difference between the pedometer readings and the number of actual steps taken by both forelegs in walk as recorded by the video).

Results from the Sign Test (U) indicate that readings from piezoelectric pedometers sited on the left foreleg significantly (p<0.0001, median = 0.29) underestimate the actual number of steps taken by both forelegs in walk and overestimate (p<0.05, median = 0.01) when sited on the right foreleg (p<0.05, median = 0.01). The piezoelectric pedometer sited on the left (p<0.0001, median = 0.26) and right (p<0.0001, median = 0.23) scapulars both overestimate the number of steps taken, and the chest piezoelectric also overestimates (p<0.0001, median = 0.11) the number of actual steps taken in walk by both forelegs.

Spring lever arm pedometers sited on the left (p<0.0001, median 0.10) and right (p<0.0001, median = 0.05) foreleg over-estimate the number of steps taken by both forelegs but when sited centrally they underestimate the amount of movement (p<0.0001, median = -0.28). There is no significant difference (p>0.05, median = -0.05) when sited on the left scapular or right scapular (p>0.05, median = -0.21).

Analysis of pedometer data at trot compared to actual movement of both forelegs

The same analysis was repeated for trot as for walk.

Regardless of position, there was a significant difference between the number of actual steps and the number recorded by the pedometer (H_{1df} = 483.68, p<0.0001; Appendix 6, Figure A6.2).

There was a significant effect on both type of pedometer and where it was positioned on the difference from actual number of step per unit in (H_1 = 483.49; p<0.0001, Figure 4).

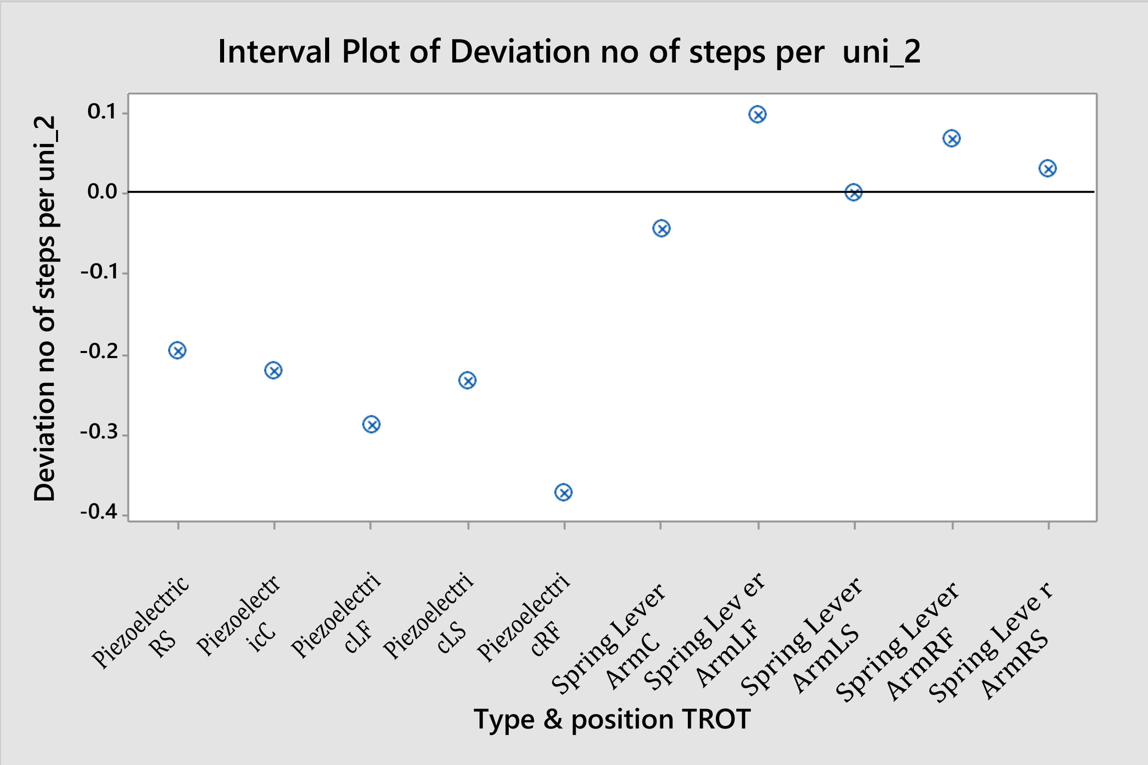


Figure 4. The deviation of number of steps per unit from actual number of steps taken by both forelegs in trot, where pedometer position is; left foreleg (LF), left scapular (LS), chest (C), right scapular (RS) and right foreleg (RF)
Uni_2 = deviation of number of steps per unit from actual number of steps taken by both forelimbs in trot

Sign Tests (U) were used to further identify differences in the type of pedometer and the positioning of the pedometer in trot, where Ho: there is no sig difference from ‘0’ (i.e. there is no significant difference between the pedometer readings and the number of actual steps taken by both forelegs in trot as recorded by the video) and Ha: is a significant difference from ‘0’ (i.e. there is a significant difference between the pedometer readings and the number of actual steps taken by both forelegs in trot as recorded by the video).

Results from the Sign Test (U) indicate that readings from piezoelectric pedometers at all sites significantly underestimate the number of actual steps taken by both forelegs in trot; chest (p<0.0001, median = -0.22), left foreleg (p<0.0001, median = -0.29), right foreleg (p<0.0001, median = -0.37), left scapular (p<0.0001, median = -0.23), and right scapular (p<0.0001, median = -0.37).

The central spring lever arm pedometer gives significantly fewer number of steps of deviation per step (p<0.0001, median = -0.04) therefore underestimating the number of steps taken by both forelegs in trot when sited where on the chest. However, when sited on the left (p<0.0001, median = 0.10) and right (p<0.0001, median = 0.07) foreleg they significantly overestimate. The spring lever arm on the right scapular significantly overestimated foreleg movement (p<0.0001, median = 0.07). There was no significant (ns) difference between the deviation of number of steps per unit and those readings recorded by the spring lever arm on the left scapular (p>0.05, median = 0.00), however this is not indicative of accuracy, rather it is an indication that the pedometer had an equal bias to both over and underestimate foreleg movement.

Analysis of pedometer data at walk compared to actual movement of individual forelegs

Next pedometer data, calculated as the deviation from actual number of steps taken per unit per lap, were compared to the number of actual steps taken by each individual foreleg in walk i.e. left foreleg movement compared to pedometer data sited on the left-hand side of the horse and right foreleg movement compared to the pedometer data sited on the right-hand side of the horse.

Regardless of position, there was a significant difference between the number of actual steps and the number recorded by the pedometer (H_{1df} = 5.93, p<0.05; Appendix 6, Table A6.3). There was a significant effect of both type of pedometer and where it was positioned on the difference from the actual number of steps per unit (H_1= 403.36, p<0.0001; Figure 5).

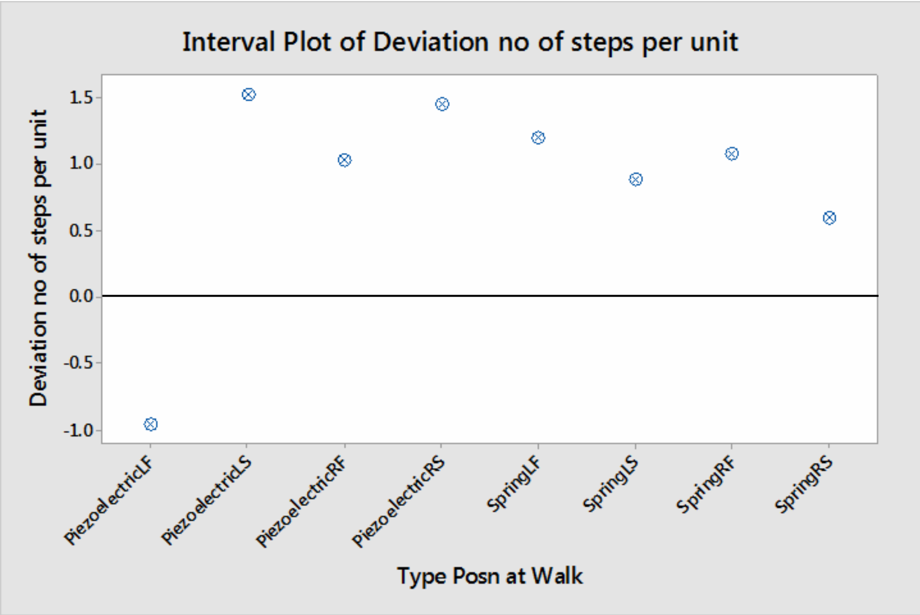


Figure 5. The deviation of number of steps per unit from actual number of steps taken by individual forelegs in walk, where pedometer position is; left foreleg (LF), left scapular (LS), right scapular (RS) and right foreleg, and pedometer type is piezoelectric and spring lever arm (spring)

Sign Tests (U) were used to further identify differences in the type of pedometer and the positioning of the pedometer in walk, where Ho: there is no sig difference from '0' (i.e. there is no significant difference between the pedometer readings and the number of actual steps taken by each foreleg in walk as recorded by the video) and Ha: is a significant difference from '0' (i.e. there is a significant difference between the pedometer readings and the number of actual steps taken by each foreleg in walk as recorded by the video).

The results indicate that the piezoelectric pedometer on the left foreleg gives significantly fewer no of steps of deviation per step (p<0.0001, median= -0.94) therefore it underestimates single leg movement at walk. Whereas the piezoelectric pedometer on the right foreleg gives significantly greater number of steps of deviation per step (p<0.0001, median = 1.45) therefore over estimating the number of steps taken. Both piezoelectric pedometers sited on the left scapular (p<0.0001, median = 1.03) and right scapular (p<0.0001, median 1.45) gave significantly greater no of steps of deviation per step therefore overestimates single leg movement at walk.

Regardless of site positioning all of the spring lever arm pedometers gave significantly greater number of steps of deviation per steps i.e. significantly overestimate movement single leg movement at walk; left foreleg (p<0.0001, median= 1.12), left scapular (p<0.0001, median= 0.89), right foreleg (p<0.0001, median= 1.08) and right scapular (p<0.0001, median= 0.60).

Analysis of pedometer data at trot compared to actual movement of individual forelegs

The same analysis was repeated for trot as it was for walk i.e. pedometer data, calculated as the deviation from actual number of steps taken per unit per lap, were compared to the number of actual steps taken by each individual forelegs in trot (left foreleg movement compared to pedometer data sited on the left hand side of the horse and right foreleg movement compared to the pedometer data sited on the right hand side of the horse).

Regardless of position, there was a significant difference between the number of actual steps and the number recorded by the pedometer (H_{1df} = 434.72, p<0.0001; Appendix 6, Table A6.4). There was a significant effect of both type of pedometer and where is was positioned on the difference from actual number of steps per unit by (H = 477.10; p<0.0001, Figure 6).

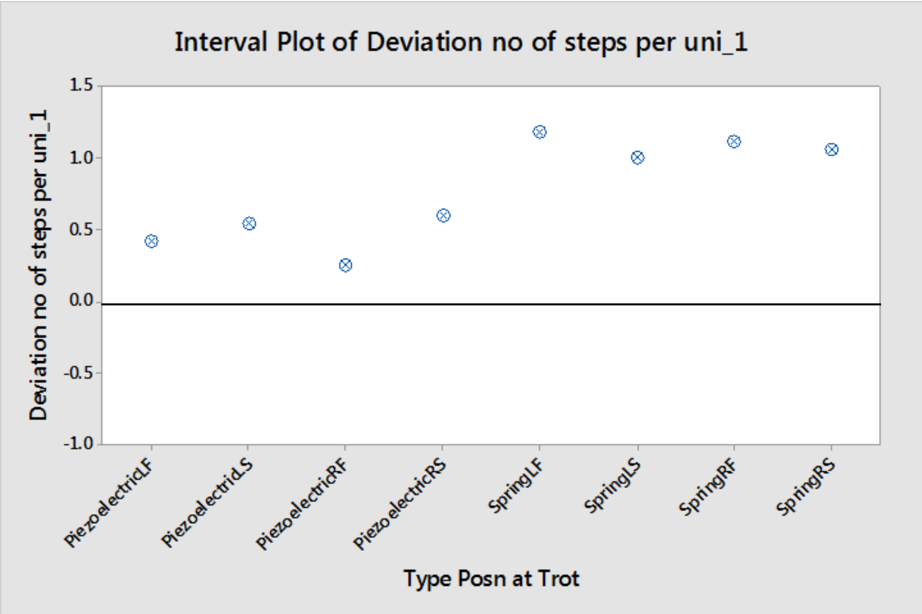


Figure 6. The deviation of number of steps per unit from actual number of steps taken by individual forelegs in trot, where pedometer position is; left foreleg (LF), left scapular (LS), right scapular (RS) and right foreleg, and pedometer type is piezoelectric and spring lever arm (spring)
Uni_2 = deviation of number of steps per unit from actual number of steps taken by both forelimbs in trot

Sign Tests (U) were used to further identify differences in the type of pedometer and the positioning of the pedometer in trot, where Ho: there is no sig difference from '0' (i.e. there is no significant difference between the pedometer readings and the number of actual steps taken by each foreleg in trot as recorded by the video) and Ha: is a significant difference from '0' (i.e. there is a significant difference between the pedometer readings and the number of actual steps taken by each foreleg in trot as recorded by the video).

