THE BI-PEDAL APE: PLASTICITY AND ASYMMETRY IN FOOTEDNESS

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ABSTRACT

A strong preference for using the right foot for skilled activities parallels a similar side bias for hand use. However, many neuropsychologists, sports scientists and sports commentators argue that right foot bias in soccer is reduced or even eliminated by practice. This sort of plasticity is an important component of the principle genetic theories of handedness; yet very little is known about the relative asymmetries in the many unipedal skills required in soccer at amateur or professional levels. The first study examined self-report of hand and foot bias in a sample (n=400) of amateur soccer players, in addition to information about their practice with the non-preferred foot. A second study quantified foot use on the pitch in a large sample (n=426) of professional soccer players. The majority of the amateurs reported a right foot bias that is very similar to that seen in the general population (≈80%). However they only endorse strong biases for "closed" (self-paced) soccer actions like penalty and other free kicks, which give players unlimited time and space for preparation and execution. Although there was a very slight tendency for less right foot bias in the professionals (≈75%), as assessed by actual foot use rather than questionnaire, few players show anything like what could be described as two-footed play. This bias, unlike in the reports of amateurs, were for all of the behaviours investigated, not just so-called "skilled" behaviours. Finally, when outcomes of preferred and non-preferred foot behaviours were contrasted, the professionals were remarkably adept on those rare occasions when they use their non-preferred foot, suggesting that skill cannot explain asymmetry of choice. These results are discussed in terms of 1) limitations of self report on questionnaires for predicting actual on the field behaviour, 2) the surprising absence of plasticity in foot use, given the importance of learning, experience and culture in models of handedness and footedness, and 3) a left hemisphere lateralised intentional system as important for the selection of movements as for their execution.

Key words: asymmetry; left hemisphere; footedness; motor control; soccer; football

1. Introduction

Language lateralisation to the left hemisphere is modulated by handedness, but in ways that remain incompletely understood (Annett, 2002; 2004; Gurd, Schulz, Cherkas and Ebers, 2006). Nevertheless, right hand bias in *Homo sapiens* and other primates has been linked to several models of great ape evolution which emphasise bipedalism, tool use (Hopkins, Russell & Cantalupo, 2007) and even gestural origins of language (Corballis, 2002).

The appeal of such handedness accounts is one reason why foot preferences have been neglected by the neuropsychological community. Foot preferences are also right-biased (approximately 80%), but are studied much less frequently than handedness. In fact, foot preference is as good as or may even be a better predictor of cerebral lateralisation than hand preference (Bryden, Roy, McManus and Bulman-Fleming, 1997; Elias and Bryden, 1998, Elias, Bryden and Bulman-Fleming, 1998; Searleman, 1980) and is less subject to cultural biases against left-sidedness (Calvert and Bishop, 1998; Chapman, Chapman and Allen, 1987). Additionally, foot-related behaviours routinely require coordination of stabilising and mobilising movements of both legs (Gabbard & Hart, 1996; Previc, 1991), while many hand-related behaviours are often performed in relative isolation. And of course, a consequence of bipedalism is that strength differences between the feet/legs are typically minimal, and therefore patterns of foot preference are not as easily “explained away” by differential strength or practice of one leg relative to the other. The non-preferred leg is just as experienced in walking, running, standing and balancing as the preferred leg, and yet behaviours such as kicking a ball are consistently lateralised to the right side in most people.

The absence of research on foot performance and preference in sport in particular is even more surprising. First, asymmetrical motor performance in soccer is present even at the highest level (e.g. Carey, Smith, Smith, Shepherd, Skriver, Ord and Rutland, 2001; Peters, 1988; Starosta, 1988), but the ways in which the preferred and non-preferred feet differ remain unknown. Second, scientists have argued that foot preferences can persist in skilled soccer players, *even though a substantial amount of training has a strong emphasis on bilateral skill development* (e.g. Capranica, Cama, Fanton, Tessitore and Figura, 1992; Starosta and Bergier, 1992). There is remarkably little data on this issue. Sports professionals also note foot bias in individual players but tend to suggest that it is a consequence of poor coaching and insufficient practice. In other words, players can be coached or trained to increase skill and use of the non-preferred foot, and one foot bias at the professional level is a consequence of a failure of coaching and practice (Carey et al. 2001).

This belief in professional soccer regarding the plasticity of foot bias is mirrored by several models of the genetics of handedness transmission. In these theories environmental, person-specific factors play a role in determining side biases, which is one reason why the genetic theories include non-genetic factors as components of their models (Annett, 2002; Annett, 2004 and associated commentaries; McManus 2002; Klar 2003). In some of these accounts, the non genetic chance factors are primarily developmental/perinatal (cf McManus, 2002) or are primarily genetic influences on subsequent development (Yeo & Gangstead, 1993), but others do hypothesise that cultural pressures, learning and practice play roles in the development of both hand choice and hand skill (e.g. “the learned left hander” of Ehrman & Perelle, 2004). In fact, in several of the models, the absence of a particular gene or set of genes specifies chance with respect to direction and/or magnitude of hand preference (i.e. Klar, 2003).

For example, in Annett’s right shift model, in the absence of the RS gene (the so-called RS—genotype), individuals are normally distributed around mean hand skill differences of zero. In fact, even individuals with an RS++ genotype may (very) occasionally have greater left hand skill, due to chance factors such as slight deviations in neural or muscular development, differential hand use (often as a consequence of the former) “*and influences of the physical and cultural environment*” (Annett, 2002, pg. 318). This theory posits genes which code for left hemisphere speech lateralisation rather than right-handedness per se. The presence of both “right shift” (RS) alleles (RS++) or one RS allele (RS+) results in a relative strengthening of speech related areas of the left hemisphere and incidental weakening of the left hand.[1] In the McManus DC model, the genes code more directly for hand preference than in the RS model. The C allele stands for chance, as CC individuals can develop left or right sided preferences (and skill) in approximately equal numbers (McManus 1991; McManus 2002). Another important distinction between the McManus and Annett accounts is the link between the genome and hand choice, rather than hand skill as in the Annett model.

In spite of these differences, the extension of both of these models to other side biases such as eye and foot preference (Annett, 2000; McManus 1999) posit the same sort of mix of genetic bias and chance environmental factors which determines side bias for hand or foot. Given practice effects (and selection biases for left footed players; see Carey et al. 2001), soccer seems ideally suited to examine plasticity of foot use and skill.

Although writing hand has historically been subject to environmental pressures[2], it is the exception to the rule; the emphasis on practice and foot preference plasticity in soccer is in stark contrast with virtually all other asymmetrically-performed manual tasks, even sports relevant skills such as throwing[3]. Therefore, performance asymmetries in kicking skill and choice seem a natural place to examine the effects of non-genetic factors on this well described but poorly understood right-sided bias. Additionally, asymmetries

[1] For example, Annett (2002) acknowledges how cultural pressures bias hand choice for different actions and that those biases become long lasting even after cultural pressure against sinistrality disappear. Nevertheless, she argues that culture or training may not completely attenuate heritable differences in hand skill. See pages 16-18, 53-56, 318. In the Laland model (Laland, Kumm, van Horn & Feldman, 1995), the genetic components that influence hand preference are not obligatory; variation in hand preference is accounted for by both cultural and developmental factors.

