

ORIGINAL ARTICLE



# Mediating Effects of Caffeine Ingestion and Post-Activation Performance Enhancement on Reactive Dive Times in Goalkeepers

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## ABSTRACT

**Background.** Reactive abilities of goalkeepers are crucial and may have direct impacts on match results. Research on factors that may enhance goalkeeper performances during diving tasks (DT), and how these factors are mediated would therefore provide valuable information for coaches and goalkeepers. **Objectives.** The purpose of this investigation was to: (i) assess the impact of caffeine consumption and post-activation performance enhancement (PAPE) on DT ability of goalkeepers and (ii) investigate the potential mechanisms responsible for changes in DT performance. **Methods.** Purposive sampling was utilised, coupled with a double-blinded cross-over study design. A total of 25 soccer goalkeepers volunteered for the study (age:  $22.50 \pm 4.32$  years; height:  $1.67 \pm 0.78$  m; mass:  $66.58 \pm 11.30$  kg). Players were evaluated for simple reaction time (SRT), dynamic reaction time (RT), jump height (JH), and reactive DT under three treatment conditions: control, caffeine, and PAPE. **Results.** Improvements in DT are mediated by improvements in RT rather than changes in JH (i.e. explosiveness) when consuming caffeine ( $\beta = -0.09$ ,  $t(48) = -3.17$ ,  $P = 0.002$ ) or performing plyometric drills ( $\beta = -0.14$ ,  $t(48) = -4.47$ ,  $P < 0.001$ ). Both treatments were similarly effective ( $M_{diff} = 0.00$  sec,  $P < 0.994$ ). **Conclusion.** Caffeine consumption or PAPE are similarly effective in improving goalkeeper DT performances. These improvements may likely be related to changes in dynamic RT thereby implying that faster information processing by the CNS is the likely source for improvements.

**KEYWORDS:** *Ergogenic, Performance Enhancement, Plyometrics, Reaction Time, Soccer*

## INTRODUCTION

Goalkeepers perform a highly specialised role in field sports such as soccer and hockey. Although goalkeepers are the last line of defence, and despite their key role in the team, evidence-based tools for goalkeeper-specific performance improvements are lacking (1, 2). Most research on goalkeepers tends to be limited to anthropometric and physiological characteristics (3, 4), or time-motion analyses (5, 6), with research on perceptual cues and anticipatory skills being much more limited (7, 8). New laws regarding penalties, such as goalkeepers being sanctioned for moving off the goal line too early,

means that goalkeepers are required to enhance their reactive ability (9). Goalkeepers therefore need to ensure that the timing of their movement coincides with ball contact, while also selecting the correct direction within a restricted timeframe (10). Clearly, reactive ability is arguably one of the most critical skills required by goalkeepers.

Data from European top division soccer leagues showed that the teams that won the 2018/2019 seasons tended to average seven shots on target per game (11). Such data would imply that, on average, a goalkeeper from the opposition would need to make game-changing

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decisions/reactions once every 13 minutes and would therefore need to be primed to maximise the likelihood of a successful outcome. Approximately 85-90% of a goalkeepers' sensory information is obtained visually, with hearing being the second most used sense (12). The time it takes a goalkeeper to respond to the sensory information is termed total response time (TRT) which is composed of simple reaction time (SRT) and movement time (MT) (13). The SRT represents the time interval between a sensory stimulus and the appropriate voluntary response to that stimulus, and is thought to represent the individual's processing speed (14). The mean reaction time for college-aged individuals is thought to be approximately 190 msec and tends to average around  $293.2 \pm 76.45$  msec across studies (14, 15). SRT performance may be affected by factors such as type of reaction test, sex, age, constitution, motivation, emotion, intensity of the stimulus, fitness, time of day, fatigue, amount of sleep, and muscles involved (15). Since effective goalkeeping is complex, the evaluation of factors that may acutely enhance dynamic RT and SRT, such as the use of ergogenic aids and muscle potentiation, are imperative (10, 16, 17).

