Plasticity of human handedness: Decreased one-hand bias and inter-manual performance asymmetry in expert basketball players

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Plasticity of human handedness: Decreased one-hand bias and inter-manual performance asymmetry in expert basketball players

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Abstract
Athletes frequently have to adapt their skills to fast changes of play, often requiring the flexible execution of a particular movement skill with either hand. To assess the influence of sport-specific expertise and extensive sport training on human laterality, a video analysis of regular basketball games was performed for professional, semi-professional, and amateur players to investigate how non-dominant hand use and proficiency change with increasing expertise. Our results showed that the right-hand (i.e. dominant hand) bias in basketball players is reduced with increasing expertise (i.e. competitive level). Accordingly, we found that professional players use their non-dominant hand more often and with greater success than semi-professional and amateur players. This was true for most of the basketball-specific skills. Based on these results, we assume that increasing amounts of bilateral practice can lead to a shift in task-specific manual preference towards a higher use of both hands in competition, as well as to a higher proficiency for non-dominant hand actions in particular. From an applied perspective, the more frequent use and higher proficiency of the non-dominant hand in professional basketball players, compared with amateurs, suggests that the context-specific and skilled use of the non-dominant hand is crucial for successful play at higher competitive levels in the sport of basketball.

Keywords: Lateral preference shift, bilateral competence, expertise, skill development, team sports

Introduction
Research on human laterality provides evidence for the dynamic nature of lateralized brain functions and the expression of hand/foot dominance in skill use (Serrien, Ivry, & Swinnen, 2006). Teixeira and colleagues (Teixeira & Okazaki, 2007; Teixeira & Teixeira, 2007) showed that lateralized practice leads to a shift of manual preference in the practised task and also generalizes to other, related motor tasks. These training effects on manual preferences were still observable after one month without lateralized practice, signifying rather persistent changes. Similar, the successful shift of handedness (i.e. left-to-right) in a large number of children in the general population is indicative of the dynamic nature of human laterality in response to specific practice (e.g. Meng, 2007; Porac, Coren, & Searleman, 1986). These two examples suggest that manual preference is not such a hard-wired, innate trait, as has been argued previously (e.g. Annett, 2002; McManus, 2002), but rather is modulated by physical practice and task constraints.

Because of this evidence, demonstrating selective shifts of participants’ lateral preference after manual training of simple tasks, Teixeira and colleagues assumed that high amounts of sport-specific practice with both limbs should lead to similar task-specific modifications in athletes (Teixeira, de Oliveira, Romano, & Correa, 2011). That is, after large amounts of bilateral practice in a particular sport, athletes should experience selective shifts of their lateral preference. Evidence for such a training-induced plasticity of human laterality, for instance, comes from soccer players, who show a weaker leg preference than novices due to pronounced bilateral practice (Teixeira et al., 2011). Also, judo experts with long practice experience use their non-dominant hand more frequently than low-level judo athletes (Mikheev, Mohrb, Afanasiev, Landis, & Thut, 2002). These findings suggest that extensive sport training can affect human laterality, which may reflect specific adaptation processes as a result of massive amounts of specific practice in expert performers.
Based on the deliberate practice approach (for detailed reviews, see Ericsson, Krampe, & Tesch-Römer, 1993; Ericsson & Lehmann, 1996), extensive amounts (i.e. more than 10 years and/or 10,000 hours) of domain-specific practice, leading to specific adaptations in (perceptual-)motor skills, are necessary to attain expert performance. This notion has been confirmed for a high number of tasks from various fields of application, such as music, typing, chess, and sports (see Ericsson & Lehmann, 1996). With regard to the deliberate practice approach and the aforementioned findings, it is likely that training-induced specific adaptations apply to human laterality and lateralized functions. To this end, high amounts of lateralized practice with only the dominant limb should amplify the dominance of one limb, having an adverse effect on game management when it comes to use the non-dominant hand/foot, whereas lateralization should be reduced when including the non-dominant limb in practice.

