Isometric Mid-Thigh Pull Characteristics in Elite Youth Male Soccer Players:

Comparisons by Age and Maturity Offset

Short Title: Isometric Mid-Thigh Pull Characteristics of Youth Soccer Players

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ABSTRACT

The purpose of this study was to: 1) provide comparative isometric mid-thigh pull (IMTP) force-time characteristics for elite youth soccer players and 2) determine the effect of age and maturation on IMTP force-time characteristics. Elite male youth soccer players (U12 n = 51; U13 n = 54; U14 n = 56; U15 n = 45; U16 n = 39; U18 n = 48) across 3 maturity offset groups (Pre n = 117; circa n = 84; Post-PHV n = 92) performed two maximal IMTP trials on a portable force platform (1,000 Hz). Absolute and relative values for peak force (PF) and impulse over 100 ms and 300 ms, were analyzed. A full Bayesian regression model was used to provide probable differences similar to that of a frequentist p value. Advanced age and maturation resulted in superior IMTP force-time characteristics. Peak force demonstrated high probabilities of a difference between all consecutive age groups (p>0.95). For absolute and relative impulse (100, 300 ms) only two consecutive age groups (U14-15's; U16-18's) demonstrated high probabilities of a difference (p>0.95) with large effects (d =0.59 to 0.93). There were high probable differences between all maturity offset groups for PF and impulse with medium to large effects ($d = 0.56$ to 3.80). These were also reduced when expressed relative to body mass (relative PF, relative impulse). This study provides comparative IMTP force-time characteristics of elite male youth soccer players. Practitioners should consider individual maturation status when comparing players given the impact this has on force expression.

Key Words: IMTP; Soccer; Strength; Maturation; Youth; Football

INTRODUCTION

The physiological requirements of soccer match play are intermittent, placing demands on both the aerobic and anaerobic energy systems (31). General movement demands during a match require players to accelerate, decelerate, change direction, jump and bound (1). These general movements equate to specific match actives that are believed to be instrumental in match outcomes (e.g., intercepting a ball, making a tackle and attempting a shot) (8). All of these motor skills and movements have been directly linked with the ability to produce large quantities of force over short periods of time (42). Therefore, the ability to produce and apply large forces quickly is considered to be important physical characteristics for soccer players (38). However, the assessment and development of strength in young athletes can be somewhat problematic in comparison to senior athletes, given the challenges of strength testing with this cohort, such as safety aspects potentially associated with dynamic repetition testing (11, 39), alongside the impact that growth and maturation may have on performance (14). As such, there is a distinct dearth of empirical data investigating the effect of age and maturation upon whole body strength in youth soccer players.

Maturation has been defined as the progress toward the mature state, which varies in timing, tempo and magnitude between different bodily systems (23). Of particular interest is a period of accelerated growth, known as peak height velocity (PHV) (28, 43) which usually occurs between 12-15 years of age in boys (24) due to subsequent increases in sex hormones (e.g., testosterone, growth hormones) during this period, which is due to puberty. These somatic and hormonal changes have been suggested to impact strength performance (6, 22). However, the large inter-individual variability in the timing of maturation and therefore development of strength, may explain the selection biases commonly associated with youth soccer including relative age effects (3) and maturational selection biases favoring the more mature player (13, 25).

The development or assessment of muscular function, including force production and power, have been investigated in a range of studies in youth populations. Studies use varying assessment methods including hand grip (15, 33), and isokinetic dynamometry (20) for force production and the CMJ for

an assessment of lower limb power (21). Such studies have shown an increase in force production and power with age and/or maturation (18, 21) but limitations exist with the techniques and variables measured in these studies. For example, some of the proposed techniques may be safe and easy to perform in a youth setting but isolate muscles groups (e.g., hand grip, isokinetic dynamometer), can be very costly and require time to undertake (e.g., isokinetic dynamometer) and some may not even be a true measure of strength like the CMJ (21) but more of an indicator into the rapid force production qualities. Furthermore, the variables collected during these assessments may not provide a comprehensive overview of the skeletal muscle function (i.e., ability to produce force rapidly; impulse) of the athlete and instead only represent one aspect (e.g., maximum force capacity). Finally, the assessment of isoinertial strength, obtained via a repetition maximum (RM) in a dynamic movement (e.g., squat) (7) provides limited information on the skeletal muscle function of the athlete and requires appropriate technique to perform. As such, isometric testing could provide extensive information on the force generating capacity of a youth athlete, such as time sensitive variables (impulse, rate of force development) along with the maximum generating capacity (peak force).

