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Augmented-Feedback Training Improves Cognitive Motor Performance of Soccer Players

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[1]Department of Neurosciences and Movement Science, University of Fribourg, Fribourg, SWITZERLAND; [2]Laboratoire de Psychologie et NeuroCognition, University Grenoble Alpes, Grenoble, FRANCE; [3]Swiss Association of Football, Muri, SWITZERLAND; and [4]Swiss Federal Institute of Sport Magglingen SFISM, Section for Elite Sport, Magglingen, SWITZERLAND

ABSTRACT

HICHEUR, H., A. CHAUVIN, V. CAVIN, J. FUCHSLOCHER, M. TSCHOPP, and W. TAUBE. Augmented-Feedback Training Improves Cognitive Motor Performance of Soccer Players. *Med. Sci. Sports Exerc.*, Vol. 52, No. 1, pp. 141–152, 2020. **Purpose:** In this study, we tested the hypothesis that augmented feedback (AF) training can improve both perceptual–cognitive and/or motor skills specific to soccer. **Methods:** Three groups of young elite players (U14–U15 categories) performed a test consisting in passing the ball as accurately and as quickly as possible toward a visual target moving briefly across a large screen located at 6 m from the player. The performed task required players to correctly perceive the target, anticipate its future location, and to adequately adjust the pass direction and power. The control group (CON) performed normal soccer training and was compared with two visuomotor training groups (AF and no-feedback [NF]) that followed the same training regime but integrated series of 32 passes three times per week over a 17-d period into their normal soccer training. Objective measurements of the passing performance were provided using a high-technology system (COGNIFOOT) before, during, and after training. During training, only players of the AF group received visuoauditory feedback immediately after each trial informing them about the accuracy of their passes. **Results:** The results show that only players of the AF group significantly improved passing accuracy, reactiveness, and global passing performance (+22%), whereas the NF group only improved passing accuracy. None of these parameters was improved in the CON group. The objectively measured changes in passing performance were compared with the more subjectively judged passing performance provided by coaches and players. Coaches' judgments were more reliable than players' judgments and exhibited a training group effect comparable to the ones objectively measured by COGNIFOOT. **Conclusions:** This study provides evidence that the training of cognitive motor performance in soccer players highly benefits from the use of augmented feedback. **Key Words:** SOCCER, PASSING PERFORMANCE, COGNITION, AUGMENTED-FEEDBACK TRAINING

The search for procedures allowing quantitative assessments of the cognitive performance of players in real situations represents a challenge for sport scientists and coaches (1). In the case of soccer, a game characterized by a huge variety of perceptual and decisional processes (2), there is no standardized test that measures the cognitive performance in field situations (3), which is in sharp contrast to the existence of several standardized field tests allowing the assessment of physical performance parameters (4).

In a recent study (5), we introduced a quantitative test to assess cognitive-motor performance (CMP). In the context of soccer, CMP is defined as the ability "to quickly gather game-relevant information and use this information to adequately execute a certain motor task." Using a simple passing test, we observed that with increasing age of the players, CMP improved linearly with average gains of 4 cm (passing accuracy), 2.3 km·h^{-1} (passing speed [PS]), and 30 ms (response time [RT]) per year of age. Importantly, coaches who were asked to evaluate CMP performance of the participating players differed considerably in their evaluation, and only the mean value of all coaches came close to the objectively assessed CMP values. This shows that it is extremely difficult to judge CMP performance without any objective and reliable measures.

In the present study, we followed an approach based on two concepts, namely *augmented feedback* (for a review, see (6)) and *perceptual learning* (for a review, see (7–9)). *Augmented-feedback learning* is well known in sport sciences: it refers to the positive role of external feedback provided to participants when learning new skills or improving the efficiency of learned skills (6). Here, external feedback corresponds to any feedback provided in addition to the feedback naturally transferred by sensory receptors during task execution (10). In visual neuroscience, *perceptual learning* refers to the "long-term performance increase resulting from visual perceptual experience," even for basic visual functions like visual acuity (9). This visual perceptual experience can be acquired through repetitive exposure to

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specific stimuli. A nice example is that of a radiologist who can identify cancer in an x-ray picture that untrained observers cannot see (9). Similarly in soccer, the repetitive exposure to specific visual stimuli allows goalkeepers to improve their prediction of penalty directions (11). In this study, goalkeepers followed home training using repetitive stimuli (temporally occluded videos of penalty kicks filmed from the perspective of the goalkeeper) and were asked to predict the direction of the ball: goalkeepers who received a feedback during training improved their anticipation skills (assessed through verbal responses of goalkeepers following presentation of occluded videos of penalty kicks) significantly more than the placebo (no feedback provided during training) and control groups.

The interaction of the underlying sensory–perceptual mechanisms with the motor execution level relies on a brain circuitry which is involved in both trial-and-error learning and augmented feedback learning (12).