Ergogenic aids are any substances (e.g. recovery aids, cellular metabolites, drugs etc.) that may enhance endurance, power, strength and speed (16). A known ergogenic aid that functions as a central nervous system (CNS) stimulant is caffeine (15-19) which tends to increase alertness and arousal as exhibited by significant reductions in SRT (15, 19, 20), as well as heightening muscle strength and power responses (21, 22). Caffeine acts as an adenosine  $A_1$  and  $A_{2A}$  receptor agonist thereby blunting the fatiguing effects of adenosine (22), and may also act on intramuscular calcium release to increase motor unit activation and maximal contractile force (23); although evidence for the latter is more varied. Evidence has shown that the effectiveness of caffeine exhibits a clear dose-response relationship whereby dosages  $< 2$  mg/kg typically show no significant improvements in performance, whereas dosages of 3 – 6 mg/kg do (18). Similarly, post-activation performance enhancement (PAPE), also considered an ergogenic aid, is known to increase muscle force production through increased (i) calcium sensitivity (especially in type-II muscle fibres),

(ii) muscle temperature, (iii) muscle blood flow, and (iv) neuronal activation (24–26). PAPE also exhibits a dose-response relationship with performance in that (i) PAPE activities that preceded performance measures by 7-10 minutes usually showed superior results, and (ii) multiple PAPE sets of moderate intensity are superior to single sets of high intensity (19). However, the extent to which the above-mentioned mechanisms function to alter reactive diving ability within soccer goalkeepers is presently unknown.

Given the importance of RT for goalkeeping performances, the purpose of this study was two-fold: (i) to assess the impact of neuromuscular perturbations, in the form of caffeine and PAPE, on reaction diving ability of goalkeepers using a double-blinded crossover study design and (ii) to determine the latent mechanisms responsible for potential changes in reactive diving performance.

## MATERIALS AND METHODS

**Study Design.** A randomised, double-blinded repeated-measures cross-over design was used. Participants completed a total of 6 sessions, each under a different treatment condition: familiarisation and baseline assessments, followed by plyometric, passive, placebo and caffeine trials completed in a randomised sequence to avoid an order effect. Each session was separated by 48-72 hours. All testing was completed at the same time of day ( $\pm 0.30$  h) to minimise the potential effect of circadian rhythms on physical performance.

**Participants.** Purposive sampling was utilised to recruit goalkeepers for the study from the Eastern Cape province of South Africa. Following the recruitment process, a total of 25 soccer goalkeepers across 10 soccer teams volunteered for this study (age:  $22.50 \pm 4.32$  years; height:  $1.67 \pm 0.78$  m; body mass:  $66.58 \pm 11.30$  kg). The *a-priory* sample size was calculated to be 55 participants (assuming:  $f^2 = 0.15$  [moderate],  $\alpha = 0.05$ , power = 0.80, and 2 predictors) (G\*Power, version 3.1.9.4). For eligibility into the study, participants had to: (i) be collegiate-level soccer goalkeepers, (ii) have at least 2 years playing experience, (iii) be free of injury prior to and during testing, and (iv) sign the informed consent form. Following eligibility into the study, participants were then informed: (i) of any potential risks and discomforts associated

with testing, (ii) to avoid strenuous exercise and caffeine 24 hours prior to testing, and (iii) to arrive for testing in a well hydrated and post-prandial state. The study was approved by the university research ethics committee and complied with the declaration of Helsinki (ethics code: H18-HEA-HMS-008).

**Experimental Protocol.** During the first visit, participants completed the (i) informed consent forms, (ii) baseline anthropometric data such as height (measured to the nearest 0.01 m) and weight (measured to the nearest 0.01 kg), and (iii) familiarisation bouts of the testing protocols and procedures. The second visit was utilised to determine baseline values for all tests (simple auditory and visual RT, fitlights RT using hands and feet, squat jump (SJ) height, and reactive dive times). Sessions 3-6, completed in a randomised order, were comprised of plyometric, passive, placebo, caffeine modifications of the same baseline tests.

**Caffeine vs. Placebo Trials.** Caffeine doses of 4-6 mg/kg BW were administered in the form of a capsule (Caffeine Anhydrous BP, Medicolab, Amalgam, Johannesburg, South Africa) (18). Placebo capsules were filled with corn flour which is similar in texture and appearance to that of powdered caffeine to ensure adequate blinding (Maizena, Bokomo Foods, Atlantis, Cape Town, South Africa). Both caffeine and the placebo were placed in non-transparent blue-red capsules to ensure that visibility of the contents was shielded from participants. To ensure a double-blinded approach, an independent researcher randomised the dissemination of capsules to the participants for each session.