Regardless of site of positioning, all of the piezoelectric pedometers gave significantly greater number of steps of deviation per step in trot i.e. the sensors significantly overestimated single foreleg movement in trot; left foreleg (*p*<0.0001, median= 0.42), left scapular (*p*<0.0001, median= 0.55), right foreleg (*p*<0.0001, median= 0.25) and right scapular (*p*<0.0001, median= 0.60).

Likewise, regardless of site positioning, all of the spring lever arm pedometers gave significantly greater number of steps of deviation per step in trot i.e. the sensors significantly overestimated single foreleg movement in trot; left foreleg (*p*<0.0001, median= 1.19), left scapular (*p*<0.0001, median= 1.01), right foreleg (*p*<0.0001, median= 1.12) and right scapular (*p*<0.0001, median= 1.05).

The scatterplots of difference of pedometer readings from actual steps taken (Appendix 5, Figure A5.1-A5.8) showed consistent effects of differences between individual horses. Therefore, this factor was included in an analysis of the effect of gait (walk v. trot) on pedometer accuracy. For spring lever arm pedometers, all eight 2-way ANOVAs had significant interaction terms (Appendix 7, Tables A7.10-A7.17). For piezoelectric pedometers, six had significant interaction terms and three did not have significant gait vs horse terms (Appendix 7, Tables A7.1-A7.9). Inspection of the size of the effects reported in the ANOVAs (adjusted mean squares values, Table 1 and 2) showed that gait had the greater influence on accuracy of piezoelectric pedometers, where horse had the greater influence on accuracy of spring lever arm pedometers

Investigation into influence of gait and individual horse on pedometer accuracy

Additional tests include a two-way Analysis of Variance (ANOVA) to investigate influence of individual horse and gait (walk vs trot) on pedometer accuracy (Appendix 7, Tables A7.1-A7.17). Whilst general linear modules (Minitab families of ANOVA) are known to be not very sensitive to the departures from normal distribution, two important factors were found; high module summary (66-94%) indicating that nothing is as important as horse and gait, and also the larger the F-Value, the greater the influence. Tables 1 & 2 summarise the data and indicate that gait is the greatest influencer on accuracy of piezoelectric pedometers, where horse is the greater influencer on accuracy of spring lever arm pedometers.

Table 1. Adjusted mean squares showing effect size, for actual steps taken by single forelegs

	Adjusted Mean Squares			
Position	Spring lever arm Horse	Spring lever arm Gait	Piezoelectric Horse	Piezoelectric Gait
Left Foreleg	1.13	1.50	0.32	39.97
Left Scapular	3.76	2.13	0.47	20.40
Right Scapular	3.79	2.83	0.96	14.22
Right Foreleg	0.55	0.08	0.16	15.30

Table 2. Adjusted mean squares showing effect size, for actual steps taken by both forelegs

	Adjusted Mean Squares			
Position	Spring lever arm Horse	Spring lever arm Gait	Piezoelectric Horse	Piezoelectric Gait
Left Foreleg	0.27	0.34	0.07	2.12
Left Scapular	0.93	0.57	0.12	4.99
Chest	0.39	1.03	0.46	2.99
Right Scapular	0.95	0.69	0.24	3.63
Right Foreleg	0.15	0.03	0.04	3.89

The objectives of this study were to determine: (1) if pedometers accurately record equine steps at walk and trot, when compared to video analysis, (2) if alternative positioning of these pedometers affected the accuracy of step detection when compared to video analysis. In summary, the analysis of the pedometer data compared to video analysis indicate that pedometers are not useful for scoring forelimb movements in horses at walk and trot, regardless of positioning. Additionally, both gait and individual horse have the greatest influence on pedometers readings, making the sensors unlikely to be of use in studies where accuracy is required.

Discussion

The role of pedometers in detecting motor laterality has previously been explored however it is believed that this is the first study to investigate the relationship between pedometer data and those derived from video recording observation and analysis. It is important that validation of both the equipment and methodology of step detection is established before inferring the existence of any motor laterality bias from pedometer data.

The results of the present study indicate that regardless of position; the spring lever arm pedometers significantly underestimate, and piezoelectric pedometers significantly overestimate the number of steps taken by both forelegs in horses at slow speeds i.e. in walk (Figure 3), however the opposite is true in trot (Figure 4). Additionally when comparing the deviation of steps per step unit for each pedometer type to the actual number of steps taken by each individual foreleg i.e. right foreleg movement with readings from the pedometers sited on the right hand side and the left foreleg movement with readings from the pedometers sited on the left hand side of the horse, it was found that regardless of position (foreleg or scapular), a significant ($p<0.05$) overall bias exists whereby piezoelectric pedometers underestimate at walk and spring lever arm pedometers overestimate at walk (Figure 5). A significant overall bias exists whereby piezoelectric pedometers underestimate at trot and spring lever arm pedometers overestimate at trot (Figure 6). Furthermore, the greatest influencers on pedometer accuracy are gait and individual horse (Table 1 & 2).

It has been established that determining measurement error in pedometers used in research is critical for maintaining confidence in data that are collected (Vincent and Sidman 2003). Welk *et al.* (2000) and Vincent and Sidman (2003) have both conducted similar walking tests prior to study utilising Yamax pedometers, both studies found the instruments to be between 2-5% of the recorded values. However, the percentage error rate ranged greatly across both types of pedometer (0-284% in some instances) during this study i.e. when sited on a horse, therefore if 5% error is deemed to be acceptable for pedometers, then the large differences found in the current study are well outside the limits of acceptable measurement error. Individual differences are accountable for some of the range of differences found in this study, however because the default 'step counter' measure for these pedometers is unable to be adjusted, they cannot be calibrated for individual differences and this has a negative impact on the sensor accuracy making them unsuitable for use in large scale studies of individual horses regardless of positioning.

Improvements to the study would have been to have conducted a pre-test which investigated the accuracy of the pedometers chosen for the experiment prior to the use on the horses. This could (and should) have been carried out either in a laboratory setting using a shake test or on humans by simply wearing the apparatus and walking 100 steps and comparing steps taken to the pedometer readings.

This would have ensured confidence in the accuracy of the equipment. Additionally, it would have been interesting to compare parameters of the individual horses i.e. height, stride length, leg length, breed or physical build such as ‘stocky’ or ‘athletic’ etc… and whether these had any influence on the accuracy of the pedometers.

Despite these possible influencers, because the sensors are unable to be adjusted to account for individual differences, the key message remains the same; that the level of inaccuracy observed in the present study (> 5%) likely means that the role of pedometers in equine studies has limited usefulness for those that require a high level of precision, however the devices might still be useful for intervention studies if it can detect day-to-day differences in individual equine activity (Chat *et al.* 2005). Additionally, with the advent of the technological advances in ‘wearables’, equipment such a tri-axis accelerometers and giros, with their increase in movement planes, are perhaps better go-to sensors than spring lever arm and piezoelectric pedometers, especially where accuracy and precision are required.

It has previously been suggested that the use of pedometers (and other movement detecting sensors) to record motor laterality in animals such as horses could eliminate logistical challenges of direct observation (Warren-Smith and McGreevy 2010), however it should be noted that in free living conditions, pedometers are subject to other sources of error (Melanson *et al.* 2004). For example, we have not considered the accuracy of pedometers when walking over different terrain, over inclines/declines and obstacles, differences in shod or unshod horses, those of different morphology and/or stride length, movement detection in canter and gallop, and during exuberant behaviour such as rolling, bucking, rearing, scratching and shaking.

This study was designed specifically to reduce external influence; the horses selected had recently passed a 5-stage vetting by a veterinarian to assess soundness and suitability for use at an equine college. In addition, each were considered to be obedient, well-schooled and balanced horses upon which to mount the pedometers. All horses were between 14.2-16.2hh, 7-14 years of age, of cob or warmblood type, however individual differences occurred in stride length depending on the arousal state of the horse. Exuberant behaviour such as bucking and cantering also occurred and resulted in the test lap being restarted and the pedometers zeroed. Ideally working the horse on a straight line would have been preferable so that there was equal movement in the forelegs however a 20m circle was chosen as lunging is a familiar form of exercise for the horses and did not require any pre-training, and also reduced the footwork for the handler, however it was necessary to have a second helper at the start and end of a lap to encourage the horse to strike off into the required gait immediately from halt and to return to halt from the desired gait i.e. halt to trot, trot to halt. It should be noted that on occasion some laps of trot had between 1-4 strides of walk which could not be helped but may have had some influence on the results.

A limitation of using pedometers is this fashion is that the readings can only be taken whilst the horse is stationary, which not only requires a cooperative horse but also means that all of movements are recorded by the pedometers between readings i.e. from halt, up to walk or trot and then back to halt. If any erroneous behaviours occur during this time frame they are recorded regardless of whether they are a true ‘step’ or not, so long as they meet the pedometers pre-set thresholds, therefore behaviours such as shaking, cantering and bucking all resulted in a wide variety of ‘steps’ being recorded even though they were not steps at all. As neither the spring lever arm and piezoelectric pedometers cannot determine the difference between the two, this severely limits the use of these pedometers to detect steps in free living conditions on horses.

The method of testing multiple devices in differing positions at a single time has previously been validated (Foster *et al.* 2005), however care must be taken not to overload the limbs with too much heavy equipment that may impede the movement and cause discomfort (Moreau *et al.* 2009); habituation of the horse to any such equipment is also necessary. It should be noted that any additional weight added to the forelimb may in fact also alter the use of the leg, therefore great care must be taken when utilising sensors to detect steps and make inference of motor laterality bias.

Regarding stride length, it should be noted that some piezoelectric pedometers can have the step threshold adjusted for individual wearers prior to using the product, whereas spring lever arms in general can only be used on their factory settings, thus any adjustments to their step threshold can only be done *post hoc*. Systematic error may allow for a correctional factor to be applied to the pedometer units known to over/under-record actual values, however, this would require testing all units before use and thus may not feasible to do in large scale studies (Beets *et al.* 2005). Additionally it also introduces other potential errors as well as increasing the volume of manual data handling (Moreau *et al.* 2009). The use of other sensors, such as accelerometers, to detect forelimb movement in horses may be more appropriate in these cases as the sensitivity level can be adjusted more readily i.e. an appropriate algorithm can be utilised to adjust the threshold of what is predetermined as a ‘step’, however this area requires further investigation.

Both Melanson *et al.* (2004) and Carroll *et al.* (2012) found that spring lever arm pedometers significantly underestimated the number of steps taken by both legs at slow speeds in humans, this trend is apparent in this experiment as well despite the different species. To be able to use pedometers in free living conditions it would be essential to investigate the mean grazing/walking speed of horses on amble substrate in order to determine what type of pedometer would be best suited to use. Chan *et al.* (2005) found that as a practical matter, the pedometers used were subject to failure if they became wet. Whilst we did not experience any failures due to weather conditions, it is an important consideration when using them in free-living conditions. Likewise, we did also experience battery failure during the experiment, therefore it would be advisable in future studies to replace all batteries at the outset.

Despite the results from this pedometer focused study which indicate that regardless of position, the analysis of the pedometer data compared to video analysis indicate that pedometers are not useful for scoring forelimb movements in horses at walk and trot, the role of other sensors, such as giros and accelerometers, in the field of laterality research should still be considered. Such devices could facilitate behavioural studies under conditions where manual observation is difficult, as for example during night grazing, in mountain environments or at very remote locations (Moreau *et al.* 2009). However care must be taken as due to the sheer volume of data that these sensors will output it can lead to increased researcher burden whilst participant burden is reduced (McClain *et al.* 2009).

Further areas of research include investigating the accuracy of sensors such as giros and accelerometers when compared to actual number of steps taken in horses and the potential influence of horse and pony morphology, stride length, during vigorous activity, different exercise surfaces and whether these surfaces increase/decrease stride length. Also, whether concussive surfaces introduce added 'noise' for sensors, and the difference between a shod versus barefoot horses on these surfaces. The use of accelerometers with time synced computer and video has already been trialled using 5-s epochs and downloadable every 7 days (Robert *et al.* 2009) however it has yet to be explored in free roaming animals with larger behavioural repertoires i.e. bucking, cantering, rolling. Additionally, further research is required to determine the long-term sustainability of this technology in the field including methods for fitting the horses with the devices, potentially adverse events, and economic viability in commercial production systems (Robert *et al.* 2009).

In conclusion researchers employing the use of accelerometers and pedometers to assess physical activity should treat their accelerometers with the same care as those working with laboratory-based chemistry to achieve good quality research. Reliability sets the limit on validity, so correct pre and post-test checks should take place in all devices with each and every use which also prevents the use of defective equipment in the field (Silva *et al.* 2011.) Also, a clear understanding of the technical capabilities of sensors, whether pedometers or accelerometers, is important for understanding the limitations of different types of research (Silva *et al.* 2011).

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Appendices

Appendix 1; Yamax Digiwalker SW-200 Product Information

YAMAX
DIGI-WALKER®
SW-SERIES

SW-200
SW-500/501
SW-650/651
SW-700/701
SW-800/801

Thank you for purchasing DIGI-WALKER.
Please read the instruction manual carefully.

