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Original article

Highly branched cyclic dextrin supplementation and resistance training: A randomized double-blinded crossover trial examining mechanical, metabolic, and perceptual responses

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SUMMARY

Background & aims: The aim of this study was to investigate the potential ergogenic effects of intra-session supplementation of highly branched cyclic dextrin (HBCD) on mechanical (number of repetitions completed and repetition velocity), metabolic (lactate concentration), and perceptual (gastrointestinal complaints and ratings of perceived exertion [RPE]) responses to resistance training.
Methods: This study used a randomized, double-blinded, placebo-controlled crossover study design. Thirty physically active individuals (15 men and 15 women) completed two experimental sessions that only differed in the supplement condition (placebo or HBCD). In each experimental session, subjects were prescribed five sets of eight repetitions with the 12-repetition maximum load during the bench press, bench pull, and squat exercises. During the sessions, participants consumed a total of 750 mL of the beverage, which either contained diluted 45 g of cyclic dextrin (HBCD condition) or only 2.5 g of the calorie-free excipients (placebo condition). The supplement (placebo or HBCD) was ingested during the inter-set rest periods (50 mL before each set).
Results: The main findings indicated that intra-session HBCD supplementation (i) was well-tolerated without causing gastrointestinal complaints, (ii) led to improved repetition velocity during RT in men but not in women, (iii) tended to generate comparable or higher lactate values, and (iv) did not significantly influence the perception of fatigue.
Conclusions: These results suggest that HBCD can be considered an ergogenic supplement, particularly for enhancing mechanical performance in men, without noticeably affecting the perception of fatigue or discomfort.

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1. Introduction

Sports drinks are frequently consumed during physical exercise to restore fluids lost through perspiration and provide an exogeneous energy source [1]. Their intake delays the onset of fatigue due to dehydration and the usage of endogenous carbohydrate (CHO) stores during prolonged exercise [2]. The ingestion of CHO-rich sports drinks before and during exercise has been shown to enhance exercise performance, likely by delaying the depletion of liver and muscle glycogen stores [3]. Therefore, it is not surprising the widespread recommendation that advocates for the consumption of CHO-rich sports drinks to optimize performance during moderate-to-high intensity endurance exercise [4]. However, there is limited and conflicting evidence regarding the potential ergogenic effects of CHO-rich sports drinks on resistance training (RT) performance [4].

The majority of RT studies have investigated the effects of CHO-rich sports drinks on the maximal number of repetitions performed to failure [4]. Some studies have reported an increase in the total number of repetitions completed within a RT session when consuming CHO-rich sports drinks compared to placebo [5,6], while others have failed to find significant differences between CHO-rich sports drinks and placebo [7,8]. Notably, to our knowledge, no study has shown inferior RT performance with CHO-rich sports drinks compared to placebo. It is worth considering that these studies have rarely included female participants and the number of sets ranged from 1 to 10. A differential response could be expected for women, attributed to documented variations in metabolic strategies during physical exertion, notably their comparatively lower utilization of muscle glycogen relative to men [9]. This assertion is substantiated by the outcomes of the only two investigations that incorporated female participants in their examination of resistance exercise, which did not discern any notable distinctions between placebo effects and CHO supplementation [10,11]. It is also plausible that the ergogenic effects of CHO-rich sports drinks may be more pronounced when increasing the number of sets, as this could result in greater depletion of muscle glycogen. Additionally, some studies have utilized a single exercise [11–13], but it is reasonable to expect that the ergogenic effects of CHO-rich sports drinks may be accentuated when multiple exercises, which is a more common practice, are executed within a RT session. Importantly, there is compelling evidence that training to failure is not an optimal strategy for maximizing muscular strength and overall athletic performance [14]. In this regard, athletes are often advised to perform all repetitions at maximal intended velocity and conclude sets when a submaximal level of fatigue is reached [15]. Given these considerations, it is important to explore the potential ergogenic effects of CHO-rich sports drinks on the maintenance of mechanical performance during non-failure RT sessions that incorporate multiple sets of lower- and upper-body exercises.

Several studies have incorporated highly branched cyclic dextrin (HBCD) as a CHO constituent in sports drinks due to its remarkable solubility, low viscosity, and resistance to retrogradation [16]. The molecular weight of HBCD is notably higher than that of most conventional CHO, which likely contributes to its unique physicochemical properties [17]. Specifically, HBCD is a branched CHO derived from waxy maize starch through the cyclization catalyzed by a branching enzyme known as 1,4-α-D-glucan: 6-α-D-(1,4-α-D-glucano)-transferase [18]. HBCD -based drinks have shown potential in attenuating the stress hormone response and decreasing urinary cytokine levels following exhaustive endurance exercise [17]. This, in turn, may lead to a more favorable perceptional response to exercise stress, resulting in lower ratings of perceived exertion (RPE) during high-intensity training [1,16]. Additionally, HBCD intake exhibits more favorable effects on other perceptual variables compared to other CHO, reducing the incidence of complaints such as reducing flatulence and belching, particularly in terms of quantity tolerance, likely attributed to its ability to increase gastric emptying rate [17,18]. However, the existing research literature on the mechanical and perceptual responses of HBCD consumption during RT remains limited.

To address the gaps in knowledge surrounding this topic, the objective of this study was to investigate the potential ergogenic effects of intra-session supplementation of HBCD on mechanical variables (number of repetitions completed and repetition velocity), metabolic variables (blood lactate concentration), and perceptual variables (gastrointestinal complaints and RPE). Our main hypothesis was that the ingestion of HBCD would enhance mechanical performance during RT exercises, attributed to its role in ensuring a sustained availability of CHO during exercise [3]. Furthermore, we anticipated that the improved mechanical performance associated with HBCD supplementation would be accompanied by lower RPE values, while the increased availability of CHO with HBCD supplementation could potentially lead to higher lactate levels post-exercise. Finally, building upon the well-established high gastrointestinal tolerance of HBCD demonstrated during endurance training [2,3], we also hypothesized that gastrointestinal complaints would not differ between the Placebo and HBCD conditions.