**Post-Activation Performance Enhancement vs. Passive Trials.** During the PAPE session, participants performed a short plyometric drill consisting of a total of 40 jumps (10 squat jumps, 10 ski jumps, 10 tuck jumps and 10 lunge jumps). The drill was followed by 3 minutes of rest prior to completing the SJ. The 40 jumps were based on previous research which suggested a volume of 40 jumps is enough to induce potentiation (19, 20). The 3 minutes rest was based on previous research which found the greatest PAPE obtained from a plyometrics bout is after 3-7 minutes (21-23). Each participant served as their own control for the PAPE session by utilising a passive session, where the participants stood still for 8 minutes prior to each test. The 8 minutes was

selected for three reasons: (i) the ATP-PC system is required for a short duration exercise bout (ii) previous research shows that the ATP-PC system recovers quickly, approximately after 4-5 minutes (24), and (iii) to minimise any arousal after having arrived at the testing station.

Adequate, dynamic warm-up protocols preceded all testing, and were followed by a 30-minute cool-down session.

**Data Collection. Reaction Time.** Simple visual RT (VRT) was used to estimate visual processing speed. Participants were required to place one foot on a pressure sensitive mat linked to a light-emitting device (Whole Body Reaction Type II, Takei Kiki Kogyo Co., LTD., Japan) (25). When a light stimulus was presented, participants were required to remove the foot from the mat as fast as possible to stop the timing system. A total of 10 successful trials were recorded, with the average being retained for analysis. For the dynamic RT tests, 8 fitlights (FITLIGHT Sports Corp, Aurora, Ontario Canada) were programmed to be activated in a random sequence for a total of 32 individual activations. The fitlights were placed in a grid formation on a wall, with each light being separated by 0.80-m. Participants were positioned 0.50-m from the wall and were required to deactivate the lights as fast as possible using their hands and feet. Following the familiarisation, the average of all 32 activations was retained for analysis.

**Squat Jump.** Jump height was measured using a jumping mat (SmartJump; FusionSport, Coopers Plains, Queensland, Australia) and measuring the flight time (26). Participants were positioned on the jump mat with arms akimbo and instructed to squat as low as possible. The bottom position was held for 1-second before exploding up as fast as possible while keeping the arms on the hips throughout the movement. Participants were directed to land with straight legs and to cushion the landing by flexing the hips, knees and ankles. A total of 3 trials were recorded for each athlete, with the highest jump being retained for analysis.

**Reactive Diving.** Participants were positioned 0.50-m behind a set of timing gates that, once triggered, would set off a second pair of timing gates positioned 1.0-m to the front, and 1.50-m on either side, of the participant. The bilateral timing gates would be set-off at random, and participants

were required to complete a total of 10 reactive dives (5 left, 5 right). The heights of the timing gates were set at 0.75-m (first set), and 0.30-m (bilateral) to simulate diving to the corners of a goal. The average reactive dive time was retained for analysis.

**Statistical Analysis.** All data are presented as mean  $\pm$  SD unless otherwise stated. Data was assessed for normality using the Shapiro-Wilk test. The mediation analysis was completed by evaluating, through regression analysis, whether the mediator (e.g. reaction time or jumping height) could predict the performance of the dependent variable to a greater extent than in the absence of the mediator (27, 28). Differences in the predictive capacity of the model between mediator inclusion and exclusion were evaluated using the Sobel Test. To evaluate the practical significance of changes in DT as a function of the treatment, equivalence testing was utilised, with confidence bounds set at  $0 \pm 0.05$  sec (29). Treatment effects (caffeine vs. PAPE), evaluated as differences from baseline ( $M_{diff}$ ), were evaluated using the paired t-test with a Tukey correction. Statistical significance was accepted at the alpha level of 0.05 (30). All statistics were conducted using Jamovi (The Jamovi Project, v1.1, Computer Software; retrieved from <http://www.jamovi.org>) and Microsoft Excel™ (29).

