ASYMMETRIES IN ISOMETRIC FORCE-TIME CHARACTERISTICS ARE NOT DETRIMENTAL TO CHANGE OF DIRECTION SPEED

ABSTRACT

The purpose of this study was to determine the impact of between limb asymmetries in IMTP force-time characteristics on change of direction speed (CODS). Twenty multisport collegiate athletes (mean ± *SD*: age: 21.0 ± 1.9 years; mass: 78.7 ± 8.9 kg; height: 1.77 ± 0.04 m) performed three unilateral stance IMTP trials per limb and three modified 505 CODS trials each side to establish imbalances between left and right, and dominant (D) and non-dominant (ND) limbs. Limb dominance was defined as the limb that produced the highest isometric force-time value or faster CODS performance. Paired sample t-tests and Hedges' *g* effect sizes revealed no significant differences in IMTP force-time characteristics and CODS performance between left and right limbs ($p > 0.05$, $g \leq 0.37$). However, significant differences were observed between D and ND limbs for all IMTP force-time characteristics and CODS performance ($p < 0.001$, $g = 0.39$-0.73). No significant correlations were observed between IMTP asymmetries and CODS asymmetry ($p \geq 0.380$, $r \leq -0.35$), and no significant differences were observed in CODS performance between athletes of lesser and greater IMTP asymmetries ($p \geq 0.10$, $g \leq 0.76$). Poor percentage agreements (40-60%) between like for like classifications of asymmetry (i.e. either both asymmetrical or both balanced) for CODS and IMTP force-time characteristics were demonstrated. Asymmetries in IMTP force-time characteristics and CODS performance were present; however, greater IMTP asymmetries had no detrimental impact on CODS performance and did not equate to greater asymmetries in CODS performance. Therefore, collegiate athletes with asymmetries within the range reported within this study (≤13%) should not experience detriments to CODS or faster performance from that limb during 180° turns.

Keywords: imbalance; performance deficit; impulse; peak force

INTRODUCTION

The ability to change direction quickly while running at high speed is essential for many multidirectional field and invasion sports (26). Change of direction speed (CODS) is of great importance and is defined as 'the ability to decelerate, reverse or change movement direction and accelerate again' (22). No immediate reaction to a stimulus is required as, the direction change is pre-planned; this requires no perceptual or decision making factors (5). Successful CODS performance is suggested to be influenced by a variety of factors including technique (body lean and posture, foot placement, stride adjustment), straight line sprint speed, and strength and power leg qualities (strength, power, rate of force development and reactive strength) (32, 38).

Importantly, the strength qualities that an athlete possesses are essential because when changing direction an athlete must possess sufficient eccentric strength (braking phase), isometric strength (plant phase) and concentric strength (propulsive phase) to allow rapid deceleration and subsequent reacceleration in the new intended direction (34, 35). Athletes must reposition their center of mass during when changing direction, with faster CODS performance associated with the application of horizontal and vertical ground reaction forces (GRFs) and impulse whilst maintaining optimal body positioning (33). Research has demonstrated that faster CODS performance (i.e. completion time) is influenced by the force production, movement mechanics and the strength capacity that an athlete possesses (9, 33-35).

Isometric strength is a fundamental mechanism underpinning change of direction ability, with several investigations demonstrating that faster athletes during CODS tasks display greater isometric peak force (PF) (7, 35, 36), and greater isometric rate of force development (RFD) (7) and impulse (IP) over 100, 200 and 300 ms (36). These specific isometric force-time characteristics can be evaluated during the isometric mid-thigh pull (IMTP), which yields high reliability (14) and low measurement error (6). Additionally, Thomas et al. (37) demonstrated faster 505 left and right performance was inversely associated with greater unilateral IMTP PF (r = -0.47 to -0.65) in male academy cricketers. Muscle strength asymmetry (MSA) refers to the relative strength differences and deficits between limbs (23), with a strength discrepancy of 10-15% or more between two sides considered to represent a potentially problematic asymmetry (27). An investigation using a unilateral stance IMTP for the assessment of MSA has recently shown significant differences in IMTP between dominant (D) and non-dominant limbs (ND) in collegiate multi-sport athletes ($p < .001$, d = 0.43–0.91) and professional male rugby league players ($p < .001$, d = 0.27–0.46) (10). Collectively, these studies highlight the importance of assessing the bilateral and unilateral force-time capabilities of athletes in relation to CODS performance.