[2] Forced handedness switch in anti-sinistral cultures is frequently discussed in the literature but there is surprisingly little data on the critical developmental time course for successful switching and the consequences for the resulting asymmetry in handwriting skill for the two hands (see Porac and Buller, 1990; Porac and Friesen, 2000; Siebner, Limmer, Peinemann, Drzezga, ,Bloem. Schwaiger et al. 2002).

[3] In baseball, some players train themselves to bat left- or right handed which provides a slight strategic advantage depending on the handedness of the opposing pitcher, but we know of no known professional baseball or cricket player who throws (or bowls) with either hand for the reciprocal strategic reason.

that remain after bilateral training in such people could provide essential insights into the innate nature of behavioural and ultimately, cerebral asymmetries.

Almost no research has been performed quantifying foot preference in soccer players. Hughes (1990) noted that 70% of all goals in a sample of professional soccer were scored with the right foot. Similarly, in their analysis of the 1978 World Cup, Starosta and Bergier (1992) found that most teams showed a bias towards right-foot shots at goals. Of course, neither of these studies speak to the incidence of right-footedness or two-footedness in individual players *per se*, because the data was pooled across players (i.e. it is impossible to tell if 70% of the players were 100% right-footed, or 100% of players used their right foot 70% of the time, or some variant in-between).

Given the ≈80% right footedness in the general population (Brown and Taylor, 1988; Gabbard and Iteya, 1996; Porac and Coren, 1981), left-footed players should be rare, in younger or amateur soccer players at least, *if* practice over time does attenuate right foot bias. Therefore, there should be a bias towards success and/or selection for the left-footer in amateur and professional soccer. In tennis, for example, there may be a disproportionate number of left-handers in the world's top ranks, often attributed to strategic advantage for being a "southpaw" (e.g. Annett, 1985; Grouios, Tsorbatzoudis, Alexandris and Barkoukis, 2000; Holtzen, 2000; Raymond, Pontier, Dufur and Moller, 1996; although see Wood and Aggleton, 1989; Aggleton and Wood, 1990; and Brooks, Bussière, Jennions and Hunt, 2003 for a similar take on batting in cricket).

Grouios, Kollias, Tsorbatzoudis and Alexandris (2002) examined this issue by recording foot preference in a large sample of professional, semi-professional and amateur soccer players using a standardised foot preference inventory, the Waterloo Footedness Questionnaire (WFQ; Elias et al., 1998). They classified 45.9% of the professionals as mixed footed, while 30.3% of the semi-professionals and only 12.6% of the amateurs were mixed-footed. A non-sporting university student sample were only 9.1% mixed-footed. The same pattern was obtained when the percentage of the sample which was classified as left-footed was examined. These data strongly suggest that even amateur soccer players are less right-footed than non-sporting samples, and that *increasing experience and skill predicts decreasing right foot bias*.

Grouios et al. (2002) did not ask questions of their soccer-playing participants about particular behaviours on the pitch. Only one item on the WFQ is related to soccer (kicking). In fact many different behaviours are performed using one foot/leg or the other in soccer, and the patterns in magnitude of preference for these behaviours might provide some insights into the nature of footedness.

Over a five year period, we have had the opportunity to question a large number of amateur soccer players about their foot preference utilising standard foot preference battery items (similar to Grouios et al. 2002) as well as a new questionnaire designed specifically to elicit different patterns of soccer-related foot preference (see Appendix 1). Additionally, we asked players a series of questions to determine how degree of experience, coaching and other factors impacted on the degree and pattern of foot preference. Finally, unlike Grouios et al. (2002), we also obtained data on hand preference from the same participants, allowing examination of the moderating effects of hand preference on footedness.

In a parallel study we have categorised and quantified the actual foot performance patterns of a large sample of high-level professional players. These latter data have allowed us to contrast self report by questionnaire in study 1 with what soccer players actually do on the pitch (study 2).

2. Study 1: foot preference in soccer assessed by questionnaire

The first study examined reported foot preference patterns in a large sample of amateur players. Grouios et al.'s (2002) data implies that degree of practice decreases the incidence of right-foot bias. Coupled with reports of coaches and soccer authorities that extended practice makes players two-footed (e.g. Brown, 1997), our first working hypothesis was that players who reported more practice using their non-preferred foot would report more symmetry in their behaviours than players who report less deliberate practice with their non-preferred foot. Second, we wanted to identify any patterns in degree of reported foot preference as a function of several different soccer-related behaviours including shooting at goal, making long and short passes, tackling, dribbling and receiving passes. The third and final goal of this study was to investigate any moderating effects of hand preference on the strength of foot preference.

2.1 Method

The sample.

We approached amateur players in the Aberdeen area, as well as via colleagues at St. Andrews, Glamorgan (in Wales) and Oxford universities (all in the United Kingdom). A small sample of Italian soccer players were also questioned in Italy. Questionnaires were distributed to groups of people playing in a local park as well as at the main athletic pitch at the University of Aberdeen. Over 500 questionnaires were distributed. All 400 that were returned have been included in this analysis. Although we made some effort to find female soccer players, the vast majority of the sample is composed of males (371/400) of various ages.

The Aberdeen Football Laterality Questionnaire (AFLQ).

Five coaching/practice items were designed to ascertain the degree of experience, coaching and practice with the non-preferred foot. Standard foot preference was assessed with 10 questions used in previously constructed inventories (Chapman et al., 1987; Peters, 1988). Unlike with the WFQ, we used a forced-choice procedure with only "left" or "right" responses For soccer-related behaviours, we asked players to rate how often they used either foot for a particular action. A 7-point Likert scale was constructed to examine reported frequency of the use of each foot on a series of unipedal soccer behaviours. Unlike in the Grouios et al. (2002) study, most of the participants were encouraged to pantomime or imagine performing the specified action wherever possible.

A 9-item, forced-choice hand preference questionnaire (modified from the Edinburgh Handedness Inventory; Oldfield, 1971) was also administered to respondents, which asked them to indicate which hand they would prefer to use for throwing a ball, brushing teeth, eating soup, combing hair, cutting bread, swinging a racquet, hammering, pointing accurately and writing. For comparison with other large samples of non-soccer playing participants, we classified our participants’ handedness dichotomously.

2.2. Results

The sample

The sample appears to be relatively representative in terms of unselected samples of hand preference (n=397), as 90.4% of the subjects were classified as right handed (5-9 items right) and 9.6% as left handed (0-4 items right) using our modified Edinburgh handedness inventory. These percentages are in general agreement with other dichotomous estimates of hand preference from short questionnaires (reviewed in Schacter, 2000).