The isometric mid-thigh pull (IMTP) test offers a safe and reliable (9, 16), strength assessment with low measurement error (17, 41) and high test-retest reliability in male youth soccer players (11). The IMTP has been used to evaluate lower limb (multi joint) skeletal muscle function of senior athletes (15, 45), adolescent surfers (36), adolescent rugby players (7) female youth soccer players (12), and even in male youth soccer players (2, 11), but no study has considered an age range from 12-18 years old and examined the effect of maturation on strength performance in boys. The IMTP (force time data) can provide extensive information about the maximum and rapid force production qualities of youth athletes within certain time epochs (e.g., 100 and 300 ms) (38), which have been associated with fast (<250 ms) and slow (>250 ms) ground contact times during sprinting and jumping, respectively (35, 42). This information could differentiate between maturation stages of development and provide comparative values for the IMTP.

Due to the importance of strength capabilities to soccer and the relationship between maturation and strength, the purpose of this study was to (1) present the IMTP force-time characteristics of elite youth soccer players aged 12-18 years; and (2) evaluate the differences between age category and maturation (i.e., Pre-PHV, Circa-PHV, Post-PHV). Such information would provide comparative data on the force production capabilities of youth soccer players whilst considering the impact of age and maturation. It was hypothesized that age and maturity would have an overall effect on all IMTP force-time characteristics, with the older and more mature athletes outperforming their younger and less mature counterparts.

METHODS

Experimental Approach to the Problem

A cross-sectional research design was used whereby anthropometric characteristics (height, body mass, sitting height, leg length), maturity offset (age at PHV) and IMTP force-time data were collected within youth soccer players from four English professional soccer club academies. Players were categorized by age (i.e., U12s, U13s, U14s, U15s, U16s and U18s) and by maturity offset (Pre-PHV, Circa-PHV and Post-PHV). This approach allowed comparisons between youth soccer players by age category and maturity offset group.

Subjects

A total of 293 male elite youth soccer players aged 12-18 years (U12 n =51; U13 n = 54; U14 n = 56; U15 n = 45; U16 n = 39; U18 n = 48), recruited from 4 professional soccer academies in England, participated in the study. Age categories were defined by chronological age on the 1st September 2015 which established their status for competition. All experimental procedures were approved by the Leeds Beckett University Ethics Committee with informed and parental consent (for players under 18 years) obtained.

Procedures

All testing was completed within a 4-week period in September 2015 in an indoor facility at the respective clubs. Players were first measured for anthropometric data, followed by the IMTP. Testing was conducted at least 48 hours post competitive match play or strenuous training. Prior to the testing, players carried out a standardized 10-minute warm-up consisting of jogging and dynamic stretching.

Anthropometry

Anthropometry included standing height (cm), sitting height (cm) and body mass (kg) which were measured by a lead researcher. Height and sitting height were measured to the nearest 0.1cm using a Seca Alpha stadiometer. Body mass was determined from body weight and taken to be BWg^{-1} (kg) with g = acceleration due to gravity measured on a commercially available portable force platform (AMTI, ACP, Watertown, MA) using a sampling rate of 1000 Hz then multiplied by 9.81 to convert to Kg. Subjects were required to stand on the force platform until a stable trace was obtained and then the average force over 5 seconds was taken forward. Subjects were instructed to keep hands on their hips to avoid any unwanted movement.

Age and Maturity offset

Chronological age was calculated as the difference between date of birth and the date of assessment. To measure maturity status, an age at PHV prediction equation was used (28). Years from PHV was calculated for each subject by subtracting the age at PHV from chronological age. Subjects were distributed to either Pre-PHV (n=117) (offset < -1 years), Circa-PHV (n=84) (≤ ±1 years) or Post-PHV (n=92) (offset > +1 years) in relation to their YPHV.