In this study, we tested the hypothesis that augmented feedback training can improve both perceptual–cognitive and motor skills during a passing situation in soccer, namely, the capacity to accurately anticipate the visual consequences of an action and/or the quality of the movement itself. This led us to design a passing situation which is more demanding than the one we previously tested (which included only static visual targets and distractors, see (5)) and closer to a typical game situation. Indeed, passing the ball to a moving partner requires the cognitive ability to correctly anticipate the future position of the partner and the motor ability to adequately adjust the pass force and direction following this estimation. To this purpose, we monitored the improvements in passing performance of three groups of young elite soccer players, each receiving different types of training or feedback.

METHODS

Participants

Players. Twenty-seven elite young soccer players (males, U14 and U15 categories) participated in this study. They belonged to the same elite youth soccer academy and were playing at a Swiss-national level (highest level in Switzerland). They had participated in the sport within a club for a minimum of 5 yr and were training for at least 7 $h \cdot wk^{-1}$ (divided into four to five sessions per week) in addition to the weekly competition yielding a minimum of 8.3 h of soccer-specific practice per week. For the purpose of the study, they were divided into three groups of nine players: the augmented-feedback training group (AF group, age = 14.6 ± 0.4 yr, whole soccer practice experience = 6.4 ± 0.9 yr, including 4.1 ± 0.8 yr at the elite level), the no-feedback training group (NF group, age = 14.3 ± 0.6 yr, whole soccer practice experience = 6.7 ± 0.9 yr, including 3.9 ± 0.9 yr at the elite level), and the control group (CON group, age = 14.3 ± 0.8 yr, whole soccer practice experience = 6.6 ± 0.7 yr, including 3.9 ± 0.8 yr at the elite level). These players were trained by five expert coaches (including one goalkeepers' coach). All participants (coaches, players, and players' parents) provided informed consent, and the research procedures were approved by the local ethics committee. The experiments took place in a covered hall within the National Youth Sports Centre of Tenero (Switzerland).

Coaches. Six coaches (one head coach of the academy and the five coaches mentioned above) participated in the study by providing their judgments about the performance level of the young players under their responsibility (see Procedure section). The coaches were experienced (10.5 ± 7.9 yr of coaching practice, including 5.8 ± 3.7 yr at the elite level) and certified trainers. They hold Union of European Football Associations-A (n = 3) and Union of European Football Associations-B (n = 3) licenses.

COGNIFOOT System

The COGNIFOOT system (patent pending at the Swiss Federal Institute of Intellectual Property under the reference *CH00215/16*) is a real-time high-technology system combining a visual environment simulator synchronized with motion capture and ball-launching systems. In the present study, we used a prototype of this system (COGNIFOOT v1—without ball-launching robots) that we installed in a turf-artificial grass playfield on which players could execute real soccer skills while facing a large screen. The whole setup is detailed below.

Playfield and support structures. The playfield size was equal to 8 × 10 × 5 m (length × width × height). Artificial-grass floor texture (PurTurf 32; Realsport ®, Rossens, Switzerland) covered the floor (see Fig. 1). Metallic structures were located around the playfield to support motion capture cameras that were placed at a height of 4.5 m (Fig. 1).

Large screen and visual environment projection. A large screen (10 × 4 m—width × height) made of a shock-absorbing tissue was located at a distance of 6 m from the ball position (Fig. 1). The visual environment was projected onto the screen using a beamer BenQ MH740 (BenQ Corporation® Taipei, Taiwan) located behind the player at a distance of 9 m to the screen and at a height of 2.9 m. The beamer was connected to a laptop (HP Elite Book; Hewlett-Packard ®, Palo Alto, CA) via the HDMI port. The generated image size was equal to 5.12 × 2.88 m (width x height). The default image background was black (same as the screen color) to ensure a constant contrast of the background over repetitions.

Real-time ball motion tracking and screen calibration. Briefly, the ball motion was tracked in real-time with 11 Optitrack Prime 17W cameras (NaturalPoint © OR, USA). Small infrared light reflective soft markers were fixed on the ball (standard diameter of 22 cm). The 3D ball position (*X, Y,* and *Z* spatial coordinates according to a reference frame centered on the initial ball position) was streamed in real time at a frequency of 360 Hz to the laptop. Ball coordinates were processed on-line using a self-written "main program" in Matlab (Mathworks Inc., Natick, MA) to compute parameters related to the CMP (see next section). The calibration of the screen was performed using four markers located at the corners of the projected image. This allowed a conversion of the target