## RESULTS

The mediating roles of RT and JH were evaluated on the relationships between treatment (T1: caffeine vs. control; T2: PAPE vs. control) and DT. In terms of T1, the results revealed that the total effects of treatment on DT (c pathway, panel A Figure 1) were significant ( $\beta = -0.14$  sec,  $t(48) = -4.75$ ,  $P < 0.001$ ,  $pr^2 = 0.32$ ) (Table 1). With the inclusion of the mediating variable (RT), the impact of the T1 on DT (c' pathway) was no longer significant ( $\beta = -0.04$  sec,  $t(47) = -1.12$ ,  $P = 0.271$ ,  $pr^2 = 0.03$ ). The indirect effects of T1 on DT through RT (ab pathway) were statistically significant ( $\beta = -0.09$ ,  $t(48) = -3.17$ ,  $P = 0.002$ ), thereby implying that the relationship between T1 and DT is fully mediated by changes in RT. The Sobel test determined that the ab effect was significantly greater than zero,  $Z = 3.08$ ,  $p = .002$ . Similarly, the mediating role of explosiveness (i.e. JH) was evaluated on the same relationship between T1 and DT (panel B, Figure 1 and Table

1). With inclusion of the mediating variable (JH), the impact of the T1 on DT was still significant ( $\beta = -0.12$  sec,  $t(47) = -4.46$ ,  $P < 0.001$ ,  $pr^2 = 0.30$ ), suggesting that the relationship between T1 and DT was not mediated by changes in JH. The Sobel test verified that the c- and c'-pathways were not significantly different,  $Z = 1.22$ ,  $P = 0.221$ .

With regards to T2, the results showed that the total effects of the treatment on DT (c pathway, panel C Figure 1) were significant ( $\beta = -0.14$  sec,  $t(48) = -4.53$ ,  $P < 0.001$ ,  $pr^2 = 0.30$ ) (Table 1). When the mediating variable (RT) was included in the relationship between T2 and DT, the association was no longer significant ( $\beta = -0.01$  sec,  $t(47) = 0.25$ ,  $P = .803$ ,  $pr^2 < 0.00$ ) (c' pathway, panel C Figure 1). The indirect effects of T2 on DT, mediated through RT (ab pathway), were found to be significant ( $\beta = -0.14$ ,  $t(48) = -4.47$ ,  $P < 0.001$ ), thereby implying that the relationship between T2 and DT is fully mediated by changes in RT. The Sobel test verified that the ab effect was significantly greater than zero,  $Z = 4.35$ ,  $P < 0.001$ . Finally, the mediating role of lower extremity explosiveness was evaluated on the relationship between T2 and DT (c pathway), which was significant ( $\beta = -0.14$  sec,  $t(48) = -4.53$ ,  $P < .001$ ,  $pr^2 < 0.30$ ) (panel D, Figure 1). Although inclusion of the mediator reduced the magnitude of the relationship between variables, the association was still significant ( $\beta = -0.11$  sec,  $t(47) = -3.65$ ,  $P < .001$ ,  $pr^2 = 0.22$ ) (c' pathway). Given that the indirect effects of T2 on DT (ab pathway) were not statistically significant ( $\beta = -0.03$ ,  $t(48) = -1.87$ ,  $P = 0.067$ ), the implication is that the relationship between T2 and DT was likely only partially mediated by JH, but not to an appreciable extent since the c- and c' pathways were not significantly different (Sobel:  $Z = 1.83$ ,  $P = 0.067$ ).

Caffeine trials yielded faster RT compared to baseline ( $M_{diff} = -0.14$  sec, 95% CI [-0.18, -0.09],  $P < 0.001$ ) as did PAPE trials ( $M_{diff} = -0.14$  sec, 95% CI [-0.17, -0.10],  $P < 0.001$ ) (Figure 2). Improvements in RT between caffeine and PAPE trials were not significantly different ( $M_{diff} = 0.00$  sec, 95% CI [-0.04, 0.04],  $p = 0.994$ ) (Figure 2), and both fell outside the equivalence bounds ( $P = 0.999$ ). Improvements in RT/DT of 0.05-0.19 sec are considered practically meaningful on the basis that this represents the discrepancy between average penalty kick velocity and goalkeeper movement time (31).