Isometric Mid-Thigh Pull

The IMTP was performed on a commercially available portable force platform (AMTI, ACP, Watertown, MA) using a sampling rate of 1000 Hz where unfiltered vertical (Fz) ground reaction force (GRF) were obtained. Participants performed the IMTP on a customized pull rack, with their shoulders placed above the bar, in a self-selected mid-thigh clean position (knee angle of 135–145°

and a hip angle of 140–150°), similar to that of the second pull of a power clean (11). Each participant was required to complete two trials of the IMTP lasting 6 seconds, with 5 minutes rest between trials. A subsequent trial was performed if a discrepancy of >250N for peak force (PF) was observed between trials (17). The initiation of the IMTP was identified using a threshold of 5SD gathered from a 1 second weighing period (standing noise period) before the start of the pull (10). The weighing period had no pre-tension and was verified by watching the athlete and the live force trace. Participants were instructed to pull as "fast and hard" as possible, and received loud, verbal encouragement for a maximum of 5 seconds after the 1 second standing noise period (10). Each participant's best trial, as determined by the highest PF was used for analysis to measure IMTP force-time variables (i.e., PF, relative PF (rPF), Impulse over 100 and 300 ms and relative impulse over 100, 300 ms). Peak force was identified as the maximum force value obtained during the best trial of the IMTP and rPF was calculated as PF / body mass. By analyzing net impulse over the specified time epochs (100 and 300 ms), this will provide practitioners with a theoretical representation of the athlete's ability to perform tasks that are associated with slow and fast SSC activities, as it allows the quantification of the mechanisms that underpin movement (32). Net impulse was calculated using force-time integration (represented as the area underneath the force time curve at 100 ms and 300 ms).

Statistical Analyses

Anthropometric data and IMTP characteristics are reported as means and standard deviations (SDs). Given recommendations made recently by the American Statistical Association (44), objective Bayesian regression was used to identity the differences between age and maturity offset groups and is similar to the traditional regression but provides the probability of a difference. 95% Higher Density Intervals (HDI) illustrate the uncertainty around the estimation and are similar to the traditional confidence intervals, but are more intuitively interpreted, as a 95% chance that a true difference is found in the HDI. They also provide distributional information rather than a mere interval of equally probable values. Probabilities were calculated for all differences between groups (e.g., U12 vs U13; Pre-PHV vs Circa-PHV), but only differences with a probability of 0.95 or greater are reported (p>=0.95). This aligns with the traditional frequentist p-value of <0.05.

Sample effects sizes were calculated using Cohen's d (4) using a MCMC (Markov Chain Monte Carlo) estimation and the uncertainty of this estimate illustrated by lower and upper 95% HDIs. Effect size (ES) values of 0.2, 0.5 and 0.8 were considered to represent small, moderate and large differences respectively (4). Intraclass correlation coefficient (ICC) of and coefficient variation (CV) analysis was conducted for the IMTP variables to report reliability using the ICC pack in R. All analysis was conducted using R (34) using a MCMC pack.

RESULTS

For both, rPF and PF, ICC and CV were $r = 0.98$ (95% CI = 0.97 – 1.00) and CV = 4.91%. Intra class correlation and coefficient of variance for net and relative impulse over 100 ms and 300 ms were $r = 0.72$ (95% CI = 0.59 – 0.87); CV = 8.8%; $r = 0.83$ (95% CI = 0.72 – 0.91); CV = 7.7%.

Table 1 shows the anthropometric each annual age category. Table 2 shows the IMTP characteristics by each annual age category. Table 3 shows the effect size and 95% HDI between consecutive age groups. Absolute PF differed across age categories with a high probability (p>0.95) of PF being greater in the older groups in consecutive age categories. The effects ranged from moderate to large ($d = 0.62$ to 1.66; Table 3) with the larger effects observed between the older age categories (e.g., 16 vs 18). For rPF, only two consecutive age groups (U12-13's & U14-15's) demonstrated a high probability of a difference (p>0.95) albeit with small effects ($d = 0.35 – 0.48$; Table 3). There were no other differences between any other consecutive age groups (p>0.95) but the U13's demonstrated higher rPF values when compared to U14's with a small effect ($d = 0.48$; Table 3). The U15-16's and U16-18's demonstrated small to moderate effects ($d = 0.48- 0.51$; Table 3) with the U18's having the greatest value for rPF.