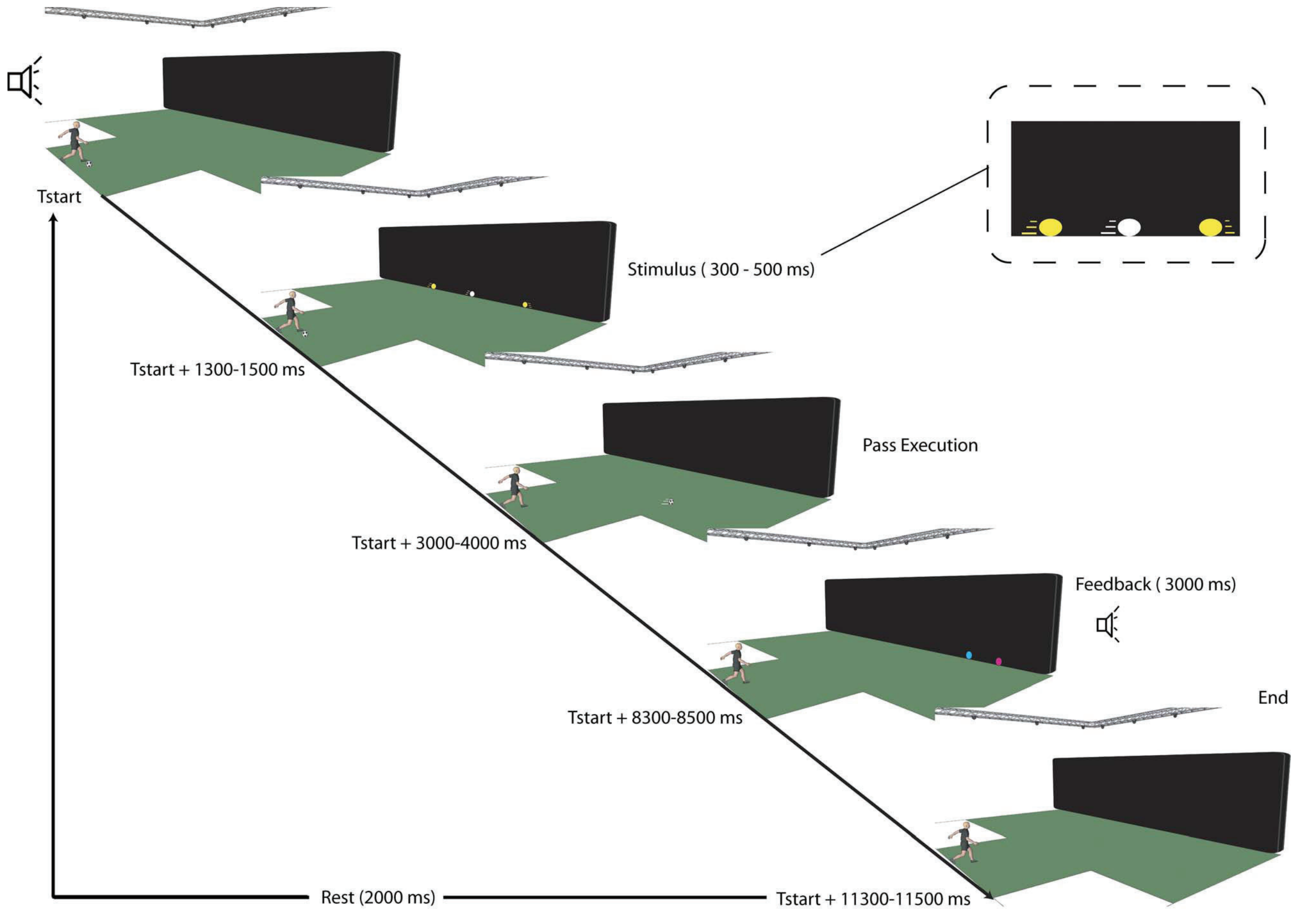

FIGURE 1—Illustration of the passing test. A trial begun with a sound emitted by the main program and was followed 1 s later by the visual stimulus onset. The player then executed a pass toward the (estimated) future position of the moving target. A visuoauditory feedback signal could be delivered at t = 8.3 to 8.5 s. The ball was brought back to the player position by two assistants and the player then replaced the ball and waited for the next sound (see text for details).

position from pixels to (Y, Z) coordinates. Postcalibration measurements guaranteed the accuracy of ball position measurements (e.g., the distance between the center of the circle displaying the ball impact position on the screen and the real ball center impact position did not exceed 1 cm). Details about this procedure can be found elsewhere (5).

Reliability of the RT measurements. The automatically computed RT were verified manually using a video-based image-by-image control procedure (see Hicheur et al. (5) for details). Nine films, recorded using a high-speed camera (CASIO EXILIM; Casio © Tokyo, Japan—sampling rate: 600 frames per second), were taken from a point of view allowing viewing simultaneously the initial ball position and the screen during a passing test. The correlation coefficient between the manually computed RT (delay between the stimulus appearance on the screen and the first movement of the ball) and automatically computed RT (COGNIFOOT v1) was equal to 0.99, guaranteeing that the computation of RT was reliable.