1. SW-SERIES LINE UP

SW-200
STEP COUNTER
See for No 2.3.4.5.6.7.14.16.17

SW-500/501
STEP COUNTER, DISTANCE (km:500/ mile:501), CLOCK
See for No 2.3.4.5.6.7.8.9.10.14.15.16.17

SW-650/651
STEP COUNTER, DISTANCE (km:650 / mile:651), CLOCK, STOPWATCH
See for No 2.3.4.5.6.7.8.9.10.11.14.15.16.17

SW-700/701
STEP COUNTER, DISTANCE (km:700 / mile:701), CALORIE
See for No 2.3.4.5.6.7.8.9.12.14.15.16.17

SW-800/801
STEP COUNTER, DISTANCE (km:800 / mile:801), CALORIE, SPEED (km/h:800 / mph:801)
See for No 2.3.4.5.6.7.8.9.12.13.14.15.16.17

2. FUNCTIONS

STEP COUNTER — Counts the number of steps taken while walking or jogging up to100,000 steps.

DISTANCE — Measures the distance covered while walking or jogging from 0.01 km or 0.01 mile to 1,000 km or 1,000 miles.

CLOCK — 12 hours system clock.

STOPWATCH — Digital Stopwatch,measures in 1 second up to 10 hours.

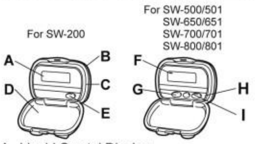
CALORIE — Measures the number of calorie burned while walking or jogging from 0.1 to 10,000 kcal.

SPEED — Measures the speed covered while walking or jogging from 0.01 km or 0.01 mile to 99.99 km or 99.99 miles.

3. NOTE ON USE

- Do not open the case except when changing battery as it contains a precision mechanism. Also avoid dropping or subjecting DIGI-WALKER to shock.
- Avoid using DIGI-WALKER in a place with excessive humidity or where it may come in contact with water.
- If you are presently under the care of a doctor or have a history of heart disease, you should consult your doctor before beginning your walking program.

4. ASSEMBLED PARTS



A. Liquid Crystal Display
B. Cover Case
C. Body Case
D. Back Case with Clip
E. Step Count Reset Button
F. Cursor
G. • Step Count, Distance Reset, Clock Time Setting Button (SW-500/501)
  • Step Count, Distance Reset, Stopwatch Reset, Clock Time Setting Button (SW-650/651)
  • Step Count, Distance Reset, Calorie Reset (SW-700/701)
  • Step Count, Distance Reset, Calorie Reset, Speed Reset (SW-800/81)
H. • Mode Selector Button
I. • Stride Length Setting Button (SW-500/501)
  • Stride Length Setting Button, Stopwatch Start Stop Button (SW-650/651)
  • Stride Length Setting Button, Body Weight Setting Button (SW-700/701, SW-800/801)

5. MAIN APPLICATIONS

DISPLAY	5-Digit Liquid Crystal Display
DISPLAY ITEM	Clock: 12 Hours Digital Clock MINIMUM Step ....1 step Distance ......0.01 km (0.01 mile) Calorie ....0.1 kcal Stopwatch ...0:00:01 (1 second) Speed ....0.01 km/h (0.01 mph) MAXIMUM Step ....99999 steps Distance ......999.99 km (999.99 mile) Calorie ....9999.9 kcal Stopwatch ...9:59:59 (9H/59 M/59 S) Speed ....99.99 km/h (99.99 mph)
SET BUTTON	Stride length can be set by pressing this button. (30-180cm/Minimum Unit: 1cm) (1 feet-6 feet/MInimum Unit: 0.05 feet) Clock time setting, Stopwatch start/stop button.
RESET BUTTON	To reset number of steps, distance, calorie and stopwatch. To set clock time.

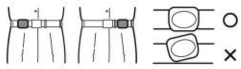
BODY SIZE	50 x 38 x 14 mm (Wide x Tall x Thin).........except CLIP Weight: Approx. 21 g (Incl. Battery)
BATTERY	Type: LR-44 Life: Approx. 3 years

6. OPENING THE COVER

Holding the Pedometer up wright, grasp the top of the clip with one hand. Use the other hand to push the projecting portion of case body between the sides of the clip away from the clip thus opening the case.

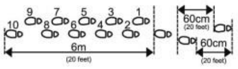
7. INSTALLATION METHOD

Attach to your belt, beltless slacks, skirts or training suits bottoms using the clip.



8. ADJUSTING YOUR STRIDE

(For SW-500/501, SW-650/651 SW-700/701, SW-800/801)
For computing the distance coverage, it is important to keep regular strides and maintain your walking form. To determine your average stride length, walk 10 steps as illustrated below and divide by 10, so the distance covered arrive at your average stride length.



9. HOW TO SET STRIDE LENGTH

(For SW-500/501, SW-650/651 SW-700/701, SW-800/801)
1) First, press MODE ("H") button to move the cursor to point "DIS" (km) or (mile). Next press SET ("I") button to input your stride length. (The cursor will point "STRIDE" (cm) or (feet).)
2) The stride length can be increased by every 1 cm or 0.05 feet (or 0.25 feet), starting with 30 cm or 1.00 feet and ending 180 cm or 6.00 feet after which the setting will return to 30 cm or 1.00 feet.
3) After setting your stride length, the cursor automatically move "DIS" (km) or (mile) in a few second.

∗ SW-701, 801...Stride length can be set in 0.25 feet intervals.

DIS 50 STRIDE → 55 STRIDE (SET)

10. HOW TO SET THE CLOCK

(For SW-500/501, SW-650/651)
1) Press MODE ("H") button to move the cursor to point "CLOCK".

CLOCK 12:00 (MODE)

2) Next press SET ("I") button to move the cursor to point "TIME SET". At this time displayed hour will continue to be flashing. Then press RESET ("G") button to set correct hour that can be increased by every 1 hour.

10:00 TIME SET (SET) → 11:00 TIME SET (RESET)

3) After setting correct hour, press SET ("I") button so that displayed minute will continue to be flashing. Then press RESET ("G") button to set correct minute that can be increased by every 1 minute.

11:00 TIME SET (SET) → 11:30 TIME SET (RESET)

4) After setting correct time completely, press SET ("I") button to return the cursor to point "CLOCK".

CLOCK 11:30 (SET)

11. HOW TO OPERATE STOPWATCH

(For SW-650/651)
1) First press MODE ("H") button to move the cursor to point "STOP-WATCH".
2) Next press SET ("I") button once to start the stop-watch. The stop-watch counts the the time that can be increased by every 1 second. While running the stop-watch operation, the cursor will continue to be flashing.

STOP-WATCH 0:00:00 (START/STOP SET) → STOP-WATCH 0:00:05

3) When you want to stop the stop-watch, press SET ("I") button again so that stop-watch operation will be stopped and freeze elapsed time.

STOP-WATCH 0:00:05 (START/STOP SET) → STOP-WATCH 0:00:00 (RESET)

4) Also if you want to reset the time counted by this stop-watch operation, press ("I") button when stop watch operation is stopped, so that "0:00:00" will be displayed.

12. HOW TO SET YOUR BODY WEIGHT

(For SW-700/701, SW-800/801)
1) First press MODE ("H") button to move the cursor point "CALORIE (kcal)". When the cursor point "CALORIE (kcal)". press SET ("I") button to input your body weight. (The cursor will point "WEIGHT" (kg) or (lbs).)
2) The body weight can be increased by every 1 kg or 1 lbs, starting with 30 kg or 70 lbs and ending 120 kg or 300 lbs and will return to 30 kg or 70 lbs.
3) After setting your body weight, the cursor automatically move "CALORIE (kcal)" in a few second.

CALORIE 70 WEIGHT (SET) → CALORIE 75 WEIGHT (SET)

13. HOW TO OPERATE SPEED METER

(FOR SW-800/801)
1) Display shows walking speed in every 10 seconds.
2) Walking speed will be displayed for about 10 seconds after calculation average speed for former 10 seconds.
3) Please note speed meter will be changed in every 10 seconds.
4) Minimum speed is 0.01 km/h or 0.01 mph.

14. RESET BUTTON

(For SW-200)
When you want to reset the date-Number of Steps, please press RESET ("E") button.
(For SW-500/501, SW-650/651, SW-700/701, SW-800/801)
When you want to reset the date-Number of Steps and Distance Meter, please press RESET ("G") button when your required mode is displayed. In case SW-700/701 and SW-800/801, the number of calorie burned is also reset.

15. MODE BUTTON

(For SW-500/501, SW-650/651, SW-700/701, SW-800/801)
Press MODE ("H") button to display your required mode. Then you can find your required mode will be displayed.

16. HOW TO REPLACE THE BATTERY

- The display will get dim as the battery begins to run down. Replace the battery as soon as possible.
- A "monitor" battery (for testing the functions at the factory) is installed in the meter, and may not be fully stored.
- Replace the battery with the (LR-44) type that you can buy in electric store or drug store.
- If the battery is accidentally swallowed, please contact a doctor immediately.
- To replace the battery, using the coin into cover case and body case and pull out the cover case from body case, then remove the "dead" battery and insert a new battery. (make sure positive "+" side faces to you.)

- After replacing the battery, you have to press the all buttons together for about 5 seconds and move your hand away from button so that "88888" will be displayed as illustration below. The date will be cleared so please input the date (such as stride length, present time etc.) again.

12345 → 0

17. WHEN UNUSUAL SEGMENT IS DISPLAYED

If the unusual segment or half segment is displayed, please press the all buttons together in about 5 seconds and move your hand away from buttons so that "88888" will be displayed and after a few second "0" will be displayed, the date will be cleared so please input the date (such as stride length, present time etc.) again.

18. YAMAX PEDOMETER WARRANTY CONDITION

YAMAX / YAMASA Pedometers have 1 year limited warranty.
Our warranty covers all trouble EXCEPT Clip Broken, LCD Broken and battery installed that is test battery. Our warranty does not cover Battery.
If your problem meet our warranty condition, we will repair your pedometer at free of charge or free replacement. YAMAX or YAMAX authorized reseller reserve rights to charge handling and repair fee if returned unit is found not to meet warranty condition and damaged caused by dropping, wet, excessive pressure or reassembled by users. Please contact store, reseller who you bought from with your proof of purchase or access our web site at www.yamaxx.com.

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http://www.yamaxx.com
PRINTED IN JAPAN

Appendix 2; Yamax Power Walker PW610/611 Product Information

YAMAX

POWER WALKER™

PW-610/611 INSTRUCTION MANUAL

1. FUNCTIONS

STEP COUNTER Counts the Number of Steps taken while walking or jogging up to 99999 steps.

DISTANCE Measures the Distance covered while walking or jogging from 0.00 km or 0.00 mile to 999.99 km or 999.99 miles. (km/PW-610 / mile/PW-611)

CALORIE Measures the Number of Calorie burned while walking or jogging from 0.00 to 9999.9 kcal.

ACTIVITY TIME Measures the Time covered while walking or jogging from 0H 00M to 23H 59M.

SPEED Measures the Speed covered while walking or jogging from 0.0 meter/minute or 0.0 mph to 999.9 meter/minute or 999.9 mph. (meter/minute/PW-610 / mph/PW-611)

CLOCK 24 hours system clock.

7DAYS MEMORY The Records of Number of Steps and Consumption Calorie are automatically saved every day up to 7 days ago.

POWER WALKING The PW sensor measures Number of Steps and calculate Burned Fat Weight in case of high pitch aerobics walking (Power Walking Mode). (g/PW-610 / oz/PW-611)

DUAL DISPLAY Wide and Easy to ready LCD shows your walking record and data.

3D SENSOR 3 directions accelerometer (3D) sensor is mounted and monitor every steps you take.

2. SPECIFICATIONS

DISPLAY DESCRIPTION

Please press MODE button to display each item.

Normal mode

Upper Display
Number of Steps
Distance
Calorie
Walking Time

Lower Display
Clock
Walking Speed

POWER WALKING (PW) mode

Upper Display
Number of Steps (In PW mode)

Lower Display
Walking Time (In PW mode)
Burned Fat Weight

FEATURES

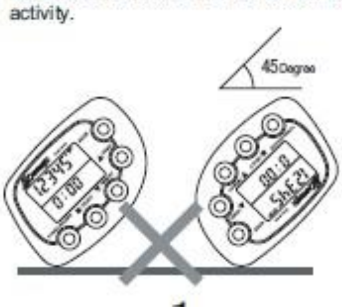
Sensor	3D Accelerometer Sensor
Display	5-Digit Dual LCD
Display Item	Number of Steps: 0 to 99999 steps
	Walking Distance: 0.00 to 999.99 km (999.99 mile)
	Calorie: 0.00 to 9999.9 kcal
	Activity Time: 0H 00M to 23H 59M
	Walking Speed: 0.0 to 999.9 m/min (0.0 to 999.9 mph)
	7 Day Memory: Steps and calorie (each 7 days)
Power Walking	Number of Steps: 0 to 99999 steps
	Activity Time: 0H 00M to 23H 59M
	Body Fat Burning: 0.0 to 9999.9 g (0.0 to 999.9 oz.)
StepCounter Accuracy	±5 % (YAMAX regulation)
ClockTime Accuracy	±30 seconds / month (normal usage)
Material	ABS Resin
Size	48.8 x 70.7 x 14.4 mm (1.92 x 2.78 x 0.57 inch H x W x D)
Weight in bulk	34 g (1.2 oz.) including the battery
Battery	CR2032 battery •Life time will be 1 year

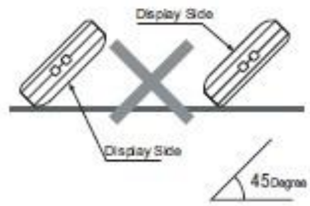
3. HOW TO USE POWER WALKER

3 directions accelerometer (3D) sensor monitor your walking and store the record in Memory.

