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Does game pressure affect hand selection of NBA basketball players?

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ABSTRACT

Purpose: The purpose of this study was to compare hand selection and accuracy of technical skills between low- and high-pressure games of the National Basketball Association (NBA) in the 2018–2019 regular season and playoffs.
Method: A notational analysis was conducted on 24 games of four teams (12 low-pressure games and 12 high-pressure games, six of each team, three in each condition). One- or two-handed actions were recorded for dribbling, passing, catching, and shooting (layups, dunks, hooks, and tips) skills.
Results: During high-pressure games, players significantly increased the frequency of right-handed passing. High-pressure games also increased the frequency of left-handed catching. For dribbling and shooting, no differences were observed in hand frequency between conditions. The success rate of all analyzed skills was similar between the hands in both low- and high-pressure conditions.
Conclusion: Our results showed that game pressure could selectively modulate hand preference for passing and catching skills in elite-level basketball while presenting no significant effect on performance between hands.

1. Introduction

Handedness has been regarded as a complex and dynamic trait of human behavior (Marcori & Okazaki, 2020). Thereby, manual preference is continuously changing over the years, as individuals accumulate a higher amount of lateralized practice on daily tasks, increasing preference for the preferred side throughout the lifespan (Marcori, Grosso, Porto, & Okazaki, 2019; Teixeira, 2008). Besides the well-documented enhancement of handedness with aging, hand preference and selection can also be affected by specific contexts (Faquin et al., 2015), such as elite competitive sports. In this scenario, athletes may have their hand preference affected by specificities of the sport, by the amount of (bi-) lateralized practice they are submitted to (Marcori, Monteiro, & Okazaki, 2019; Stöckel & Vater, 2014), and by particularities of game situations.

For instance, Stöckel and Weigelt (2012) addressed basketball players' lateral preference by analyzing the frequency of hand use during shooting, passing, catching, and dribbling skills of three different competitive levels (amateur, semi-professional, and professional). They found a linear inverse relationship between the competitive level and the relative use of preferred hand – as competitive level increases, players become less lateralized for those skills. Similar results are also verified in other modalities. Expert athletes are known to have higher ambidexterity levels in wrestling (Ziyagil, Gursoy, Dane, & Yuksel, 2011), boxing (Gursoy, 2009), Kung Fu (Maeda, Souza, & Teixeira, 2014), and soccer (Grouios, Kollias, Tsorbatzoudis, & Alexandris, 2002; Teixeira, de Oliveira, Romano, & Correa, 2011). These outcomes suggest that symmetric preference (frequency of left and right side used) and performance are expected due to specific practice (Teixeira & Okazaki, 2007; Teixeira & Teixeira, 2007). Thus, athletes would become more proficient while increasing their adaptability to unpredictable game situations. In light of these data, the dynamic nature of limb selection becomes evident in the sporting context.

Lateralized practice might not be the only factor capable of modulating handedness in expert athletes. From a theoretical standpoint, previous research have already proposed that handedness emerges from an interplay between an individual's intrinsic dynamics and its interaction with environmental and social constraints (Marcori, Grosso, dos, Porto, & Okazaki, 2019; Marcori, Monteiro, & Okazaki, 2019; Marcori & Okazaki, 2020). Within this reasoning, the ecological dynamics

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approach can also be applied to explore expert performance in the sporting context, as this framework emphasizes how the performer-environment relationship is critical to understand behavioral outcomes (Warren, 2006). Considering the performer, either spontaneously or through practice, an athlete's movement system converges to form a stable coordinative state (i.e., attractor – Gibson, 1966), leading to a consistent hand preference to perform a given skill. However, in basketball, athletes must present skilled behavior with both hands for optimal outcomes. Hence, there is a need to also perform well with the non-preferred hand, requiring a state of multi-stability, which is the ability to shift between more than one stable coordinative pattern under certain constraints (Kelso, 2012; Kelso & Schöner, 1988). Indeed, an aspect of expert performance is exactly the capacity to achieve success in a motor act with different solutions (i.e., movement degeneracy; Seifert, Button, & Davids, 2013), which in this case would be using both hands. As such, higher levels of ambidexterity in professional basketball players, as compared to amateurs, have already been reported (Stöckel & Weigelt, 2012) - providing preliminary evidence of movement degeneracy in this population by means of handedness analysis. However, basketball athletes may vary their hand selection based on distinct environmental constraints (Esteves, Oliveira, & Araújo, 2011), but investigations addressing this issue with professional players and in practical settings are still lacking in the literature.