Procedure

Visual stimulus. The properties of the visual environment (e.g., the number, location, and duration of the stimuli, inter-trial displays) were programmed using self-written Matlab routines and the Psychophysics Toolbox extensions (13–15) in Matlab. A total of 32 stimuli (one stimulus per trial) were used during a single test or training session. The target plus the distractor(s) constituted one stimulus (Fig. 1). The player faced a large screen onto which a white circular target (diameter = 0.20 m) appeared randomly (players could not anticipate the location of the upcoming target) at one of three randomly generated eccentricities (left, center, and right), and at a height of 0.10 m (so that the whole target was viewed as "lying on the floor"). The central position of the target was located directly in front of the initial ball position (distance of 6 m, 0 degree of visual angle along the eye–target longitudinal axis, perpendicular to the screen). The left and right positions were located −1.71 and +1.71 m away (−15.9° and 15.9° of visual angle) from the player. The target then immediately moved horizontally in the left or right directions, respectively. The animation (speed and direction) of the target motion were fixed differently in the pretraining/posttraining and training sessions, respectively. The target appeared without distractors in one third of the trials.

Yellow circular distractor(s) (one or two, same size as the target) appeared together with the target in two-thirds of the trials. Both distractors' positions and movements were pseudo-randomized across trials. The stimulus duration was equal to 500 ms: the choice of such a short duration prevented players from kicking the ball before or during stimulus presentation, as tested in our previous study (5). The target position and motion direction were set so that targets appearing first in the center could move leftward or rightward while targets appearing first in the left/right parts of the screen could move rightward/leftward, respectively.

Passing test. *Instructions.* Players were asked to (a) pay attention to the target motion which will quickly disappear and (b) pass the ball as accurately and as quickly as possible toward the future position of the—nonvisible—target. In agreement with the coaches, we told players that this situation was similar to the one where they would have to pass the ball to a running teammate. Players were, thus, required to correctly anticipate the future (virtual) target location and to adjust the passing force and passing direction. They were orally instructed to find the optimal trade-off between reactiveness and passing accuracy.

Familiarization trials. Before each testing protocol, players performed six passes to become familiar with the task. They all received feedback about their performance at this stage (see Feedback Structure section).

Passing test sequence. The structure of a complete passing test with feedback is provided in Figure 1. Briefly, players were stepping in place nearby the ball which was always placed at the same initial position (6 m). To maintain a good consistency when measuring the RT, players were not allowed to execute more than one step before foot-to-ball contact after stimulus onset. A trial begun with the same sound and was followed 1 s later by the visual stimulus onset (Fig. 1). The player then executed a pass toward the (estimated) future position of the moving target. Once the ball had hit the screen, the ball was sent back to the player by two assistants who were located at the edges of the screen. A visuoauditory feedback signal was delivered at t = 8.3 to 8.5 s to all players during the familiarization trials only and to players of the AF group during all training trials (see Augmented Feedback section). The player then placed the ball at the initial position and waited for the next sound. A period of 12.3 to 12.5 s separated the end of the stimulus appearance and the sound announcing the subsequent trial so that a single trial lasted at least 13.3 s. A rest period of 25 s was included after 16 trials. Each player performed a total of 32 trials during a particular session (pretraining, training, or posttraining—see next section). The passing test typically lasted around 7 min and 30 s.

Passing test conditions. The 32 passes/trials performed by players during one session were divided into four main visuomotor conditions, which were categorized as PC-VR, PC-VL, PL-VL, and PR-VR, respectively. PC, PL, and PR denote passes toward the center, left, or right (eccentric) parts of the screen, respectively. VL and VR denote leftward or rightward visual motion directions of the target, respectively. For each visuomotor condition, the speeds of the visual target were determined with coaches during pilot tests. Hence, two target speeds were tested during both pretraining and posttraining sessions (1.20 and 1.63 $m \cdot s^{-1}$, for *moderate* and *fast* speeds, respectively) and could be combined with four types of distractors' movements (zero distractor, one or two distractors moving in a direction similar to that of the target but at different speeds and two distractors moving in opposite directions—with one direction similar to that of the target motion), yielding a total of eight possibilities for each category of pass. The speed of distractors varied from trial to trial: it was randomly selected among speeds ranged between 100% and 144% of the *moderate* and *fast* target speeds, respectively. During the training session, the target speed also varied from trial to trial (see next section). All conditions were randomly generated so that players could not anticipate the upcoming stimulus.

Augmented feedback. We provided both visual and auditory feedback signals to inform players about their performance (through a gamification routine) while maintaining a high level of motivation throughout training sessions. The visual feedback consisted in presenting for 3 s on the screen both the ball impact position (a purple circle) and the virtual target position at the instant of impact (a blue circle showing the position of the target if it would have continued moving until impact, see Fig. 1). A sound was simultaneously provided at the beginning of the visual display. The sound (maximum duration of 2 s) was played from a sample list of 12 sound files (extracted from the game Super Mario Kart, 1992; Nintendo©) which were classified following a positive/negative reinforcement approach (16): six sounds were classified as positive and were used to reinforce accurate passes (error <30 cm), whereas six sounds were classified as negative and were used to indicate insufficient accuracy (error >30 cm). Within each category, the sound changed with 5-cm intervals (positive sound P1 was played for errors less than 5 cm, P2 was played for errors comprised between 5 and 10 cm, and so on). This gamification of training was dedicated to keeping a high level of motivation of players by informing them of both their commitment to and their progress on the task (1). All "AF group" players declared that both visual and auditory components of the feedback signal motivated them to perform better throughout training sessions.

