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ORIGINAL RESEARCH

Sensory and locomotor responses following CrossFit, Les Mills and traditional resistance trainings in sedentary subjects

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Abstract

Background: There is a paucity of literature on the effects of fitness programs such as CrossFit (CF), Les Mills (LM), and traditional resistance training (TRAD) on sensorimotor responses, which define overall motor skills levels that are major factors in improving quality of life of fitness training practitioners. **Objective:** The purpose of this study was to assess and compare the sensorimotor responses after 16 weeks of CF, LM and TRAD trainings. **Methods:** A total of one hundred and seven sedentary participants (81 men, 26 women, age 30.5 ± 5.7 years, weight 78.9 ± 11.1 kg, height 174.9 cm, fat mass 25.4 ± 5.3%) were assigned randomly into 3 groups CF (n = 34), LM (n = 33) and TRAD (n = 40), they followed the training allocated at the rate of 5 sessions/week for 16 weeks. On three occasions: before (T0), after eight (T1) and sixteen weeks (T2) of training, participants underwent different tests of sensorimotor measures; coordination (Extremity Motor Coordination Test), accuracy (Motor Accuracy Test), agility (Illinois Agility Test) and balance (Y Balance Test). **Results:** Coordination improved only in the LM group for upper (T0-T1: p < .001, d = 0.09–0.13; T1-T2: p < .001, d = 0.16–0.18) and lower limbs coordination (T0-T1: p < .001, d = 0.16–0.25; T1-T2: p < .001, d = 0.24–0.26). Agility test showed improvements for LM (T0-T1: p < .001, d = 0.55; T1-T2: p < .001, d = 0.87) and CF (T0-T1: p = .002, d = 0.20; T1-T2: p < .001, d = 0.40) and no difference for TRAD. For balance, results showed improvements in lower limbs for CF (T0-T1: p < .001, d = 0.08–0.14, T1-T2: p < .001, d = 0.05–0.23) and TRAD (T0-T1: p ≤ .003, d = 0.05–0.08, T1-T2: p < .001, d = 0.08–0.13) and at T2 for LM (p = 0.04, d = 0.06–0.2), for the upper limbs, results showed improvements for CF (T0-T1: p < .001, d = 0.04–0.09; T1-T2: p < .001, d = 0.15–0.28), at T2 for TRAD (p = .01–.03, d = 0.03–0.10) and no difference for LM. For motor accuracy, results did not show any difference. **Conclusions:** CF and LM trainings helps develop agility; however, CF and TRAD are more oriented to balance while LM are to coordination improvement, all three trainings have no effect on motor accuracy.

Keywords: indoor training, motor skill, functional training, combined training

Introduction

Motor skill is the ability of a person to generate singular or multiple movements performed with a high degree of precision and accuracy; additionally, it involves the coordinated motion of various joints, nerves and limbs of the body to achieve a desired action (Srimathveeravalli & Thenkurussi, 2005). According to Nazarenko (2015), the effectiveness of complex motor actions is determined by the kinesiological potential and human motor activity characterized by coordinative areas: agility, accuracy, balance, flexibility, mobility, etc. Improved motor skills are desirable outcomes from exercise interventions for a number of practical (Wulf, 2007), applied (Wulf et al., 2010), and even clinical purposes (Tallent et al., 2021). Those wishing to become more proficient at sport-specific activities or those simply wishing to improve their quality of life will benefit from improved motor skills, for instance high motor skills have been shown to enhance physical activity, and improve health-related physical fitness while promoting a healthy weight status (Stodden et al., 2008), conversely, low motor skills has been shown to cause difficulties in every-day tasks (Hands, 2008) and lower levels of academic attainment, reduced participation in social and leisure activities (Preston et al., 2017), the level of motor function allows us to know the severity of an impairment, activity limitation or participation restriction (Beckung & Hagberg, 2002). Therefore, numerous studies demonstrated the use of varied physical activity and exercise interventions as one of the solutions to develop motor skills characteristics in different populations (Han et al., 2018; Preeti et al., 2019), thus, the ability of an exercise program to improve overall motor skills is of great importance to practitioners.