- You can use POWER WALKER in pocket but do not use in back pocket, this may cause the damage to your product.

- Please do not expose in 45 degree as illustrated. 3D sensor cannot monitor the activity.



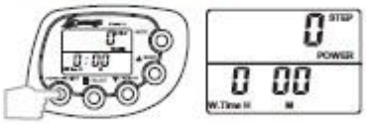


4. POWER WALKING mode

In Power Walking (PW) mode, The PW Sensor measures the Number of Steps and calculate Burned Fat Weight in grams (or ounces). PW sensor only catch high pitch walking that is faster than 110 steps per minutes and considered as aerobics exercise.

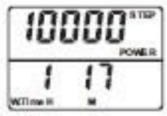
1) To start PW mode

Press POWER WALKING blue button and make sure "POWER" is displayed in right upper display. If you need PW data, please do not change to Normal Mode (just keep Display in PW mode. "POWER" should be in upper display). Even during PW mode, normal walking records are monitoring.



2) How do you know Walking data in PW mode

Upper Display shows Number of Steps in PW mode. Lower Display shows Walking Time in PW mode.



Press POWER WALKING blue button once. Lower Display shows Burned Fat Weight in gram (or ounce).

3) Reset PW record

Press RESET button for 2 seconds in PW mode to clear all PW record.

– 1 –

YAMAX

POWER WALKER™

PW-610/611 INSTRUCTION MANUAL

5. HOW TO DO INITIAL SETTING

Please do not forget setting date before you using POWER WALKER™.

SETTING DATA

Time Setting	0:00 to 23:59 (24 Hours Display)
Stride Length	30 to 180 cm (each 1 cm) ＊for PW-610 1.00 to 6.00 feet (each 0.25 feet) ＊for PW-611
Body Weight	30 to 120 kg (each 1 kg) ＊for PW-610 70 to 300 lb (each 1 lb) ＊for PW-611

SETTING PROCEDURES

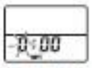
First of all, please make sure Display shows Normal Walking mode (not PW mode nor 7 DAYS Memory mode).

1)Time setting

Press "■/SELECT" button (keep press for more than 2 second)

⬇

"Hour" blinking



⬇

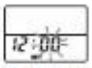
Press ▲ button to increase or ▼ button to decrease data.

⬇

Press "■/SELECT" button

⬇

"Minute" blinking



⬇

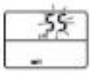
Press ▲ button to increase or ▼ button to decrease data.

⬇

Press "■/SELECT" button

⬇

2)"Stride Length" blinking (*Stride Length setting)



⬇

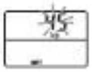
Press ▲ button to increase or ▼ button to decrease data.

⬇

Press "■/SELECT" button

⬇

3)"Body Weight" blinking (Body Weight setting)



⬇

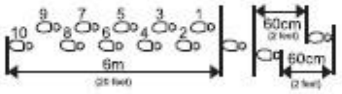
Press ▲ button to increase or ▼ button to decrease data.

⬇

4)Press MODE green button when you finish initial setting.

*Stride Length setting

For measuring the distance coverage, it is important to keep regular strides and maintain your walking form. To determine your average stride length, please walk 10 steps as illustrated below. Then please measure distance (toe to toe) of your 10 steps and divide distance by 10. You can calculate your average one step (stride length).



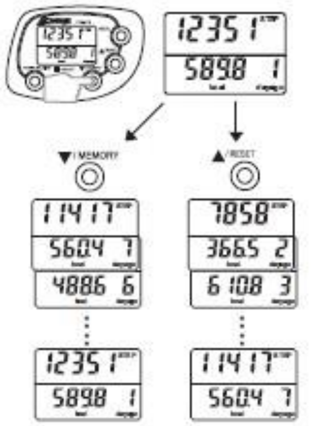
6. 7 DAYS MEMORY

1)Auto Memory and Reset

The Number of Steps and Consumed Calorie of the day are automatically stored in memory device in Power Walker at 2:00 am every day up to 7 days ago. So at 2:00 am, Display shows zero(0).

2)How to Recall the 7 Days Records

Please press MEMORY button first in Normal Walking mode. Display shows The Number of Steps and consumed calorie of the previous day (One(1) day ago). To continue recall records of each day, press ▲/RESET button or ▼/MEMORY.



7. BATTERY CHANGE

- Battery life time is approx 1 year.
- You can purchase replacement battery CR2032 at grocery store, electronic retail shops, etc.
- Please use coin to open battery case and change battery. Please make sure that Plus(+) side is facing up.

-2-

8. RESET

1)Manual Reset

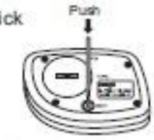
If you want to clear record of the day, please press ▲/RESET button for approx 2 seconds until display shows zero(0) in Normal Walking Mode or PW mode.

2)Auto Reset

At 2:00 am every day, the data of Number of Steps and Consumed Calorie are automatically saved in Memory Device in POWER WALKER. Then display shows zero(0).

3)System Reset

When you want to delete all personal data and walking record and to be in factory default mode, please put small stick in RESET whole and push button on the back case.



We strongly recommend you do this System Reset operation only -

- When unusual segment or irregular item is displayed due to electric trouble.
- Right after changing battery.

After you complete system reset procedure, please start initial setting. (showing in HOW TO DO INITIAL SETTING)

9. ⚠IMPORTANT INFORMATION

⚠CAUTION

- Please treat your products with care and keep it in a clean place.
- Please do not put your product in back pocket.
- Please do not open the case. There are sensitive mechanism inside.
- POWER WALKER is not water resident, please do not expose your product to liquid or moisture or humid place.
- Please do not expose your product to extreme high or low temperature place.
- Please do not throw and drop your product.

⚠WARNING

- Please do not throw your product into the fire or explosive area. Your product may explode.
- Please keep your product and accessories incl. battery out of the children's reach.
- Please keep your product and accessories incl. battery out of your pet's reach.
- If your product or the battery is accidentally swallowed, please contact doctor immediately.
- For disposing the battery, Please check local regulation and follow their direction.

Appendix 3; GoPro Hero 3 Black Edition Product Information

SET UP

NTSC / PAL

The **NTSC** and **PAL** settings govern **Video** recording frame rate and playback when viewing **Video** on a TV/HDTV. Select **NTSC** when viewing a TV/HDTV in North America. Select **PAL** if viewing on a PAL TV/HDTV (most televisions outside of North America) or if viewing on a PAL TV/HDTV in any region.

NTSC (Default)	**PAL**
4k/15fps	4k/12.5fps
4k Cin/12fps	4k Cin/12fps
2.7k/30fps	2.7k/25fps
2.7k Cin/24fps	2.7k Cin/24fps
1440p/48fps	1440p/48fps
1440p/30fps	1440p/25fps
1080p/60fps	1080p/50fps
1080p/48fps	1080p/48fps
1080p/30fps	1080p/25fps
1080p/24fps	1080p/24fps
960p/100fps	960p/100fps
960p/48fps	960p/48fps
720p/120fps	720p/100fps
720p/60fps	720p/50fps
WVGA/240fps	WVGA/240fps

CAMERA SETTINGS

The HERO3: Black Edition offers the following Video Capture modes:

Video Resolution	NTSC fps	PAL fps	std Mode	Protune	Field of View (FOV)	Screen Resolution
4k / 4k Cin	15 12	12.5 12	No	Yes	Ultra Wide	3840x2160, 16:9 4096x2160, 17:9
2.7k / 2.7k Cin	30 24	25 24	Yes	Yes	Ultra Wide	2704x1524, 16:9 2704x1440, 17:9
1440p	48 30 24	48 25 24	Yes	Yes	Ultra Wide	1920x1440, 4:3
1080p	60 48 30 24	50 48 25 24	Yes	Yes	Ultra Wide Medium Narrow	1920x1080, 16:9
960p	100 48	100 48	Yes	Yes No	Ultra Wide	1280x960, 4:3
720p	120 60	100 50	Yes	Yes No	Ultra Wide Narrow*	1280x720,16:9
WVGA	240	240	Yes	No	Ultra Wide	848x480, 16:9

*Medium and Narrow FOV will be available in an upcoming software update. Note: 720p120 and 720p100 only support Ultra Wide and Narrow FOV.

Note: Protune *mode is only possible in select* **Video** resolutions.

Appendix 4; Tables A4.1 & A4.2 Normality and Outlier

Table A4.1 Normality and outlier analysis of walk data for spring lever arm and piezoelectric pedometers

Walk Pedometer Data		Anderson Darling Normality Test					Grubbs Test			
	Position of pedometer	Mean	StDev	N	AD	P-Value	Min	Max	G	P Value
Piezoelectric	LF	59.74	8.51	102	0.839	0.030	40.00	79.00	2.32	1.0000
	LS	79.08	17.72	102	0.713	0.061	44.00	123.00	2.48	1.0000
	C	68.76	15.55	102	0.624	0.101	25.00	118.00	3.17	0.1210
	RS	74.59	14.73	102	1.188	<0.005				
	RF	61.92	7.73	102	0.350	0.467	47.00	48.00	2.60	0.8560
Spring Lever Arm	LF	72.91	13.22	102	1.746	<0.005	48.00	98.00	1.90	1.0000
	LS	52.82	26.70	102	1.930	0.018	7.00	107.00	2.03	1.0000
	C	47.04	16.12	80	3.186	<0.005	20.00	76.00	1.80	1.0000
	RS	55.51	29.47	102	2.164	<0.005	3.00	115.00	2.02	1.0000
	RF	68.62	10.91	102	1.395	<0.005	47.00	87.00	1.98	1.0000

The position of pedometer, left foreleg (LF), left scapular (LS), chest (C), right scapular (RS) and right foreleg (RF), of pedometer on horse (*n*=5) is also shown.

Table A4.2 Normality and outlier analysis of trot data for spring lever arm and piezoelectric pedometers

Trot Pedometer Data		Anderson Darling Normality Test					Grubbs Test			
	Position of pedometer	Mean	StDev	N	AD	P-Value	Min	Max	G	P Value
Piezoelectric	LF	37.81	15.47	90	1.869	<0.005	0.00	84.00	2.99	0.2010
	LS	43.19	17.97	90	1.217	<0.005	13.00	90.00	2.60	0.7260
	C	40.14	11.87	90	0.366	0.427	14.00	72.00	2.68	0.5630
	RS	40.82	19.84	90	1.524	<0.005	0.00	89.00	2.43	1.0000
	RF	33.29	14.75	90	1.802	<0.005	0.00	113.00	5.40	0.0000
Spring Lever Arm	LF	61.59	24.43	90	3.904	<0.005	30.00	115.00	2.10	1.0000
	LS	56.58	22.96	90	3.263	<0.005	23.00	106.00	2.15	1.0000
	C	53.71	21.03	90	3.739	<0.005	28.00	100.00	2.20	1.0000
	RS	58.63	23.50	90	3.850	<0.005	31.00	107.00	2.06	1.0000
	RF	60.46	22.18	90	3.395	<0.005	35.00	109.00	2.19	1.0000

The position of pedometer, left foreleg (LF), left scapular (LS), chest (C), right scapular (RS) and right foreleg (RF), of pedometer on horse (*n*=5) is also shown.