Training protocol. *Structure of the training protocol.* All players (AF group, NF group, and CON groups) were tested before (PRE) and after (POST) the training period which lasted 17 d on average. No feedback was provided to them during these sessions (except for the six PRE "familiarization" passes described above). During the training period, all players followed a normal training program in the academy. In addition, players of the AF group and NF group performed eight COGNIFOOT-training sessions (TR01 to TR08, three sessions per week) while players of the CON group did not (and served as controls). Players of the AF and NF groups performed their COGNIFOOT training during normal training sessions. Thus, all groups (AF, NF, and CON) received a comparable overall training time during the whole intervention. Three players (one from the AF group and two from the CON group, respectively) were slightly injured during a competition game on week 2, and their remaining training/posttraining sessions were delayed by 1 wk. Players who followed the training sessions performed the posttraining tests 4 d after the last training session: this was done to exclude any fatigue effect at retesting and to favor the consolidation of potential training-related CMP improvement.

Pretraining and posttraining test sessions. The PRE session allowed us recording a baseline CMP level for all players who were re-tested in similar conditions after the training period (POST). During each of these test sessions, players perform 32 passes without receiving feedback following the conditions described above.

Training sessions. During each training session, players of the AF group and the NF group also performed 32 passes. However, although only four target speeds (two target speed magnitudes × two possible directions) were used in PRE and POST trials, the target speed magnitude and direction varied from trial to trial during the training session. The target speeds were randomly selected among 32 uniformly distributed speeds ranged between 100% and 144% of the *moderate* and *fast* target speeds (relatively to the PRE/POST trials' conditions), respectively. The rationale for this was that such randomly presented target speeds (including more than half of "suprathreshold" speeds—compared with the *fast* speed used in PRE and POST trials) prevented players from learning only specific speeds across training sessions. Such variety in visual stimuli resulted in increased task difficulty: this was expected to facilitate CMP improvement during the POST session (see Walton et al. (1) for a discussion of how task difficulty should be increased during cognitive training). The most important difference of the training sessions between groups was that only AF group players received an augmented feedback signal (as described above) after each pass.

Measures

A total of 1728 passes were recorded during the PRE and POST sessions (27 players × 32 conditions = 864 passes for each session); 4608 passes were recorded during the training sessions (18 players × 32 conditions × 8 sessions). The trials where players shot before the appearance of the stimulus (negative RT) were excluded from the analysis. This represented a total of 6 passes (of 1728) and 42 trials (of 4608) for the PRE/POST and training sessions, respectively. As mentioned earlier, passes were divided into four visuomotor categories (passes toward the center PC-VR/PC-VL and eccentric passes PL-VL/PR-VR) based on the part of the screen where the ball was sent (center, left, or right) and the direction of the target visual motion (left or right).

Passing performance: Objective measurements. The RT (in milliseconds), the passing spatial error (PSE, in centimeters), and PS (in kilometers per hour) of players were computed automatically as described previously (see Hicheur et al. (5) for details). Briefly, RT was computed as the delay between the instant of stimulus onset and the first instant of physical ball motion. Passing spatial error was computed as the absolute distance between the ball position at impact (ball center) and the virtual position of the target at the instant of impact (e.g., the position of the target if it would have continued moving until impact). In addition, we computed a global passing performance index (GPP). The GPP index was computed as GPP = $(RT_p + PSE_p)/2$, where RT_p and PSE_p were expressed as percentages of minimum RT (500 ms) and PSE (20 cm) values, respectively. The GPP was higher for players with both greater reactiveness (smaller RT) and greater passing accuracy (smaller PSE). Note that we tested other ways to compute the GPP (multiplying the RT and PSE parameters in their original dimensions or testing different RT and PSE values to compute RT_p and PSE_p) and that this yielded similar effects.

Passing performance: Coaches and players' judgments. Coaches were asked to judge the passing performance level of all tested players before and after the PRE and POST sessions. Players and coaches were also asked to judge potential improvements of players. Importantly, they were both told that their judgments had to be based on a passing situation on the pitch, where a particular player would have to pass the ball to a moving teammate running 5 to 10 m away from him (the closest situation to the passing test designed for the present study). Coaches were not informed about the performance of players during the passing tests when providing judgments.

They were asked to assess four aspects of the passing performance of every player. This was done through individual interviews between coaches and the same experimenter. A questionnaire had to be filled by each coach, and the role of the experimenter was to explain the assessment procedure and instructions to coaches. For every line (player) of the questionnaire table, coaches had to use three graduated five-point horizontal scales to assess, from low to high, the reactiveness (RE), the passing accuracy (PA) and the PS/power (PS, see 5 for details). Objective measurements of the passing performance were compared to coaches' judgments. For this purpose, COGNIFOOT measurements (RT, PSE, and PS) were converted into REscore, PAscore, and PSscore using the same five-point scales used by coaches (see Hicheur et al. (5) for details). The GPPscore was computed as (PAscore + REscore)/2. The evolution of the passing performance measured by COGNIFOOT (POST minus PRE scores) was compared with coaches and players scores obtained from the questionnaires. The detailed procedure for collecting judgments was adapted from our previous study (see Hicheur et al. (5) for details) and is detailed in the Appendix (see Supplemental Material, Methods section, http://links.lww.com/MSS/B711).