Both absolute and relative impulse (100 and 300 ms) only demonstrated a high probability of a difference between the U14-15's and U16-18's age categories with moderate-large effects ($d =0.59$ to 0.93; Table 3). However, U13's demonstrated superior performance when compared to the U14's, for impulse over 100 ms and relative impulse over 100 and 300 ms but not for impulse over 300 ms.

INSERT TABLE 1 HERE

INSERT TABLE 2 HERE

Table 4 shows the anthropometric characteristics by maturity offset groups with effect size and 95% HDI. Table 5 shows the IMTP characteristics by maturity offset groups with effect size comparisons between groups (95% HDI). Similar to the differences found in age categories, there was a high probability (p>0.95) of a greater PF and impulse over 100 and 300 ms between maturity offset groups, with medium to large effects ($d = 0.56$ to 3.8; Table 5). The relative force-time characteristics were also greater for the advanced maturity offset groups (p>0.95) but with small to moderate effects ($d = 0.03$ to 0.59; Table 5). The probability of a difference (p>0.95) between Pre-Circa-PHV for rPF and relative impulse over 100 ms was not high with small effect ($d=0.03-0.23$; Table 5).

INSERT TABLE 3 HERE

INSERT TABLE 4 HERE

INSERT TABLE 5 HERE

DISCUSSION

The aims of this study were to (1) present the IMTP force-time characteristics of elite youth soccer players aged 12-18 years; and (2) evaluate the differences between age category and maturation (i.e., pre-PHV, circa-PHV, and post-PHV). Findings suggest that age and maturation influence absolute PF and impulse in youth male soccer players but has less effect on relative strength variables (rPF and relative impulse). Therefore, when absolute measures of IMTP strength are evaluated and used to compare between athletes of the same age, practitioners should account for maturation status of individual athletes when evaluating strength qualities. These data provide reference strength data for elite youth male soccer players, which can be used when monitoring player development and talent identification.

Influence of Age on force-time characteristics

Dos'Santos et al. (11) published IMTP performance in youth soccer players and the values when compared to the current U18's cohort for PF (2230N vs 2267N, respectively), were similar. Dos'Santos et al. (11) however, did not have the age range to conduct age group comparisons unlike this study (U12-18's). The age group comparisons suggest advanced age results in increased PF during the IMTP in youth soccer players. These findings are similar to those reported by Emmonds et al. (12) in female soccer players using the IMTP. When PF was expressed relative to body mass, differences between most consecutive age categories did not demonstrate high probabilities ($p>0.95$). These findings are also similar to those reported by Emmonds et al. (12) for the IMTP, Nikolaidids (33) and Manna (26) in isometric measurements (back and hand grip, respectively). This highlights the impact body mass may have on strength assessments which is important for practitioners working with youth athletes to consider given the variability of body size within annual-age categories, as a result of the large inter-individual variability of maturation. Importantly, these findings and the cited study of Emmonds et al (2017), demonstrate that rPF does not appear to increase across age groups in youth soccer, potentially highlighting poor strength training practices within youth soccer, for both males and females. Therefore, practitioners should look to improve the relative force generating capacity of youth soccer players.

Peak force is single metric at a single time point (23) that represents an athlete's ability to express force maximally (40), albeit in this case, for 0.001 seconds (when sampled at 1,000 Hz). Although peak force can provide information on the maximal force generating capacity, it fails to provide extensive information about rapid force production capabilities of an athlete. As such, net impulse is a determinant for tasks such as jumping (32) and is arguably the most functional and important measure to be taken from an isometric contraction but is not widely used (23). This study demonstrated that from U12 to U18 absolute and relative impulse (100 ms and 300 ms) increased with high probabilities of a difference occurring between some consecutive age categories. However, these differences were not always apparent, for example, the U13's demonstrated superior performance compared to the U14's in impulse over 100 ms and relative impulse over 100 ms (Table 2). Furthermore, the

differences for impulse tended to exist between the older age categories (for e.g., 15 vs 14's, 18 vs 16's; Table 2). This may be explained by factors such as training age, strength training experience as the older players were exposed to specific resistance training sessions and the younger age groups were not, although this specific information was not accounted for in this study. Finally, it must be noted that as age increases so does muscle mass and peak weight velocity (14), which would also contribute to the trend in increasing force production across age categories along with advanced maturity.