Present in virtually every sport modality, a crucial environmental constraint that may be able to affect an athlete's behavioral pattern of hand selection is game pressure. Regardless of competitive level, players experience different game pressure according to a given situation. Previous research has shown that game pressure, understood as any factor or combination of personal and environmental factors that increase the importance of performing well on a particular occasion (Baumeister, 1984), indeed affects performance on team sports (González-Díaz, Gossner, & Rogers, 2012). “Important games/moments,” “high expectations,” and “the presence of audience” are primary reasons to be associated with game pressure and detriment of performance (Hill & Shaw, 2013). In basketball, Maher and colleagues (2018) verified that players' perceptions of affected performance were associated with expectation and self-pressure, game importance, fear, and crowd influence. Based on the raised evidence, we can speculate that game pressure may interfere with the individual dynamics and modulate motor behavior. In a high-pressure scenario, it can be expected that the self-organizing motor system would fluctuate towards the more stable attractors (i.e., the preferred hand) to assure accurate performance. Hence, our research question addresses if this environmental constraint (pressure) can induce modifications in the behavioral pattern of hand selection in elite-level basketball players.

For instance, the tournament's playoff phase presents these above-cited factors and is known to imply higher pressure as compared to the regular season (Cao, Price, & Stone, 2011; Otten & Miller, 2015). During the playoff phase, professional players are inclined to lower the game pace (ball possession index) in attempt to minimize errors, revealing a more concerned type of gameplay (Mandić, Jakovljević, Erèulj, & Štrumbelj, 2019; Sampaio & Janeira, 2003). In fact, Mandić et al. (2019) also showed that playoff games had slower pace (indicated by number of possessions) and less player rotation when compared to regular season games in the National Basketball Association (NBA). The reduced player rotation can be understood as a strategy to keep on court the most efficient players for a greater amount of time - a characteristic seen in higher-pressure scenarios. Additionally, differences in game-related statistics are also observed when comparing the playoffs against the regular season (García, Ibáñez, De Santos, Leite, & Sampaio, 2013; Teramoto & Cross, 2010). In the NBA, playoff games presented fewer two-point attempts and assists, and more three-point attempts and fouls committed when compared to the regular season (Mandić et al., 2019). Taken together, these results suggest that distinct levels of pressure indeed characterize regular season and playoff games, accounting for an important environmental constraint that can modulate the behavioral pattern of the players and possibly modulate hand selection.

Besides being submitted to distinct game contexts and environmental constraints, expert athletes in team sports must consistently perform well with both limbs, regardless of the situation. Hence, it becomes relevant to understand whether game pressure can influence or not hand selection. Our literature review did not identify any research investigating these relevant features of competitive sports: game pressure, hand preference, and performance. To approach this issue, we compared hand selection and success rate for basketball skills performed by elite-level players on low-vs. high-pressure game contexts during the 2018-19 NBA season. This specific championship was selected due to its impact on the basketball scenario and the high-level performance of the athletes. We hypothesized (H1) that the more stable coordinative pattern (attractor) would emerge more frequently in the face of environmental constraints, increasing the preferred hand use during high pressure games. Considering the evidence suggesting diminished performance in high-pressure scenarios (Cao et al., 2011; Otten & Miller, 2015), we also hypothesized (H2) performance would decrease for all skills from low-to high-pressure games. The present study may advance our understanding of the effect of environmental constraints on lateral preference during basketball games (regular season and playoff). These results are important for coaches and athletes in the context of optimizing training sessions to equally develop both hands skills. Selecting the proper hand to perform a motor skill in interaction with the dynamic environment, considering the presence of distinct constraints, could be a key factor to achieve better performance in basketball.

2. Methods

2.1. Data acquisition and procedures

To compare low- and high-pressure situations, we analyzed the same team playing in both conditions. For that purpose, we identified the NBA teams of the 2018-19 season that played at least three playoff away-games (not on home court). Fifteen teams met the criteria, and four of them were randomly selected: San Antonio Spurs, Denver Nuggets, Milwaukee Bucks, and Toronto Raptors. We characterized low-pressure games (LPG) as the first three home games of the regular season, and high-pressure games as the last three playoff away-games (HPG). In total, we analyzed 24 games: 12 regular-season home games (three of each team) and 12 playoff away-games (three of each team). The playoff away-games analyzed were the last ones of each team, further characterizing an increased pressure scenario due to the possibility of elimination and the presence of the opposing audience.