Statistical Analysis

We performed repeated-measure ANOVA to compare the mean performance of players (RT, PSE, PS, and GPP variables) during the PRE and POST sessions across AF group, NF group and CON group. This was done for the 1728 recorded passes and for the three groups of players (the six missing passes were replaced with the median value across players for a particular condition). Because we focused on the differential effect of the type of training on a potential performance improvement, we report in details the *training* (POST − PRE) × *training group* (AF group/NF group/CON group) interaction effect in the main article. The main effects of the pass category (PC-VR, PC-VL, PL-VL, and PR-VR), the target speed (moderate or fast), and the type of distractors' motion (no distractor, one distractor or two distractors), as well as any significant interaction effect, are detailed in the Appendix (see Supplemental Digital Content, section Effects of training on passing performance, http://links.lww.com/MSS/B711). ANOVA were preceded by visual inspection of the normal probability plots of the residuals. In case of violations of normality, we applied Box–Cox transformation to the data (17). We also performed Levene tests to check for homogeneous variances across periods and groups' comparisons.

The evolution of the performance gain over the eight training sessions was analyzed using repeated-measures ANOVA (N = 4608 passes, here also, the 42 missing passes were replaced with the median value across players for a particular condition of a particular training session). All ANOVA were followed up with planned contrasts.

The internal consistency of coaches' judgments was measured using the ω_h coefficient (18,19): a value of ω_h equal to or above 0.7 indicates that scores are coherent across coaches (which would then validate the computation of mean coaches' scores). We then performed ANOVA to compare the effects of the training group on the perceived performance changes across PRE and POST sessions.

RESULTS

Effects of Training on Passing Performance

The PRE and POST passing performance parameters are presented in Figure 2. The differential effects of the type of training on the passing performance parameters are detailed. All other statistically significant effects (main effects of training, target speed, visual distractors and category of passes, and associated interaction effects) are documented in the Appendix (see Supplemental Digital Content, section Effects of training on passing performance, http://links.lww.com/MSS/B711). Importantly, we did not observe any statistically significant difference between AF group/NF group/CON group players before training (PRE) for each of the computed performance parameters (RT/PA/GPP/PS, $P > 0.05$).

Response times. On average, RT were significantly shorter after training ($F(1,24) = 32.0$, $P < 0.01$, $\eta_p^2 = 0.57$; 911 ± 103 vs 831 ± 91 ms for PRE and POST sessions, respectively). However, a statistically significant PRE/POST training x group effect ($F(2,24) = 10.0$, $P < 0.01$, $\eta_p^2 = 0.45$), followed by planned contrasts (AF group vs NF group/CON group: $t(24) = 4.46$, $P < 0.001$) indicated that RT were significantly shorter after training only for the AF group (AF group: 943 ± 68 vs 774 ± 68 ms; NF group: 902 ± 105 vs 873 ± 92 ms; CON group: 888 ± 131 vs 846 ± 90 ms for PRE vs POST sessions, respectively; Fig. 2A). Thus, only players of the AF group significantly improved their reactiveness after training (the corresponding evolution of performance is indicated as percent in Fig. 2A).

Passing spatial error. On average, PSE (Fig. 2B) decreased by 7.43, 7.42, and 1.11 cm after training, for the AF group, NF group, and CON group, respectively. Here, we observed normality violations so PSE were normalized before ANOVA using a Box–Cox transformation ($\lambda = 0.25$; $PSE_n = (PSE^{\lambda} - 1)/\lambda$). Levene tests also revealed that variances were unequal across