Foot bias in the sample

Average soccer preference score, the standard foot preference items and the response to the penalty kick[4] item provided very similar dichotomous estimates of right foot bias in the sample: 83.7% (see Figure 1), 79.7% and 84.0% respectively. Inspection of Figure 1 shows that there are very few players in the middle portion of the average soccer preference score distribution, which suggests that players can be subdivided into right- and left-foot preference groups. Using the soccer preference score items[5] or the standard footedness questionnaire items provide roughly similar trichotomous estimates: 68.9% right-footed, 13.0% left-footed and 18.5% mixed-footed from the soccer-specific questions and 70.5% right-footed, 17.0% mixed-footed and 12.5% left-footed from the standard foot preference items[6].

insert Figure 1 about here

Our figures most closely match those of the Grouios et al. (2002) group of amateur soccer players, who were classified as 78.0% right footed, 12.6% mixed footed and 9.0% left footed.

Deliberate practice

We asked the respondents to report on a 7-point scale how much deliberate practice they had engaged in with their non-preferred foot, from 1- (considerable deliberate practice) to 7- (no deliberate practice). Deviation from

[4] Players who selected 5, 6 or 7 for the penalty kick item were classified as right-footed and players who selected 3, 2 or 1 were classified as left-footed. Half of the 14 players who (much to our surprise) selected 4 (equal) were classified as right-footed and half as left-footed. For classification with standard footedness items, we considered respondents who selected more than 5 items (of 9) as one footed (60 left footed and 284 right footed) and we split the 34 respondents who indicated 5 as half left-footed and half right-footed.

[5] We divided the 7-point range into 3 equivalent sections (with a marginally smaller central bin: 3.01-4.99) representing mixed-footedness, and defined each respondent as above by mean soccer preference score.

[6] To divide the possible response into three equal sized bins, the data was recoded such that a right response was assigned a value of 1.5 (in the WFQ always right=2, usually right =1) and a left response was assigned a value of -1.5. Using the ten-item questionnaire, the scores obtained ranged from -15 to +15; mixed-footedness was defined as a score > -5 and less than +5.

equal preference (i.e. 4, the midpoint of the 7-point scale) was calculated using the average foot preference score for the soccer specific items. One way analysis of variance revealed a significant influence of deliberate practice ($F_{(6,387)}=13.52$ $p<0.001$). Figure 2a shows that players who report less deliberate practice believe that they have an increased reliance on one foot.

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insert Figure 2 about here

Importance of two footed play

We also asked respondents to quantify how important two footed play is for a skilled soccer player. In spite of the fact that many of the world's most skilled players have a strongly favourite foot, our amateurs strongly endorsed the link between skill and two-footed play (mean=6.08/7, S.D.=1.25) The distribution for this question appears in Fig 2b.

Patterns of bias in the soccer-specific questions

Figure 3 shows frequency histograms of the responses to the soccer-specific questions. J-shaped distributions suggest strong right-bias in the majority of the sample for corner kicks and penalty kicks, and a strong left foot bias for the same behaviours in a smaller number of players. For the other 8 items the distributions are slightly biased towards right-foot preference; nevertheless, for 4 of the 8 remaining items (one touch pass, receive a short pass, make a short pass, and slide tackle) the modal response was "equal". Dribble approximates this pattern as well. *These data suggest that the players tend to report nearly equal foot choice for most of the behaviours with the exceptions of the two set piece skills*.

Item-total score correlations confirm that set pieces (corner kick r=.899; penalty kick r=.899) were very strong predictors of overall foot bias, although volleying (r=.874) making a long pass (r=.871), and receiving a long pass (r=.846) were also very good predictors of average foot preference score.

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insert Figure 3 about here

Does hand preference predict soccer-specific foot preference?

Previous studies have suggested that right hand preference makes right foot preference more likely. For example, Peters and Durding (1979) suggest that up to 95% of right handers have a right foot preference while only 50% of left handers have a right foot preference. Annett & Turner (1974) suggest a range of 87-96% right foot preference for "weak" and "strong" right handers and 53 and 84% left footedness in weak and strong left handers. Right handed people (n=359) are 89% right footed as classified by average soccer preference score while the left handed people (n=38) are only 66% left footed. The relationship between foot and hand preference scores is less dramatic in the right handers [$r_{(357)}$=.17, $p<0.002$] group than in the left hand preference [$r_{(36)}$ =.33, $p<0.05$] group.

2.3. Discussion

These data suggest some plasticity in foot use, as players claim to only use their preferred foot exclusively in set piece conditions (Figure 3), and those who report more deliberate practice with their non-preferred foot have a weaker foot bias (Figure 2). Of course these data may simply reflect a type of social desirability, given the fact that players report two-footed play as an important skill for a soccer player (Figure 3b). Players who believe they are less two-footed than their counterparts may use the idea of less practice as a justification for the lack of an important soccer related ability.

Nevertheless, given these data on practice and Grouios et al,'s (2002) data on right footedness decreasing with increased proficiency (also see Porac and Coren, 1981), right foot bias should be substantially less in professional samples than in amateurs. Such a shift from dramatic right footedness should reflect itself in performance on the field. In a previous study, we took advantage of the fact that televised professional soccer matches provided a unique opportunity to classify and quantify actual foot use (Carey et al. 2001). We found players to be remarkably one footed when classified dichotomously, or when foot use was examined as a continuous variable. The dichotomous estimate was 79.8%, not remarkably lower than our dichotomous estimates of foot preference in amateurs of 79.7% (by standard foot preference items) or 83.7% (by soccer specific questions).

In that study, we made several observations which are not easily reconciled with the amateur players' self reports. As with the amateur self reports of study 1, when we classified the professionals dichotomously they were as right footed as a group as non-soccer-playing samples. Second, the on-pitch foot use data from the professionals produced a bimodal distribution very similar to the bimodal distribution for average soccer preference score (Fig 1). Third, and most remarkably, these professionals were highly *symmetrical* in terms of the outcomes of their preferred and non-preferred actions as assessed on a success-failure basis. However, this last conclusion was made tentatively, because non-preferred foot play was so rare, estimating success rates for each action for many individual players was impossible. Subsequent to Carey et al. (2001) we have had the opportunity to add additional data from 226 new players, and also substantially increased the amount of data we have on individual players from the initial sample, which allowed for unique estimates of preferred and non-preffered foot skill in individual players.

3. Study 2: Patterns of footedness in soccer assessed by performance[7]

The assumption that players are more skilled with their preferred foot is ubiquitous, despite the absence of any hard evidence from actual gameplay for such a position. In study 1, this assumption is supported by players' self-report; most of the respondents to open-ended questions about how their preferred foot differed from their non-preferred foot, indicated that their preferred foot was stronger, more reliable and more accurate. If such is indeed the case, then the proportion of successful outcomes during matches should be higher in the preferred foot of individual players, independent of the fact that more behaviours per se are engaged in with the preferred foot.