2. Material & methods

2.1. Participants

This study involved 30 healthy, physically active participants—comprising 15 men and 15 women—who voluntarily enrolled. Of these, one male participant was excluded from all statistical analyses due to his inability to attend the second testing session because of an injury unrelated to the study. Furthermore, due to technical issues during data collection, one female participant's data for the bench pull and one male participant's data for the squat were not included in the analysis. The characteristics of the participants accounted for in the statistical analyses are outlined in Table 1. All participants engaged in RT at least three times per week, and had prior experience with the three tested exercises. Participants were instructed to avoid any intense physical exercise during the course of the study. Women were asked to monitor their menstrual cycle to avoid performing the sessions during the early follicular phase to prevent side effects (i.e. abdominal cramps) from affecting the results [19,20]. Prior to the experimental sessions, all participants were informed about the purpose and procedures of the study, and signed the informed consent form. The study protocol adhered to the principles outlined in the Declaration of

Table 1
Basic characteristics of the participants included in the statistical analysis.

	All	Men	Women
Sample size	29	14	15
Age (years)	23.4 ± 2.9	24.6 ± 3.2	22.3 ± 2.1
Body height (cm)	170.4 ± 9.0	176.0 ± 7.1	165.1 ± 7.4
Body mass (kg)	74.1 ± 15.8	84.6 ± 13.0	64.3 ± 11.4
Body mass index ($Kg \cdot m^{-2}$)	25.3 ± 3.8	27.3 ± 3.9	23.4 ± 2.5
Bench press 12RM	50.7 ± 19.4	67.6 ± 13.1	35.0 ± 6.9
Bench pull 12RM	53.9 ± 18.7	69.8 ± 11.5	37.9 ± 6.9
Squat 12RM	70.0 ± 25.1	92.2 ± 18.0	50.7 ± 9.0

Mean ± standard deviation. RM, repetition maximum. Note that due to technical issues during data collection, one female participant's data for the bench pull and one male participant's data for the squat were not included in the statistical analyses.

Helsinki and was approved by the Local Research Ethics Committee of Junta de Andalucía (approval number: 0513-N-22).

2.2. Study design

This study used a randomized, double-blinded, placebo-controlled crossover study design. A preliminary session was conducted to determine the 12RM load for each of the three exercises, and to familiarize participants with lifting at maximal intended velocity, the RPE scale, and the gastrointestinal Likert scale. Following this, participants randomLy performed two experimental sessions that only differed in the supplement condition (Placebo or HBCD). The three sessions were separated by a minimum of 72 h of rest. Each experimental session consisted of performing five sets of the bench press, bench pull, and squat exercises in a sequential order. The supplement (Placebo or HBCD) was ingested during the inter-set rest periods. Participants were instructed to maintain a similar diet and abstain from consuming caffeine within 8 h before each experimental session. The experimental sessions were conducted within the controlled environment of the university's laboratory facilities, and we scheduled each participant's session at consistent times of the day to mitigate potential circadian variations in RT performance [21].

2.3. Familiarization session (session 1)

At the onset of the session, participants were familiarized with the RPE and gastrointestinal Likert scales. Following this, a general warm-up routine was conducted, including jogging and dynamic stretching exercises. Following the warm-up, participants performed a series of exercises in a specific order: bench press, bench pull, and squat. First, an incremental loading test was performed to estimate the 1RM through the individualised load–velocity relationship [14]. The initial load was set at 20 kg for all exercises and progressively increased from 10 to 20 kg until the mean velocity (MV) of the barbell was below 0.35 m s^{-1} for the bench press, 0.70 m s^{-1} for the bench pull, and 0.55 m s^{-1} for the squat. Rest periods of 3 min were given between sets. Participants executed two repetitions with light to moderate loads (MV $\geq$ 0.50 m s^{-1} for bench press, MV $\geq$ 0.80 m s^{-1} for bench pull and MV $\geq$ 0.70 m s^{-1} for squat) and one repetition with heavier loads (MV < 0.50 m s^{-1} for bench press, MV < 0.80 m s^{-1} for bench pull and MV < 0.70 m s^{-1} for squat) [22,23]. The highest MV achieved with each load was used to determine the individual load–velocity relationship, and the 1RM was estimated as the load linked to a general mean velocity threshold of 0.17 m s^{-1}, 0.50 m s^{-1}, and 0.30 m s^{-1} for the bench press, bench pull, and squat exercises, respectively [14]. Finally, participants were instructed to perform two sets of repetitions to failure, with 5 min of rest between sets, using 60 % and 80 % of their estimated 1RM. The total number of repetitions completed to failure (RTF) and the fastest MV achieved in each set were recorded. The individual RTF-MV relationship was established using a validated procedure [22–24], and the individual MV associated with 12 RTF was determined to guide the loading prescription in the first experimental session.

2.4. Experimental sessions (sessions 2–3)

The baseline level of gastrointestinal complaints was measured before the beginning of the session. Participants followed the same general warm-up routine as described in session 1, and then proceeded to perform the bench press, bench pull, and squat exercises in sequential order. To prepare for the session, participants engaged in a specific warm-up where they performed repetitions at maximal intended velocity against increasing loads until they reached the MV associated with 12 RTFs determined in session 1. Once this MV was reached, participants rested for 5 min before being instructed to perform five sets of eight repetitions using the 12RM load. Despite participants being instructed to complete eight repetitions per set, variations in the actual number performed were observed, often due to the challenging protocol involving a high number of exercises, sets and the prescribed repetitions being close to their failure limit. Participants were instructed to perform all repetitions at maximal intended velocity. Immediate feedback on MV was provided after each repetition to enhance motivation, competitiveness, and mechanical performance [14]. RPE values were reported by the participants 15 s after completing each set. Lactate measurements were taken 90 s after completing the fifth set of each exercise, and gastrointestinal complaints were recorded 30 s after completing the fifth set of each exercise. Rest period of 2 min was provided between sets of the same exercise, and there was a 10-min rest period between different exercises.

The two sessions only differed in the supplement condition (Placebo or HBCD). At the beginning of the session, a trained nutritionist prepared the designated beverage and handed it to each participant. During the session, participants consumed a total of 750 mL of the beverage, which either contained diluted 45 g of HBCD [(Cluster Dextrin, Glico Nutrition Co., Ltd, Osaka, Japan; HBCD condition)] or only 2.5 g of the calorie-free excipients (placebo condition). A 250 mL bolus was consumed during each exercise, with participants drinking 50 mL before each set. The supplements were packaged with numeric labels by the original distributors (Life Pro Nutrition industries, Madrid, Spain) to ensure blinding, and the drinks were designed to be indistinguishable in terms of appearance, smell, and taste once dissolved into 750 mL of water. The content of the packages was only revealed after an independent researcher conducted the statistical analyses, thus preventing evaluators' bias.