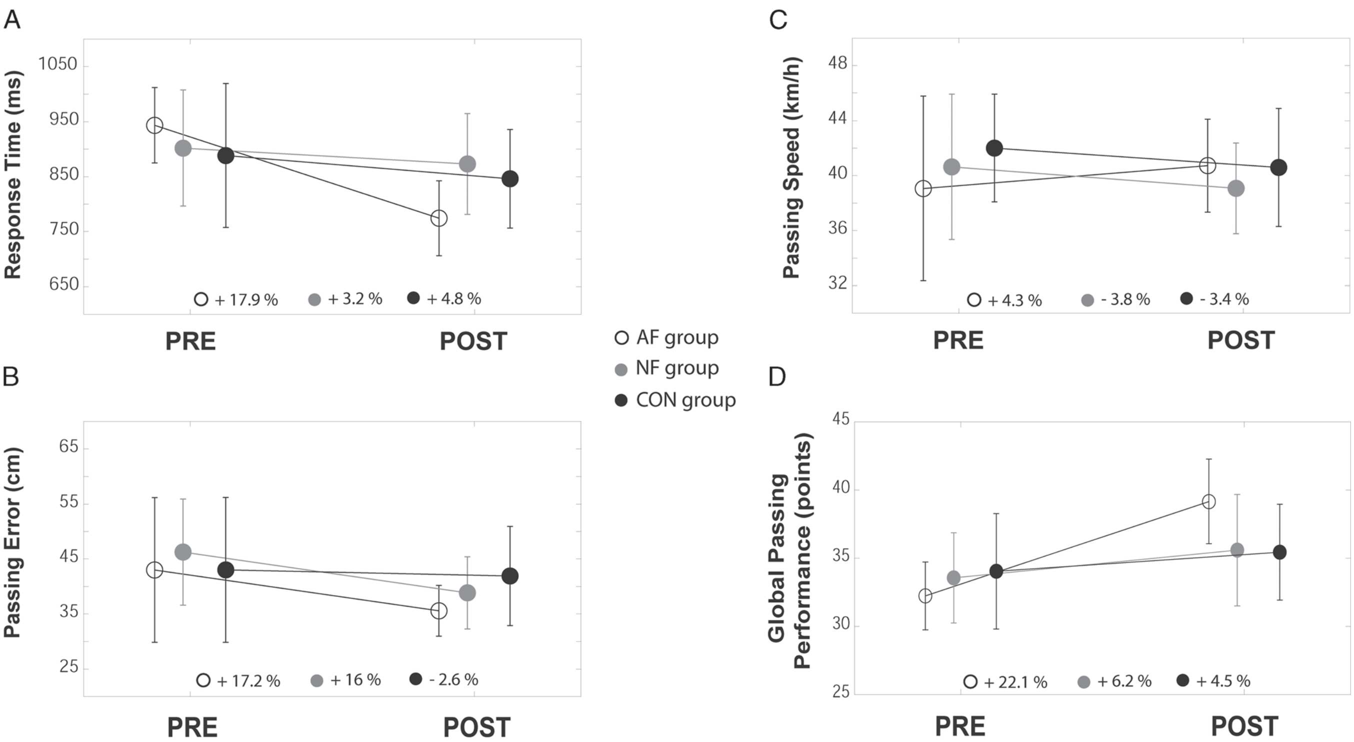

FIGURE 2—Passing performance levels (A, RT; B, passing error; C, PS; and D, GPP) measured by COGNIFOOT before (PRE) and after (POST) the training protocol for the three groups of players (Augmented-Feedback AF group and No-Feedback NF group, and control CON group).

groups for the POST training period ($F(2,24) = 3.93$, $P = 0.03$). Interestingly, the Levene test was not significant when only AF group and NF group data were included ($P > 0.05$): the variability of PSE became significantly smaller for the AF group/NF group data compared with the CON group after training. We, therefore, excluded the CON group data from the following ANOVA. ANOVA revealed a significant effect of *training* on PSE ($F(1,16) = 5.02$, $P = 0.04$, $\eta_p^2 = 0.24$), with smaller PSE after *training* (mean ± SD: 44.5 ± 11.4 and 37.2 ± 5.7 cm for *PRE* and *POST* sessions, respectively). No PRE/POST training–group effect was observed ($P > 0.05$, $\eta_p^2 = 0$), indicating that AF group and NF group players improved their passing accuracy to a similar extent after training.

Passing speed. On average, PS (Fig. 2C) increased by 1.7 $km \cdot h^{-1}$ and decreased by 1.6 and 1.4 $km \cdot h^{-1}$ after training, for the AF group, NF group, and CON group, respectively. These changes were not found to be significantly affected by training or by a PRE/POST training–group effect ($P > 0.05$, $\eta_p^2 = 0.01$).

Global passing performance. On average, GPP (Fig. 2D) increased by 6.93, 2.04, and 1.40 points after training for the AF group, NF group, and CON group, respectively. Here, we observed normality violations so GPP were normalized before ANOVA using a Box–Cox transformation ($\lambda = 1.75$; $GPP_n = (GPP^{\lambda} - 1)/\lambda$). ANOVA revealed that GPP significantly increased after training (33.3 ± 3.43 and 36.7 ± 3.59 cm for PRE and POST periods, respectively; $F(1,24) = 30.0$, $P < 0.001$, $\eta_p^2 = 0.55$). A significant PRE/POST–group interaction effect ($F(2,24) = 4.70$, $P = 0.019$, $\eta_p^2 = 0.28$), followed by planned contrasts (AF group vs NF group/CON group: $t(24) = 9.38$, $P < 0.01$) indicated that GPP was significantly larger after training only for the AF group (32.2 ± 2.49 and 39.2 ± 3.09 cm for PRE and POST periods, respectively). No statistically significant PRE/POST difference ($P > 0.05$) was observed when testing NF group and CON group. Therefore, passing performance significantly improved in the AF group only (+22%, Fig. 2D).