Increased membership and participation in sports clubs/fitness facilities by athletes or by the general population to

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beyond 180 million members has led to a market increase in specialized fitness centers (León-Quismondo et al., 2020). Fitness centers/gyms had to adapt their offer of sports services in demand of this remarkable increase in participants, as a result, several fitness trends have been created (Thompson, 2019). For those seeking to partake in structured exercise, especially in order to make improvements in motor function, selecting the appropriate program can be difficult due to the variety of programs (Wulf, 2007).

As a consequence of this increase in fitness trends, a large number of commercial and non-commercial training programs exist; however, CrossFit®, Les Mills® and Traditional resistance training (Bodybuilding), are perhaps the most notable fitness destinations for recent sedentary or athletic participants (Riseth et al., 2019). CrossFit® (CF) is a cross-type functional training program performed at high intensity in sessions called Workout of the Day (WOD) using different techniques inspired by gymnastics (e.g., pull-ups, push-ups, hand-stand, etc.), weightlifting (e.g., clean, snatch, squats, etc.) and endurance sports (e.g., running, rowing, swimming, etc.; CrossFit, 2019). Though there are a rising number of studies examining CF, most investigate the effects of training on different physical qualities with limited studies having examined motor skills qualities (Claudino et al., 2018). LesMills® (LM) is another high-intensity intermittent training (HIIT) program, designed in the form of choreographed movements influenced by the latest trends in music and fitness culture, and performed in structured group classes around the world. These choreographed classes involve movements inspired by combat and sport lasting from 45 to 55 min (Les Mills, 2019). Traditional resistance training (TRAD) is based on the use of progressive resistance exercises to promote increases in strength and skeletal muscle hypertrophy (Kraemer & Ratamess, 2004), practitioners of this type vary from general strength and conditioning to more competitive bodybuilding. Progressive resistance exercise is performed using various controlled, weighted movements with Olympic bars, dumbbells and/or stationary machines. Though each training program has garnered popularity CF, LM and TRAD utilize different training philosophies. CF and LM are looking to improve functional and sport compound movements efficiency based on the multi-joint, fascia and tissue connectivity hypothesis. On the other hand, TRAD is looking to improve muscle qualities (e.g., strength, power and hypertrophy) using isolated and compound exercises (Angleri et al., 2017).

To the best of our knowledge, there have been several studies that have examined the effect of resistance training on balance (Orr et al., 2008), agility (Taheri et al., 2014) and coordination (Park et al., 2015); however, very few have examined motor accuracy. Conversely, for CF, previous work has only focused on muscular responses and is limited to motor skills (Claudino et al., 2018), similarly for LM, previous work failed to address the effect on motor skills, leaving a dearth of knowledge in this field. Importantly, CF purports that performing movements inspired by gymnastics and weightlifting in their WODs allows for the development of motor skills (e.g., coordination, balance, agility, accuracy; CrossFit, 2019), while studies have suggested that LM program can influence the development of motor skills positively through exercising in sync with music (Halttunen & Närhi, 2013). Although these purported outcomes are interesting, empirical evidence is lacking. Therefore, the purpose of this study was to evaluate changes, in sensorimotor responses: coordination, balance, agility and motor accuracy following 16 weeks of CF, and LM training and to compare to a widely utilized TRAD program in physically inactive participants. In this regard, it was hypothesized that there would be a significant increase in motor skills characteristics after these training interventions.