A practical example, in which both the dominant and non-dominant limbs are involved in training and competition, is the game of basketball. The success of basketball players during competitive play often relies on their capability to perform different skills equally well with the dominant and non-dominant hand. With regard to the flexible use of the dominant and non-dominant hand, it can be assumed that those athletes who are able to handle the ball well on both sides of the body have an advantage, because they can readily adopt the execution of skills to fast changes of play (e.g. while switching from the dominant to the non-dominant hand), enabling them to flexibly adjust to new situations. In contrast, athletes who are not able to handle the ball with equal efficiency on both sides may not be able to adjust their play sufficiently to new situations and are (therefore) constrained to perform a particular skill with the dominant hand, even when the situation requires the use of their non-dominant hand. Thus, it is assumed that the generation of optimal solutions for different game situations in basketball is highly dependent on the athlete’s ability to perform a specific skill with either side of the body, without much decrement in performance when being required to use the non-dominant hand. We refer to this as the athlete’s individual bilateral competence and suggest that a certain degree of bilateral competence is needed if athletes are to be successful in modern team sports, such as basketball.

Since the game of basketball benefits from athletes with a high degree of bilateral competence and weak lateral dominance, players receive extensive amounts of non-dominant hand practice during their career. Accordingly, we suggest that the one-limb dominance usually observed in the general population (Raymond & Pontier, 2004) is selectively reduced for most of the basketball-specific skills with increasing expertise in the game of basketball. This notion was first tested in a study by Bale and Scholes (1986), who hypothesized for elite basketball players that “individuals who show a very strong lateral dominance are less likely to be found in the professional National League basketball teams since the ability to use both hands equally well is an essential characteristic of this symmetrical sport” (Bale & Scholes, 1986, p. 146). To test this hypothesis, they used the Edinburgh Handedness Inventory (Oldfield, 1971) to assess the lateral preference of elite basketball players. The results revealed a less pronounced lateral preference compared with the general population, which led them to conclude that: “one of the fundamental abilities required of top-class basketball player is to be able to use both sides of the body with equal facility” (Bale & Scholes, 1986, p. 145). They further suggested that elite basketball players are familiar enough with pressure arising from different game situations, to which they can optimally respond by using both hands. In contrast, amateurs are not (yet) able to readily adjust their own actions to fast changing game situations, because of their lateral dominance during skill execution.

The findings of Bale and Scholes (1986), however, may be of limited inferential value, because of the testing tool used. The Edinburgh Handedness Inventory (Oldfield, 1971) assesses people’s hand preference for activities of daily living (i.e. the test battery includes items like writing, drawing, and striking a match). The game of basketball, however, requires the sports-specific implementation of complex skills, which may be different from the generation of simple actions of daily living. Thus, the Edinburgh Handedness Inventory (Oldfield, 1971) may not be adequate to draw inferences about athletes’ lateral dominance for skill execution during the game. To address the influence of extensive sport training on lateral preferences and the sport-specific implementation of both hands more adequately, it is important to examine the execution of particular skills during the game, or at least for game-like situations, as has been done by Carey et al. (2001, 2009) in soccer.

The purpose of the present study was to investigate if the specific demands and practice regimes in basketball, which include high amounts of non-dominant hand practice, affect handedness. It seems reasonable to assume that athletes, who are able to use both hands for the execution of basketball-specific skills (e.g. throwing, passing, and dribbling) with equal efficiency, reflecting a high degree of individual bilateral competence, are more successful in finding the best action solutions during competitive play. On the other hand, it is assumed that athletes with a strong lateral dominance will be...
forced more often to commit mistakes by their defenders (Eastwood, 1972). Generally, we hypothesize that the right-hand bias (signifying a strong lateral dominance) present in 85–93% of the general population (Raymond & Pontier, 2004) is reduced in basketball players. More specifically, both the frequency (manual preference) and the proficiency (performance asymmetry) of non-dominant hand actions are expected to depend on the level of the player’s expertise. Accordingly, professional athletes from higher leagues should use their non-dominant hand more often and with higher proficiency (i.e., display a greater degree of individual bilateral competence) than semi-professionals or amateurs. Consequently, we expect a significant reduction of the one-hand bias in basketball players as a function of their expertise as a result of extensive amounts of bilateral/non-dominant hand practice. This assumption is tested by examining basketball players’ behaviour directly in terms of their skill execution with the dominant or non-dominant hand during competitive play.