Appendix 5; Pedometer count vs actual steps taken

Table A5.1 Pearson Correlation for walk data

Piezoelectric recordings vs Actual steps taken by left foreleg	0.59
Piezoelectric recordings vs Actual steps taken by right foreleg	0.59
Piezoelectric recordings vs Actual steps taken by both forelegs	0.60
Spring lever arm recordings vs Actual steps taken by left foreleg	0.36
Spring lever arm recordings vs Actual steps taken by right foreleg	0.37
Spring lever arm recordings vs Actual steps taken by both forelegs	0.37

Table A5.2 Pearson Correlation for trot data

Piezoelectric recordings vs Actual steps taken by left foreleg	0.68
Piezoelectric recordings vs Actual steps taken by right foreleg	0.68
Piezoelectric recordings vs Actual steps taken by both forelegs	0.68
Spring lever arm recordings vs Actual steps taken by left foreleg	0.97
Spring lever arm recordings vs Actual steps taken by right foreleg	0.97
Spring lever arm recordings vs Actual steps taken by both forelegs	0.97

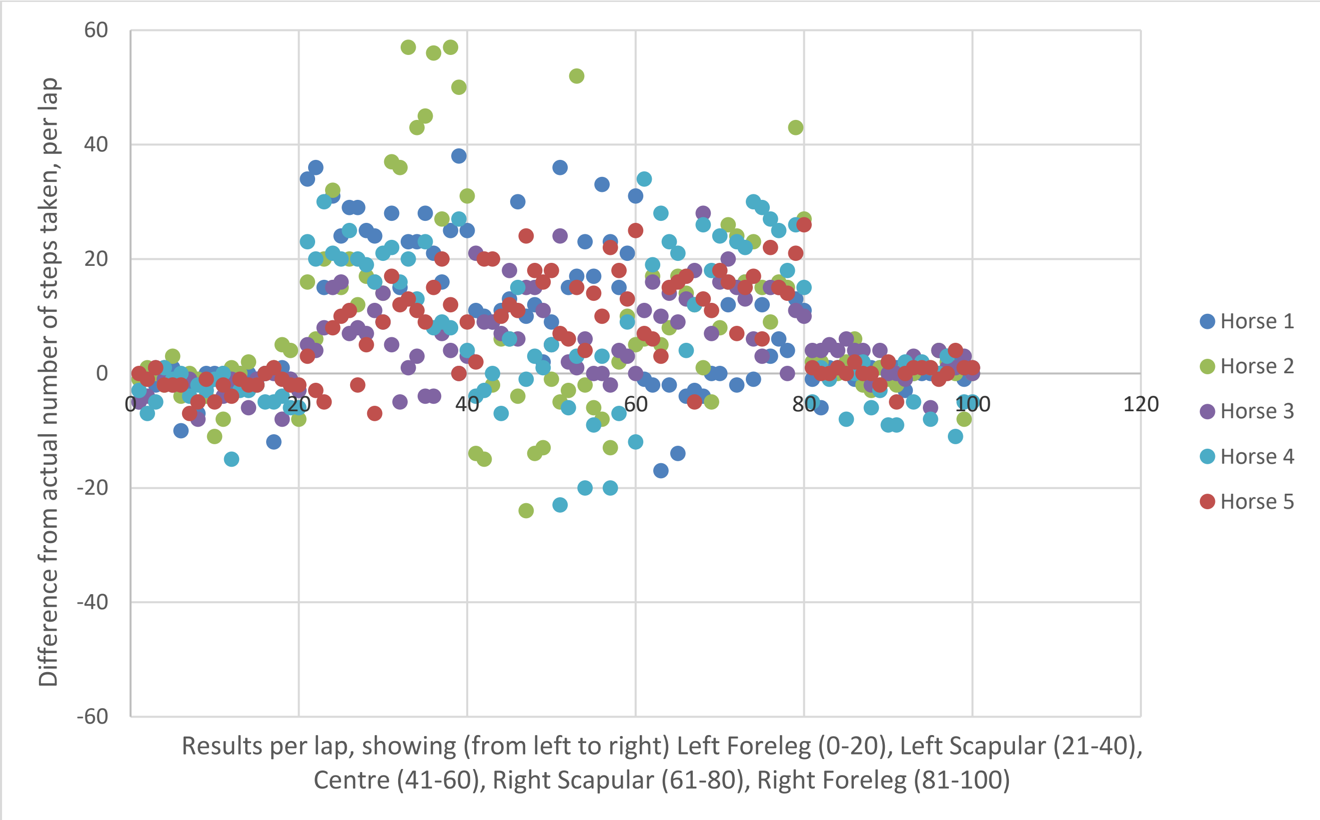


Figure A5.1 Piezoelectric pedometer data distribution compared to actual steps taken by both forelegs in walk per lap

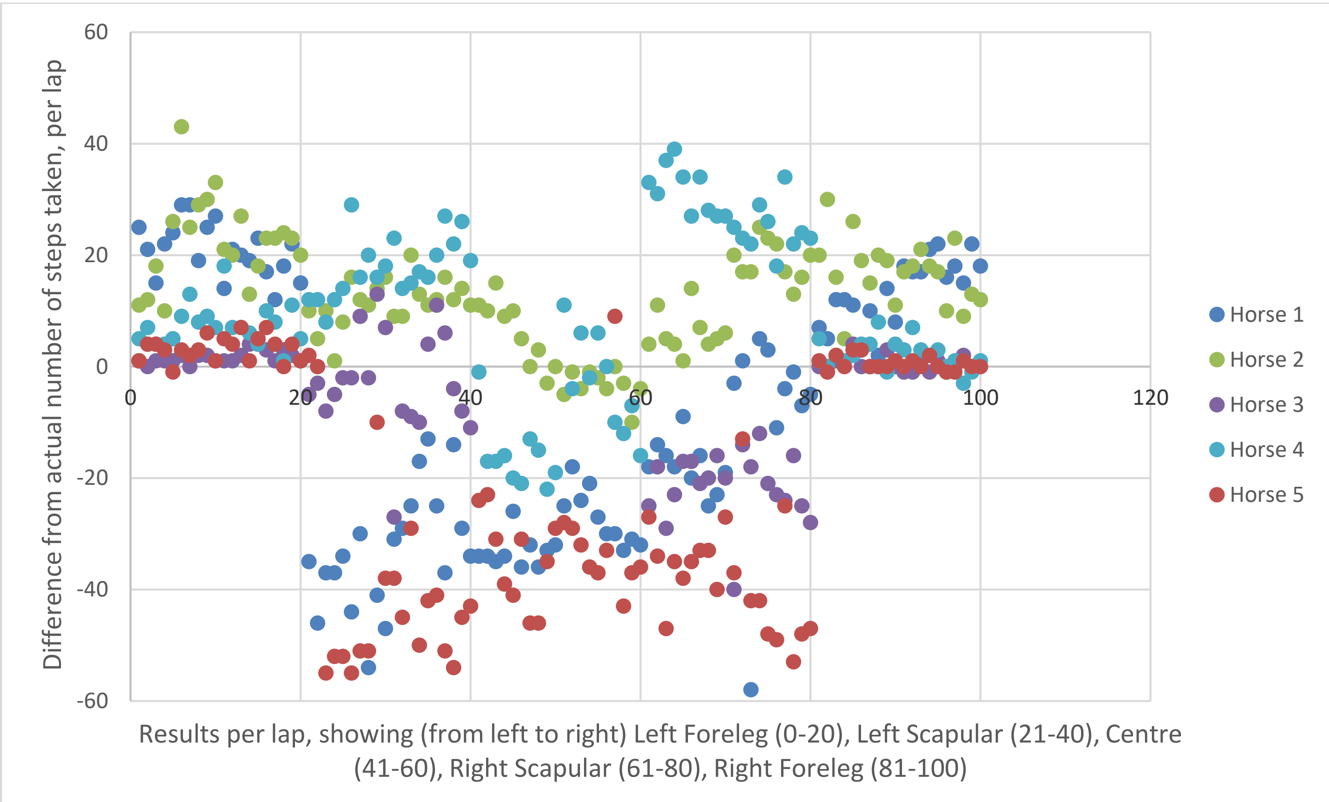


Figure A5.2 Spring lever arm pedometer data distribution compared to actual steps taken by both forelegs in walk per lap

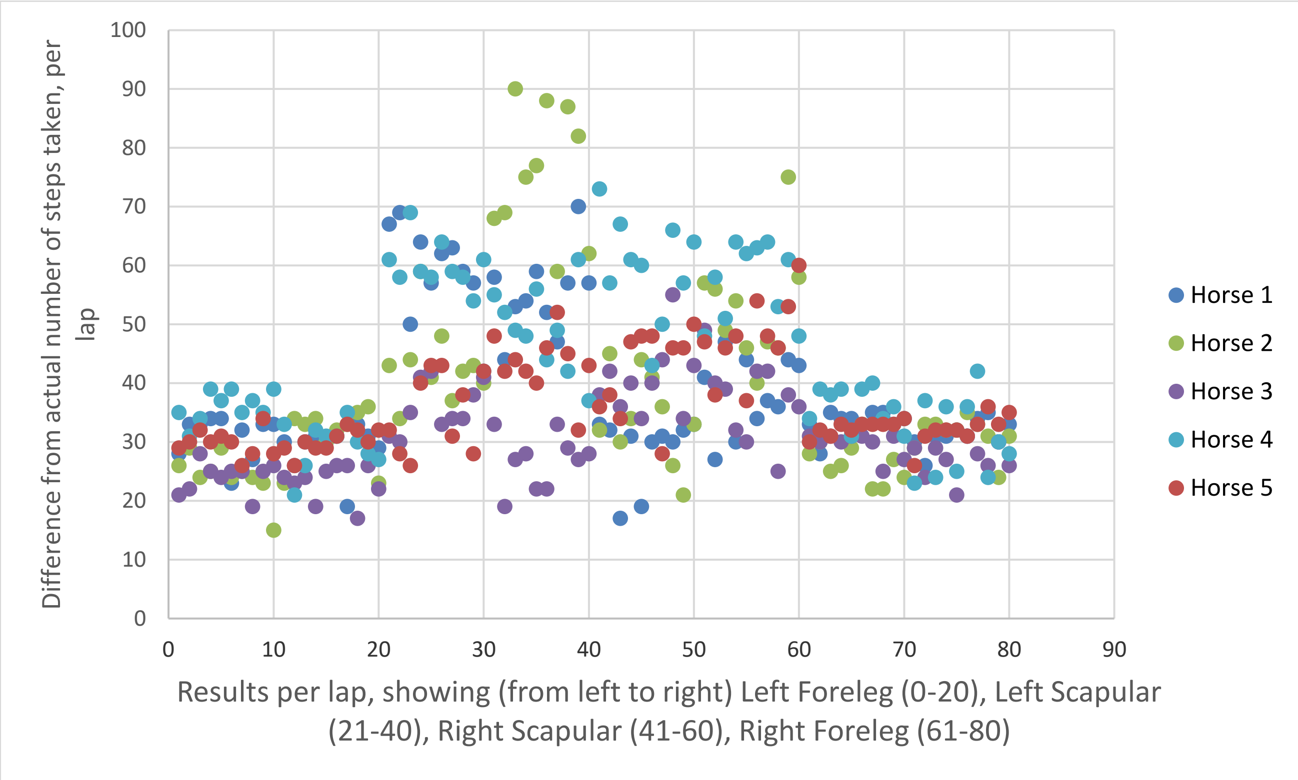


Figure A5.3 Piezoelectric pedometer data distribution compared to actual steps taken by single forelegs in walk per lap

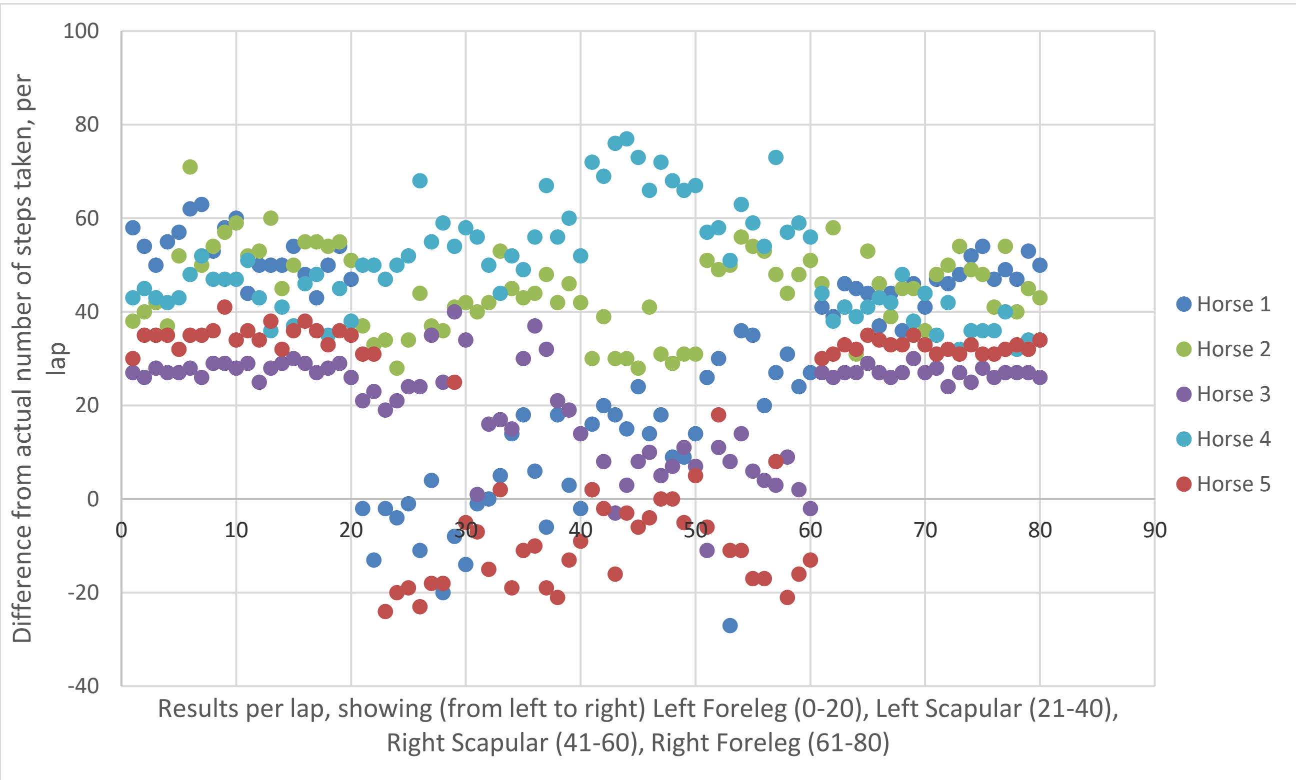


Figure A5.4 Spring lever arm pedometer data distribution compared to actual steps taken by single forelegs in walk per lap