Methods

Procedures

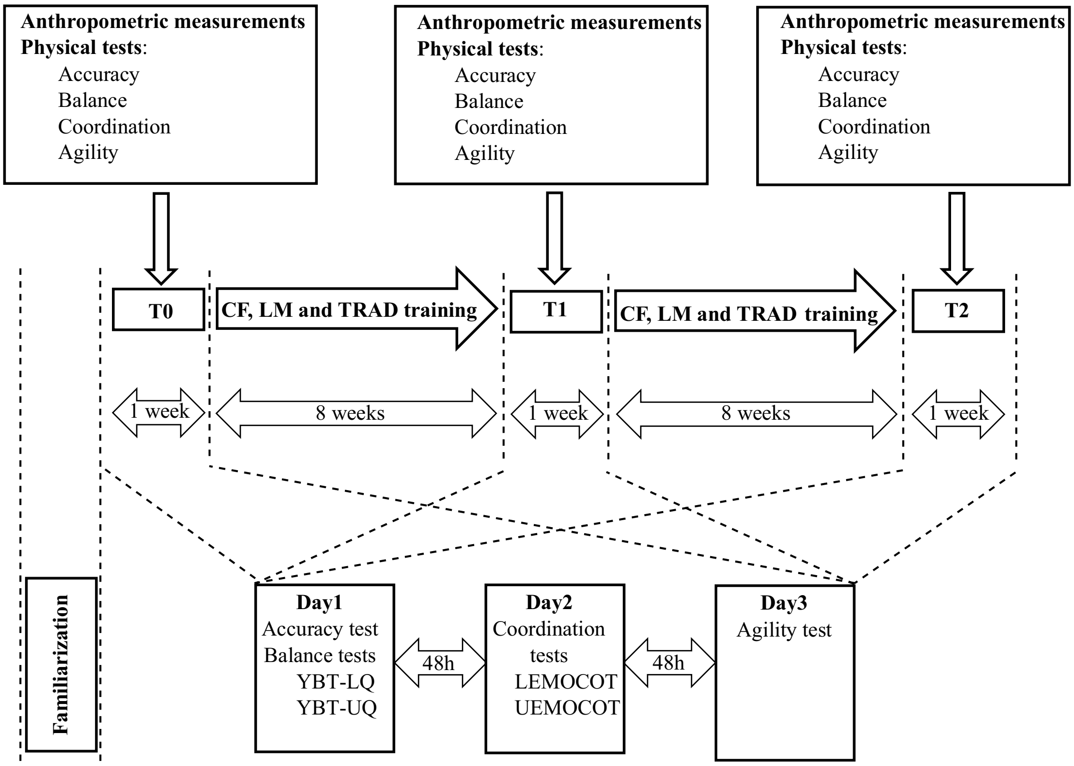
All tests and protocols of this study are in agreement with the declaration of Helsinki and were approved by the Ethical Committee on Human Research of the University of Manouba, Tunisia. Participants were asked to visit the exercise physiology laboratory in four separate sessions throughout the 16-week intervention: familiarization, pre-training (T0), 8 weeks (T1), and 16 weeks (T2). Three days after familiarization with testing protocols and sub-dividing groups procedures, the first session (T0) consisted of anthropometric measurements and physical assessments of accuracy (Motor Accuracy Test) and balance (Y Balance Test). Anthropometric and physical assessments were repeated for the 2nd session to assess coordination (Lower and Upper Extremity Motor Coordination Test), while the 3rd session was dedicated to agility (Illinois Agility Test), see Figure 1.

The 16-week interventions were carried out in two different fitness facilities. The first facility is an affiliate of the CF program, and the second is a multidisciplinary center affiliated with the LM program and offers personalized training sessions following the TRAD method.

Participants

A total of 120 inactive, overweight males and females were enrolled in the study. After signing an informed consent, participants were assigned randomly to one of the three intervention groups, a total of 107 completed the study: CF (n = 34), LM (n = 33), or TRAD (n = 40). Table 1 presents the characteristics of the participants. Height and weight were measured with an electric balance scales Tanita BC-545N (Tanita Corp., Tokyo, Japan), body composition was assessed by 4 sites skinfold measurements (Durnin/Womersley formula) using Slim Guide Skinfold Caliper (Creative Health Products, Ann Arbor, MI, USA), all measurements were carried out by the same investigators for all the participants at the same time of day. The enrollment of participants occurred in the form of a questionnaire that presented questions of the inclusion/exclusion criteria, the inclusion criteria were having no health problems and no muscle, tendon, or bone trauma, no experience with resistance training, availability during the study period and coming after a period of physical inactivity (not achieving moderate/vigorous physical activity threshold of 75–150

Figure 1 The study and test sessions



Note. CF = CrossFit; LM = Les Mills; TRAD = traditional resistance training; YBT-LQ = Y Balance Test Lower Quarter; YBT-UQ = Y Balance Test Upper Quarter; LEMOCOT = Lower Extremity Motor Coordination Test; UEMOCOT= Upper Extremity Motor Coordination Test.