Previous research has used similar strategies to characterize game pressure, considering both game location and season period (Otten & Miller, 2015; Tauer, Guenther, & Rozek, 2009). Along with these strategies, we examined other in-game variables from the analyzed matches in order to differentiate low-from high-pressure games (Bransen, Robberechts, Haaren, & Davis, 2019; Fryer, Tenenbaum, & Chow, 2017): final score difference (LPG: 13,3 points; HPG: 8,5 points), attendance capacity (LPG: 96%; HPG: 100%) and score margin per minute (Fig. 1). Score margin represents the score difference between the teams throughout the game. Games with small score differences are decided in the final minutes, characterizing increased pressure. In Figure 1, each wave represents a single game. Panel A reveals increased positive score differences favoring the analyzed teams during most of the home, regular season games, identified by taller and darker curves in the positive values. Contrarily, Panel B shows reduced score differences, identified by smaller and darker curves centered around zero, indicating more changes of the leading team and a higher-pressure scenario. Further sustaining the high-pressure scenario on the playoffs, the final outcome of the playoff series of each team were: San Antonio Spurs lost 3–4 in the first round of the playoffs, Denver Nuggets lost 3–4 in the western conference semifinals; Milwaukee Bucks lost 2–4 in the eastern

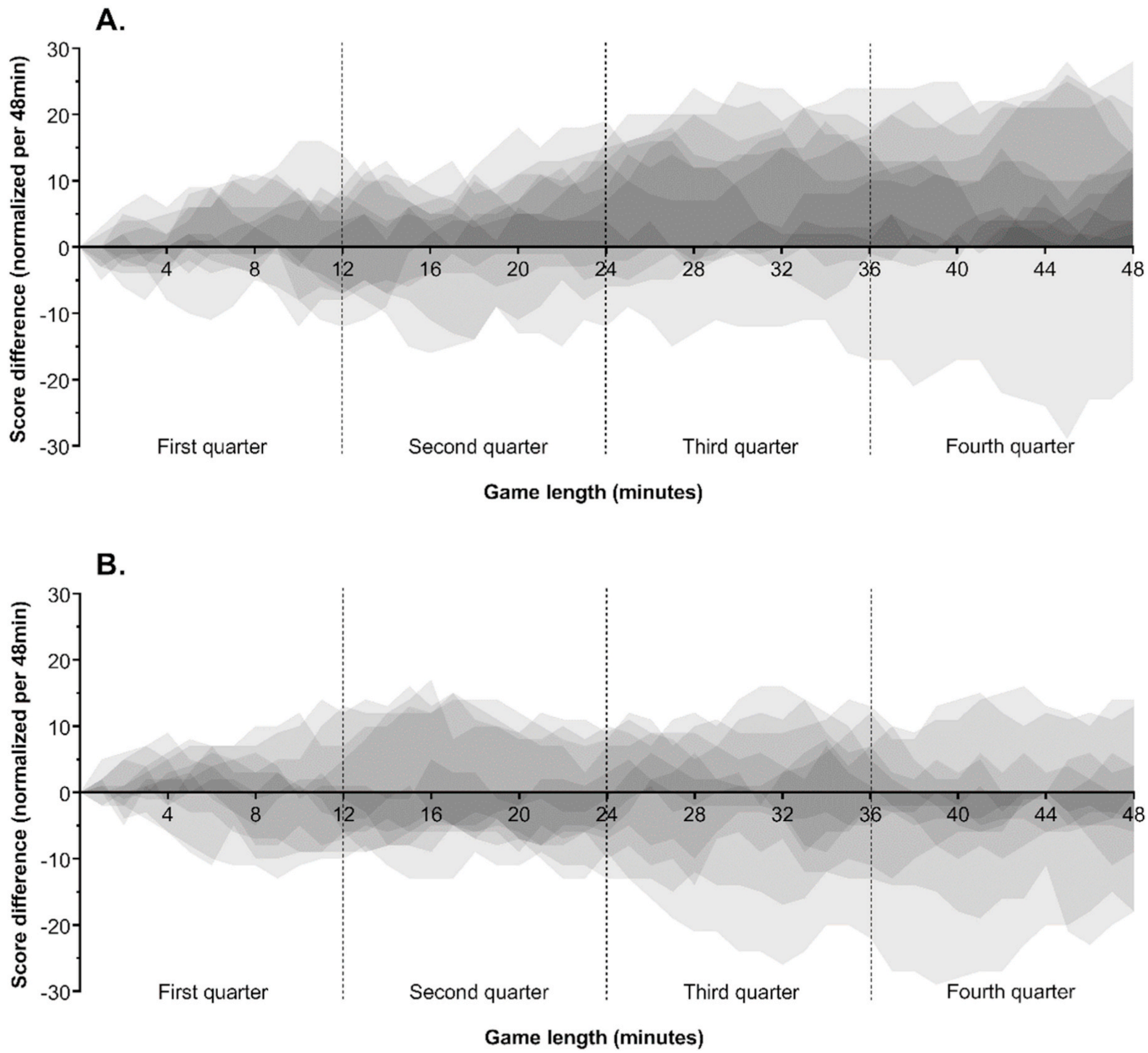

Fig. 1. Superimposed score differences between analyzed and opposing teams along the game (A: low-pressure games; B: high-pressure games). Positive values indicate advantage for the analyzed team. Each wave represents a single game.

conference finals, and Toronto Raptors won 4–2 the NBA finals.

A systematic notational analysis was conducted, in which all ball contacts with the preferred and non-preferred hands were registered on coding sheets. The coding sheet was designed before the investigation, providing detailed instructions for the researchers about the data acquisition process. Three researchers underwent a 4h training session for this particular data coding. The same three researchers analyzed one random NBA game from the 2017-18 season, and the intra-class correlation (ICC) was used to test the inter-rater accuracy for all selected skills. Inter-rater ICC indicated excellent reliability scores across all analyzed skills (dribbling: 0.999; passing: 0.987; catching: 0.976; shooting: 0.914).