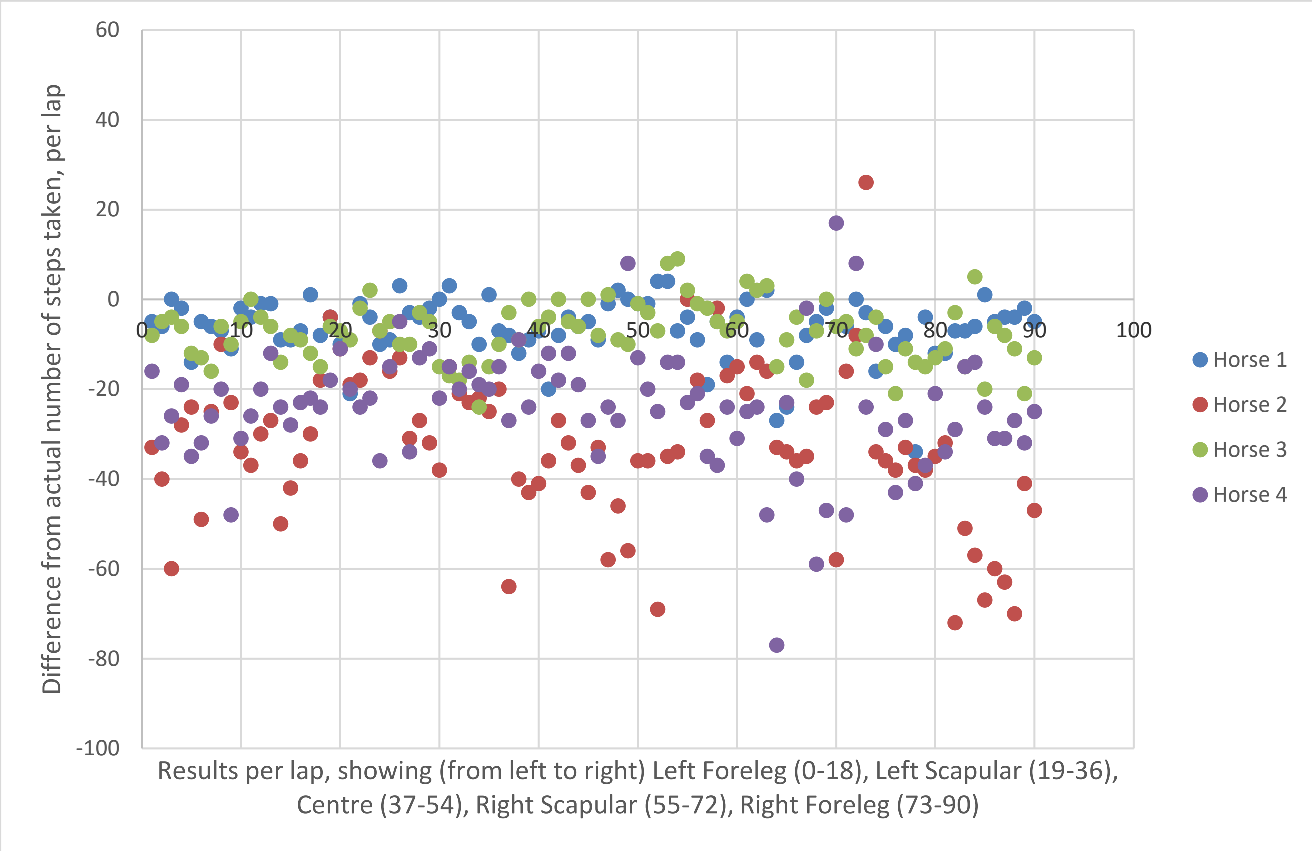


Figure A5.5 Piezoelectric pedometer data distribution compared to actual steps taken by both forelegs in trot per lap

Figure A5.6 Spring lever arm pedometer data distribution compared to actual steps taken by both forelegs in trot per lap

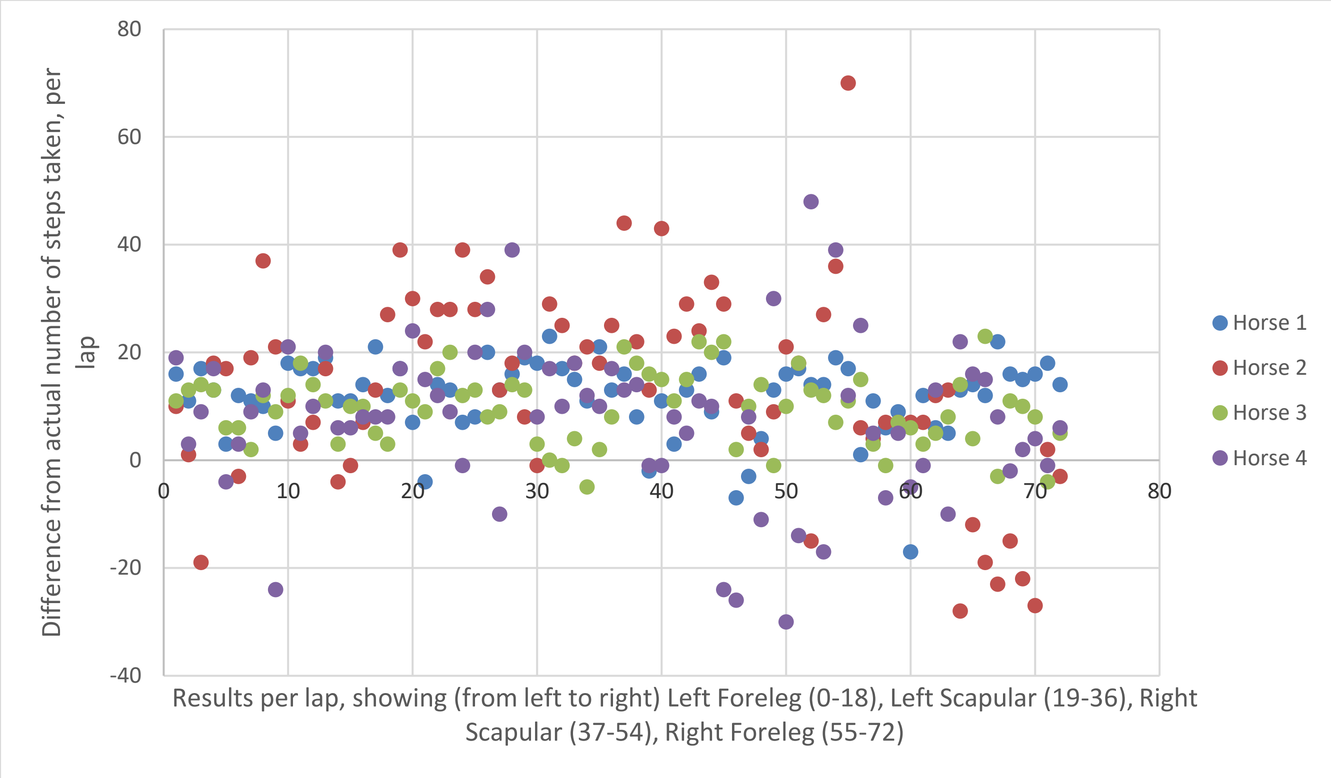


Figure A5.7 Piezoelectric pedometer data distribution compared to actual steps taken by single forelegs in trot per lap

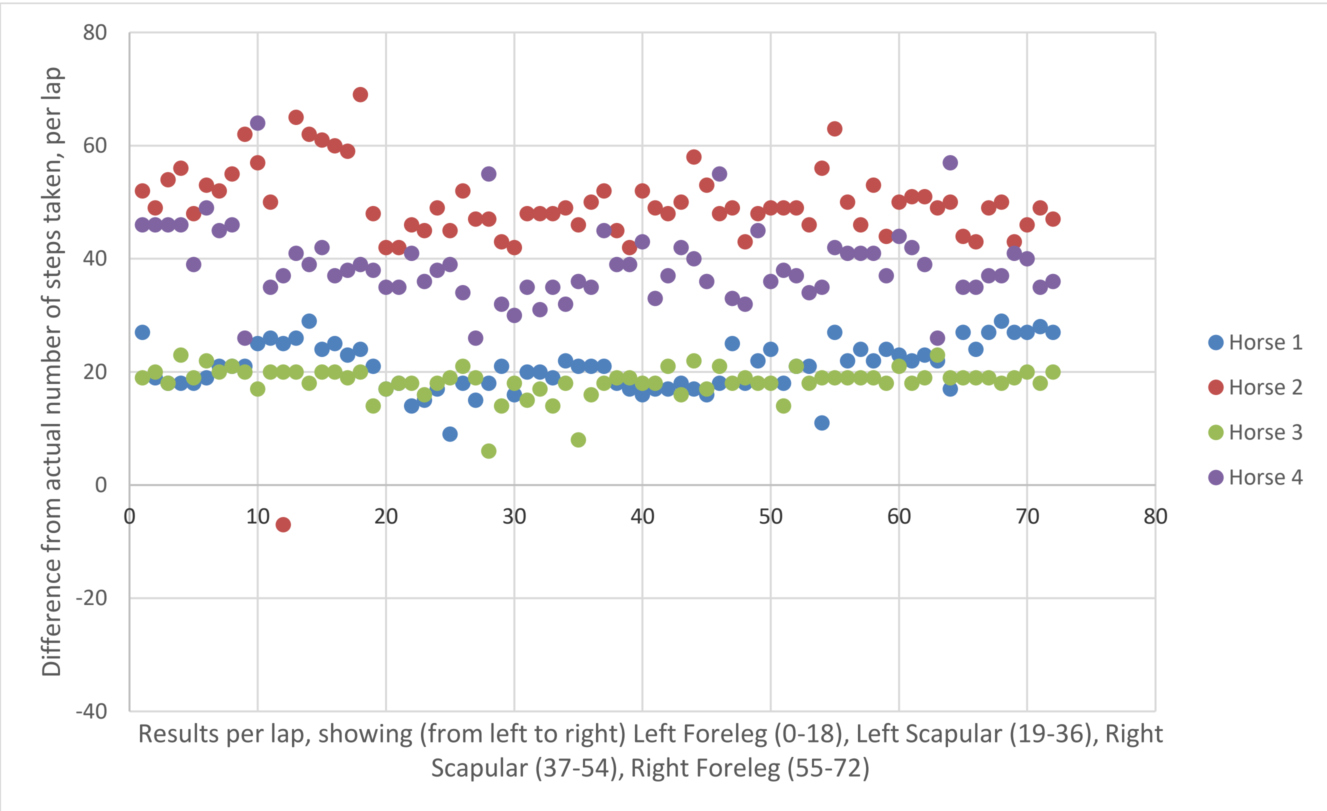


Figure A5.8 Spring lever arm pedometer data distribution compared to actual steps taken by single forelegs in trot per lap

Appendix 6; Difference from actual steps taken per step unit

Table A6.1 Kruskal-Wallis Test on the deviation of number of steps per unit from actual number of steps taken by both forelegs in walk

Pedometer type	N	Median	Ave Rank	Z
Piezoelectric	510	0.05364	542.00	4.76
Spring Lever Arm	488	0.01942	455.10	-4.76
Overall	998		499.50	
H = 22.63 D.F. = 1 P<0.0001 (adjusted for ties)				

Table A6.2 Kruskal-Wallis Test on the deviation of number of steps per unit from actual number of steps taken by both forelegs in trot

Pedometer type	N	Median	Ave Rank	Z
Piezoelectric	450	-0.46384	550.1	-24.63
Spring Lever Arm	450	0.02778	640.50	21.89
Overall	900		450.50	
H = 483.68 D.F. = 1 p<0.0001 (adjusted for ties)				

Table A6.3 Kruskal-Wallis Test on the deviation of number of steps per unit from actual number of steps taken by individual forelegs in walk.

Pedometer type	N	Median	Ave Rank	Z
Piezoelectric	408	1.039	388.40	-2.43
Spring Lever Arm	408	1.095	428.60	2.43
Overall	816		408.50	
H = 5.93 D.F. = 1 p<0.05 (adjusted for ties)				

Table A6.4 Kruskal-Wallis Test on the deviation of number of steps per unit from actual number of steps taken by individual forelegs in trot.