A contentious issue in strength and conditioning and rehabilitation is MSA and its influence on athletic performance and risk of injury. Greater MSA has been linked to negative performance during vertical jumping (1, 3), while asymmetries in unilateral drop jump height (29, 38) and isokinetic eccentric hamstring strength (27) may also be detrimental to CODS. Conversely, investigations have failed to demonstrate a negative impact of asymmetries in jump distance and height (vertical, horizontal and lateral) (26), unilateral vertical jump power (19) and isokinetic quadriceps strength (27) with CODS. These conflicting results may be explained by the fact that the magnitude of MSA are task dependent (18, 23), may vary between different muscle strength qualities such as concentric, eccentric, isometric, reactive and dynamic strength (18, 23, 27), and fluctuate between different athlete populations (28). Moreover, the magnitude of asymmetry can be further influenced by the equation to calculate MSA (4).

Direction changes require high braking forces and impulses during the penultimate foot contact and final foot contact to reduce the momentum (9, 16, 24), and high propulsive forces and impulses to redirect into the new intended direction (9, 16, 24, 33, 34). D and ND turns are defined by the plant foot which initiates direction; however, a limitation of the research is the assumption that the D and ND legs are in fact the leg used exclusively or predominantly for that performance. Hart et al. (15) has reported performance deficits of ~10% between D and ND directions during the AFL agility test. It could be assumed that being equally proficient in force production would be advantageous for the braking and propulsive requirements of directional changes; however, it is inconclusive whether MSA negatively impacts CODS (19, 26, 27, 29, 38). Previous studies have investigated asymmetries in reactive strength, eccentric and concentric muscle strength qualities on CODS (19, 26, 27, 29, 38). However, no study has yet to determine the effect of between limb asymmetries in isometric force-time characteristics on CODS assessed via the IMTP. There is a pre conceived notion that a stronger limb will lead to faster performance from that limb during CODS tasks (31, 38), however it is unclear if between limb asymmetries in isometric PF and impulse during time intervals similar to CODs ~300 ms (9, 33) will correspond to faster performance from that limb during a 180˚ turn.

The aims of this study were to: 1) compare IMTP force-time characteristics and CODS between left and right, and D and ND limbs, and to determine if significant differences and imbalances were present between limbs in collegiate multi-sport athletes; 2) explore the relationship between the IMTP force-time characteristics asymmetries and CODS asymmetries; 3) compare CODS performance between athletes of lesser and greater asymmetries; 4) examine if a stronger limb equates to superior performance from that limb (direction) during CODS. A modified 505 (mod505) was chosen to assess CODS due to the high reliability and task difficulty (2). It was hypothesized that no significant differences would be found between comparisons of left and right limbs for IMTP force-time characteristics and CODS directions; however, significant differences would be found when comparing D to ND limbs. It was additionally hypothesized that greater isometric asymmetrical differences would be associated with greater CODS asymmetries and athletes with greater isometric asymmetries would demonstrate slower CODS performance. Furthermore, it was hypothesized directional dominance would also be exhibited.

METHODS

Experimental Approach to the problem

A cross sectional analysis of collegiate multisport athletes was conducted whereby the impact of between limb asymmetries in IMTP force-time characteristics on CODS asymmetries and performance were investigated. Pearson's correlation analysis was performed to determine if significant relationships were present for IMTP force-time characteristics between limb asymmetries with CODS asymmetries. Paired sample t-tests were conducted between left and right, and D and ND limbs for unilateral IMTP force-time characteristics and CODS performance to determine if any between limb differences were present, similar to previous MSA research (10, 15, 23, 30). Additionally, subjects were divided into greater and lesser asymmetry groups (asymmetry threshold mean imbalance + 0.2 SD) and independent sample t-tests were performed to explore any differences in CODS between groups (26). Percentage agreements between like for like identifications of asymmetry were performed to determine if asymmetrical limbs corresponded to directional dominance during the mod505 (12).