Methods

Data capture and procedure

Fourteen regular basketball games were captured on videotape, using a Panasonic digital camcorder (Panasonic NV-DX 100). Basketball games from higher leagues were recorded directly from television broadcasts, whereas games from lower leagues, which were not shown on television, were recorded by two research assistants. This video footage was used to conduct a systematic, explorative video analysis, in which all ball contacts with the dominant and non-dominant hand of the basketball players were noted on elaborated coding sheets. These coding sheets contained detailed instructions for the scorers about how to collect the data. All coding sheets were designed before the investigation and the four scorers underwent a 4 h training session in data coding (e.g. how to record ball contacts for different skills). The first video was coded by all four scorers, which resulted in a correlation coefficient of 0.96. Therefore, each of the remaining videos was coded by one scorer only.

The following data were collected: (1) player’s age; (2) competitive playing level (professional, semi-professional, amateur); (3) handedness (right vs. left hander); (4) playing position on the field (guard, forward, centre); and (5) number of ball contacts. Ball contacts were noted separately for dribbling (dominant vs. non-dominant hand), passing (dominant vs. non-dominant hand vs. two-handed), catching (dominant vs. non-dominant hand vs. two-handed), and throwing (dominant vs. non-dominant hand). Also, the success rates for passing and throwing were collected for each athlete. A pass was considered successful when the ball was caught by the teammate, while a throw was classified as successful when it resulted in points for the attacking team or free throws. When necessary, rapid sequences of playing action were viewed frame-by-frame to identify all ball contacts accurately. Although the actions of all players in a game were coded, only those players with more than 20 ball contacts per game were included in the data analysis to avoid distortions in the handedness distributions, which otherwise might arise from players with little playing time after the percentage rate for ball contacts with the dominant and non-dominant hand were calculated. This was done in accordance with Carey et al. (2001), who showed for a sample of soccer players that misclassifications can be avoided when using 20 or more actions of each player.

General description of the data sample

Overall, 24,225 ball contacts were recorded (including dominant, non-dominant, and two-handed ball contacts). These came from 206 male basketball players, who were between 14 and 35 years of age (mean = 24.2 years). Any player with fewer than 20 touches was removed from the original dataset (n = 229 players), resulting in a sample of 206 players. Altogether, 193 were right-handed (93.7%) and 13 were left-handed (6.3%) athletes. Handedness was defined by the hand used for free throws. In the case no free throws were recorded for a player, other datasets were screened for the handedness of these players. We used this dichotomous estimate, because in free throws athletes will always use their dominant, more skilled hand, as they have enough time to prepare the action. With regard to handedness/hand preference, the sample of 206 basketball players appears to be relatively representative in terms of an unselected sample when compared with the general population (Raymond & Pontier, 2004). All players performed in one of 28 teams at three different competitive levels: (1) 63 professional players at the highest international and national level; (2) 43 semi-professional players at the regional and supra-regional level; and (3) 100 amateur players at the junior and recreational level.