Table 1 Basic anthropometric characteristics (*M* ± *SD*) of the participants at baseline

Characteristic	CF (*n* = 34)	LM (*n* = 33)	TRAD (*n* = 40)
Men (count)	24	25	32
Women (count)	10	8	8
Age (years)	30.7 ± 6.8	29.2 ± 4.9	31.5 ± 5.3
Weight (kg)	77.2 ± 12.7	79.2 ± 9.3	80.4 ± 11.2
Height (cm)	173.3 ± 7.4	176.1 ±7.6	175.3 ± 7.8
Fat mass (%)	25.3 ± 6.7	25.8 ±4.5	25.1 ± 4.8
BMI (kg·m^{-2})	25.6 ± 2.6	25.5 ±2.2	25.9 ± 2.8

Note. CF = CrossFit; LM = Les Mills; TRAD = traditional resistance training; BMI = body mass index.

min/week), the exclusion criteria were presence of any type of illness, suffering from cardiac, muscular and/or neurological disorders and doing other types of training.

Training intervention

Participants were allocated to train for a maximum of five times a week, no less than four times. For the CF training, the WOD programming was provided by a level 2 CF trainer and approved in accordance with the CF method. LM training was provided by certified instructors using ancillaries (video, audio and script) sent by the LM Group. The classes provided were the most accessible by members according to a survey made before; BODYPUMP™, BODYCOMBAT™, BODYATTACK™, RPM™, BODYSTEP™ (Les Mills, 2019).

Participants in the TRAD group were provided with a personalized strength training program created using baseline testing scores. A one-repetition maximum (1RM) was assessed for the squat, bench press and deadlift. Participants performed a standardized warm-up leading to a 6-repetition maximum. This was used to establish an estimated 90% 1RM, which served as the starting point for the incremental 1RM test. Loads were increased by 2.5–5.0 kg for each set until failure, the last successful rep was recorded as the 1RM. Participants were given three min of rest between attempts. For all other movements, the predicted 1RM was assessed by performing a series of 10 repetitions with a gradually incremented load until the ability to perform only 9 or fewer repetitions occurred, this information was placed into the Brzycki formula for the estimated 1RM (Brzycki, 1993).

The programing selected was that of a traditional 5-day split routine common in bodybuilding. The five workouts isolated specific regions of the body to avoid targeting a particular muscle group more than twice a week, allowing adequate recovery. Each training session consisted of a specified warm-up (3 min of walking on a treadmill followed by whole body and targeted muscle group light static stretching). Following this, participants would begin one of the five prescribed workouts (Table 2) starting with multi-joint exercises and progressing to isolated single-joint exercises (Kraemer & Ratamess, 2004). The following repetition cadence was prescribed to the participants: 2 s concentric phase and 2 s eccentric phase (2:2), with a rest

Table 2 Training used in the traditional resistance training group

Training day	Exercises	Total sets
Day 1: Pectoral	bench press, incline press, decline press, chest press, dumbbell incline chest fly[a], cable crossover[a], dumbbell pullover	23
Day 2: Posterior chain	deadlift, weighted back extension, lateral pull down, weighted pull up, dumbbell rowing, low pulley, cable straight arm pull down[a]	22
Day 3: Legs	squat, lunges, leg press, leg extension, leg curl[a], single leg kick back, calf raise[a]	23
Day 4: Shoulders	military press, Arnold press, barbell upright row[a], clean press, lateral raise[a], frontal raise[a], high row, shrug	28
Day 5: Arms and abdominals	barbell biceps curl, dumbbell hammer curl, triceps extension, dumbbell over-head extension, reverse curl, barbell wrist curl, cable crunches, cable Russian twist	24

Note. Unless indicated otherwise, each exercise was performed in 3 sets (loads are percentages of one repetition maximum): 10 repetitions at 70% load, 8 repetitions at 80% load, and 6 repetitions at 90% load. [a]4 sets: 14 repetitions at 60% load, 12 repetitions at 70% load, 10 repetitions at 80% load, and 8 repetitions at 90% load.

time of 50–180 s between sets and 120 s between exercises. The prescription of exercises remained consistent over the 16 weeks.

Accuracy

Motor Accuracy Test (MAT) test was used (Diny et al., 2015). The participant followed a black pattern with a red pen, trying to stay as strictly as possible inside the black outline. After testing, ImageJ software version 1.52 (ImageJ, National Institutes of Health, Bethesda, MD, USA) was used to measure the area drawn only in red, which is expressed in cm^2, that area represents the incorrect trace of the pattern. As suggested before (Diny et al., 2015), we limited the time of each test to 5 s to equalize the conditions between all participants.