2.5. Measurement equipment and data analysis

The bench press, bench pull, and squat exercises were conducted using a Smith machine (Multipower Fitness Line, Peroga, Murcia, Spain). For the bench press exercise, participants adhered to the standardized 5-point body position and utilized the touch-and-go technique. In the bench pull exercise, the barbell was intentionally paused for 1–2 s on the telescopic holders of the Smith machine when both elbows were fully extended, and following this pause, participants pulled the barbell until it contacted with the bottom surface of the bench (thickness of 11.0 cm). During the squat exercise, participants descended until their thighs were parallel to the floor, and immediately after performed the lifting phase at maximal intended velocity without allowing any form of take-off from the ground.

Participants' body height and mass were measured at the beginning of the familiarization session (Seca model 654, Seca®, Hamburg, Germany). A GymAware RS linear position transducer (Kinetic Performance Technologies, Canberra, Australia) was mounted vertically onto the barbell of the Smith machine to record the MV of each repetition, with the individual repetitions' MV and the fastest MV of the set serving as dependent variables. The total number of repetitions completed also served as a critical variable in evaluating mechanical performance due to inability of some subjects to complete the prescribed number of repetitions. Perceptual fatigue was assessed using the OMNI-Resistance Exercise Scale (OMNI-RES), where participants reported their RPE on a pictograph scale ranging from 0 (extremely easy) to 10 (extremely hard). Gastrointestinal complaints (nausea, bloating, intestinal cramps, and urge to vomit) were measured using a 10-point Likert scale, where scores below five indicated a normal state and scores above five indicated severe discomfort [3]. Blood lactate concentration was measured from the right earlobe using a portable analyser (Lactate Pro 2, Arkray, Kyoto, Japan) [25].

2.6. Statistical analyses

Descriptive values of the dependent variables are presented as means and standard deviations. The normal distribution of the variables was explored by the Shapiro–Wilk test. The normal distribution assumption was violated for the gastrointestinal complaint variables (nausea, bloating, intestinal cramps, and urge to vomit), the total number of repetitions completed, and RPE values ($p < 0.05$). Consequently, the non-parametric Wilcoxon signed ranks test was used to compare the abovementioned outcomes between the supplement conditions (placebo *vs.* HBCD). Velocity and lactate values were normally distributed ($p > 0.05$). A two-way repeated measures ANOVA (supplement [placebo *vs.* HBCD] × set number [set 1 *vs.* set 2 *vs.* set 3 *vs.* set 4 *vs.* set 5]) with Bonferroni post hoc corrections was used to compare the fastest MV of the set separately for each exercise (bench press, bench pull, and squat). The Greenhouse-Geisser correction was used when the assumption of sphericity was violated according to the Mauchly's test ($p < 0.05$). Paired samples *t* tests were used to compare the MV of the individual repetitions and lactate values between the supplement conditions. The magnitude of the differences was explored through the Cohen's *d* effect size (ES), which was interpreted according to the following scale: negligible (ES < 0.20), small (ES = 0.20–0.49), moderate (ES = 0.50–0.79), and large (ES ≥ 0.80) [26]. Statistical analyses were conducted on both the entire cohort and stratified by gender. While direct comparisons of dependent variables between males and females were not conducted—aligning with the study's objectives—this stratified analysis enabled an examination of CHO supplementation's effectiveness within each gender subgroup. Statistical analyses were performed using the software package SPSS (IBM SPSS version 25.0, Chicago, IL, USA). Statistical significance was set at $p < 0.05$.

3. Results

The incidence of gastrointestinal complaints was extremely low and showed no significant differences between the supplement conditions during any exercise (*p* values ranged from 0.109 to 1.000) (Table 2).

The total number of repetitions did not differ between the supplement conditions during the bench press (37.8 ± 3.7 and 37.4 ± 4.7 repetitions for placebo and HBCD, respectively; $p = 0.916$), bench pull (39.7 ± 1.0 and 39.9 ± 0.4 repetitions for placebo and HBCD, respectively; $p = 0.059$), or squat (40.0 ± 0.0 and 39.9 ± 0.7 repetitions for placebo and HBCD, respectively; $p = 0.317$). No significant differences were generally observed for the MV of the individual repetitions in any exercise (Fig. 1). However, small differences in favour of HBCD compared to placebo was observed in a total of 22 repetitions (2 in bench press, 13 in bench pull, and 7 in squat). The remaining magnitude of the differences were always trivial with the only exception of a small difference in favour of placebo compared to HBCD for the fourth repetition of the

Table 2
Magnitude of gastrointestinal complaints reported prior to the initiation of the resistance training session and immediately after completing the bench press, bench pull, and squat exercises.

Complaint	Exercise	Supplement	Magnitude of the complaints					*p*-value
			None (0)	Slight (1)	Mild (2–3)	Moderate (4–5)	High (6–7)	
Nausea	Pre-session	Placebo	28 (96.6 %)	0 (0 %)	0 (0 %)	1 (3.4 %)	0 (0 %)	0.317
		HBCD	29 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	
	Bench press	Placebo	28 (96.6 %)	1 (3.4 %)	0 (0 %)	0 (0 %)	0 (0 %)	0.317
		HBCD	29 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	
	Bench pull	Placebo	25 (89.3 %)	2 (7.1 %)	1 (3.6 %)	0 (0 %)	0 (0 %)	1.000
		HBCD	26 (92.9 %)	1 (3.6 %)	1 (3.6 %)	0 (0 %)	0 (0 %)	
	Squat	Placebo	25 (89.3 %)	1 (3.6 %)	2 (7.1 %)	0 (0 %)	0 (0 %)	0.564
		HBCD	25 (89.3 %)	1 (3.6 %)	2 (7.1 %)	0 (0 %)	0 (0 %)	
Bloating	Pre-session	Placebo	29 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0.317
		HBCD	28 (96.6 %)	0 (0 %)	0 (0 %)	1 (3.4 %)	0 (0 %)	
	Bench press	Placebo	29 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0.109
		HBCD	26 (89.7 %)	0 (0 %)	2 (6.9 %)	1 (3.4 %)	0 (0 %)	
	Bench pull	Placebo	26 (92.9 %)	1 (3.6 %)	1 (3.6 %)	0 (0 %)	0 (0 %)	0.336
		HBCD	24 (85.7 %)	1 (3.6 %)	3 (10.7 %)	0 (0 %)	0 (0 %)	
	Squat	Placebo	25 (89.3 %)	1 (3.6 %)	2 (7.1 %)	0 (0 %)	0 (0 %)	0.593
		HBCD	25 (89.3 %)	1 (3.6 %)	1 (3.6 %)	1 (3.6 %)	0 (0 %)	
Intestinal cramps	Pre-session	Placebo	29 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1.000
		HBCD	29 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	
	Bench press	Placebo	29 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1.000
		HBCD	29 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	
	Bench pull	Placebo	28 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1.000
		HBCD	28 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	
	Squat	Placebo	28 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1.000
		HBCD	28 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	
Urge to vomit	Pre-session	Placebo	29 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1.000
		HBCD	29 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	
	Bench press	Placebo	27 (93.1 %)	0 (0 %)	1 (3.4 %)	0 (0 %)	0 (0 %)	0.458
		HBCD	27 (93.1 %)	2 (6.9 %)	0 (0 %)	0 (0 %)	0 (0 %)	
	Bench pull	Placebo	24 (85.7 %)	1 (3.6 %)	2 (7.1 %)	1 (3.6 %)	0 (0 %)	0.785
		HBCD	25 (89.3 %)	1 (3.6 %)	1 (3.6 %)	1 (3.6 %)	0 (0 %)	
	Squat	Placebo	23 (82.1 %)	0 (0 %)	2 (7.1 %)	2 (7.1 %)	1 (3.6 %)	0.465
		HBCD	23 (82.1 %)	0 (0 %)	4 (14.3 %)	0 (0 %)	1 (3.6 %)	