Captured data came from games of the World Championship 2006 in Japan, the Euro League (season 2006/2007), and regular games of all German leagues from the first national league to the junior leagues (season 2006/2007). The selection was based on availability via television (i.e., World Championships 2006, Euro League or First National League), arrangements with regional basketball clubs and associations, as well as the aim to cover at least
two games each for the complete range from highest to lowest level in German basketball. Because of this classification of a different number of leagues into one of the three competitive levels (professional, semi-professional, and amateur players), the sample sizes vary per league and player. To avoid biased results due to differences in manual preference profiles between left- and right-handers, we compared percentage of dominant and non-dominant hand as well as two-handed ball contacts between left- and right-handed players in a 3 (hand) × 2 (handedness) analysis of variance (ANOVA). The absence of a main effect for handedness (F_{1,204} = 0.38, P = 0.54) and the absence of an interaction between hand and handedness (F_{2,203} = 1.50, P = 0.23) indicated that no differences in manual preference profiles between left- and right-handers apply to the present sample. Note, right- and left-handed athletes will not be further compared for overall effects of handedness, because of the small number of left-handed players (13 of 206 or 6.3%) in each group. Therefore, players’ performance was analysed for their use of the dominant and non-dominant hand (instead of the right and left hand).

**Data analysis**

To examine a possible right-hand bias in basketball players, the overall distribution of left- and right-handed players was analysed in the first step. To this end, the percentages of ball contacts with the right hand (relative to all ball contacts with the right and the left hand) were computed for each player. These percentage rates were then submitted to a test for normality in the frequency distribution (a) for the whole sample and (b) separately by competitive level. This was done to determine whether (1) the right-hand bias extends to hand preference for on-court behaviour, and (2) if it depends on players’ expertise. Therefore, skewness and kurtosis statistics were performed to analyse the strength of a potential bias in the data.

In the second step, the percentage rates of ball contacts with the dominant and non-dominant hand for the different skills (e.g. dribbling, passing, catching, and throwing) were calculated to look for a distinct hand preference during competitive play. To examine possible differences for ball contacts with the non-dominant hand between the three competitive levels, all percentage rates of ball contacts with the non-dominant hand were submitted to a 4 (skill: dribbling vs. passing vs. catching vs. throwing) × 3 (playing level: professionals vs. semi-professionals vs. amateurs) multivariate analysis of variance (MANOVA), with the within-participant factor of ‘skill’ and the between-participant factor of ‘playing level’.

Whenever warranted, simple post-hoc comparisons were performed using Sidak adjustment. Correlative statistics were computed to test for the nature and strength of the relation between the percentage rates of ball contacts with the non-dominant hand and players’ competitive level.

The success rates of direct passes to a teammate (i.e. passing) were computed by subtracting the number of failed passes from the total number of passes for each hand separately. The resulting absolute value of successful passes was then divided by the total number of passes and was multiplied by 100, providing the percentage rates of successful passes with the dominant and non-dominant hand. The success rates for throwing were calculated in the same manner for each hand separately. Higher percentage values indicate better throwing performance. The success rates were then compared between the three competitive levels by two separate one-way analyses of variance (ANOVA) and correlative statistics, as well as simple post-hoc comparisons (Sidak). Following the procedure of Carey et al. (2009), only athletes with at least 10 data points of the specified action were included in the analyses of success rates.

Based on the notion of Bale and Scholes (1986) that non-dominant hand use is affected by playing position, percentage rates of all non-dominant ball contacts were analysed relative to the athletes’ playing position in the last step. To this end, a 4 (skill: dribbling vs. passing vs. catching vs. throwing) × 3 (playing position: guard vs. forward vs. centre) MANOVA was calculated with ‘skill’ as a within-participant factor and ‘playing position’ as a between-participant factor. For all significant main effects and for the interactions, post-hoc pairwise comparisons, using the Sidak adjustment, were performed between any two given conditions (e.g. between professionals and amateurs for percentage rates in dribbling).