Balance

For the lower limbs we used the Y Balance Test Lower Quarter (YBT-LQ; Shaffer et al., 2013). The participant, barefoot and with hands clasped on the hip, was standing on one leg resting on the central platform of the test kit (Move2Perform, Evansville, IN, USA) while maintaining the same posture, the participant tried to push the indicator box along the three directions: anterior, posteromedial and posterolateral. After three trials, the best values were recorded. Failure was the inability to maintain the posture, leaning on the indicator box for each direction or moving hands from the hip. Prior to beginning the assessment, the participant performed 6 practice trials for familiarization.

To provide a more holistic view of balance, we included the Y Balance Test Upper Quarter (YBT-UQ; Gorman et al., 2012). Participants in a plank position next to the testing kit, with the support of one hand positioned on the central platform, feet shoulder-width apart. The participant pushed each indicator box according to its direction (medial, uperolateral and inferolateral) with the free hand, the best value was recorded after three trials. The test failed if the participant could not maintain a unilateral stance on the platform or used the reach indicator for stance support.

Coordination

Lower-Extremity Motor Coordination Test (LEMOCOT; Antosiak-Cyrak et al., 2015) was used. The participants sitting on a chair with their hands on the sides, barefoot, were asked to touch two circles 30 cm apart located in front of the chair (distanced based on a 90° bend in the knee) with the ball of the foot as quickly as possible above a stick raised 15 cm from the ground for 20 s, recording began as soon as the participant touches the first point, the total number of touches was measured and recorded using a photoelectric cell (OptoJump Next photocell system, Microgate, Bolzano, Italy). To measure the coordination of the upper limbs, we adapted the same test with conditions suitable for the arms (UEMOCOT; Kauranen & Vanharanta, 1996). The participant, with the same previous position and the same photocell, was asked to touch two points 40 cm apart on a platform adjusted to the height of their chest as quickly as possible above the same stick and for 20 s.

Agility

The Illinois Agility Test was used. At the start of the test, the participant lay in a prone position, then got up and sprinted between spaced cones in the configuration of the Illinois Agility Test (Raya et al., 2013), the time from the participant's first movement from the initial position to the finish line was measured using two photocell sensors (TC-PhotoGate, Brower Timing System, Draper, UT, USA) the best time was recorded after three trials. If the participant could not follow the course diagram as indicated or touched a cone, they were required to test again as needed.

Statistical analysis

The data were analyzed with the statistical program SPSS version 23.0 for Windows (SPSS Inc., Chicago, United States) and the statistical significance level was established at $p < .05$. Descriptive statistics are presented as means ± standard deviations. All data were normally distributed, and this was assessed by the Shapiro-Wilk test. The homogeneity of the variances was confirmed before analysis using the Levene test. Single-factor analysis of variance was used to verify the non-existence of statistically significant differences in pre-intervention measures. A 3 (group: CF, LM, TRAD) × 3 (time: T0, T1, T2) repeated measures mixed-model analysis of variance was used to assess the training effect during the intervention period. In addition, the Bonferroni post-hoc test was used to determine the difference between the measures and to compare the changes between the different training sessions. Finally, the size of the effect of the differences between variables effects was interpreted using the partial eta-squared (η_p^2), where an effect size smaller than .01 indicates a negligible difference, between .01 and .06 a small difference, between .06 and

.14 a medium difference and greater than .14 a large difference. Effect sizes for pairwise comparisons were calculated as Cohen's *d* where appropriate, where an effect size smaller than 0.2 indicates a negligible difference, between 0.2 and 0.5 a small difference, between 0.5 and 0.8 a moderate difference and greater than 0.8 an important difference.