HBCD, highly branched cyclic dextrin. None of the participants reported very high (8–9) or maximum (10) complaints.

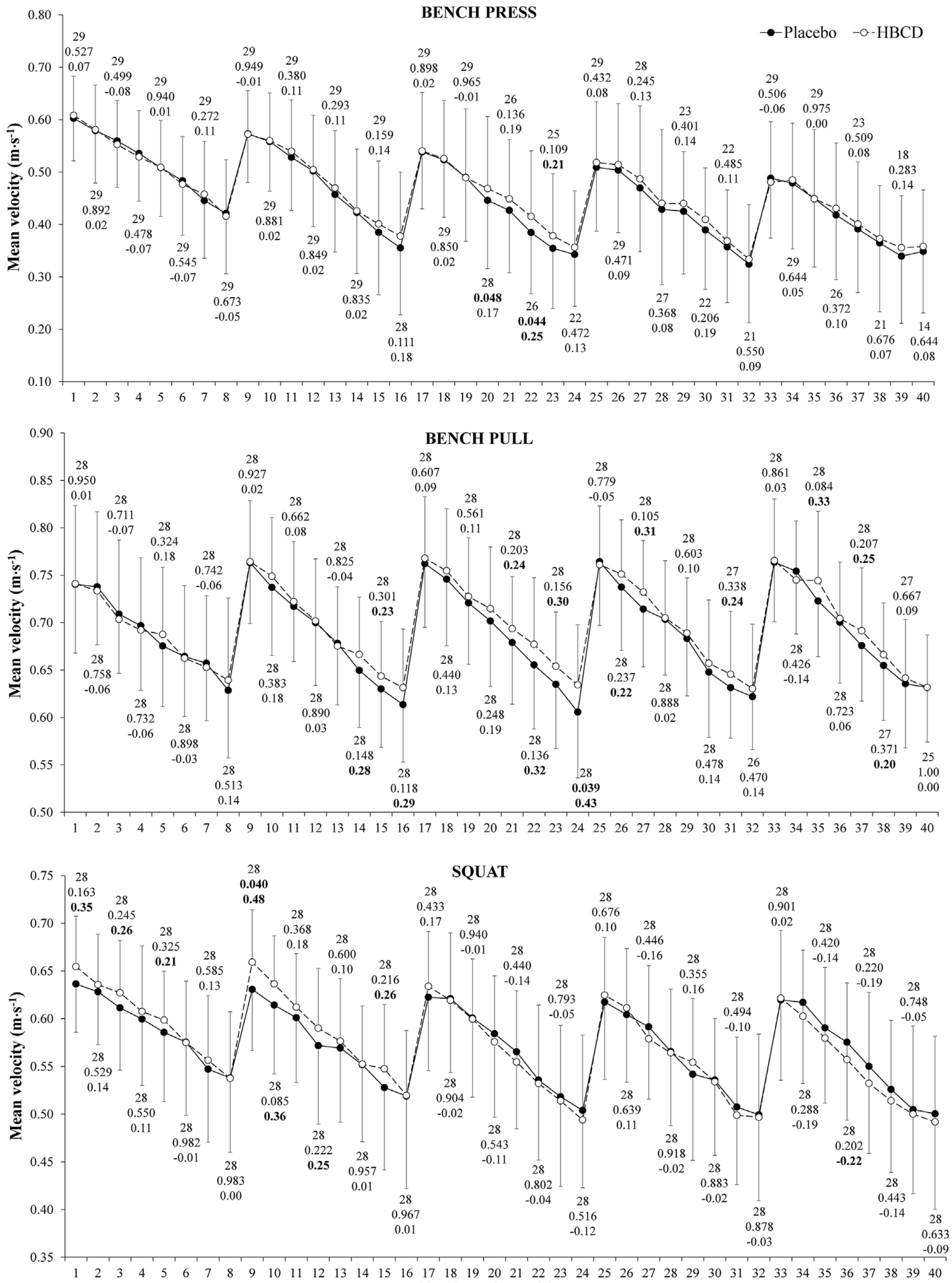

Fig. 1. Comparison of the mean velocity attained at the individual repetitions between the Placebo (filled dots and straight line) and highly branched cyclic dextrin (HBCD; empty dots and shaded line) conditions during the bench press (upper panel), bench pull (middle panel) and squat (lower panel) exercises. Upper numbers represent the sample size, middle numbers represent the p-value, and lower numbers represent the Cohen's d effect size (ES = [HBCD mean value − Placebo mean value]/pooled standard deviation). Bold numbers represent significant differences ($p < 0.05$) and non-negligible differences (ES $\geq$ 0.20).

fifth set of the squat exercise. Regarding sex differences, non-negligible differences (ES $\geq$ 0.20) in favour of HBCD compared to placebo was observed in a total of 55 repetitions for men (5 in bench press, 28 in bench pull, and 22 in squat) and only in 10 repetitions for women (6 in bench press and 4 in bench pull) (Fig. 2). On the other hand, non-negligible differences (ES $\geq$ 0.20) in favour of placebo compared to HBCD was observed only in 1 squat repetition for men but in 29 repetitions for women (8 in bench pull and 21 in squat).