**Results**

The following information is provided in order to obtain a general impression of the data. The majority of the 24.225 ball contacts were with the dominant hand (52.6%), while the non-dominant hand (22.6%) was used almost as often as the two hands together (24.8%). The numbers of ball contacts for the different skills were 13.273 for dribbling (54.8%), 5.283 for catching (21.8%), 3.993 for passing (16.5%), and 1.676 for throwing (6.9%). The average number of ball contacts per player and game was 118 (dribbling = 64, catching = 26, passing = 19 times, and throwing = 8). The playing time of each athlete was about 15 min on the field, when he scored 6.9 points on average.
Right-hand bias in basketball

To investigate the influence of a (potential) right-hand bias in basketball, percentage values of all ball contacts with the right hand were calculated for all players across the different skills and submitted to a test for normality in the frequency distribution. Note, that for this distribution analysis only right- and left-hand contacts were included (i.e. right-hand contacts relative to all contacts with the right and the left hand), since two-handed ball contacts would obscure the data when examining the factor hand preference. Also, all ball contacts for free throws and throws taken from a distance of over 1 m (4.4% of all contacts) were excluded, because these strongly one-sided actions were considered for estimating athletes’ handedness. In fact, these throws were always executed with the dominant hand. Skewness and kurtosis statistics (skew = –1.18, \( s_x = 0.16 \); kurtosis = 1.64, \( s_x = 0.32 \)) indicate a right-skewed distribution with a mean right-hand bias of 74.0% across all players and ball contacts.

Interestingly, this right-hand bias was smaller in professional athletes (67.6%) and in semi-professional athletes (65.4%) compared with amateur players (82.1%). The difference between professionals and semi-professionals on the one hand and the amateurs on the other hand proved to be significant (both \( P < 0.001 \)), which was supported by a one-way ANOVA for the factor competitive level (\( F_{2,203} = 16.33, P < 0.001, \eta^2 = 0.14 \)). The difference was supported by the frequency distributions for percentage of right-hand contacts separated by competitive level (see Figure 1) and the respective kurtosis statistics with stronger negative skews in amateurs (skew = –2.0, \( s_x = 0.24 \)) and semi-professional athletes (skew = –1.12, \( s_x = 0.37 \)) than in professionals (skew = –0.07, \( s_x = 0.30 \)). This indicates an overall reduction of the right-hand bias in players of higher professional leagues.

Ball contacts with the non-dominant hand

The percentage rates of ball contacts with the non-dominant hand for the different skills across the three professional playing levels are displayed in Figure 2. As can be seen, the use of the non-dominant hand becomes more frequent with an increasing level of professional play (i.e. 11.5% in amateurs, 21.4% in semi-professionals, and 26.3% in professionals). Likewise, the number of ball contacts with the dominant hand decreases from 59.2% in amateurs, to 49.6% in semi-professionals, and to 48.8% in professionals. An analysis of variance yielded statistical differences for all ball contacts with the non-dominant hand (\( F_{2,203} = 22.84, P < 0.001, \eta^2 = 0.18 \)). Simple comparisons between the different playing levels revealed the differences between professionals and semi-professionals and between semi-professionals and amateurs to be significant (both \( P < 0.05 \)), indicating a linear relationship between competitive level and the relative use of the non-dominant hand under competitive play. The step-wise increase of the use of the non-dominant hand with higher playing level is illustrated in Figure 2. Correlation analysis of this step function proved to be significant (\( R = 0.42, P < 0.001 \)). Thus, the rate of use of the non-dominant hand increases across all skills with higher levels of professional play, whereas that of the dominant hand decreases (\( R = 0.39, P < 0.001 \)).

Figure 1. Frequency histograms depicting percentage right-handed play in basketball for professional, semi-professional, and amateur players. The data demonstrate a stronger right-skew distribution in amateur players (\( r = 0.93 \)) compared with professional (\( r = 0.74 \)) and semi-professional players (\( r = 0.64 \)), indicating that the right-hand bias is reduced as a function of playing level.