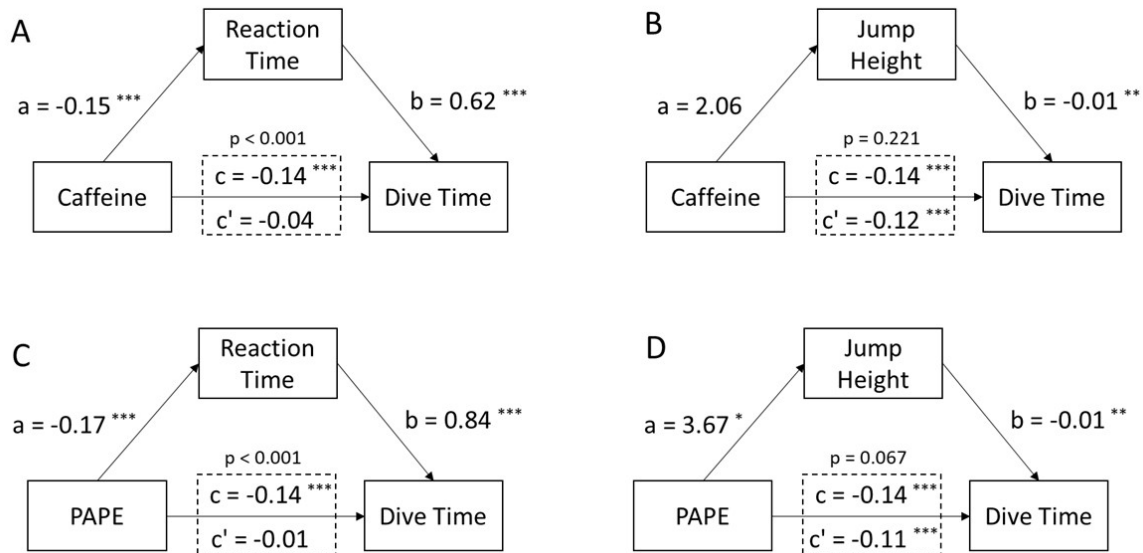


Figure 1. Mediated relationship between treatment condition (i.e. caffeine; PAPE) and reactive diving times with either RT or jump height as the mediator

Table 1. Model Summaries for Mediation Analyses

Model: Caffeine → RT → DT	F	P	R <sup>2</sup>
Treatment Condition predicting Diving Times	(1, 48) = 22.56	<0.001	0.32
Treatment Condition predicting RT	(1, 48) = 54.52	<0.001	0.53
Treatment Condition and RT predicting Diving Times	(2, 47) = 19.50	<0.001	0.45
Model: Caffeine → JH → DT	F	P	R <sup>2</sup>
Treatment Condition predicting Diving Times	(1, 48) = 22.56	<0.001	0.32
Treatment Condition predicting JH	(1, 48) = 1.82	0.184	0.04
Treatment Condition and JH predicting Diving Times	(2, 47) = 17.23	<0.001	0.42
Model: PAPE → RT → DT	F	P	R <sup>2</sup>
Treatment Condition predicting Diving Times	(1, 48) = 20.51	<.001	0.30
Treatment Condition predicting RT	(1, 48) = 64.56	<.001	0.57
Treatment Condition and RT predicting Diving Times	(2, 47) = 29.14	<0.001	0.55
Model: PAPE → JH → DT	F	P	R <sup>2</sup>
Treatment Condition predicting Diving Times	(1, 48) = 20.51	<0.001	0.30
Treatment Condition predicting JH	(1, 48) = 5.87	0.019	0.11
Treatment Condition and JH predicting Diving Times	(2, 47) = 15.51	<0.001	0.40

Where: RT, reaction time; DT, dive time; JH, jumping height; PAPE, post-activation performance enhancement

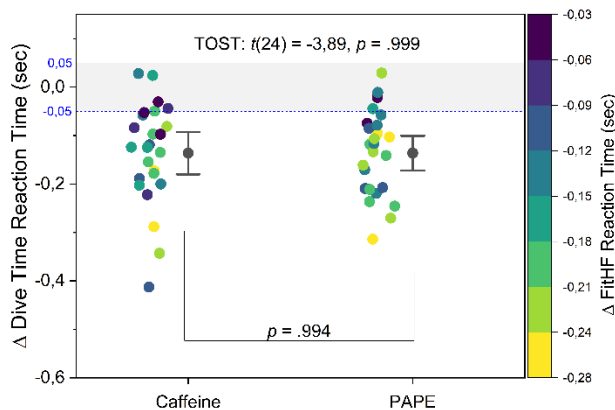


Figure 2. Data for paired t-test of the mean difference between treatment (caffeine and PAPE) and baseline, and equivalence bounds for the two one-sided t-test (TOST). Data points are color-mapped based on the dynamic RT results (FitHF)

## DISCUSSION

The novel findings of the present study showed that: (i) both caffeine and PAPE, when compared to control conditions, can improve reactive diving in goalkeepers, and (ii) the potential mechanisms of the improvement in diving performance are likely mediated by changes in dynamic reaction time, which may be considered a proxy for central nervous system processing, rather than changes in explosiveness, which may be considered a proxy for muscular force output.