The ANOVAs applied to the fastest mean velocity of the set did not reveal a significant main effect for the supplement (bench press: F = 0.2, p = 0.660; bench pull: F = 0.1, p = 0.776; squat:

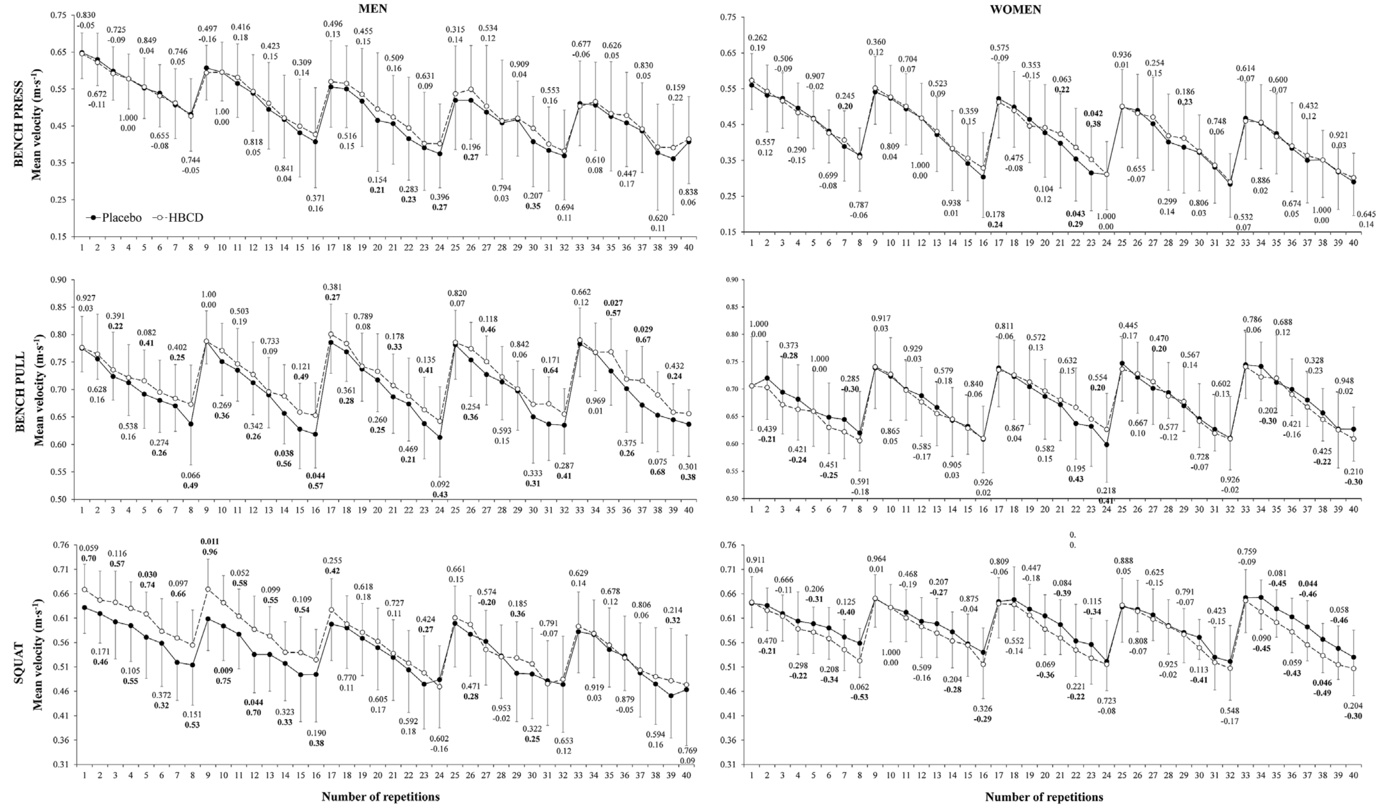

Fig. 2. Comparison of the mean velocity attained at the individual repetitions between the Placebo (filled dots and straight line) and highly branched cyclic dextrin (HBCD; empty dots and shaded line) conditions during the bench press (upper panel), bench pull (middle panel) and squat (lower panel) for men (middle panels) and women (right panels). Upper numbers represent the p-value and lower numbers the Cohen's *d* effect size (ES = [HBCD mean value − Placebo mean value]/pooled standard deviation). Bold numbers represent significant differences ($p < 0.05$) and non-negligible differences (ES $\geq$ 0.20).

F = 0.4, $p = 0.531$) or for the set × supplement interaction (bench press: F = 0.5, $p = 0.742$; bench pull: F = 0.6, $p = 0.600$; squat: F = 2.4, $p = 0.051$). However, the main effect of set was significant (bench press: F = 52.0, $p < 0.001$; bench pull: F = 5.9, $p = 0.002$; squat: F = 4.4, $p = 0.012$) due to a progressive decline in velocity with increasing number of sets for the bench press and squat exercises, while the set 1 produced the lowest mean velocity during the bench pull exercise. Pairwise comparisons between the supplement conditions never reached statistical significance and the magnitude of the differences were always trivial with the only exception of the small differences in favour of HBCD compared to placebo for the first and second sets of the squat exercise (Fig. 3). However, when men and women were independently analysed, non-negligible differences (ES $\geq$ 0.20) in favour of HBCD compared to placebo was observed in 6 sets for men (1 in bench press, 2 in bench pull, and 3 in squat), whereas non-negligible differences in favour of placebo compared to HBCD was observed in 2 sets (both in the squat) for women.

No significant differences in lactate values were detected between the supplement conditions (Fig. 4). Considering the whole sample, the magnitude of the differences was trivial for the bench press and squat exercises (ES < 0.20), while small differences in favour of HBCD were observed during the bench pull exercise (ES = 0.22). When both sexes were analysed separately, greater lactates values using HBCD compared to placebo were observed in the bench pull and squat exercises for men and in the bench press exercise for women.

No significant differences in RPE values between the supplement conditions were generally observed with the only exception of the greater RPE values for the HBCD compared to placebo following the fifth set of the squat exercise (Fig. 5). However, when men and women were separately analysed, lower RPE values were observed for men in two sets of the bench pull when using HBCD compared to placebo, whereas women reported greater RPE values in one set of the squat using placebo compared to HBCD.