Figure 2. Percentage non-dominant hand use in professional, semi-professional, and amateur basketball players for different skills and across all ball contacts. Error bars indicate the standard error within each group.
The same pattern can be observed for each single skill, except for throwing. As shown in Figure 2, the rates of non-dominant hand use increased with increasing competitive level for dribbling ($R = 0.49$), passing ($R = 0.28$), and catching ($R = 0.28$; all $P < 0.001$), but not for throwing ($R = -0.02$, $P = 0.79$). Interestingly, professional athletes dribbled the ball with their non-dominant hand (47.0%) almost as often as they did with their dominant hand (53.0%). In contrast, the use of the non-dominant hand for dribbling in amateurs was low (19.9%). Thus, it seems that the individual bilateral competence of a player poses a general constraint for the particular hand used under competitive play. In other words, a player who uses his non-dominant hand more often for dribbling should also use his non-dominant hand more often for catching and passing. Correlation analysis confirmed this notion and found the correlations between the actual rates of non-dominant hand use in dribbling, passing, and catching to be significant (all $P < 0.001$).

**Success of non-dominant hand passes and throws**

The mean percentage rates of successful passes and throws with the non-dominant hand for the three competitive levels are displayed in Figure 3. For professional athletes (95.8%) and semi-professional athletes (97.3%), almost all passes conducted with the non-dominant hand were received by a teammate, whereas performance was somewhat worse for amateur players (78.8%). A one-way ANOVA revealed these group differences to be significant ($F_{2,104} = 4.43$, $P < 0.05$, $\eta^2 = 0.08$). Post-hoc comparisons yielded significant differences between amateurs and semi-professionals, as well as between amateurs and professionals (both $P < 0.05$). Furthermore, the correlation between the success of non-dominant hand passes and playing level was significant ($R = 0.24$, $P < 0.01$).

For professionals (95.7%) and semi-professionals (93.9%), the rates of successful dominant hand passes were very similar to the rates of successful non-dominant hand passes. Only amateur players performed significantly better with their dominant hand when passing the ball (89.3%), as compared to passes with the non-dominant hand ($P < 0.05$).

A somewhat different pattern was observed for throwing with the non-dominant hand over distances of less than 1 m. The success rate for professional athletes was 57.8%, that for semi-professional athletes 35.4%, and that for amateurs 35.8%. However, these differences were not significant (one-way ANOVA: $F_{2,52} = 1.55$, $P = 0.22$).

**Effect of playing position on non-dominant hand use**

The 4 (skill) × 3 (playing position) MANOVA did not reveal a significant main effect for playing position ($P = 0.50$), or a significant interaction between playing position and skill ($P = 0.82$). Accordingly, there were no effects of playing position on the rate of non-dominant hand use. That means that the effects of playing level on non-dominant hand use reported above generalize across all playing positions.

**Discussion**

We examined the influence of extensive sports training on human handedness. A video analysis of regular games was conducted for three different competitive levels in basketball to investigate how non-dominant hand use and proficiency change with increasing expertise. Based on the notion that the
modulation of lateral preference is particularly important for sports in which bilateral proficiency is advantageous for high performance (Teixeira et al., 2011), we anticipated that the specific demands of basketball lead to a reduction of the one-hand bias due to extensive amounts of practice with both the dominant and the non-dominant hand. Previous studies, such as those by Bale and Scholes (1986) in basketball and by Grouios and colleagues (Grouios, Kollias, Tsorbatzoudis, & Alexandris, 2002) in soccer, which suggested a reduction of the right hand/foot bias in professional game sports, must be considered with caution, because they used traditional paper-and-pencil tests to assess handedness (i.e. Edinburgh Handedness Inventory; Oldfield, 1971) or footedness (i.e. Waterloo Footedness Questionnaire-Revised; Elias, Bryden, & Bulman-Fleming, 1998; Martin & Porac, 2007) in elite players. We took a more direct approach, which included the assessment of ball contacts with the dominant and non-dominant hand for the execution of different skills during regular basketball competitions, as used previously by Carey et al. (2001) to assess the foot preference of soccer players.