Subjects

Male collegiate athletes (soccer n = 8, rugby n = 6 and cricket n = 6) participated in this study (n = 20; mean ± sd: age: 21.0 ± 1.9 years; mass: 78.7 ± 8.9 kg; height: 1.77 ± 0.04 m). A minimum sample size of 19 subjects was determined from an a priori power analysis using G*Power (Version 3.1, Univeristy of Dusseldorf, Germany) (11) based upon squared multiple correlation of 0.36 - value of maximum prediction coefficient reported in literature for similar studies (29), a power of 0.8 and type 1 error or alpha of 0.05. Data collection took place in season for collegiate athletes, who at the time of testing were performing a strength maintenance mesocycle. All athletes: 1) participated in a sport that required multiple turns and sprints for the last twelve months; 2) had minimum one-year resistance training experience and were free from lower limb injuries six months prior to testing; 3) instructed to wear appropriate clothing and footwear, not have consumed alcohol 24 hours or caffeine two hours prior to testing, and to maintain their normal diet and refrain from training 48 hours prior to the testing session. The institutional ethics review board approved the investigation, and all subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved consent document to participate in the study.

Procedures

On arrival, all participants had their height (Stadiometer; Seca, Birmingham, United Kingdom) and body mass assessed (Seca Digital Scales, Model 707), measured to the nearest 0.1 kg and 0.1 cm, respectively.

Pre-isometric warm up

All subjects performed a standardized warm-up comprising of 5 minutes of dynamic stretching before advancing to dynamic mid-thigh clean pulls. One set of 5 repetitions was performed with an empty barbell (Werksan Olympic Bar, Werksan, Moorsetown, NJ, USA) followed by 3 unilateral stance isometric efforts on each limb at perceived intensities of 50%, 70%, and 90% of maximum effort, interspersed with 1-minute recoveries.

Unilateral stance isometric mid-thigh pull protocol

Unilateral stance IMTP testing followed the same protocols used in previous research (10, 36). The IMTP testing was performed on a portable force plate sampling at 600 Hz (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia) using a portable IMTP rack (Fitness Technology, Adelaide, Australia). The force plate was interfaced with computer software Ballistic Measurement System (BMS), which allowed direct measurement of force-time characteristics.

A collarless steel bar was positioned to correspond to the athlete's second-pull power clean position (14) just below the crease of the hip. The bar height could be adjusted (3 cm increments) at various heights above the force plate to accommodate different sized athletes. Athletes were strapped to the bar and positioned in their self-selected mid-thigh clean position (6) established in the familiarization trials and told to adopt a unilateral stance whereby one foot was on the force platform with the other unsupported limb flexed at 90˚ knee flexed over the toes, shoulders were just behind the bar, and torso was upright. Knee (144 ± 5˚) and hip (146 ± 6˚) angles were consistent between limbs. Standardized instructions to pull as "fast and as hard as possible" and push their foot into the force plate until being told to stop were provided. Once the body was stabilized (verified by watching the subject and force trace) the IMTP was initiated with the countdown "3, 2, 1 pull," with subjects ensuring that maximal effort was applied for 5 seconds based on previous protocols (14); data was collected for a duration of 8 seconds. Minimal pre-tension was applied to ensure there was no slack in the body prior to initiation of the pull. Strong verbal encouragement was provided for all trials. Subjects performed six unilateral maximum effort trials (three with left and right limbs each) in an alternating order, interspersed with 2-minutes rest. Any trials whereby subjects lost balance or demonstrated a countermovement were excluded, and further trials were performed after a further 2-minute rest period.

Isometric Force-Time Curve Assessment

Isometric force-time data was analysed via BMS software and demonstrated high intraclass correlation coefficients (ICC) and low coefficient of variation (CV) (ICC = 0.71-0.86, CV = 4.4-8.8%). The maximum force recorded during the 5-second unilateral IMTP trials was reported as PF and expressed relative to body mass ($N \cdot kg^{-1}$). Impulse during 200 (IP200) and 300 (IP300) ms were also calculated (area under the force-time curve for each window) from the onset of contraction (40 N threshold), and have demonstrated high reliability measures (ICC ≥ 0.948, CV ≤ 3.2%) (6, 36).

Change of Direction Speed Assessment

After completing the IMTP testing, all subjects received 10 minutes' rest before completing CODS testing. All subjects performed a standardized progressive warm up directed by the investigator similar to the warm ups performed before field based sessions for their sports. The warm up included five minutes of non-fatiguing dynamic stretches, activation and mobilization exercises including body weight squats and lunges before progressing to 10 minutes of foot work, running and turning drills and practice trials of the mod505.