Results from the Grouios et al. studies suggest that our previous estimates of prevalence of left and two-footed professional players may have been gross underestimates, so the first aim was to revisit the depth and breadth and pattern of right foot bias in actual gameplay in professionals. A second aim was to examine asymmetries in use and outcomes for three different foot behaviours, rather than just the two actions examined in Carey et al. (2001). Additionally, for this latter aim, we examined success rates as a function of foot used using unique estimates obtained from the same players.

3.1 Method

The sample

Nine games of the 1998 World Cup in France were analysed. Sixteen different teams were included (50% of the 32 teams in the tournament), and 3 of these teams (Brazil, France and Scotland) played in two different games. Details of these games can be found in Carey et al. (2001). Fourteen teams were included in the new sample of 13 games, chosen quasi-randomly from a sample of videotaped Premiership and English League Cup games recorded from the 1997-1998 season. Five of the games were chosen so that at least two games from each of the four most successful Premiership teams were represented. These teams were Arsenal, Manchester United, Liverpool and Chelsea. The games selected were all from the regular season matches of the Carling Premiership except Arsenal v. Chelsea (Coca-Cola Cup semi-final match, 28/01/98).

The analysis

We attempted to code every unipedal touch of the ball for each player, through the entire match and any added injury time. The only events that were excluded were those in which an individual player could not be identified, or when the two raters could not agree (after repeated observation of the event) on the foot used, how to categorise the particular behaviour (see below) or the outcome. Very few events in each game could not be coded. Over 1200 individual touches of the ball (or near touches in instances of tackles and missed first touches) were analysed for each full game. Over 260 different players participated in at least one of the 13 Premiership and Champions League matches that were analysed. Combined with the previous sample from Carey et al. (2001) and excluding players for who we had less than 20 actions, the new dataset included 472 unique players.

We have developed a set of criterion to try to classify each touch of the ball as a success or a failure (Carey et al. 2001). Any such set of criteria will have to trade reliability of classification for validity, since observer biases over player intention and the like will inevitably produce disagreements. For example, in our scheme the behaviour "pass" was rated as a success when "next touched by a player from the same team". Although over many such events successful passes are indeed touched next by players from the same team, a few passes would be classified as failures if the defending team made interceptions etc. Similarly, some poorly hit passes will end up with players on the same team who were not the intended target of the pass in the first place, and therefore be classified as successes. Some "professional" tackles are intended to make contact with the opposing team player, rather than with the ball, and would be coded as failures in our scheme, when some observers might be more likely to code such an event a success. The behaviours and definitions of outcome appear in Appendix 2. Independent coding of 30 minutes of one match by two teams revealed satisfactory reliability: the 5% limits of agreement (cf Bland and Altman, 1986) for classifying magnitude of right foot preference were ±5.94%. For all 22 players who were coded in this sub-sample, there was 100% agreement in direction of foot preference (Carey et al. 2001).

These behaviours must all have been clearly unipedal; two-footed tackles, passes from the head etc. were not coded. We also did not code behaviours that occurred after a stoppage in play. If a player was fouled and both raters agreed that he would have received a pass had he not been fouled, we coded the preceding pass as successful but did not code first touch of player who was fouled. If the foul was committed with a unipedal tackle, then that tackle would be coded as unsuccessful.

3.2 Results

A total of 43,938 individual behaviours were coded. First, the overall incidence of foot preference pattern by player was established. Any player with fewer than 20 touches was removed from the dataset, resulting in a sample of 426 players[8]. First, players were defined as either right- or left - footed based on which foot had the majority of touches. Our sample is composed of 329 (77.2%) right-footers and the remaining 97 players (22.8%) were left-footed. The frequency distribution for percentage of total touches made using the right foot appears in Figure 4.

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insert Figure 4 about here

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[8] In Carey et al. (2001) we showed that sample estimates of foot bias are relatively independent of the number of touches required for inclusion. We have observed that if only the first 20 actions of players (with 100 touches or more in total) are used to classify direction of foot bias, no players are ever misclassified.

When the left- and right-footed players are considered separately, both distributions have kurtosis and skewness statistics within two times the associated standard error from zero[9] (0 = perfect normality; Coolican, 2004). These results suggest two normal distributions, which represent populations of players who are predominantly right- or left-footed.

Subsequent analyses focussed on left-footed and right-footed players as separate groups. First, we wanted to try to establish if any of the behaviours were more or less lateralised than any others. Table 1 shows the percentage of right and left-foot touches for the 7 different behaviours identified as a function of foot preference group (left versus right). Unsurprisingly, both groups preferred to use their favoured foot for set pieces (free kicks, penalty kicks, corner kicks). In professional matches, typically there is one left footed player on the pitch who will take these kicks when appropriate, so there is no need for another player to use his left, non-preferred foot (although see footnote 6). As we noted in Carey et al. (2001), players were also quite biased for all of the other behaviours. Nevertheless, for all seven behaviours there is a trend for the right-footed group to be more biased than the left footed group.[10]

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insert Table 1 about here

Second, we revisited our earlier claim that, in spite of large differences in the use of each foot, professional players are quite successful with either foot. Because non-preferred foot play is so rare, in our original attempt to investigate this question we pooled all of the raw data across left-footed and right-footed players (i.e. all of the dribbles of the preferred foot in all left footers were used to generate the accuracy estimate). That procedure is impossible to analyze statistically as different individuals contributed different numbers of the behaviour to the mean estimate.

With this expanded dataset, we now have a substantial number of behaviours for both preferred and non-preferred foot in a number of individual players. A unique estimate for preferred and non-preferred foot actions for each was calculated that allowed for inferential statistical analysis. We selected those players for whom we have at least 10 examples of the specified action having been performed by the non-preferred foot. Mean success rates were calculated for first touches, dribbles and passes (the most frequent events in the sample). Figure 5 shows mean success rates as a function of foot for left-and right-footed groups for the three actions. Paired samples t- tests showed no differences for the three actions in the left footed group and only 1 significant advantage (for preferred foot dribbling) in the right

[9] Right footers skew=-0.74, SE=0.195, kurtosis=0.616, SE=0.387; left footers skew=-0.45, SE=0.316, kurtosis=.-0.623, SE=0.623.

[10] It is difficult to compare these mean success rates statistically, as different individuals contributed more or less to each foot/action estimate, depending on how frequently they played in the sample and how frequently they engaged in a particular behaviour.

footed group ($t_{(30)}$=2.13, $p<0.05$). This significant advantage does not survive Bonferoni correction for the 6 comparisons (which reduces the alpha for significance to $p<0.0083$).

insert Figure 5 about here

4. General discussion

The data from study two provide the strongest evidence to date for a mismatch between skill and use in a series of well practiced unipedal skills. These new data make it hard to understand foot use asymmetry in terms of gross differences in foot skill, at least in the most skilled players in the world. Paradoxically, the amateurs endorse strong biases for set piece closed skills such as penalty kicks only; for all of the other actions they report substantial use of their non-preferred foot. The professionals show strong biases for all of the actions we coded (although the strongest are seen for the set piece actions).