The following data were collected: (1) player's age and league experience; (2) handedness (right- and left-hander), defined by the hand that performs the free-throw; and (3) number of ball contacts. Ball contacts were separately coded for: a) dribbling (preferred and non-preferred), b) passing (preferred, non-preferred, and two-handed), c) catching (preferred, non-preferred, and two-handed), and d) shooting (preferred, non-preferred, and two-handed). The shooting category was further subdivided into layups, dunks, hooks, and tips. Only two-handed dunks comprised the two-handed shooting category. Jump shots, set shots, and free-throws were not analyzed due to lack of hand variation.

We also analyzed the success rate of dribbling, passing, and shooting skills. A pass was considered unsuccessful when the ball was intercepted by an opponent, hit a teammate's foot, or went directly out of bounds. Unsuccessful dribbles were those stolen, deflected by defensive players, or executed out of bounds. A shot was classified as successful when it resulted in points for the attacking team or in a shooting foul (free-throws). Whenever necessary, quick sequences of playing action were viewed frame-by-frame to identify all ball contacts accurately.

2.2. General description of the data sample

Based on previous investigation on the topic (Stöckel & Weigelt, 2012), players were excluded from the analysis if they had less than 20 ball contacts in a game (n = 11) or did not play all games of both conditions (n = 21). No left-handed players met the inclusion criteria.

Twenty-six players were included in the final analysis, and a total of 18,899 ball contacts were recorded, including right, left, and two-handed actions. Players were aged between 22 and 34 years old (mean ± standard deviation = 28.1 ± 3.4), right-handed, based on the free-throw criteria, and had from 2 to 13 years of experience in the NBA (mean ± standard deviation = 6.7 ± 3.8). An average of 126 ball contacts/player/game was verified, being subdivided into 115 dribbling, passing, and catching actions, and 11 shooting actions (layups, hooks, dunks, and tips).

The shooting category comprises the summed data of layups, hooks, tips, and dunks. The success rate of two-handed shooting actions was not included in the inferential analysis since they represent only two-handed dunks. Of the 46 two-handed dunks observed in all 24 games, only three were not converted into points or shooting fouls, representing a 93% success rate.