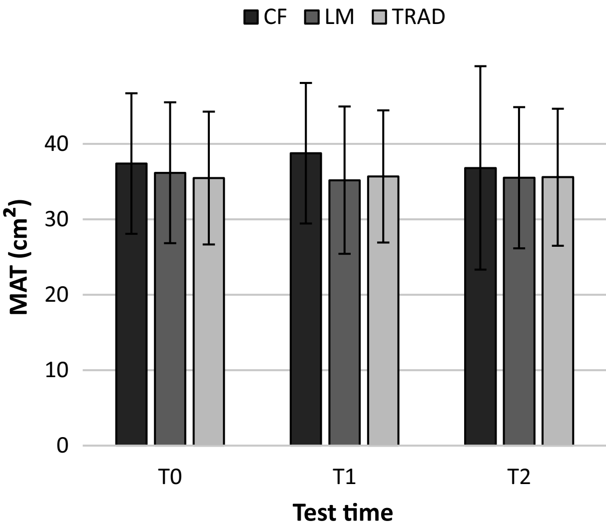
Results

TRAD participants failed to achieve the prescribed repetitions until the 12th week (particularly the 3rd/4th set at 90%). They were encouraged to complete as many as they could in each session. Following the 3rd week participant completion rate steadily increased. With the increasing number of completed repetitions per week, participants experienced an increase in volume and load. Their completion percentage is as follows. During the first three weeks only 93% of the total repetitions prescribed were achieved (week 1: 93 ± 9.2%, week 2: 93 ± 8.9%, week 3: 93 ± 8.5%), with a gradual increase to 99% following week eight (week 4: 95 ± 6.7%, week 5: 96 ± 4.7%, week 6: 98 ± 2.9%, week 7: 98 ± 2.6%, week 8: 99 ± 1.6%) through week 16 (week 9: 99 ± 1.6%, week 10: 99 ± 1.6%, week 11: 99 ± 1.6%, week 12: 100 ± 1.4%; week 13: 100 ± 1.25%, week 14: 100 ± 1.1%, week 15: 100 ± 0.92%, week 16: 100 ± 0.66%).

MAT test results did not demonstrate any significant difference in time ($F(2, 104) = 4.27$, $p = .89$, $\eta_p^2 < .001$) or in group factor ($F(2, 104) = 0.36$, $p = .70$, $\eta_p^2 = .007$), see Figure 2.

YBT-LQ demonstrated a significant time effect on the right and left leg balance (Table 3). Bonferroni test demonstrated significant improvements of balance for CF in anterior direction (right T0-T1: $p < .001$, $d = 0.13$; right T1-T2: $p < .001$, $d = 0.23$; left T0-T1: $p < .001$, $d = 0.12$; left T1-T2: $p < .001$, $d = 0.21$), posteromedial direction (right T0-T1: $p < .001$, $d = 0.09$; right T1-T2: $p < .001$, $d = 0.15$; left T0-T1: $p < .001$, $d = 0.1$; left

Figure 2 Results of the Motor Accuracy Test



Note. CF = CrossFit; LM = Les Mills; TRAD = traditional resistance training; T0 = tested before training; T1 = tested after 8 weeks of training; T2 = tested after 16 weeks of training.

Table 3 Means, standard deviations (in cm), and analysis of variance (ANOVA) for the Y Balance Test Lower Quarter

				ANOVA			
Variable	CF	LM	TRAD	Effect	*F*-ratio	*p*	η_p^2
Anterior right							
T0	50.0 ± 6.1	50.3 ± 6.3	50.1 ± 6.1	G	0.05	.96	.001
T1	50.8 ± 5.6	50.5 ± 6.3	50.6 ± 6.2	T	84.61	< .001	.450
T2	52.2 ± 6.0	50.9 ± 6.4	51.4 ± 6.4	G × T	9.46	< .001	.150
Anterior left							
T0	50.3 ± 6.9	50.9 ± 6.9	51.1 ± 6.5	G	0.08	.92	.002
T1	51.1 ± 6.8	51.0 ± 7.0	51.6 ± 6.7	T	81.83	< .001	.440
T2	52.4 ± 6.8	51.4 ± 6.9	52.4 ± 7.0	G × T	9.15	< .001	.150
Posteromedial right							
T0	90.6 ± 9.2	91.1 ± 7.7	90.2 ± 9.4	G	0.08	.93	.001
T1	91.3 ± 8.8	91.2 ± 7.6	90.7 ± 9.5	T	83.83	< .001	.440
T2	92.7 ± 9.2	91.7 ± 7.9	91.5 ± 9.7	G × T	9.34	< .001	.150
Posteromedial left							
T0	89.8 ± 8.3	90.0 ± 7.0	90.0 ± 8.4	G	0.05	.96	.001
T1	90.6 ± 8.4	91.1 ± 8.1	90.5 ± 8.4	T	82.62	< .001	.440
T2	91.0 ± 8.5	91.5 ± 8.1	91.3 ± 8.6	G × T	9.18	< .001	.150
Posterolateral right							
T0	85.2 ± 9.8	85.1 ± 9.5	84.0 ± 9.8	G	0.25	.78	.005
T1	86.0 ± 9.9	85.3 ± 9.6	84.5 ± 10.0	T	87.76	< .001	.430
T2	87.4 ± 9.7	85.7 ± 9.7	85.3 ± 10.3	G × T	8.95	< .001	.140
Posterolateral left							
T0	85.2 ± 9.8	85.1 ± 9.5	84.0 ± 9.8	G	0.17	.85	.003
T1	86.0 ± 9.9	85.3 ± 9.6	84.5 ± 10.0	T	82.39	< .001	.440
T2	87.4 ± 9.7	85.7 ± 9.7	85.3 ± 10.3	G × T	9.43	< .001	.150