Performance Gain during Training

We investigated the evolution of each mean CMP parameter over training sessions (Fig. 3). ANOVA followed by polynomial contrasts (linear and quadratic) were performed on the training sessions to test for any trend describing the effect of training on each CMP parameter.

Response times. The mean RT decreased over all training sessions in the AF group while this held only for the first three sessions in the NF group (Fig. 3A). We observed a significant effect of the group ($F(1,6) = 4.57$, $P = 0.048$, $\eta_p^2 = 0.22$), of the training session rank ($F(7, 112) = 3.77$, $P < 0.01$, $\eta_p^2 = 0.19$), and a training session rank–group interaction effect $F(7, 112) = 4.01$, $P < 0.001$, $\eta_p^2 = 0.20$). The AF group/NF group difference in RT started to diverge at T2 and increased over the following sessions, with a larger variability for NF group. Planned contrasts (AF group vs NF group, and linear/quadratic trends) revealed a different AF group/NF group linear trend across sessions ($t(112) = 2.51$, $P = 0.0230$). Performing the analysis separately on each group revealed that RT evolution over sessions followed (i) a linear and also a quadratic trend over sessions ($t(56) = -2.70$, $P = 0.016$ and $t(56) = 2.14$, $P = 0.048$, respectively) in the AF group, (ii) a quadratic trend over sessions

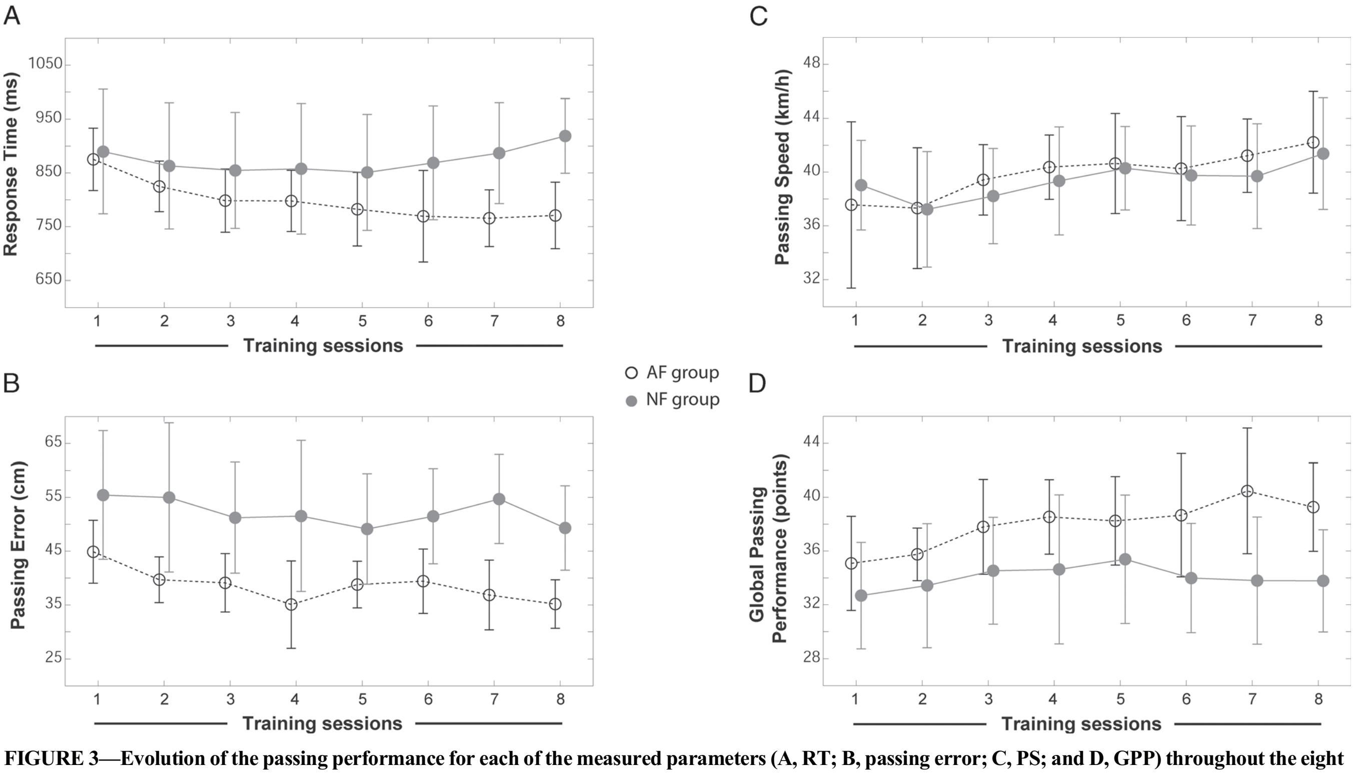

FIGURE 3—Evolution of the passing performance for each of the measured parameters (A, RT; B, passing error; C, PS; and D, GPP) throughout the eight training sessions for the AF group/NF group.