4. Discussion

This study was designed to investigate the potential ergogenic effects of HBCD supplementation during a RT session involving both lower- and upper-body exercises performed with high levels of effort. The main findings indicated that intra-session HBCD supplementation (i) was well-tolerated without causing gastrointestinal complaints (hypothesis confirmed), (ii) led to improved mechanical performance during RT in men but not in women (hypothesis partially confirmed), (iii) tended to generate comparable or higher lactate values (hypothesis partially confirmed), and (iv) did not significantly influence the perception of fatigue (hypothesis refuted).

Glycogenolysis takes place during moderate-to-high intensity RT, leading to a consistent reduction in total muscle glycogen stores. The depletion of glycogen could potentially impair muscle contraction, thereby influencing muscle fatigue [4]. The present study revealed an intriguing trend towards enhanced MV in individual repetitions for the HBCD condition among men, while no such trend was observed among women. The only two studies that previously included women in their sample also failed to find significant differences between placebo and CHO supplementation during resistance exercise [10,11]. A possible physiological explanation for the difference between sexes could be due to a lower use

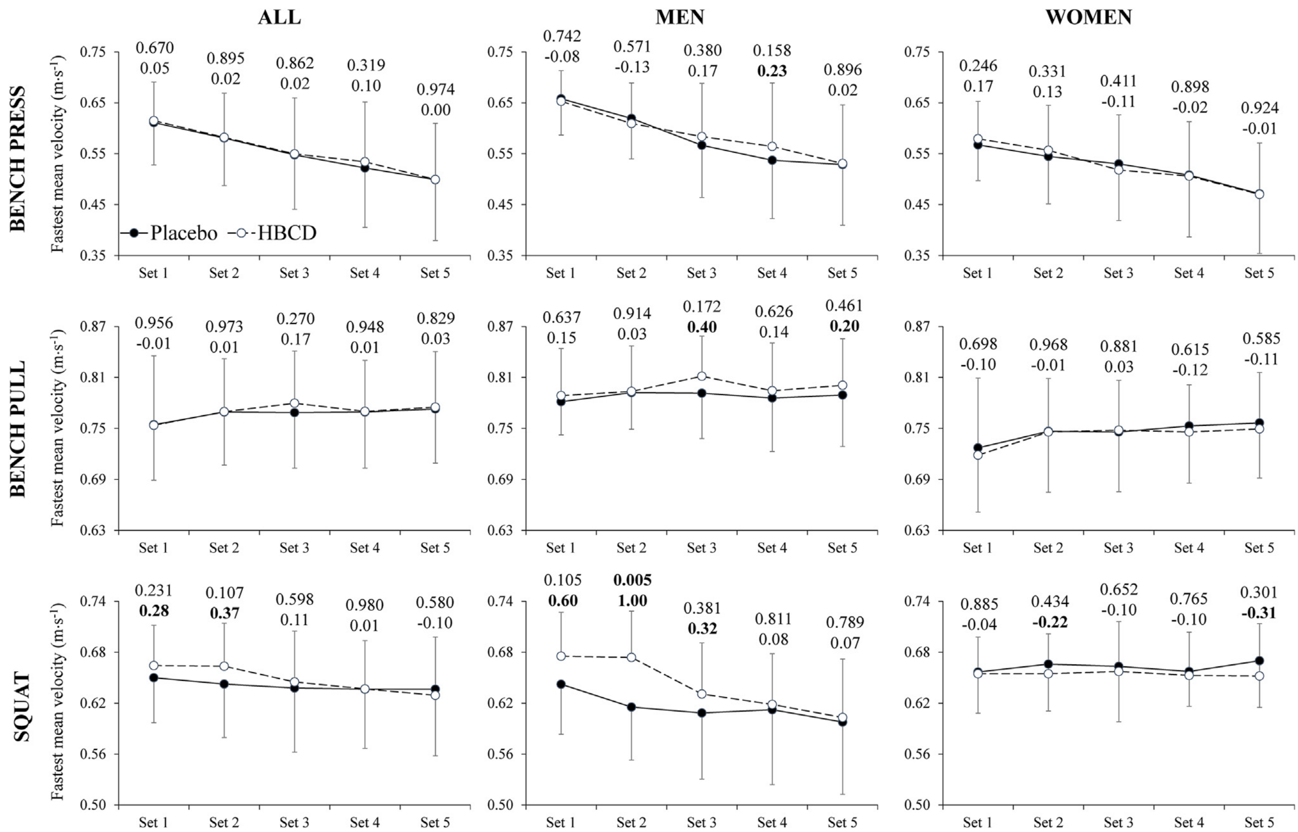

Fig. 3. Comparison of the fastest mean velocity of the set between the placebo (filled dots and straight line) and highly branched cyclic dextrin (HBCD; empty dots and shaded line) conditions during the bench press (upper panel), bench pull (middle panel) and squat (lower panel) for the whole sample (left panels), men (middle panels), and women (right panels). The upper and lower numbers represent the p-value and Cohen's *d* effect size (ES = [HBCD mean value − Placebo mean value]/pooled standard deviation), respectively. Bold numbers represent non-negligible differences (ES ≥ 0.20).

of muscle glycogen by women [27]. Furthermore, men may exhibit higher motivation levels than women when faced with the challenge of lifting at maximum velocity [9]. This increased level of competitiveness could assist in detecting the small differences between supplements. In fact, women have a greater preference for lower-body exercise (e.g. squat) [9] where non-negligible differences were found in favour of placebo compared to HBCD. On the other hand, when considering only males in the study sample, RT performance indicators, such as total number of repetitions completed or mechanical variables (force, velocity, and power), were generally improved for the CHO condition compared to placebo [6,28–31]. Nonetheless, some studies conducted with men did not show significant differences between placebo and CHO conditions [12,13,32], and none suggested a potential decrease in performance for the CHO condition. An interesting aspect to consider is that previous studies typically instructed subjects to perform sets until volitional failure [6,8,12,30], whereas our study introduced sets with high levels of effort without initially reaching failure. Our findings support existing scientific evidence that in men, CHO ingestion (HBCD in our study) induces trivial to small improvements in mechanical performance during RT, whereas in women, the intra-session supplementation of HBCD seems to have little impact.