Change of direction speed was assessed by a mod505 (5 m entry and 5 m exit) test on an indoor track (Mondo, SportsFlex, 10 mm; Mondo America Inc., Mondo, Summit, NJ, USA) in the University human performance laboratory following the same procedures as described by Thomas et al. (36). Completion time was measured using single beam (accuracy to 1/1000th of a second) Brower timing gates (Draper, UT, USA) placed approximately at hip height for all athletes and demonstrated high ICCs (ICC = 0.80-0.83) and low levels of variance (CV = 1.9-2.4%). All subjects performed six trials in an alternating order; three changing direction with a left foot plant (CODS left), and three changing direction with a right foot plant (CODS right) interspersed with two minutes' rest between trials. Subjects were allowed three practice attempts to familiarize themselves with the movement patterns required. Athletes were instructed to sprint to a line marked 5 m from the start (starting 0.3 m behind the start line), planting their left or right foot on the line, turn 180° and sprint back 5 m through the finish. Subjects placed their left or right foot on or past the line depending on the trial and were instructed to perform the task as fast as possible. If the subject changed direction before hitting the turning line, or turned off the incorrect foot, the trials was disregarded and the subject completed another trial after a two minute rest period.

Asymmetry index

Asymmetry index (imbalance between right and left limbs) was calculated by the formulae (right leg – left leg/ right leg × 100) for unilateral IMTP variables (30). Limb dominance was defined as the limb that produced the highest isometric force-time value or faster CODS performance (23). Asymmetry index for D and ND limbs was calculated by the formulae (dominant leg – non dominant leg/ dominant leg x 100) for unilateral IMTP variables and CODS performance, in accordance to previous research (30).

Statistical Analyses

Mean ± SD were calculated for all dependent variables and the best performance from each side or limb was used for statistical analysis. Normality was confirmed for all variables using a Shapiro Wilks-test. Magnitude of differences between limbs were assessed with paired sample t-tests, effect sizes calculated using Hedges' *g* method (17) and mean differences with 95% confidence intervals; effect sizes were interpreted using Hopkins' scale (21).

Relationships between imbalances between D and ND limbs for CODS and IMTP force-time characteristics were analyzed using Pearson's product-moment correlation and were Bonferroni corrected to reduce likelihood of type 1 error; correlations were evaluated using Hopkins' scale (20). All statistical analyses were performed using SPSS (version 23, IBM, New York, NY, USA).

To assess the agreement between the D limb for IMTP force-time characteristics and D CODS performance, asymmetry thresholds for each IMTP parameter were established as mean + (0.2 *SD* of the mean) and mean - (0.2 *SD* of the mean) for CODS imbalance (26). Subjects with imbalances which exceeded the threshold were classified as asymmetrical, imbalances below the threshold were subsequently classified as balanced. The overall level of agreement between like for like asymmetries (or balanced) for CODS and IMTP characteristics were calculated by counting the frequency and percentage of like for like classifications of asymmetry i.e. either both asymmetrical or both balanced using the equation (frequency of like for like classifications/ number of subjects) x 100 (12). Percentage agreements ≥ 80% were considered good. Additionally, comparisons in CODS performance were made between lesser (LA) and greater asymmetry (GA) groups via an independent samples t test, similar to previous research (26). The criterion for significance was set at $p \leq 0.05$.

RESULTS

No significant differences were observed between right and left CODS (2.71 ± 0.15 s vs. 2.77 ± 0.14 s, $p = 0.055$, $g = 0.37$), right and left IMTP relative PF (33.8 ± 4.4 $N.Kg^{-1}$ vs. 34.7 ± 4.7 $N.Kg^{-1}$, $p = 0.081$, $g = 0.20$), right and left IP200 (261.2 ± 41.9 N•s vs. 269.9 ± 39.5 N•s, $p = 0.313$, $g = 0.21$) and IP300 (443.9 ±75.8 N•s vs. 467.5 ± 71.9 N•s, $p = 0.122$ $g = 0.31$) However, directional dominance was observed for CODS ($p < 0.001$, $g = 0.71$) and small to moderate significant differences were observed between D and ND limbs for all unilateral IMTP force-time characteristics ($p < 0.001$, $g = 0.39$-0.73) (Table 1). No significant correlations were observed between IMTP relative PF imbalance ($r = -0.03$, $p = 1.000$), IP200 imbalance ($r = -0.11$, $p = 1.000$) and IP300 imbalance ($r = -0.35$, $p = 0.380$) with CODS imbalance. Athletes were divided into greater and lower asymmetry groups with the data presented in Table 2. Significant differences were only observed between IMTP force-time characteristics imbalances between GA and LA groups ($p < 0.001$, $g = 2.15$-2.64), whereas no significant differences in mod505 performance between LA and GA were demonstrated ($p \geq 0.10$, $g \leq 0.76$) (Table 2).