It seems unlikely from our data that practice really attenuates right foot bias, at least in terms of selection for use. A more probable explanation is that for the non-soccer related tasks in standard foot preference questionnaires, and for non set piece items in our soccer specific questions, players make assumptions about foot choice given that they are accomplished soccer players.

Our data provide support for the idea of a lateralised motor control system that is responsible for the selection and sequencing of motor behaviour (cf Kimura, 1993; Goodale, 1988; Schluter, Krams, Rushworth and Rassingham, 2001). This “praxis” system is lateralised to the left hemisphere in the majority of people. Players at these high proficiency levels plan movements in terms of intended outcomes and do so at such speed that, in open play at least, many of those decisions are probably made with little deliberation, or even without conscious awareness. At this level of motor planning, effector selection (in this context, which foot to use and the bilateral movements required to position the body for the action and prepare for its’ consequences in terms of inertia etc.-see Flanders, Daghestani and Berthoz 1999 re: arm movements and postural control) is of course determined by many external contingencies such as the direction and speed of an incoming pass, the position of defenders and available space and direction of play when dribbling, and so on.

As we have noted previously, over many matches and many players the affordances for left-footed play should be equivalent to those for right-footed play. Notational analyses of matches reveals that the pitch is used symmetrically, which is unsurprising given the adversarial nature of the game: opponents on their right side of the pitch attack defenders on their left side of the pitch. In this view, few players will ever be classified as completely one-footed, as long as they are observed for a sufficient number of actions, because under some conditions the motor affordances *demand* non-preferred foot selection and execution. Our data make it clear that under most circumstances in virtually all players, the lateralised motor control system biases the mechanism towards the dominant side, in spite of substantial skill in the non-preferred foot. These data suggest that, for extremely skilled foot movements of these professionals at least, differences in execution may be rather small[11], and are unlikely to explain away more dramatic asymmetries in movement selection.

Measuring lateral preference or performance?

This distinction between execution and selection also speaks to the unique nature of our measure of lateral dominance used in study 2 and in Carey et al. (2001). In the handedness literature, much has been made about distinctions between measures of hand preference (i.e. which hand would you use to thread a needle?) and hand performance (how much better is one hand at actually threading a needle?). The few performance tasks in the literature are often criticised because they are either rather arbitrary or are confounded with practice based on experience such as handwriting (see Calvert and Bishop, 1998 for review). We have examined performance on the pitch in terms of foot use – which arguably includes some elements of both preference and performance (Carey et al. 2001; also see Greenwood, Greenwood, McCullaugh, Beggs & Murphy, 2007).

A few tasks designed to assess hand preference in a behavioural fashion involve picking up objects placed across the workspace; the more “one-handed” the participant, the further s/he will reach with their preferred hand, in spite of the proximity of the target to the non-preferred hand (e.g. Bishop, Ross, Daniels and Bright, 1996; Bryden, Singh, Steenhuis and Clarkson, 1994). For example, Gonzalez, Ganel and Goodale (2006) have identified differences in the number and type of grasping movements made by left- and right-handers in a bimanual context. When their participants used bimanual movements to complete puzzles, the right handers used their right hand 72%, the left handers used their right hand 52% of the time. Left handers also were much less likely than right handers to reach across their body midline with their dominant hand than the right handers were. The authors conclude that there is an important relationship between the left hemisphere praxis system and right handed grasping, even in many left-handers. This conclusion has appeal because language lateralisation, usually associated with praxis, is left hemisphere dominant in roughly 65% of left handers. These data require replication with a larger sample of left handers, but are important as they demonstrate a substantial asymmetry (i.e. an asymmetry which is not the same in right and left-handers, Peters, 2000) that is related to selection *of which hand to use* in a series of unconstrained hand movements where participants are concentrating on the puzzle and the next piece to grasp and place, rather than which hand to use to do so.

Professional soccer players use one foot most of the time (~85% of the time), in spite of affordances to use either foot over a great many different

[11] As we noted in Carey et al. (2001), kinematic and kinetic analyses of kicking movements in amateur soccer players have uncovered small differences which often favour the preferred foot. For example, see Numone, Ikegami, Kozaki, Appriantono and Sano (2006).Van Rossum and Wijbenga (1991) have data on amateur players of different levels which suggests that between feet differences in passing accuracy are somewhat lessened with greater experience (see their Figure 2). See Carey et al (2001) for more examples.

soccer situations (see Figure 4). This bias seems innate, given that the proportions of right- and left-footers are so similar to the general population. More remarkably, this system is apparently impervious to the acquired skills of the non-preferred foot (Figure 5).

This lack of plasticity in spite of practice and experience is puzzling given the role that environment may play in several of the genetic models of side bias (Klar, 2005; Laland et al. 1995), which have recently been extended to foot and eye (Annett, 2000; McManus, 1999). It is puzzling that the environmental consequences of many years of soccer experience (particularly in the professionals) does not seem to lead to two-footed play (or at least a larger proportion of left footers) at these levels compared to amateur and non-professional samples. However, the dissociation between foot choice and foot skill is consistent with predictions by McManus that choice of effector is specified by genetics, and that skill is a gradual consequence of differential use. He and his colleagues have shown that autistic children are just as right biased to choose the right hand for grasping as controls but that their hands do not differ in skill (McManus, Murray, Doyle and Baron-Cohen, 1992). It the context of these data, the relative lack of plasticity in foot choice, in spite of substantial skill in both feet, is particularly telling.

Little is known about how much experience with non-preferred foot play the professionals will have actually had. In fact, pilot observations using our behavioural coding schemes with 45 amateur indoor soccer players at the University of Aberdeen show very similar levels of 80-85% preferred foot bias. We have no strong evidence to suggest that similar levels are not present in soccer players even early in childhood, as footedness for kicking seems present from early youth (but may become even more right footed by ages 8-11; Gabbard and Gentry, 1995). If this bias, as we hypothesise, is innate and relatively impenetrable, then in all instances of open play soccer players will in some sense be “practising” roughly 4 times more frequently with their preferred foot. It is conceivable that some draconian experiment which prevents preferred foot play in very young children could be concocted which might drive more two-footed play over time. Nevertheless, analogous “experiments” with handwriting switch have been of limited success in left-handers who are not innately ambidextrous (Porac and Friesman, 2000; Searleman and Porac, 2001; 2003). Our data suggest that foot bias has a similar innate quality, in most if not all players at any level of skill.

Conclusions

These data show a striking discrepancy between foot bias report limited to set piece, closed skills in amateurs, versus strong one foot bias in professionals for all the measured behaviours. Contrary to suggestions in the sport science and neuropsychological literatures, our results suggest plasticity in footedness is limited to skill in execution and is largely independent of choice of effector, at least in open play conditions. These data are consistent with a largely innate lateralised intentional system which is at least as important for movement selection as it is for movement execution.

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Table 1. Percentage preferred foot touches for seven unipedal soccer behaviours.