The increase in force production across age groups observed in this study are important given the role the impulse-momentum relationship has with dynamic performance, such as jumping (32) and the potential issues associated with measuring one metric, like PF (23). Peak force clearly differs between most consecutive age categories but the rapid force production qualities (i.e., impulse) are inconsistent. Therefore, most consecutive age groups are similar in rapid force production qualities that are fundamental in human movement (impulse) but are not reflected by PF. If practitioners were to rely solely on PF as a metric to differentiate and discriminate between athletes, they may run the risk of wrongfully interpreting and miss important information regarding an athlete's full-strength capabilities. Following this, the lack of probable differences between most consecutive age categories may be explained with the limitations of annual age grouping and large inter variability of maturation within age categories (3).

Influence of Maturation on force-time characteristics

Brownlee et al. (2) used the IMTP in youth soccer players according to maturation group but failed to compare between maturity groups with limited variables analyzed (allometrically scaled PF). Brownlee et al. (2) reported elite players are stronger at baseline performance compared to a control group. Findings from the present study demonstrate maturation impacts on both, PF and impulse in elite youth male soccer players, with those who are more mature achieving superior results. These are in line with findings from Emmonds et al. (12) who demonstrated PF was most likely to very likely greater for more mature players during the IMTP. However, Emmonds et al. (12) reported, impulse

over 100 and 300 ms was likely greater at pre-PHV than circa-PHV, which are different to the current findings. One primary reason may be the gender differences of the two studies. It is understood that female adolescents experience a significant regression in hip abduction strength relative to body mass in the year they transition from pre-pubertal to pubertal status (Circa-PHV) and a decrease in relative strength from pre–post maturation (13). However, the development of strength in boys during puberty demonstrates marked increase in strength as a result of neuromuscular and morphological changes of the muscle around puberty (14, 24, 35). These observations are important for practitioners working within youth development (e.g., talent identification, strength and conditioning) as they should be mindful of the pubertal variation when making direct comparisons between athletes who may differ in maturity status. They should also consider using force-time data that fully represents the maximum and rapid force production capabilities of athletes (38).

Relative PF and relative impulse at 100 ms did not show high probable differences between the Pre and Circa-PHV groups. Similarly, to age, these findings could potentially be explained by poor strength practices in youth soccer environments. Further, during maturation adolescent boys have substantial increases in body mass, comprising of both lean mass and skeletal tissue (25), which may therefore affect relative force generating capacity. Therefore, practitioners should aim to improve rPF within youth soccer players given there is strong associations with performance in athletic tasks (e.g., sprinting, jumping) (5).

In conclusion, the present study presents IMTP force-time characteristics of elite youth soccer players aged between 12 and 18 years and provides comparative data for the assessment of strength via the IMTP. Age and maturation had an overall effect upon IMTP performance, suggesting maximal and time sensitive variables increase with age and maturation. Peak force increased with age and maturation throughout the consecutive age groups and all of the maturity age groups. Impulse is the most functional measure to be taken from an isometric contraction (23) and similarities exist between most consecutive age groups (i.e., U12-13s, U13-14's) but all of the maturity groups were different (i.e., Pre-Circa-PHV). When expressed relative to body mass these findings are reduced, both, rPF

and relative impulse (100 ms) failed to demonstrate the consecutive differences that were observed for some of the absolute values (i.e., U13-14s) and for the maturity groups Pre-Circa-PHV. However, high standard deviations demonstrate that there is large inter-individual variation in IMTP characteristics between individuals within chronological annual-age groups, within youth soccer. This may occur due to numerous factors including maturation, training age, physical ability and response to training. Furthermore, practitioners should consider analyzing both maximal and time sensitive variables when identifying talent, assessing individual player's strengths and weaknesses, and monitoring player development for a true assessment of their force generating qualities. As such, this study only inspected PF and impulse over 100 and 300 ms, and further research is required inspecting potential force time-specific force values at different time epochs (i.e. 50, 200 ms).