First, our data do not support the notion of a general reduction of the right-hand bias for basketball-specific actions in the present sample of basketball players, at least not to the same extent as reported by Bale and Scholes (1986) using the Edinburgh Handedness Inventory (Oldfield, 1971). This can be seen in the frequency distribution of all right-hand ball contacts during the games analysed. The vast majority (77.7%) of the players used their right hand to execute basketball-specific skills, while the remainder were mixed-handed (17.9%) or left-handed (4.4%). Hence, the right-hand bias was somewhat reduced in basketball players compared with the general population, but not to the extent suggested by Bale and Scholes (1986). Most importantly, this right-hand bias was much smaller in professional and semi-professional athletes than in amateur players. Thus, in the present study the reduction of the right-hand bias occurred as a function of individual playing level. Accordingly, the game of basketball does not seem to require an equal implementation of both hands per se, but the data suggest at least a need for less lateralized athletes to play at (or advance to) higher or even the highest competitive levels in basketball.

In addition, further data analyses yielded a strong relationship between the players' level of competitive play and the use of their non-dominant hand. Athletes of higher playing levels used their non-dominant hand for skill execution more often during competitive play than lower level athletes. Most notably for the dribbling skill, professional athletes used their non-dominant hand as often as their dominant hand, whereas amateur players showed a strong dominant hand preference during skill execution. This pattern of results was also present across the other skills under investigation (i.e. passing, catching). In contrast to the findings of Bale and Scholes (1986), no differences were observed between the three playing positions (i.e. guard, forward, centre). We suggest that: (a) the capability to use both hands in competitive play is important to play at (or advance to) higher competitive levels in basketball; and (b) that a high level of individual bilateral competence is equally important for all playing positions on the field when it comes to the execution of different skills during the basketball game. This finding of athletes' individual bilateral competence as a modulating factor for professional play is at odds with previous studies in soccer, suggesting that a one-foot bias cannot only be observed in amateur players (Carey et al., 2009, Study 1; Grouios et al., 2002), but can also be found in actual "on-the-field-behaviour" in elite soccer players (Carey et al., 2001, 2009, Study 2). Carey and colleagues' analysis of nine games of the Soccer World Cup 1998 in France (Carey et al., 2001), together with a sample of 13 Premiership and English League Cup games (Carey et al., 2009, Study 2), revealed that most professional soccer players (~85%) display a strong foot preference during the game. Such a strong lateral preference in soccer is at odds with the notion that athletes with a high degree of bilateral competence and weak lateral dominance would generally benefit in their sports. The specific demands in basketball seem to require a context-specific implementation of skills with the dominant and non-dominant hand, rather than a general implementation of both hands during the game. Such a context-specific implementation can be achieved by a high level of individual bilateral competence and may enable the athlete to react sufficiently to the fast interactions and rapid changes during competitive basketball (Remmert, 2003). Strategic advantages appear to be the reason for the higher implementation of the non-dominant limb (for a similar suggestion, see Puterman, Schorer, & Baker, 2010) in expert basketball players compared with professional soccer players (cf. Carey et al., 2001, 2009).

Of course, the notion of athletes' individual bilateral competence as a modulating factor of professional play only holds if professional basketball players are more successful with their non-dominant hand than amateur players. When analysing the successful use of the non-dominant hand for throwing to the basket and passing to a team member, results showed better performance with an increasing level of competitive play. Thus, higher level athletes not only use their non-dominant hand during the
game more often, but they are more successful when it comes to completing a pass to a teammate or scoring points at the basket.

From a theoretical perspective, the finding of a reduced one-hand bias in basketball players as a function of expertise supports the notion of the dynamic nature of human laterality. Based on the higher use and proficiency of the non-dominant hand in professionals, compared with semi-professionals and amateurs, it is very likely that the increasing amounts of basketball-specific practice (i.e. training of both the dominant and non-dominant hand) at the higher competitive levels result in a modulation of lateral preference. From the perspective of the deliberate practice approach (Ericsson & Lehmann, 1996; Ericsson et al., 1993), these results indicate that also human laterality and lateralized functions are affected by extensive domain-specific training. Extensive amounts of bilateral practice (or lateralised practice) seem to result in specific performance adaptations (modulations) of lateral preferences to the domain-specific task constraints. This finding is in line with previous studies indicating a training-induced plasticity of handedness (or footedness) (e.g. Mikheev et al., 2002; Teixeira & Okazaki, 2007; Teixeira et al., 2011). Furthermore, the more successful non-dominant hand actions (along with a more frequent use of the non-dominant hand) of professionals and semi-professionals than amateurs provides support for the notion that manual preference evolves as a function of superior performance of one hand compared with the other hand (Bishop, 1989). To statistically test for this notion, we analysed success rates of the non-dominant hand for passing and throwing actions in relation to use compared with the dominant hand. The present data do not provide evidence for the proficiency approach. The non-dominant hand was not used more often when performing with higher proficiency, whether for passing ($r = 0.15$, $P = 0.11$) or for throwing ($r = 0.07$, $P = 0.58$). Hence, an alternative approach would better explain the present findings.