	First touch	**Clearance**	**Dribble**	**Pass**	**Set piece**	**Shot**	**Tackle**
Right-footers	70.7	70.7	85.8	84.5	86.2	71.8	71.2
Left-footers	70.4	63.3	71.4	75.6	86.2	68.7	66.0

Figure captions

Figure 1. Histogram of mean average soccer preference score. Scores greater than 4 scores indicate endorsement of right foot bias, less than 4, left foot bias.

Figure 2. A. Deviation from two-footedness (4/7) using mean average soccer preference score as a function of deliberate practice with the non-preferred foot. Error bars=standard error of the mean. Although the effect is statistically significant the sample sizes (from 38 for DP7, 78 for DP3, smallest and largest n's respectively) and associated power are large, η_p^2=1.73, conventionally described as a small effect (Hays, 1994). B. Responses to the "how important is two footed play" question. The magnitude of this bias surprised us.

Figure 3. Frequency histograms showing side bias for the 10 soccer-related actions in amateur soccr players. The lower panels provide the X and Y scales for these data. Note how only the two "closed" skills, penalty kick and corner kick, receive fairly one-footed ratings. The J-shapes provided mimic those scene from typical hand or foot preference questionnaires where the number of preferences are summed. For the remaining behaviours players report less bias, and in may instances, the either foot response ("4") is modal.

Figure 4. Frequency histogram depicting percentage right-footed play in professional soccer players. These data demonstrate two normal distributions, the left-footed players appearing to the left. As in our earlier sample, it is hard to see any obvious central distribution which would represent two-footed players.

Figure 5. Percentage success rates as a function of footedness group and foot used. The only significant advantage was right footed dribbling which was statistically better in the right footed group using t-tests uncorrected for multiple comparisons. Right footer n's: 1st touch 68, pass 55, dribble 31. Left footer n's: 1st touch 18, pass 9, dribble 9.

Table caption:

Table 1. Percentage preferred foot touches for seven unipedal soccer behaviours.

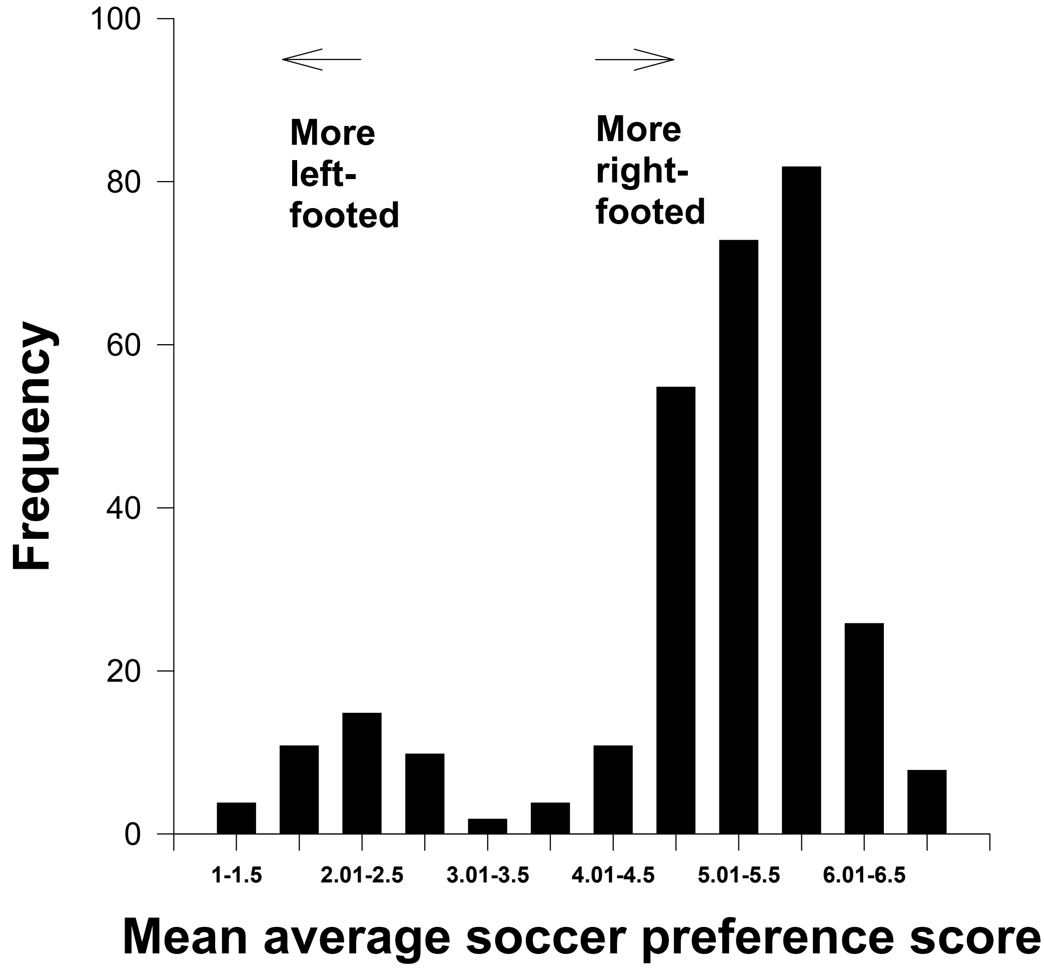
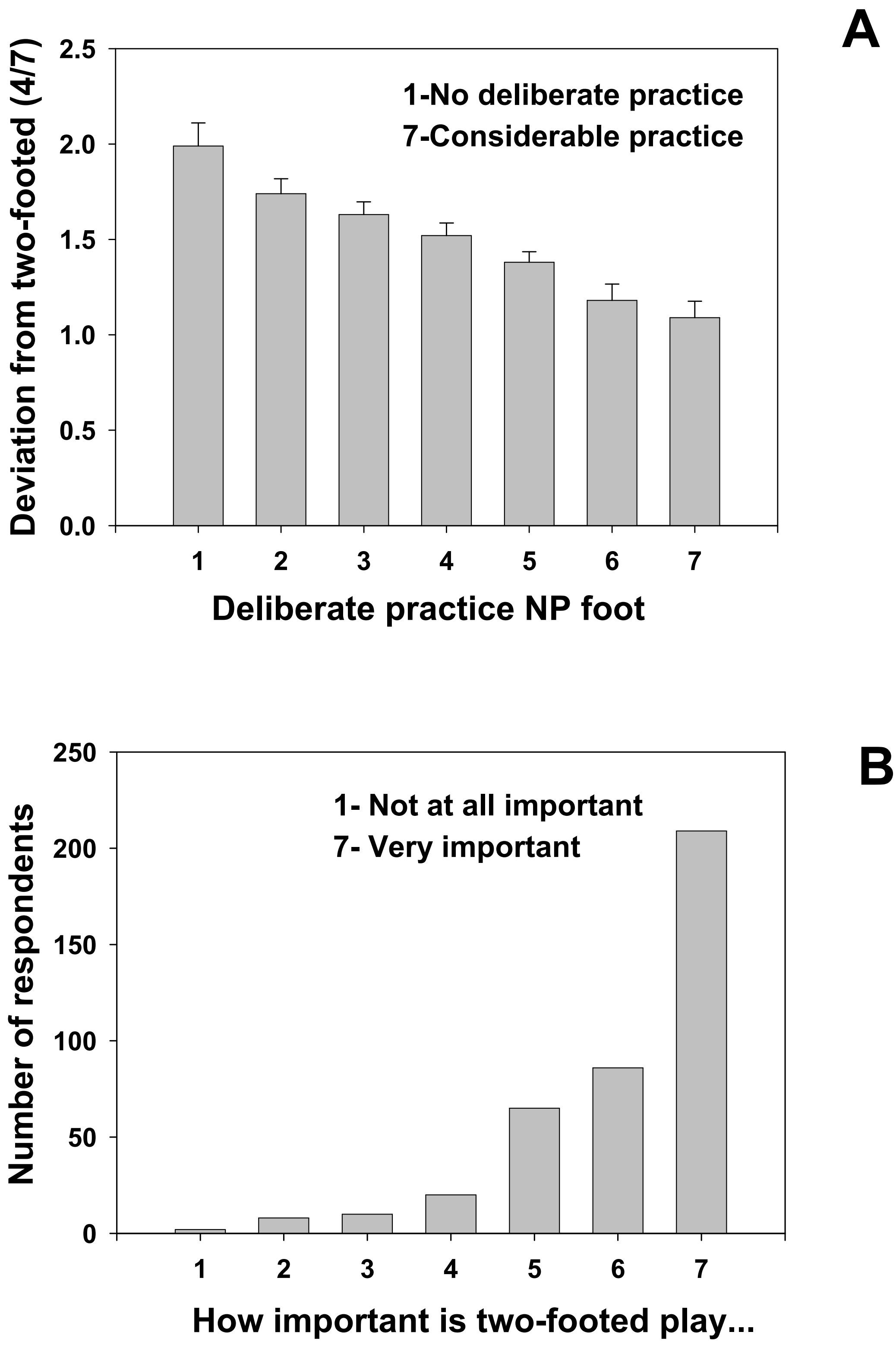