We did not detect significant differences in blood lactate concentration between HBCD and placebo conditions. Consistent with the observations for RT performance indicators, RT studies demonstrated that CHO ingestion before or during RT led to either greater [6,29] or comparable [12,33] post-exercise blood lactate concentrations compared to placebo. It is known that blood lactate concentration values are positively associated with training volume [4]. Thus, the similarity in repetitions completed between the placebo and CHO conditions in our study may account for the absence of differences in blood lactate concentration. Furthermore, the timing of blood lactate level measurements can impact the results. For instance, Kulik et al. [12] reported comparable lactate levels between the placebo and CHO conditions immediately after completing sets of the squat exercise to exhaustion, but observed a higher lactate concentration for the CHO condition at the 1-h post-training measurement. HBCD is digested slowly in the gut, so while exercise efficiency increases, lactate levels do not increase rapidly. The fact that the six effect sizes computed in our study (men and women for the bench press, bench pull, and squat exercises) were greater for the HBCD condition, though of negligible/small magnitude, suggests that consuming intra-session HBCD during RT might facilitate the utilization of greater anaerobic energy sources.

Participants tolerated well the administration of HBCD, and did not report more gastrointestinal issues compared to placebo. Interestingly, this finding suggests that HBCD passes through the digestive system without causing any notable disruption. These findings align with previous research indicating that during 3-h endurance exercise CHO-based drinks maintain stomach fullness, abdominal cramping, and nausea unchanged [3]. Notably, HBCD has been shown to reduce flatulence and belching compared to other CHO-based drinks due to its faster gastric emptying rate [2], although it is important to note that this prior study did not involve exercise completion.

Moreover, in our study, the supplement condition did not impact the RPE, consistent with the findings of Kulik et al. [12], who

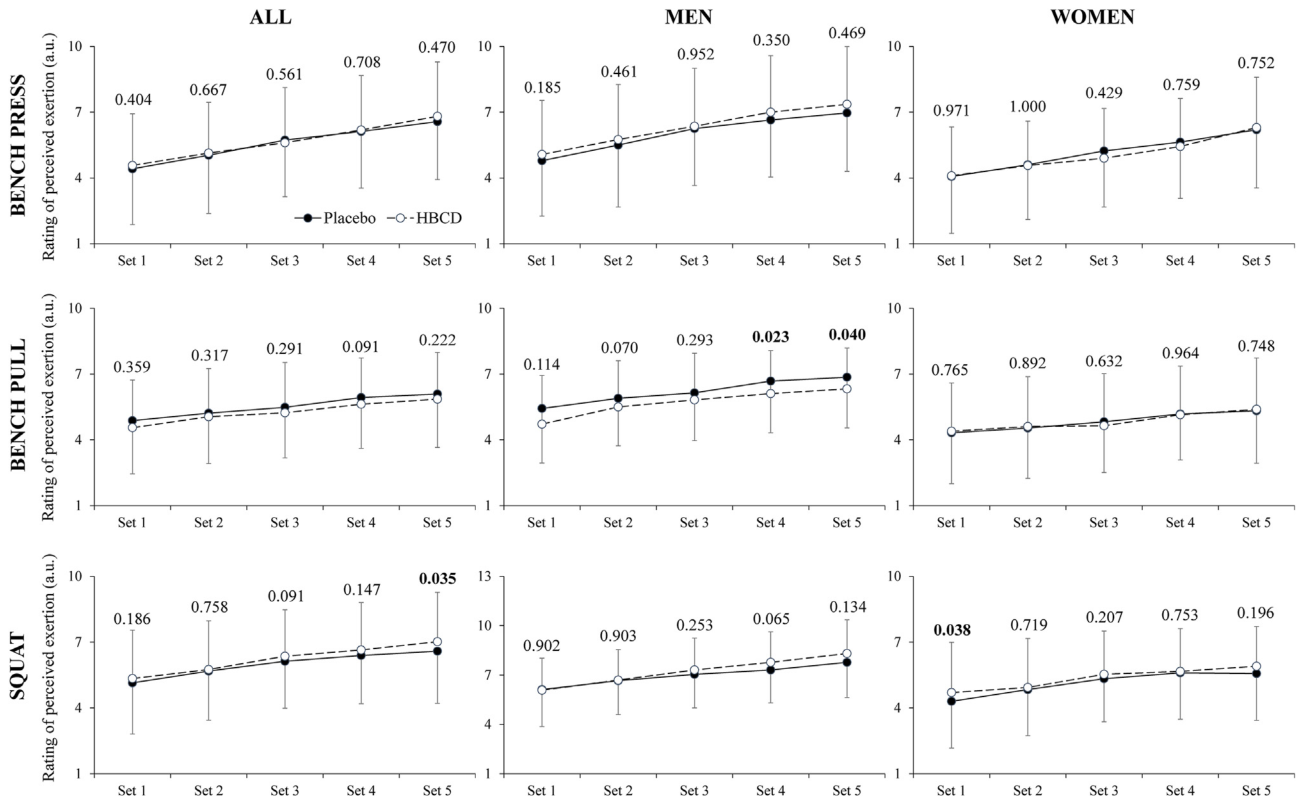

Fig. 4. Comparison of lactate values between the placebo (filled dots and straight line) and highly branched cyclic dextrin (HBCD; empty dots and shaded line) conditions during the bench press (upper panel), bench pull (middle panel) and squat (lower panel) for the whole sample (left panels), men (middle panels), and women (right panels). ES, Cohen's *d* effect size (ES = [HBCD mean value − Placebo mean value]/pooled standard deviation). Bold numbers represent non-negligible differences (ES ≥ 0.20).

reported no significant differences in RPE between CHO-based drinks and placebo during sets of the squat exercise performed to failure. Compared to placebo, HBCD and CHO-based drinks have been shown to decrease RPE values during endurance and HIIT exercises [1,16]. On the other hand, a lower-body resistance exercise protocol induced higher RPE for CHO supplementation compared with placebo, but the timing of the measurement was different (30 min *vs.* immediately after) [31]. Overall, our study's results, along with the existing literature, support the notion that HBCD supplementation is well-suited for physically active, healthy young adults in terms of effort perception and gastrointestinal comfort during RT.

The present randomized, double-blinded, placebo-controlled crossover trial is robust regarding the study sample and testing procedures. Notably, this investigation stands out as the first to explore the effects of HBCD specifically on female participants, providing valuable insights into gender-specific responses. Furthermore, it pioneers the standardization of a uniform distribution of CHO across the RT sets, avoiding potential biases introduced by asymmetric ingestion observed in other studies [34]. Incorporating HBCD from the onset of exercises, such as weight training which typically involves lower energy expenditure compared to endurance sports, may offer distinct advantages. Early supplementation could potentially optimize performance by maintaining glucose availability and delaying fatigue, allowing for sustained mechanical output over the course of the RT session [35]. The efficacy of this supplementation strategy in RT merits deeper exploration to elucidate its full advantages.