Pedometer type	N	Median	Ave Rank	Z
Piezoelectric	360	0.4667	198.90	-20.85
Spring Lever Arm	360	1.0909	52.10	20.85
Overall	720		360.50	
H = 434.72 D.F. = 1 p<0.0001 (adjusted for ties)				

Appendix 7; ANOVA of gait and horse

ONLY RIGHT – Piezoelectric Data

Table A7.1 General Linear Model: (LF-left AST)/AST left versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	1.277	0.3193	3.46	0.011
Gait	1	39.974	39.9738	432.62	0.000
Horse*Gait	4	1.186	0.2966	3.21	0.016
Error	90	8.316	0.0924		
Total	99	50.753			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.303972	83.62%	81.98%	79.77%

Table A7.2 General Linear Model: (LF-Both)/AST Both versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	0.3033	0.07583	3.28	0.015
Gait	1	2.1243	2.12428	92.03	0.000
Horse*Gait	4	0.3314	0.08286	3.59	0.009
Error	90	2.0775	0.02308		
Total	99	4.8366			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.151933	57.05%	52.75%	46.97%

Table A7.3 General Linear Model: (LS-left AST)/AST left versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	1.888	0.4720	7.84	0.000
Gait	1	20.397	20.3969	338.91	0.000
Horse*Gait	4	1.655	0.4136	6.87	0.000
Error	90	5.417	0.0602		
Total	99	29.356			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.245324	81.55%	79.70%	77.22%

Table A7.4 General Linear Model: (LS-Both)/AST Both versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	0.4704	0.11760	7.80	0.000
Gait	1	4.9924	4.99244	331.04	0.000
Horse*Gait	4	0.4228	0.10570	7.01	0.000
Error	90	1.3573	0.01508		
Total	99	7.2430			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.122806	81.26%	79.39%	76.86%

Table A7.5 General Linear Model: (C-Both)/AST Both versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	1.83705	0.45926	27.53	0.000
Gait	1	2.99548	2.99548	179.53	0.000
Horse*Gait	4	0.04965	0.01241	0.74	0.565
Error	90	1.50167	0.01669		
Total	99	6.38385			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.129171	76.48%	74.12%	70.96%

Table A7.6 General Linear Model: (RS-right AST)/AST right versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	3.848	0.9620	11.20	0.000
Gait	1	14.218	14.2178	165.51	0.000
Horse*Gait	4	4.569	1.1422	13.30	0.000
Error	90	7.731	0.0859		
Total	99	30.366			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.293090	74.54%	71.99%	68.57%

Table A7.7 General Linear Model: (RS-Both)/AST Both versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	0.9691	0.24229	11.40	0.000
Gait	1	3.6302	3.63018	170.86	0.000
Horse*Gait	4	1.1167	0.27918	13.14	0.000
Error	90	1.9122	0.02125		
Total	99	7.6282			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.145761	74.93%	72.43%	69.05%

Table A7.8 General Linear Model: (RF-right AST)/AST right versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	0.6349	0.1587	2.04	0.096
Gait	1	15.2971	15.2971	196.30	0.000
Horse*Gait	4	0.1028	0.0257	0.33	0.857
Error	90	7.0135	0.0779		
Total	99	23.0483			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.279155	69.57%	66.53%	62.43%

Table A7.9 General Linear Model: (RF-Both)/AST Both versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	0.15825	0.03956	2.03	0.097
Gait	1	3.89484	3.89484	200.03	0.000
Horse*Gait	4	0.02381	0.00595	0.31	0.873
Error	90	1.75244	0.01947		
Total	99	5.82934			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.139540	69.94%	66.93%	62.89%

MTB >

ONLY RIGHT – Spring Lever Arm Data

Table A7.10 General Linear Model: (LF-left AST)/AST left_1 versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	4.523	1.13068	33.47	0.000
Gait	1	1.496	1.49626	44.29	0.000
Horse*Gait	4	2.566	0.64140	18.98	0.000
Error	90	3.041	0.03379		
Total	99	11.625			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.183811	73.84%	71.23%	67.71%

Table A7.11 General Linear Model: (LF-Both)/AST Both_1 versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	1.0780	0.269488	32.59	0.000
Gait	1	0.3380	0.338034	40.87	0.000
Horse*Gait	4	0.6394	0.159839	19.33	0.000
Error	90	0.7443	0.008270		
Total	99	2.7997			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0909412	73.41%	70.76%	67.18%

Table A7.12 General Linear Model: (LS-left AST)/AST left_1 versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	15.053	3.76318	48.56	0.000
Gait	1	2.128	2.12781	27.46	0.000
Horse*Gait	4	11.143	2.78569	35.95	0.000
Error	90	6.975	0.07750		
Total	99	35.298			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.278380	80.24%	78.26%	75.61%

Table A7.13 General Linear Model: (LS-Both)/AST Both_1 versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	3.7285	0.93213	47.70	0.000
Gait	1	0.5669	0.56694	29.01	0.000
Horse*Gait	4	2.7706	0.69264	35.45	0.000
Error	90	1.7586	0.01954		
Total	99	8.8247			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.139787	80.07%	78.08%	75.40%

Table A7.14 General Linear Model: (RS-right AST)/AST right_1 versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	15.148	3.78692	225.90	0.000
Gait	1	2.830	2.83001	168.82	0.000
Horse*Gait	4	9.624	2.40593	143.52	0.000
Error	90	1.509	0.01676		
Total	99	29.110			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.129474	94.82%	94.30%	93.60%

Table A7.15 General Linear Model: (RS-Both)/AST Both_1 versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	3.7884	0.947098	227.90	0.000
Gait	1	0.6684	0.668388	160.84	0.000
Horse*Gait	4	2.3839	0.595969	143.41	0.000
Error	90	0.3740	0.004156		
Total	99	7.2147			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0644648	94.82%	94.30%	93.60%

Table A7.16 General Linear Model: (RF-right AST)/AST right_1 versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	2.21649	0.55412	44.58	0.000
Gait	1	0.07724	0.07724	6.21	0.015
Horse*Gait	4	1.36091	0.34023	27.37	0.000
Error	90	1.11879	0.01243		
Total	99	4.77344			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.111494	76.56%	74.22%	71.06%

Table A7.17 General Linear Model: (RF-Both)/AST Both_1 versus Horse, Gait

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horse	4	0.59029	0.147573	50.02	0.000
Gait	1	0.02790	0.027902	9.46	0.003
Horse*Gait	4	0.34023	0.085058	28.83	0.000
Error	90	0.26554	0.002950		
Total	99	1.22396			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0543176	78.31%	76.14%	73.22%

Appendix 8; Raw Data - Walk

Horse	Cash
Gait	**Walk**
Circle Direction	**Right**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	52	69	39	59	55	64	63	64	57	73	26	27	53
2	57	62	41	73	58	68	61	66	67	86	28	28	56
3	49	69	47	54	49	67	59	64	54	65	25	24	49
4	51	85	59	61	53	63	54	62	57	58	26	27	53
5	56	68	59	70	55	79	61	63	54	79	27	26	53
6	51	75	51	69	61	98	71	60	69	74	27	28	55
7	49	61	25	61	47	74	61	49	56	64	24	25	49
8	49	67	36	51	47	79	61	53	54	70	25	25	50
9	49	69	40	48	54	83	67	50	58	72	26	27	53
10	40	65	50	59	50	84	67	51	57	62	25	26	51
Sum	503	690	447	605	529	759	625	582	583	703	259	263	522
Mean	50.3	69	44.7	60.5	52.9	75.9	62.5	58.2	58.3	70.3	25.9	26.3	52.2
Standard Deviation													

Horse	Cash
Gait	**Walk**
Circle Direction	**Left**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	54	99	57	88	60	83	71	57	82	79	31	31	62
2	66	101	62	89	66	85	74	64	82	83	32	33	65
3	66	123	118	82	66	93	86	62	83	87	33	33	66
4	65	106	61	86	64	76	76	62	88	81	31	32	63
5	61	108	57	78	64	81	74	61	86	80	31	32	63
6	63	119	55	72	67	86	75	59	85	73	31	32	63
7	64	90	50	79	65	86	79	63	80	86	31	32	63
8	66	118	63	76	61	85	73	58	74	70	31	30	61
9	68	114	74	107	56	87	78	54	80	77	32	32	64
10	54	93	67	89	62	82	73	58	82	74	31	31	62
Sum	627	1071	664	846	631	844	759	598	822	790	314	318	632
Mean	62.7	107.1	66.4	84.6	63.1	84.4	75.9	59.8	82.2	79	31.4	31.8	63.2
Standard Deviation													

Horse	Snickers
Gait	**Walk**
Circle Direction	**Right**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	74	100	73	111	72	82	89	76	110	82	39	38	77
2	69	96	73	95	77	83	88	59	107	76	38	38	76
3	73	108	78	106	77	82	86	61	115	80	39	39	78
4	77	97	69	99	77	80	88	60	115	77	38	38	76
5	76	97	83	98	69	82	91	57	111	79	39	38	77
6	78	103	93	82	78	87	107	57	105	82	39	39	78
7	73	97	76	89	79	90	93	64	111	81	38	39	77
8	77	98	82	105	73	87	99	64	107	87	40	39	79
9	74	93	78	95	74	86	93	55	104	76	39	38	77
10	79	101	85	104	71	87	98	61	107	84	40	40	80
Sum	750	990	790	984	747	846	932	614	1092	804	389	386	775
Mean	75	99	79	98.4	74.7	84.6	93.2	61.4	109.2	80.4	38.9	38.6	77.5
Standard Deviation													

Horse	Snickers
Gait	**Walk**
Circle Direction	**Left**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	65	87	42	81	56	83	88	76	90	68	32	33	65
2	56	87	65	94	73	78	85	67	94	78	35	36	71
3	55	78	61	80	53	65	73	64	80	61	29	29	58
4	66	82	49	99	71	75	86	67	98	71	34	35	69
5	64	89	57	95	58	70	82	72	92	69	33	33	66
6	67	80	75	99	72	82	92	72	90	72	36	36	72
7	74	88	59	104	82	87	106	69	113	80	39	40	79
8	65	77	62	87	58	70	91	57	91	66	35	34	69
9	63	96	78	95	64	80	95	62	93	68	35	34	69
10	60	70	54	81	61	71	85	50	89	67	33	33	66
Sum	635	834	602	915	648	761	883	656	930	700	341	343	684
Mean	63.5	83.4	60.2	91.5	64.8	76.1	88.3	65.6	93	70	34.1	34.3	68.4
Standard Deviation													

Horse	Shrek
Gait	**Walk**
Circle Direction	**Left**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	53	62	81	77	57	58	30	*	17	56	29	28	57
2	48	44	51	64	48	50	41	*	35	48	25	24	49
3	50	53	53	65	55	54	43	*	34	53	26	26	52
4	45	54	57	57	52	55	41	*	39	50	26	25	51
5	52	49	53	56	47	57	57	*	32	54	27	26	53
6	53	49	53	68	57	56	64	*	30	52	27	26	53
7	53	60	51	68	54	54	59	*	29	53	27	26	53
8	42	54	54	50	51	53	46	*	34	52	25	25	50
9	53	54	57	65	57	56	46	*	29	54	27	27	54
10	48	54	51	61	51	52	40	*	23	51	26	25	51
Sum	702	786	825	884	743	769	555	0	362	741	375	366	741
Mean	50.14286	56.14286	58.92857	63.14286	53.07143	54.92857	39.64286	#DIV/0!	25.85714	52.92857	26.78571429	26.14285714	52.9285714
Standard Deviation													

Horse	Shrek
Gait	**Walk**
Circle Direction	**Right**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	48	58	74	64	57	54	48	*	28	53	27	26	53
2	48	56	61	68	56	52	49	*	34	52	26	26	52
3	54	61	62	63	58	54	45	*	24	54	26	27	53
4	51	67	59	66	56	53	47	*	29	53	26	26	52
5	49	67	69	60	57	52	49	*	34	55	25	26	51
6	52	60	59	66	57	55	51	*	36	53	27	26	53
7	51	60	67	70	56	52	61	*	31	52	26	26	52
8	46	61	69	82	52	56	52	*	34	54	27	27	54
9	52	65	65	61	58	56	67	*	38	57	27	27	54
10	53	68	59	70	54	55	61	*	34	54	27	27	54
Sum	504	623	644	670	561	539	530	0	322	537	264	264	528
Mean	50.4	62.3	64.4	67	56.1	53.9	53	#DIV/0!	32.2	53.7	26.4	26.4	52.8
Standard Deviation													

Horse	Babel
Gait	**Walk**
Circle Direction	**Left**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	59	87	95	71	60	73	28	34	56	77	29	30	59
2	55	73	73	56	55	79	29	40	59	75	29	29	58
3	61	84	78	77	61	81	36	37	3	78	31	30	61
4	62	85	85	61	62	81	45	41	67	83	31	31	62
5	62	91	80	75	63	86	50	36	66	85	32	31	63
6	62	83	95	65	62	79	37	32	51	78	31	31	62
7	50	78	85	68	65	74	25	32	58	80	31	31	62
8	65	89	79	68	67	82	50	31	63	79	32	32	64
9	62	101	84	76	62	85	34	32	56	85	31	32	63
10	61	89	95	75	65	79	30	32	59	82	32	32	64
Sum	599	860	849	692	622	799	364	347	538	802	309	309	618
Mean	59.9	86	84.9	69.2	62.2	79.9	36.4	34.7	53.8	80.2	30.9	30.9	61.8
Standard Deviation													

Horse	Babel
Gait	**Walk**
Circle Direction	**Right**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	62	101	78	66	66	92	32	33	49	74	34	33	67
2	67	103	77	65	61	88	21	33	53	72	34	33	67
3	67	84	78	52	70	84	32	34	53	81	34	35	69
4	67	97	77	64	67	88	29	32	48	78	33	33	66
5	67	90	79	52	67	90	32	40	57	77	33	33	66
6	57	96	97	63	66	96	23	31	47	70	34	33	67
7	66	97	78	65	69	97	38	36	52	78	34	34	68
8	61	93	80	64	69	87	14	32	43	70	34	34	68
9	65	89	67	65	66	90	24	32	42	79	32	33	65
10	66	75	75	66	67	93	19	34	47	74	33	33	66
Sum	645	925	786	622	668	905	264	337	491	753	335	334	669
Mean	64.5	92.5	78.6	62.2	66.8	90.5	26.4	33.7	49.1	75.3	33.5	33.4	66.9
Standard Deviation													