2.3. Statistical analysis

Due to the categorical nature of our data, we fitted a generalized mixed-effects model (binomial distribution with logit link function) to compare the distribution of right- and left-handed actions between skills and conditions (two-handed actions were not considered in this comparison). For this purpose, "skills" and "pressure" (LPG and HPG) were employed as fixed effects and "players" as a random effect. This analysis served to estimate if the right-hand bias is present over all ball contacts, and whether overall hand selection differs between pressure conditions.

To investigate the specific effects of game pressure on hand selection for each skill separately, we fitted a generalized mixed-effects model employing "pressure" as a fixed effect and "players" as a random effect. For dribbling and shooting, that only right- and left-handed actions were possible, the model was applied with binomial distribution with logit link function. For passing and catching, that right-, left-, and two-handed actions were possible, the model was applied with multinomial distribution with logit link function.

To compare skills accuracy (successful vs unsuccessful actions) between hands and conditions, we fitted a generalized mixed-effects model, with "hand" and "pressure" as fixed effects and "players" as a random effect, using binomial distribution with logit link function. When necessary, post-hoc comparisons were carried out using the LSD method. Significance was set at 5% ($p < 0.05$), and all data were processed in SPSS v.25 (IBM Statistics, USA).

3. Results

An overall right-hand bias was observed based on the first model applied, indicated by the intercept (Estimate = 0.356; SE = 0.09; Z = 3.378; $p < 0.001$). Additionally, post-hoc comparisons indicated that the proportion of hand selection is different between all skills ($p < 0.05$ for all comparisons). The significant effect of pressure suggests that hand selection is influenced by game pressure across all skills (Estimate = 0.340; SE = 0.17; Z = 2.932; $p < 0.01$). Based on this finding, we sought to further investigate if game pressure modulated hand selection differently in each skill.

The separate comparisons of each skill indicated that, for dribbling, inferential analysis showed a significant intercept (Estimate = 0.124; SE = 0.05; Z = 2.680; $p = 0.014$), indicating a higher frequency for the preferred hand when compared to the non-preferred hand (54 vs. 46%, respectively). The model revealed no effect of pressure on hand selection for dribbling (Estimate = 0.021; SE = 0.04; Z = 0.462; $p = 0.64$).

For shooting, we found a significant intercept (Estimate = 1.871; SE = 0.21; Z = 9.083; $p < 0.001$), indicating a higher frequency of the preferred hand when compared to the non-preferred hand (79% vs. 16%, respectively - the other 5% actions comprised two-handed dunks and were not included in the analysis). Also, pressure did not affect hand selection for shooting (Estimate = −0.157; SE = 0.21; Z = −0.743; $p = 0.49$).

For passing, the multinomial comparison indicated a significant intercept for all contrasts (PH vs. NPH vs. TH), indicating a higher frequency of preferred hand passing (51%), followed by two-handed (37%) and non-preferred hand passing (12% - $p < 0.01$ for all comparisons). We found a significant effect of pressure when comparing PH and TH passing proportions between conditions (Estimate = 0.146; SE = 0.07; Z = 2.212; $p = 0.03$), indicating an increase in PH passes (LPG: 49%; HPG: 53.5%) and a decrease in TH passes (LPG: 38.7%; HPG: 35.4%) from LPG to HPG.

For catching, the model also showed a significant intercept for all contrasts (PH vs. NPH vs. TH), indicating a higher frequency of two-handed catching (75%), followed by preferred (15%) and non-preferred hand catching (10% - $p < 0.05$ for all comparisons). Also, we found a significant effect of pressure on all contrasts for this skill: NPH vs. PH (Estimate = 0.269; SE = 0.17; Z = 2.323; $p = 0.02$), PH vs. TH (Estimate = 0.319; SE = 0.08; Z = 3.802; $p < 0.001$), and NPH vs. TH (Estimate = 0.589; SE = 0.10; Z = 5.868; $p < 0.001$). These results indicate a decrease in TH catches (LPG: 78.6%; HPG: 72.5%), and an increase in both NPH (LPG: 7.4%; HPG: 11.7%) and PH (LPG: 14%; HPG: 15.8%) catching actions from LPG to HPG. Fig. 2 illustrates all the outcomes of hand selection frequency.