This approach can be derived from the neurosciences. From this perspective, it is not surprising that task-specific handedness changes in response to specific training. Using brain imaging techniques, researchers have provided evidence for a training-induced structural (Draganski et al., 2004; Scholz, Klein, Behrens, & Johansen-Berg, 2009; Taubert et al., 2010) and functional (Taubert, Lohmann, Marquelsi, Villringer, & Ragert, 2011) plasticity of the human brain. It has been reported that there are structural grey and/or white matter changes in relevant brain networks as well as changes in functional connectivity in response to juggling (Draganski et al., 2004; Scholz et al., 2009) and balance training (Taubert et al., 2010, 2011). With regard to the specific demands in basketball, the non-dominant hand is consequently involved in training across the whole career of a basketball player. Due to the large amounts of practice required to advance to the highest levels, it is very likely that training-induced structural and functional changes in the human brain extend to handedness, resulting in a kind of plasticity of human handedness through training.

It is therefore likely that, besides the genetic predisposition of handedness (Annett, 2002; Corballis, 1997; McManus, 2002), there are higher capacities for adaptations to specific requirements, new environments, specific situations and/or tasks than have been assumed previously. Because many studies support the notion that handedness is strongly connected to functional asymmetries in the human brain [e.g. a lateralized motor control system that is responsible for the selection and sequencing of motor behavior (Goodale, 1988; Schluter, Krams, Rushworth, & Passingham, 2001); the relation between speech lateralization and handedness (Knecht, 2000)], future studies should investigate the kind of neural modifications resulting from bilateral training, which in turn may lead to functional changes in decision making regarding hand selection for performing specialized skills.

In conclusion, the present data provide much insight into both the dynamic nature of human laterality and the specific demands of basketball skill execution. On the one hand, the results demonstrate the plasticity of handedness in response to extensive basketball-specific practice. That means that increasing amounts of bilateral practice can lead to a shift in task-specific manual preference towards a higher use of both hands in competition, as well as to greater proficiency, particularly for non-dominant hand actions. Those findings support the idea that human handedness is not such a hardwired, innate trait, as has been argued before (Annett, 2002; McManus, 2002), but can rather be modulated by practice and task constraints depending on specific demands. On the other hand, the higher use and proficiency of the non-dominant hand in professional versus amateur basketball players indicates that a context-specific implementation of the dominant and non-dominant hand in basketball is crucial for successful play in the sport of basketball. Since in competitive play athletes are not really conscious of decision-making processes (i.e. which hand to use) and the selection of appropriate actions (i.e. which skills to execute) and “automatically” prefer the recall of well-developed skills (i.e. skills proven successful in competitive play), their individual level of skill (i.e. throwing accuracy over short distances, quality of passing, safe dribbling) should be equal for both hands. Therefore, both hands should be involved during practice.
sessions to ensure an equal performance under competitive play. Recent studies, focusing on such bilateral practice schedules, have already demonstrated that bilateral training can improve the execution of simple (Senn & Weigelt, 2011) and complex motor skills (e.g. Stöckel & Weigelt, 2011; Stöckel, Weigelt, & Krug, 2011). The effects of bilateral training on athletes’ individual competence and their progression to higher levels of competitive play should be the focus of future studies.

References