Insert Table 1 around here

Insert Table 2 around here

Insert Table 3 around here

The overall agreement between like for like classifications of identifications (including asymmetrical or balanced) are provided in Table 3 along with frequency of asymmetry classification and individual asymmetry classifications. Poor levels of agreement were observed (40-60%) between like for like identifications of IMTP force-time characteristics and CODS (Figure 1). Specifically, nine subjects were considered asymmetrical for relative PF, however, only one subject displayed directional dominance from the same limb for CODS (Table 3, Figure 1). Similarly, six and seven subjects were classified as asymmetrical for IP200 and IP300, respectively, but only one subject demonstrated an asymmetry that corresponded to directional dominance for CODS (Table 3, Figure 1).

Insert Figure 1 around here

DISCUSSION

The aims of this study were to determine the impact of between limb asymmetries in IMTP force-time characteristics on CODS asymmetries, and to examine if greater between limb asymmetries were detrimental to CODS performance. The primary findings were small to moderate significant differences were revealed between D and ND limbs for all IMTP force-time characteristics ($p < 0.001$, $g = 0.39$-0.73), with faster CODS ($p < 0.001$, $g = 0.71$) to the D side also observed; in agreement with the hypothesis. However, no significant relationships were observed between IMTP and CODS asymmetries, suggesting greater asymmetries in IMTP force-time characteristics will not equate to greater asymmetries in CODS performance ($r \leq -0.35$, $p \geq 0.380$). Contrary to expectations, no significant differences in CODS performance were observed between athletes of LA and GA ($p \geq 0.10$, $g \leq 0.76$), indicating that asymmetries in isometric strength were not detrimental to CODS.

Consistent with the results of previous research comparing strength characteristics between limbs via IMTP (10), isokinetic dynamometry (23, 30), hops (18) and jumps (19), significant differences were revealed in IMTP force-time characteristics between D and ND limbs ($p < 0.001$, $g = 0.39$-0.73). Anecdotally it is thought that a possessing a stronger limb may lead to faster CODS performance from that D limb (31, 38). However, a noteworthy observation was no significant relationships ($r \leq -0.35$, $p \geq 0.380$) and poor agreements (40-60%) between IMTP and CODS asymmetries. Specifically, nine subjects were considered asymmetrical for relative PF, however, only one subject displayed directional dominance from the same limb for CODS (Figure 1). Likewise, six and seven subjects were classified as asymmetrical for IP200 and IP300, respectively, but only one subject demonstrated an impulse asymmetry that corresponded to directional dominance for CODS (Figure 1). These findings refute the notion that a stronger limb as defined by IMTP will equate to superior performance from that limb during COD tasks (31, 38), and agree with the findings of Maloney et al. (29) that observed jump height and vertical stiffness asymmetries did not correspond to CODS asymmetry.

Interestingly, no significant differences in CODS performance was observed between greater and lesser asymmetry groups for IMTP IP200 and IP300 ($p \geq 0.40$, $g \leq 0.07$). In addition, although not statistically different (p = 0.10-0.48), athletes with greater relative PF asymmetries demonstrated slightly faster CODS performance (g = 0.33-0.76), respectively. The results of this study are in agreement with Lockie et al. (26) who also observed no significant differences in 505 and T-Test performance between athletes of GA and LA during unilateral jump tasks. Likewise, Hoffman et al. (19) also observed no detrimental effect of asymmetries in unilateral vertical jump power between D and ND limbs performing the L-run. Conversely, Maloney et al. (29) reported a positive correlation between unilateral drop jump height asymmetry and CODS completion time (r = 0.60, p = 0.009) which contained two 90° cuts. Moreover, Lockie et al. (27) reported mixed and conflicting results within their study regarding the effect of MSA on CODS. Faster athletes during a T-Test demonstrated both significantly greater imbalances in knee extensor torque (assessed at 240°/s) and significantly smaller imbalances in eccentric knee flexor torque (assessed at 30°/s) compared to slower performers. As such, based on the findings of the present study greater asymmetries in isometric force-time characteristics were not detrimental to CODS.