The analysis of the success rate of all skills between LPG and HPG is presented in Table 1. We did not observe significant differences in any category. All athletes maintained their success rate with each hand in both game pressure conditions. Additionally, we did not find the effect of hand, indicating similar performance with both hands in all skills.

4. Discussion

In the present study, we compared the frequency of hand use (preferred, non-preferred, and two hands) and success rate of basketball-specific actions between low-vs. high-pressure game contexts, characterized by season period (regular season vs. playoffs) and game location (home-game vs. away-game). During HPG, players increased the frequency of preferred hand passing, but also increased the frequency of non-preferred hand catching, as compared to LPG. For dribbling and shooting, hand frequency was similar between conditions. Therefore, our first hypothesis suggesting that the preferred hand selection would increase during HPG was not accepted. Independent of pressure conditions, our results showed an increased frequency of preferred hand use for all basketball-specific actions. Another relevant outcome was the maintenance of the success rate between LPG and HPG in all of the analyzed skills, rejecting our second hypothesis of decreased performance in the HPG. These results suggest that 1) game pressure (an environmental constraint) can modulate hand selection for specific skills, 2) the preferred hand bias is still present in elite-level basketball, and 3) game pressure does not impair the success rate for these athletes, highlighting movement degeneracy in this population.

Throughout their career, basketball players accumulate several hours of bilateral training in order to enhance bilateral competence. This type of training is particularly important due to the dynamic nature of invasion sports, which demands flexible adjustments from players to select one of the limbs (e.g., hands or feet) whenever necessary. Previous investigations have shown that bilateral competence is associated with successful performance in technical skills in soccer and basketball (Grouios et al., 2002; Stöckel & Weigelt, 2012). Thus, it seems that proper limb selection raises more possibilities of actions and increases the chances of success of a technical skill (Carey et al., 2001). Within this context, our results revealed that the success rate of the analyzed technical skills did not differ between hands, despite different pressure contexts. Dribbling, passing, and shooting presented similar percentage accuracy with both hands (Table 1). Hence, NBA players maintained their performance on both low- and high-pressure conditions. Indeed, athletes at this level of performance present well-developed movement degeneracy, reflected as the ability to perform the same function with structurally different elements (Edelman & Gally, 2001) – which would be understood as efficiently using both hands in our analysis. This trait is crucial in the sporting context, as it allows the athlete to be adaptable and still display accurate performance under task and environmental constraints, showing variability in movement organization as a healthy sign of adaptive behavior (Seifert et al., 2013). Additionally, we suggest that the NBA players may already be used to playing under high pressure, further accounting for their ability to maintain a similar success rate with both hands in these situations. In fact, Ibáñez, Santos, and García (2015) verified that elite-level basketball athletes were less

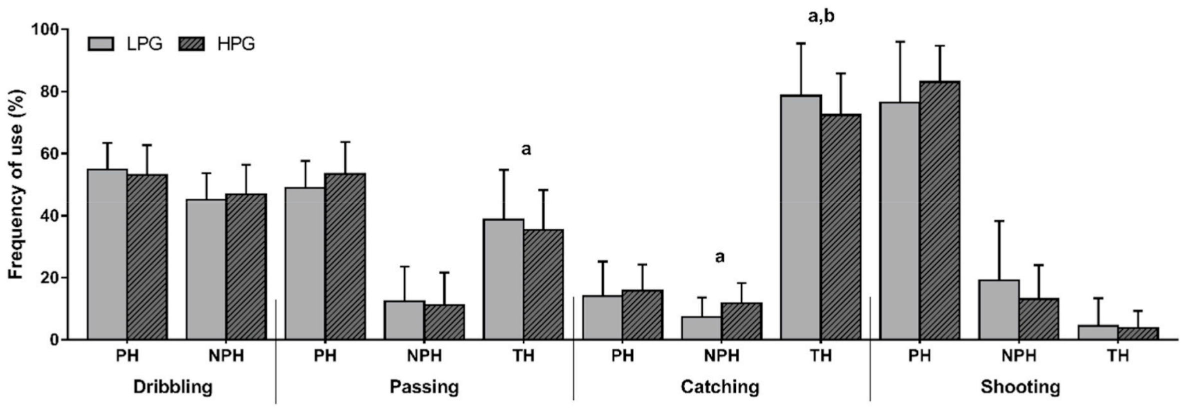

Fig. 2. Hand use frequency in low- (LPG) and high-pressure games (HPG) for different skills (PH: preferred hand; NPH: non-preferred hand; TH: two hands). Pressure effect significance from the generalized mixed-effects model is shown as: a = $p < 0.05$ vs PH and b = $p < 0.05$ vs NPH. Data are presented in mean and standard deviation.