Horse	Bay
Gait	**Walk**
Circle Direction	**Left**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	60	79	69	78	57	67	24	34	25	62	31	31	62
2	57	73	67	68	61	65	16	32	48	62	31	30	61
3	61	75	77	77	63	69	33	30	20	62	31	31	62
4	60	73	66	79	63	63	12	26	20	64	31	31	62
5	60	71	76	68	63	67	20	25	14	62	31	31	62
6	63	78	73	85	62	70	22	30	14	62	32	31	63
7	66	85	87	80	65	69	14	74	40	64	33	32	65
8	64	77	83	79	69	65	11	22	12	66	32	33	65
9	62	64	77	85	65	68	19	27	16	64	32	32	64
10	66	77	93	94	69	69	25	32	21	68	34	34	68
Sum	619	752	768	793	637	672	196	332	230	636	318	316	634
Mean	61.9	75.2	76.8	79.3	63.7	67.2	19.6	33.2	23	63.6	31.8	31.6	63.4
Standard Deviation													

Horse	Bay												
Gait	**Walk**												
Circle Direction	**Right**												

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	58	61	60	65	59	59	60	34	31	59	29	29	58
2	62	60	83	69	63	67	63	40	29	62	32	31	63
3	63	57	82	65	62	66	7	31	15	64	31	31	62
4	62	72	74	79	65	67	12	25	29	64	32	32	64
5	63	75	77	81	65	64	13	24	27	68	32	33	65
6	61	74	74	80	65	66	8	32	28	66	31	32	63
7	59	64	90	61	66	68	15	20	33	66	33	33	66
8	61	71	84	79	66	69	15	20	33	66	33	33	66
9	69	63	86	81	68	76	60	35	30	70	35	35	70
10	60	74	83	83	67	66	27	36	38	66	32	33	65
Sum	618	671	793	743	646	668	280	297	293	651	320	322	642
Mean	61.8	67.1	79.3	74.3	64.6	66.8	28	29.7	29.3	65.1	32	32.2	64.2
Standard Deviation													

Appendix 9; Raw Data - Trot

Horse	Cash
Gait	**Trot**
Circle Direction	**Right**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	54	83	23	87	113	96	92	83	95	106	44	43	87
2	41	70	41	63	47	89	82	79	86	91	40	41	81
3	21	62	38	54	45	94	82	81	83	87	40	41	81
4	63	73	50	89	53	101	91	89	98	99	45	46	91
5	57	68	45	64	48	88	85	78	90	85	40	41	81
6	41	83	63	75	53	97	93	89	94	96	44	46	90
7	64	73	57	68	51	97	90	88	94	95	45	44	89
8	84	81	57	80	59	102	99	96	105	98	47	47	94
9	66	58	46	73	57	107	92	90	97	93	45	44	89
10	81	86	55	85	32	99	95	91	96	97	47	47	94
Sum	572	737	475	738	558	970	901	864	938	947	437	440	877
Mean	57.2	73.7	47.5	73.8	55.8	97	90.1	86.4	93.8	94.7	43.7	44	87.7
Standard Deviation													

Horse	Cash
Gait	**Trot**
Circle Direction	**Left**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	55	62	56	56	17	101	91	84	93	95	44	45	89
2	42	47	21	45	28	89	82	76	89	84	39	40	79
3	45	37	29	39	18	31	80	73	80	80	38	37	75
4	61	73	32	53	21	109	92	87	92	93	44	44	88
5	41	70	55	67	31	107	93	87	95	96	45	46	91
6	40	59	46	59	19	102	89	82	90	84	41	41	82
7	50	64	17	28	16	103	92	83	92	89	43	43	86
8	56	61	51	70	45	102	89	85	89	92	43	43	86
9	71	69	55	81	42	113	94	88	101	92	44	45	89
10	61	57	43	76	23	103	91	82	92	95	44	45	89
Sum	522	599	405	574	260	960	893	827	913	900	425	429	854
Mean	52.2	59.9	40.5	57.4	26	96	89.3	82.7	91.3	90	42.5	42.9	85.4
Standard Deviation													

Horse	Snickers
Gait	**Trot**
Circle Direction	**Right**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	55	53	44	48	47	82	74	67	80	77	36	35	71
2	38	59	61	49	60	81	70	60	74	76	35	35	70
3	43	49	45	34	40	80	69	64	74	76	34	35	69
4	53	48	56	35	29	82	77	69	79	77	36	36	72
5	28	41	51	39	36	71	68	59	64	68	32	31	63
6	39	35	53	40	30	85	74	68	72	79	36	35	71
7	45	56	59	46	34	81	75	69	77	77	36	35	71
8	47	62	48	43	46	80	68	59	73	72	34	33	67
9	0	14	21	0	14	50	50	46	60	50	24	24	48
10	0	37	31	0	21	64	61	53	61	59	29	29	58
Sum	348	454	469	334	357	756	686	614	714	711	332	328	660
Mean	34.8	45.4	46.9	33.4	35.7	75.6	68.6	61.4	71.4	71.1	33.2	32.8	66
Standard Deviation													

Horse	Snickers
Gait	Trot
Circle Direction	Left

Sensor Type	Piezoelectric Pedometer					Spring Lever Arm Pedometer					Actual Steps Taken		
Sensor Location	LF	LS	C	RS	RF	LF	LS	C	RS	RF	Left Foreleg	Right Foreleg	Both
Lap Number													
1	72	90	68	26	74	115	106	100	107	109	51	52	103
2	36	51	38	39	47	66	63	61	64	66	31	31	62
3	39	37	32	19	45	66	59	56	62	65	29	30	59
4	52	49	72	62	40	73	67	64	77	69	32	32	64
5	35	39	46	0	28	68	60	59	66	67	29	30	59
6	39	51	47	20	36	75	68	62	72	75	33	34	67
7	39	43	37	79	35	68	63	29	68	71	31	31	62
8	39	41	47	13	29	69	67	58	64	65	31	30	61
9	39	48	49	71	38	70	66	63	67	68	31	32	63
10													0
Sum	390	449	436	329	372	670	619	552	647	655	298	302	600
Mean	43.33333	49.88889	48.44444	36.55556	41.33333	74.44444	68.77778	61.33333	71.88889	72.77778	33.11111111	33.55555556	60
Standard Deviation													

Horse	Shrek
Gait	Trot
Circle Direction	Left

Sensor Type	Piezoelectric Pedometer					Spring Lever Arm Pedometer					Actual Steps Taken		
Sensor Location	LF	LS	C	RS	RF	LF	LS	C	RS	RF	Left Foreleg	Right Foreleg	Both
Lap Number													
1	29	31	26	19	31	34	23	28	38	36	17	17	34
2	37	32	38	28	22	39	33	34	36	37	19	18	37
3	32	21	27	32	41	38	36	34	37	37	18	18	36
4	28	17	24	16	14	37	32	32	35	36	17	17	34
5	20	16	33	27	28	35	34	31	35	35	17	17	34
6	28	22	33	36	28	38	32	35	32	37	18	18	36
7	29	14	31	32	27	39	37	36	40	39	19	19	38
8	22	19	42	29	13	36	25	32	35	35	17	17	34
9	21	26	45	25	23	38	34	32	37	38	18	18	36
10	30	28	32	33	30	41	35	34	38	38	19	19	38
Sum	276	226	331	277	257	375	321	328	363	368	179	178	357
Mean	27.6	22.6	33.1	27.7	25.7	37.5	32.1	32.8	36.3	36.8	17.9	17.8	35.7
Standard Deviation													

Horse	Shrek
Gait	Trot
Circle Direction	Right

Sensor Type	Piezoelectric Pedometer					Spring Lever Arm Pedometer					Actual Steps Taken		
Sensor Location	LF	LS	C	RS	RF	LF	LS	C	RS	RF	Left Foreleg	Right Foreleg	Both
Lap Number													
1	30	32	35	40	30	38	33	36	37	38	19	19	38
2	32	30	28	36	33	39	36	34	37	37	19	18	37
3	32	27	36	34	21	36	36	35	37	37	18	18	36
4	33	37	33	34	18	43	38	38	37	38	20	19	39
5	24	38	32	29	25	37	34	33	36	36	18	18	36
6	26	32	39	34	25	42	38	36	40	40	20	19	39
7	20	31	31	40	21	38	37	35	34	36	18	18	36
8	30	26	30	38	23	39	39	35	40	37	18	18	36
9	28	28	38	41	27	39	38	38	36	42	19	19	38
10	33	33	44	39	29	42	39	34	38	38	20	19	39
Sum	288	314	346	365	252	393	368	354	372	379	189	185	374
Mean	28.8	31.4	34.6	36.5	25.2	39.3	36.8	35.4	37.2	37.9	18.9	18.5	37.4
Standard Deviation													

Horse	Babel
Gait	**Trot**
Circle Direction	**Left**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	38	36	31	13	33	45	38	38	38	37	20	20	40
2	38	40	41	18	35	47	42	37	46	48	21	21	42
3	35	36	38	22	30	43	34	76	36	42	18	18	36
4	40	44	41	33	42	47	41	42	42	47	21	20	41
5	32	38	40	36	36	50	41	40	44	49	21	20	41
6	30	34	38	37	35	43	38	35	38	47	19	20	39
7	34	31	45	35	37	45	42	41	42	48	20	21	41
8	41	41	44	34	38	43	41	39	41	48	20	20	40
9	31	32	32	39	34	43	40	38	31	47	19	20	39
10	35	29	36	37	45	47	39	36	40	47	20	20	40
Sum	354	361	386	304	365	453	396	422	398	460	199	200	399
Mean	35.4	36.1	38.6	30.4	36.5	45.3	39.6	42.2	39.8	46	19.9	20	39.9
Standard Deviation													

Horse	Babel
Gait	**Trot**
Circle Direction	**Right**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	36	37	33	37	38	47	41	37	42	48	20	21	41
2	28	24	22	25	18	36	34	33	35	39	17	17	34
3	34	13	25	15	28	35	35	33	34	41	17	17	34
4	29	30	24	26	21	34	30	30	31	37	16	15	31
5	20	30	14	20	26	35	32	32	34	41	17	17	34
6	29	24	26	30	0	36	34	34	34	40	17	17	34
7	27	24	29	33	29	37	25	32	35	39	16	17	33
8	28	38	29	26	23	39	36	32	34	40	18	17	35
9	22	30	28	35	21	38	32	31	32	38	17	16	33
10	27	34	36	14	19	37	33	31	33	37	17	16	33
Sum	303	301	297	292	247	409	362	357	376	438	188	186	374
Mean	27.54545	27.36364	27	26.54545	22.45455	37.18182	32.90909	32.45455	34.18182	39.81818	17.09090909	16.90909091	34
Standard Deviation													

Horse	Bay
Gait	**Trot**
Circle Direction	**Right**

Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	31	39	45	45	31	57	52	50	52	54	27	27	54
2	31	41	40	41	27	59	54	51	54	55	28	27	55
3	29	38	47	36	21	56	53	51	53	56	27	27	54
4	28	43	43	47	27	56	55	52	65	55	28	27	55
5	0	43	56	48	31	62	58	48	56	61	30	30	60
6	40	52	43	59	39	59	55	54	53	60	27	28	55
7	46	44	53	45	40	61	58	53	56	59	30	29	59
8	46	46	50	47	41	56	55	50	52	58	28	28	56
9	60	51	58	51	38	30	57	53	55	61	28	29	57
10	39	49	91	42	33	61	49	54	60	64	29	30	59
Sum	350	446	526	461	328	557	546	516	556	583	282	282	564
Mean	35	44.6	52.6	46.1	32.8	55.7	54.6	51.6	55.6	58.3	28.2	28.2	56.4
Standard Deviation													

Horse	Bay												
Gait	**Trot**												
Circle Direction	**Right**												
Sensor Type	**Piezoelectric Pedometer**					**Spring Lever Arm Pedometer**					**Actual Steps Taken**		
Sensor Location	**LF**	**LS**	**C**	**RS**	**RF**	**LF**	**LS**	**C**	**RS**	**RF**	**Left Foreleg**	**Right Foreleg**	**Both**
Lap Number													
1	31	39	45	45	31	57	52	50	52	54	27	27	54
2	31	41	40	41	27	59	54	51	54	55	28	27	55
3	29	38	47	36	21	56	53	51	53	56	27	27	54
4	28	43	43	47	27	56	55	52	65	55	28	27	55
5	0	43	56	48	31	62	58	48	56	61	30	30	60
6	40	52	43	59	39	59	55	54	53	60	27	28	55
7	46	44	53	45	40	61	58	53	56	59	30	29	59
8	46	46	50	47	41	56	55	50	52	58	28	28	56
9	60	51	58	51	38	30	57	53	55	61	28	29	57
10	39	49	91	42	33	61	49	54	60	64	29	30	59
Sum	350	446	526	461	328	557	546	516	556	583	282	282	564
Mean	35	44.6	52.6	46.1	32.8	55.7	54.6	51.6	55.6	58.3	28.2	28.2	56.4
Standard Deviation													