Practical Applications

Present findings provide comparative data for English academy soccer players by annual-age-category (U12-18s) and maturation groups (Pre-Circa-Post-PHV) for IMTP performance and as such only represent the average of the population used in the current study and may not necessarily be optimal. It is recommended that such data should be used by strength and conditioning coaches and player development staff to assess, identify and compare the strength and weakness of their player's force-time characteristics. The effect body mass has on IMTP performance is also apparent and direct comparison could be made to dynamic tasks such as sprinting and jumping and coaches should not disadvantage youth athletes based upon size. Furthermore, the large degree of inter player maturation observed highlights the importance of tracking the development of characteristics on an individual and longitudinal basis. Finally, there are differences between age categories and absolute strength but little difference exists when expressed relative to body mass. This finding is quite concerning as the older athletes should have a greater training age which further supports the need to improve a soccer player's relative strength. Therefore, practitioners should aim to improve their youth athlete's relative strength and rapid force production capabilities which are important for dynamic tasks such as sprinting, jumping and changing direction, all of which are integral actions in soccer.

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Table 1. Mean and SD (±) for Anthropometric measurements by age category in Elite Youth Soccer Players.

	U12 (n=51)	U13 (n=54)	U14 (n=56)	U15 (n=45)	U16 (n=39)	U18 (n=48)
Age (years)	11.7 ± 0.3	12.6 ± 0.3	13.6 ± 0.3	14.5 ± 0.3	15.6 ± 0.3	17 ± 0.6
Maturity Offset (years)	-2.4 ± 0.4	-1.6 ± 0.58	-0.66 ± 0.8	0.4 ± 0.76	1.39 ± 0.67	2.5 ± 0.68
Height (cm)	148.87 ± 5.5	156.57 ± 8.14	162.55 ± 10.47	171.13 ± 7.81	175.65 ± 6.76	179.34 ± 6.17
Leg Length (cm)	76.14 ± 4.52	81.21 ± 5.7	82.74 ± 6	86.2 ± 4.57	87.43 ± 4.52	88.4 ± 4.42
Siting Height (cm)	73.5 ± 3.5	76.5 ± 4.4	80.5 ± 5.8	85.4 ± 5.1	88.4 ± 4.2	91 ± 3.5

	U12 (n=51)	U13 (n=54)	U14 (n=56)	U15 (n=45)	U16 (n=39)	U18 (n=48)
Body Mass (Kg)	39.5 ± 5	44.4 ± 6.8	52.1 ± 10.7	60.21 ± 8.6	66.1 ± 8.1	71.4 ± 7.2

Impulse @100 ms (N.s)	18.85 (14.9, 23.1)	22.7 (13.2, 32.5)	21.9 (12, 31.5)	33.5 (23.7, 43.8)[abc]	32.8 (23.1, 43.2)[abc]	45.9 (36.2, 55.7)[abcde]
Relative Impulse @100 ms (N.s/Kg)	0.48 (0.42, 0.55)	0.52 (0.37, 0.68)	0.42 (0.26, 0.58)[a]	0.56 (0.4, 0.73)[c]	0.50 (0.34, 0.67)[c]	0.64 (0.48, 0.8)[abcde]
Impulse @ 300 ms (N.s)	130.2 (113.4, 148.3)	148 (107.8, 189.6)	167.6 (126.1, 208.5)[ab]	223.8 (182.6,267.6)[abc]	243.8 (202.4, 287.6)[abc]	292.7 (251.8, 334.2)[abcde]
Relative Impulse @300 ms (N.s/Kg)	3.3 (3.07, 3.64)	3.4 (2.7, 4.1)	3.2 (2.5, 3.9)	3.7 (3, 4.5)[ac]	3.7 (3, 4.4)[ac]	4.1 (3.4, 4.8)[abcde]
Peak Force (N)	1130.7 (1055, 1213)	1320.5 (1136, 1511)[a]	1491.9 (1301, 1678)[ab]	1806.2 (1617, 2006)[abc]	2039.3 (1850, 2239)[abcd]	2267 (2079, 2456)[abcde]
Relative Peak Force (N·Kg^{-1})	28.7 (28.9, 30.4)	29.8 (28, 31.7)[a]	28.6 (26.7, 30.4)	29.9 (28.3, 32.1)[ac]	30.9 (29, 32.8)[abc]	31.7 (30.2, 34.7)[abcd]

Table 2. Mean and 95% Higher Density Interval (HDI 95%) for Isometric Mid-Thigh Pull characteristics by age category in Elite Youth Soccer Players.

[a]p>0.95 >U12's, [b]p>0.95 >U13's, [c]p>0.95 >U14's, [d]p>0.95 >U15's, [e]p>0.95 >U16's, [f]p>0.95 >U18's