Figure 1. Carey et al.



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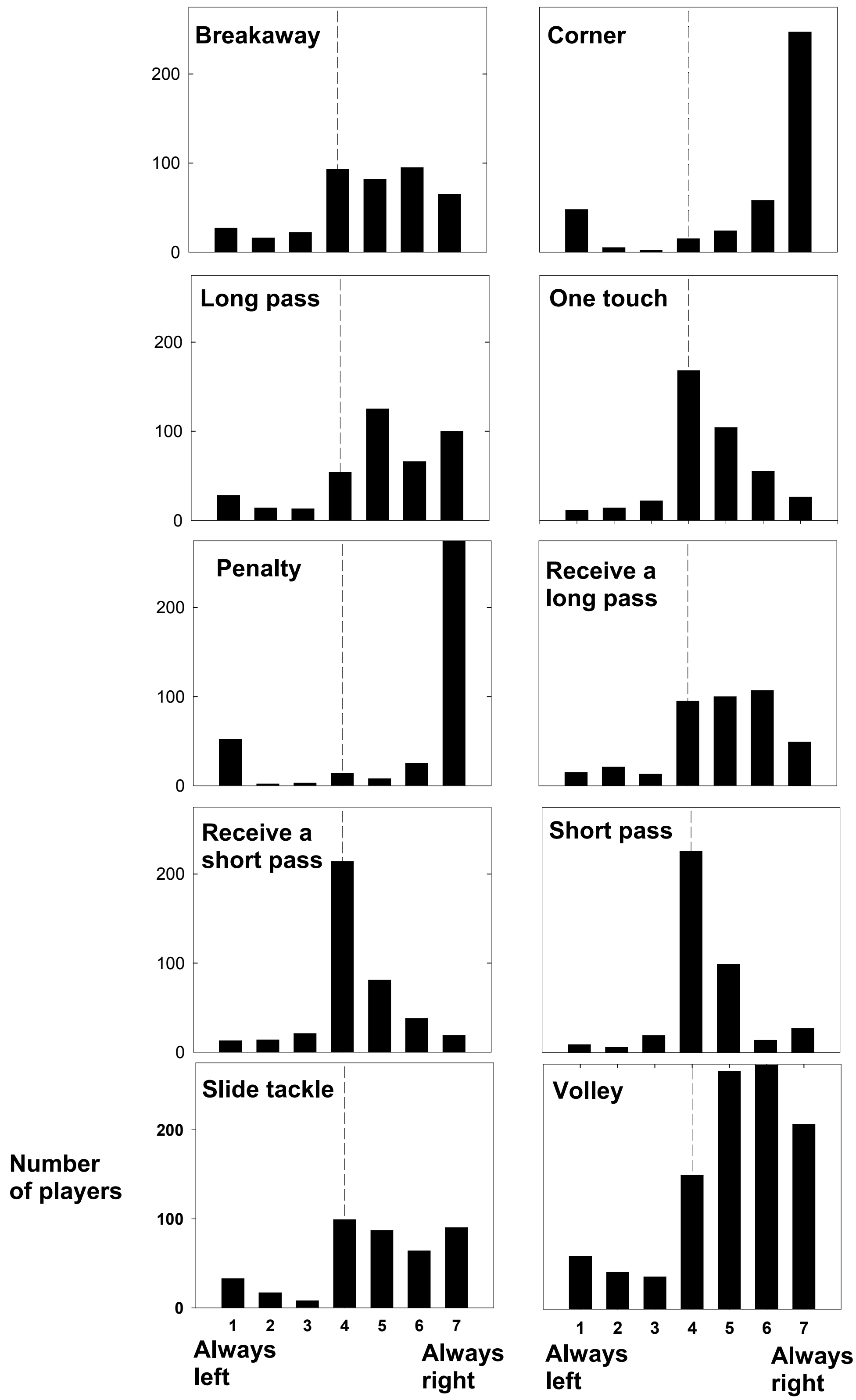