Table 1
Success rate (%) in LPG and HPG for each hand and technical skill.

	LPG			HPG			*Estimate*	Z	p
	Left hand	Right hand	Two hands	Left hand	Right hand	Two hands			
Dribbling	99.4 ±0.27	98.9 ±0.48	–	98.1 ±0.55	98.6 ±0.68	–	−0.014	−0.026	0.934
Passing	93.3 ±5.19	96.9 ±0.56	97.6 ±0.71	97.3 ±1.71	97.1 ±0.68	98.6 ±0.37	0.025	0.096	0.924
Shooting	50.5 ±8.03	58.5 ±4.88	–	52.7 ±8.73	55.4 ±6.11	–	−0.112	−0.720	0.472

Note. LPG = low-pressure games; HPG = high-pressure games; Estimate, Z, and p values reported from the pressure effect shown by the generalized mixed-effects model. Data are presented in mean ± standard error.

affected by high-pressure scenarios in their free-throw performance as compared to amateur ones. Previous investigations have also verified no changes in the success rate of shooting skills (2-point and 3-point field goals) between the regular season and the playoffs phase in professional basketball (García et al., 2013; Otten & Miller, 2015). The long-term bilateral practice led professional basketball players to similar proficiency with both hands (Stöckel & Weigelt, 2012), and our results extend this finding by revealing that the success rate of NBA players is not affected by game pressure, as defined in our research.

The long-term bilateral practice of these athletes would lead us to expect a symmetric frequency of hand selection during the game. Contrarily to that assumption, we found a higher number of preferred hand actions in all analyzed skills. Even though there is a bias reduction of hand selection in expert basketball players as compared to amateurs (Stöckel & Weigelt, 2012), we did not observe an equal 50-50 distribution of hand use in our analysis. Dribbling was the skill most close to a symmetric frequency (54 vs. 46%, favoring the preferred hand), while shooting was on the other end of this continuum, with more than 75% of actions being performed with the preferred hand. Although we did not record other shooting actions (set-shots, jump shots, and free throws) that would further increase the number of actions performed with the preferred hand, the right-hand bias for the shooting skills was still verified in our analysis.

Within this context, task complexity and its interaction with the individual's intrinsic dynamics (i.e., inherent coordination disposition) may explain why some skills present a more asymmetrical hand preference than others. According to previous research on handedness, more complex motor tasks are primarily performed with the preferred hand, even in environmental settings that would facilitate using the non-preferred hand (Bryden, 2016; Marcori & Okazaki, 2020). Motor complexity can be defined based on the number of task components (sequential elements) and how they are connected (coordinative elements) (Serrien, Ivry, & Swinnen, 2007; Spedden, Maling, Andersen, & Jensen, 2017). From the ecological dynamics approach, the less complex tasks would provide an optimal scenario for multi-stability, as more stable states of coordinative patterns can emerge to provide the motor solution since the gap between the individual dynamics and the task demand is small (Seifert et al., 2013). As can be observed in basketball, dribbling is a less complex skill in which athletes display a great variety of motor patterns. This multi-stability pattern can reflect creativity from the behavioral standpoint, resulting in distinct functional solutions (i.e. dribbling movements) to the intended task goals (Hristovski, Davids, Araújo, & Passos, 2011). Consequently, higher levels of ambidexterity (i.e., multi-stability) are observed in this skill in both LPG and HPG. Opposed to dribbling, an offensive shooting action (layup, dunk, hook, or tip) requires a higher level of motor complexity, providing fewer opportunities for the emergence of stable attractors (from the handedness point of view), thus creating the need to rely more on the preferred hemisphere. Hence, the athlete would rather use the preferred hand to perform a more complex motor task during the game (i.e., shooting), while both hands could be used to perform the simpler tasks (i.e., dribbling).