However, the main limitation of our study, unlike many studies assessing CHO supplementation effects, is that our participants did not undergo any fasting period, which might have influenced the results. Nevertheless, we intentionally opted not to impose strict diet restrictions to enhance the ecological validity of our study, making it more representative of real-world scenarios. Another limitation of our study is the inability to determine if the observed improvement in mechanical performance among men under the HBCD condition resulted from delayed muscle glycogen depletion, due to our incapacity to record this variable. It is also important to highlight that although the ergogenic effects of HBCD were observed in men and not in women, the CHO intake relative to body weight was actually lower in men than in women. This raises an intriguing question about whether the outcomes would vary if both sexes received an equivalent CHO intake per kilogram of body weight, suggesting a potential avenue for future research. Finally, while our sample was stratified by gender with similar age ranges among participants, the study did not employ a Matched Pair Case-Control design to match men and women by exact age, body mass, or other characteristics, which may have introduced variability that could affect the generalizability of the findings.

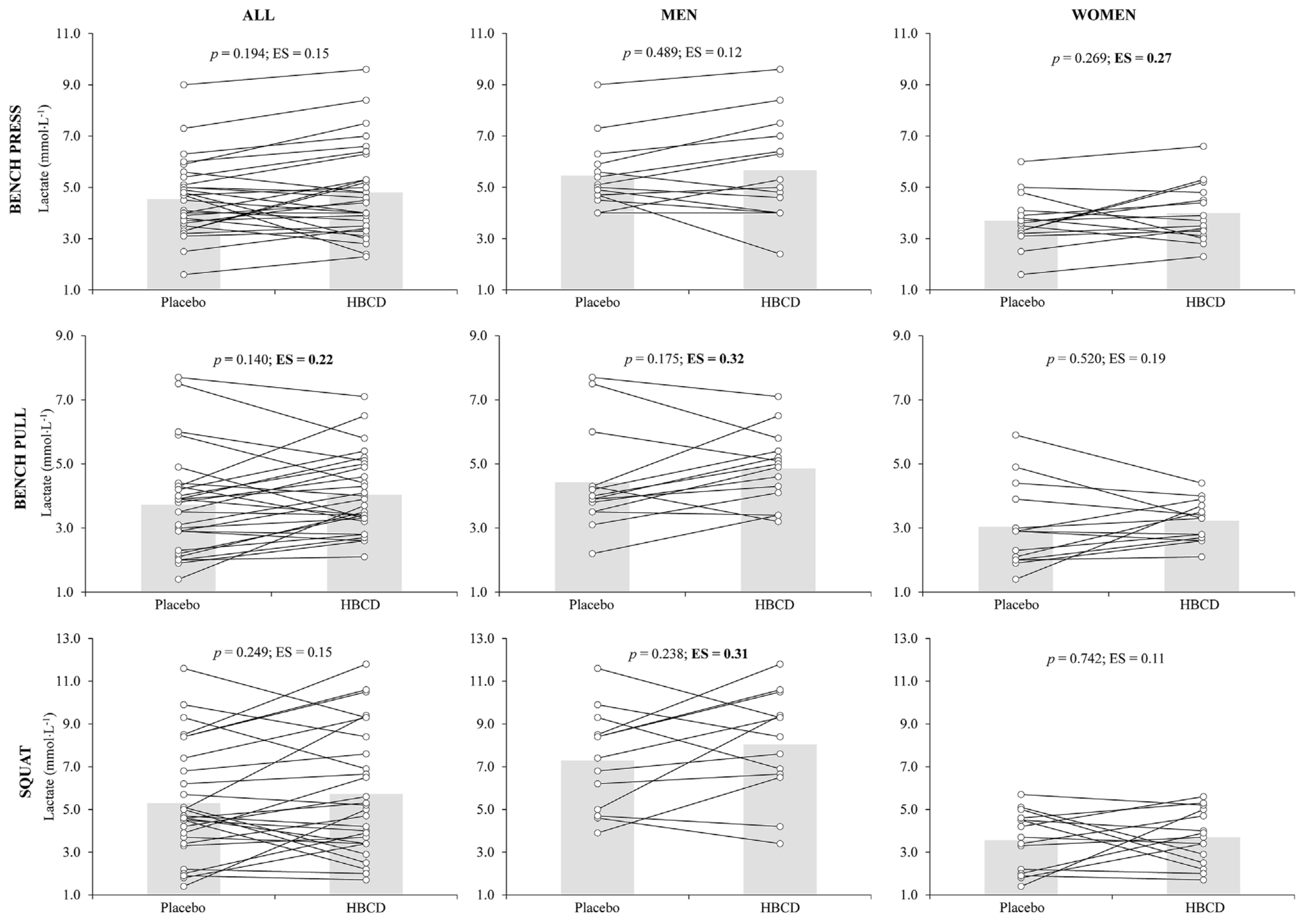

Fig. 5. Comparison of and ratings of perceived exertion between the placebo (filled dots and straight line) and highly branched cyclic dextrin (HBCD; empty dots and shaded line) conditions during the bench press (upper panel), bench pull (middle panel) and squat (lower panel) for the whole sample (left panels), men (middle panels), and women (right panels). Numbers represent the *p*-value derived from the Wilcoxon signed ranks test. Bold numbers represent significant differences ($p < 0.05$).

5. Conclusions

HBCD can be considered an ergogenic supplement in men, particularly for augmenting mechanical performance, while not significantly impacting blood lactate concentration or the perception of fatigue and discomfort. No performance benefits were detected in female participants. Future research is crucial to determine if the noted gender-specific responses result from variations in CHO intake relative to body weight and to confirm the ergogenic potential of HBCD in men.

Authors contribution

Conceptualisation, A.G.-R. and C.A.-F.; methodology, S.M.-M., A.G.-R. and P.J.-M.; formal analysis, D.J.; data collection, S.M.-M., M.D.M.-A, S.C–V and J.J.M.-O.; writing—original draft preparation, M.D.M.-A.; writing—review and editing, A.G.-R., M.D.M.-A., J.J.M.-O. and P.J.-M. and supervision, C.A.-F and M.C. All authors have read and agreed to the published version of the manuscript.

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Declaration of competing interest

PJ-M, DJ, JM-O, MC, and CA-F serve as scientific advisors for the sports supplement brand Life Pro Nutrition. The other authors affirm that their research was conducted impartially, without any commercial or financial affiliations that might be perceived as a conflict of interest.

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