It is worth noting that the present study only investigated isometric strength qualities and a 180˚ turn task; however, MSA is suggested to be task dependent (18, 23), population specific (30) and the biomechanical demands of CODS tasks are angle dependent (8, 13). This in turn may explain the conflicting findings with previous studies regarding the effect of MSA on CODS (27, 29). Assessment of alternative strength qualities also important to CODS such as eccentric, concentric, dynamic or reactive strength may have provided different results (33-35) than those found in the present study. Consequently, there is a requirement for further research conducting a comprehensive assessment of lower limb muscle strength qualities and various angled CODS tasks, to improve our understanding of the impact of MSA on CODS.

Significant differences in CODS were demonstrated between D and ND sides ($p < 0.001$, $g = 0.71$) corroborating the findings of previous research (15, 38). Specifically, seven subjects demonstrated an imbalance in CODS between sides greater than the asymmetry threshold - 4.48% and an overall mean imbalance of 3.83 ± 3.25% (~0.10 second imbalance) was also revealed. Although the CODS imbalance is not as high as the ≥ 10-15% value which has been suggested to represent a significant deficit (25), the CODS imbalance still indicates slower CODS to the ND side, which can therefore be interpreted as a meaningful difference. This could be viewed as problematic in multidirectional sports where it would be advantageous to be equally proficient in changing direction effectively off both limbs due to the unpredictable nature of the sport. Consequently, scientists and practitioners are recommended to inspect both directions in CODS testing batteries; firstly, to eliminate bias to athletes with directional dominance when examining only one direction. Secondly, to identify any imbalances in completion time between sides which can indicate slower change of direction ability to a side.

The results from this study indicate that isometric strength ($p < 0.001$, $g = 0.39$-0.73) and CODS asymmetries ($p < 0.001$, $g = 0.71$) exist in collegiate athletes; however, there were no significant relationships between isometric asymmetries and CODS asymmetries ($r \leq -0.35$, $p \geq 0.380$). In addition, asymmetries in isometric strength were not detrimental to CODS and athletes with an isometrically stronger limb did not display superior turning performance from that D limb during 180° turn tasks (Table 3, Figure 1). However, with a mixed heterogenous sample and low number of subjects displaying high asymmetries > 10-15% (Figure 1), the findings from this study should be interpreted with caution. For example, only three subjects demonstrated relative PF imbalances greater than 10% and no imbalances exceeded 15%; which is suggested to be a problematic asymmetry (25) (Figure 1). Therefore, between limb asymmetries observed in the present study (small to moderate) may not have been high enough to have a detrimental impact on CODS performance. Nonetheless, the present study found no significant relationships between IMTP and CODS asymmetries, no significant differences in CODS performance between athletes of greater and lesser IMTP asymmetries, and poor percentage agreements between like for like identifications of asymmetry. As such, the results of this study indicate collegiate athletes with asymmetries within the range reported in this study (~13%) should not necessarily experience faster CODS performance from that limb, or experience associated detriments in CODS performance. Further research is required to determine the underlying causes of asymmetry in CODS.

PRACTICAL APPLICATIONS

Collegiate athletes display directional dominance during 180˚ CODS performance; therefore, practitioners are encouraged to assess both directions when assessing CODS performance in their athletes to eliminate bias and to identify performance deficits between directions. The unilateral stance IMTP produces reliable measures of isometric force-time characteristics and small to moderate significant differences between D and ND limbs were observed in collegiate male athletes. However, isometric strength asymmetries were not detrimental to CODS, thus collegiate athletes with asymmetries less than the imbalances reported in this study (~13%) should not experience detriments to CODS. Furthermore, the D limb for IMTP force-time characteristics does not necessarily correspond to faster performance from that limb during 180° turns (plant foot).

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