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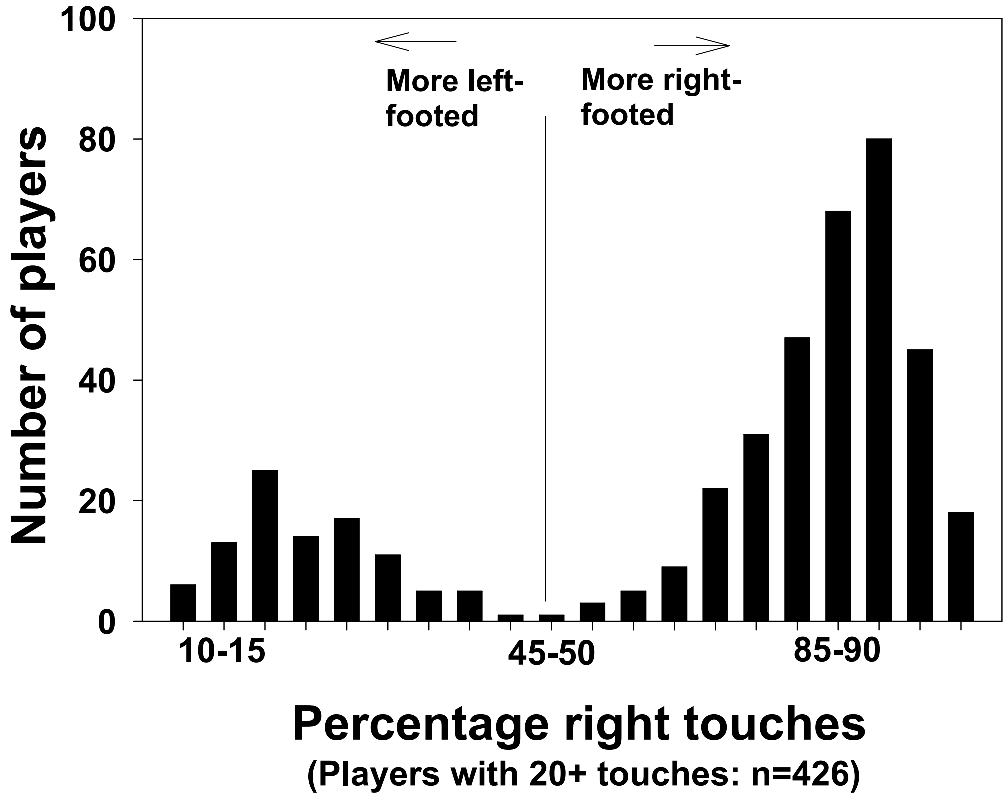

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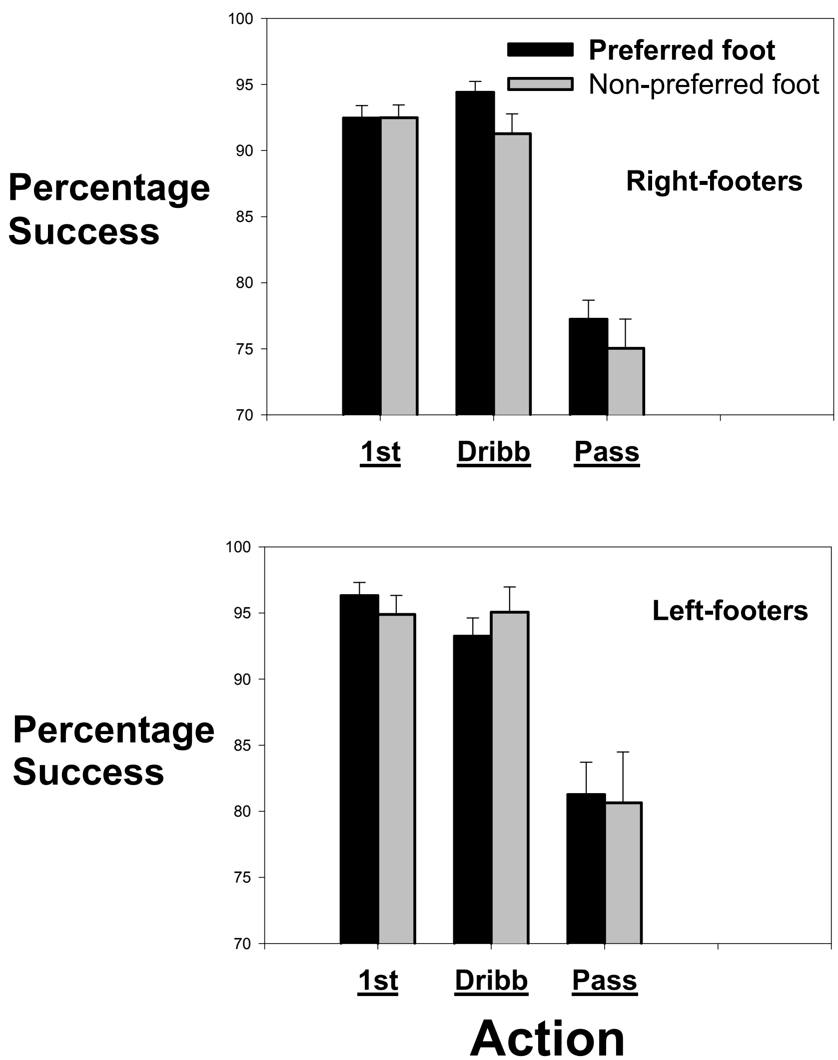

Figure 5 Carey et al.

Appendix 1. The Aberdeen Football Laterality Questionnaire (AFLQ)

1. *How many years have you played organised team football (e.g. school teams, league teams, intramurals at school/university/college etc.)?*
2. *How many of these years included coached practice/training by a coach, manager or player-manager?*
3. *Have you* ***ever*** *been encouraged by a coach/manager/player-manager to practice using your non-preferred foot? (Yes / No).*
4. *If yes, what proportion of your managers/coaches actually made you practice with your non-preferred foot (e.g.1/2, 2/4, 6/8)?*
5-16. Soccer-specific questions (7 point Likert, 1=Always left, 4=Equal, 7=Always right). Corner kick, long pass or clearance, slide tackle (leading leg), penalty kick, short pass, one-touch pass, volley, receive a short pass, receive a long pass, during a breakaway, which foot would you touch the ball forward with?, and if you have to turn quickly, which way would you turn? (with the ball).
17. *How alike are your two feet in terms of kicking performance?*"(1=Not at all alike, 7=Extremely alike).
18. H*ow important do you think "two-footedness" (e.g. being equally skilled with both feet) is for a skilled football player?* (1=Not at all important, 7=Very important).

Appendix 2. Scoring criteria for the seven unipedal behaviours.

Behaviour	**Definition**	**Successful if…**
Set piece	*Free kick*	Next touched by player on same team *or* on target. On target=within or against frame of goal, or, if ambiguous and requiring a save from the goalkeeper
	Corner kick	Next touched by player on same team or a goal (keeper does not touch)
	Penalty kick	Goal
	Goal kick	Next touched by player from same team
Clearance	*Obvious attempt to place the ball out to touch or out of the x-yard box*	Out to touch, or out of harm's way
Pass	*Attempt to get the ball to a player on the same team*	Next touched (in any way) by player from same team
First touch	*First touch of the ball, except when an obvious attempt to "first time" (volley) the ball*	Next touched by the same player
Dribble	*Touch to oneself after the first touch*	Next touched by the same team player
Shot at goal	*Shot obviously directed at goal*	On target (see above)
Tackle	*Touch on ball or opposing player in posession of the ball*	Removes ball from opposing player and not a clear foul (May override referee errors based on replay)

These behaviours must all have been clearly unipedal; two-footed tackles, passes from the head etc. were not coded. We also did not code behaviours which occurred after the whistle. If a player was fouled and both raters agreed that he would have received a pass had he not been fouled, we coded the preceding pass as successful but did not code first touch of player who was fouled. If the foul was committed with a unipedal tackle, then that tackle would be coded as unsuccessful.