Considering the modulation of hand selection by game pressure, our results revealed two significant outcomes: increased reliance on the preferred hand for passing, and increased frequency of non-preferred hand catching during the HPG as opposed to decreased two-handed catching. The increased frequency of preferred hand passing observed in the playoffs can be explained by the constraints-led approach. Taking into account the interaction between the individual, the environment, and the task (Glazier & Davids, 2009), it seems that the more stable attractor (preferred-hand passing) emerges more frequently due to the environmental constraint of pressure. In other words, when confronted with a more pressing scenario, the individual's motor system fluctuates toward the most consistent pattern of coordination to assure accurate performance, thus relying more constantly on the preferred hand. Indeed, the higher use of the preferred hand for passing during HPG may be an active strategy to deal with situations in which using the non-preferred hand would be riskier, as suggested by Carey et al. (2001). Hence, the athletes rely on their preferred hand to guarantee the motor act is performed precisely and accurately when it matters the most (Stöckel & Vater, 2014).

The increased frequency of non-preferred hand catching and the decreased frequency of two-handed catching during the HPG requires additional explanation. A more concerned type of gameplay characterizes the playoff phase (Mandić et al., 2019; Sampaio & Janeira, 2003). Thus, the defensive effort might be enhanced to increase the number of turnovers and keep the offensive actions at bay. We speculate this higher defensive effort does not allow the attacking team to always catch the ball in favored situations, forcing the athlete to use the hand that is available at the moment, thus increasing non-preferred and reducing two-handed catching frequency in HPG. A question may be raised as to why this increased defensive effort would lead to an increment of non-preferred hand use only in catching, and not on the other skills. From the notion that specific behavioral patterns emerge from the interaction between the individual, the task, and the environmental constraints (Glazier & Davids, 2009), catching is the only skill that is passively performed. In other words, the athlete has to adapt to a circumstance in which he has no direct control of the ball. Hence, the defensive effort may have a greater ability to influence an opponent's catching position. On the other hand, dribbling, passing, and shooting are skills that the player is in possession of the ball. And even though defensive players may be more active in the high-pressure scenario, a choice between the right and the left hand could still be made by the athlete. In this case, the pressure would likely induce the opposite effect (i.e., increase the use of the preferred hand), as observed for the passing skill and previously discussed. This finding suggests that an environmental constraint can interact with the individual's perception-action cycle to modulate his motor behavior in different ways depending on the task at hand.

This research is not without limitations. The pressure conditions were defined based upon previous literature, and not measured on-site. We should also mention that professional athletes might perceive the constraints related to game pressure differently when compared to amateur ones, likely being less affected by crowd influence and important games (such as the playoffs). Therefore, the results must be interpreted with caution outside this context and population. Further investigations in the topic should include more contextual information of defensive settings (e.g. driving side induced by the defender, distance between attacker and defender, or which side of the court the action is being performed) aiding to explain how specific constraints can modulate the selection and accuracy of manual actions in basketball.

Our results expand those of previous investigations by showing how game pressure modulates hand frequency in each skill differently. Moreover, some practical perspectives could be explored based on our results. Practitioners could develop defensive strategies to diminish the shooting efficiency of the opposing team. For example, if there is an 80% chance of a shooting action to be performed with the preferred hand, defensive efforts should be primarily directed to that hand in order to prevent or intercept the action. Coaches could use this knowledge to properly manipulate environmental constraints, such as pressure, and allow the athletes to explore distinct and variable behavioral outcomes, such as non-preferred hand actions. Similarly, athletes might benefit from increasing their bilateral competence across all skills to (1) increase possibilities of actions and thus become more unpredictable for the defense, and (2) become less susceptible to be affected by context-related variables.

5. Conclusion

Our results showed that game pressure could selectively modulate hand preference for passing and catching skills in elite-level basketball. The NBA players increased the frequency of preferred hand passing and non-preferred hand catching during high-pressure situations while decreasing the two-handed catching frequency. Moreover, the right-hand bias was observed for all skills, but more strongly for the shooting actions (layups, dunks, tips, and hooks). Interestingly, the success rate was similar between the hands in both low- and high-pressure conditions for all skills, evidencing movement degeneracy in this population.

CRediT authorship contribution statement

Bruno Giovanini: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Alexandre Jehan Marcori:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Pedro Henrique Martins Monteiro:** Conceptualization, Investigation, Writing - original draft, Writing - review & editing. **Victor Hugo Alves Okazaki:** Conceptualization, Writing - review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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