Caffeine appears to be an effective ergogenic aid for achieving acute increases in muscle power expressed as a single vertical jump height (32). While several different mechanisms have been proposed to underlie the performance-enhancing

effects of caffeine, the main pathway appears to be stimulation of the central nervous system (CNS) (33). The caffeine-mediated antagonism of adenosine receptors tends to induce higher catecholamine concentrations in the brain, which reduce downregulation of adenosine, thereby increasing arousal and nervous system activity (34). Although the present study showed that caffeine consumption was associated with greater jumping height, this was not significantly different from the control condition. Therefore, at least within the present study, the most likely mechanism by which caffeine appears to attenuate improvements in DT is via enhanced dynamic RT.

PAPE, on the other hand, tends to enhance performance via increased force or power output following some form of high-intensity voluntary contractions (35, 36). Interestingly, compared to the control condition, the PAPE treatment was associated with a significantly greater jumping height, however, this did not appear to be the mediating mechanism by which DT was improved. Instead, it seems as though PAPE also enhanced the CNS stimulation by improving the dynamic RT in a similar manner to that achieved by the caffeine treatment. Like caffeine, exercise can induce a neurotransmitter-receptor interaction. In fact, PAPE and caffeine treatments were similarly effective in improving reactive DT. To be practically meaningful, the DT would need to improve by at least 0.05-0.19 sec to increase the probability of initiating a save (31). Therefore, the 0.14 sec improvements achieved in either treatment fell well within these bounds.

Based on the potential limitations of successfully initiating PAPE during soccer match-play, caffeine may trump PAPE as the favoured mechanism by which performance could be enhanced. The half-life of caffeine is approximately five hours (range 1.5 – 9.5 hours), implying is that caffeine concentration will only decrease by half every five hours (37). The acute performance-enhancing effects from caffeine, although not assessed within the present study, are therefore likely sustained for a whole soccer match, including extra time. The acute effects of PAPE, on the other hand, are tapered within several minutes of its initiation (38, 39) and would likely need to be repeated sporadically throughout discreet periods of match-play. Combining the two ergogenic aids could also be an effective

alternative as caffeine may facilitate the release of  $Ca^{2+}$  from the sarcoplasmic reticulum, which is the primary mechanism known to enhance excitation-contraction coupling following a conditioning activity (40). Guerra et al. (22) reported a 5.75% increase in vertical JH following a combination of caffeine ingestion and plyometrics in professional male soccer players. However, based on the results of the present study, it is unlikely that improvements in JH lead to improvements in goalkeeper-specific performances. The potential synergistic effects of caffeine and PAPE could offer a practical method for optimising goalkeeper performance which should be considered for future research in order to gain insight into its application in practical settings.

## LIMITATIONS

Although there are numerous strengths to the present study, several limitations were also present. Firstly, the interindividual caffeine metabolism kinetics were unknown, and it is therefore unclear how quickly caffeine could be absorbed and metabolised across individuals. Secondly, no objective measures of gastric emptying of caffeine or caffeine tolerance, nor consideration of familiarity with plyometrics or fitness levels were assessed during this study. These might have impacted the magnitude of the intervention response. Thirdly, only male participants were included in the sample, therefore the generalisability to female goalkeepers is unknown.

## CONCLUSION

Consuming 4-6 mg/kg BW of caffeine or completing a short plyometric drill to induce a PAPE effect, appear to be similarly effective in enhancing reactive diving ability of goalkeepers. In both instances the likely mechanism for the improvement appears to be mediated through changes in dynamic RT thereby implying that faster CNS processing is the likely source for improvement.

## APPLICABLE REMARKS

Goalkeeper reactive diving performances (DT) are enhanced by similar mechanisms when ingesting caffeine or completing a PAPE drill. The ergogenic improvements are likely to be transferred to on-field performances on the basis that DT was enhanced within practically meaningful ranges.

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