Note. CF = CrossFit; LM = Les Mills; TRAD = traditional resistance training; T0 = tested before training; T1= tested after 8 weeks of training; T2 = tested after 16 weeks of training; G = group; T = time.

T1-T2: $p < .001$, $d = 0.05$) and in posterolateral direction (right T0-T1: $p < .001$, $d = 0.08$; right T1-T2: $p < .001$, $d = 0.14$; left T0-T1: $p < .001$, $d = 0.08$; let T1-T2: $p < .001$, $d = 0.13$), similarly significant improvement for TRAD in anterior direction (right T0-T1: $p = .002$, $d = 0.08$; right T1-T2: $p < .001$, $d = 0.13$; left T0-T1: $p = .002$, $d = 0.07$; left T1-T2: $p < .001$, $d = 0.12$), posteromedial direction (right T0-T1: $p = .002$, $d = 0.05$; right T1-T2: $p < .001$, $d = 0.08$; left T0-T1: $p = .003$, $d = 0.06$; left T1-T2: $p < .001$, $d = 0.09$) and in posterolateral direction (right T0-T1: $p = .002$, $d = 0.05$; right T1-T2: $p < .001$, $d = 0.08$; left T0-T1: $p = .003$, $d = 0.05$; let T1-T2: $p < .001$, $d = 0.08$), while LM group developed balance only after 16 weeks in anterior direction (right: $p = .04$, $d = 0.09$; left: $p = .04$, $d = 0.07$), posteromedial direction (right: $p = .04$, $d = 0.08$; left: $p = .04$, $d = 0.2$) and only in posterolateral left direction ($p = .04$, $d = 0.06$). When comparing the groups, we did not notice any significant difference.

YBT-UQ test results demonstrated a significant time effect (Table 4). Bonferroni test showed significant balance improvements for CF in medial (right T0-T1: $p < .001$, $d = 0.06$; right T1-T2: $p < .001$, $d = 0.21$; left T0-T1: $p < .001$, $d = 0.09$; left T1-T2: $p < .001$, $d = 0.28$), superolateral (right T0-T1: $p < .001$, $d = 0.04$; right T1-T2: $p < .001$, $d = 0.15$; left T0-T1: $p < .001$, $d = 0.09$; left T1-T2: $p < .001$, $d = 0.28$) and in inferolateral direction (right T0-T1: $p < .001$, $d = 0.06$; right T1-T2: $p < .001$, $d = 0.18$; left T0-T1: $p < .001$, $d = 0.07$; left T1-T2: $p < .001$, $d = 0.23$), for TRAD in medial (right T0-T2: $p = .01$, $d = 0.06$; left T0-T2: $p = 0.01$, $d = 0.09$), superolateral (right T1-T2: $p = .04$, $d = 0.03$; T0-T2: $p = .01$, $d = 0.05$; left T1-T2: $p = .04$, $d = 0.07$; T0-T2: $p = .01$, $d = 0.10$) and inferolateral direction (right T0-T2: $p = .03$, $d = 0.06$; left T0-T2: $p = .03$, $d = 0.07$), while for LM group there was no significant difference

LEMOCOT demonstrated a significant interaction time × group for the coordination of the right ($F(2, 104) = 13.43$, $p < .001$, $\eta_p^2 = .20$) and left leg ($F(2, 104) = 12.83$, $p < .001$, $\eta_p^2 = .20$) and a significant time effect for the right ($F(2, 104) = 26.61$, $p < .001$, $\eta_p^2 = .2$) and left leg ($F(2, 104) = 25.66$, $p < .001$, $\eta_p^2 = .20$) yet no significant effect of group (Figure 3). Post-hoc test showed a significant increase for LM during the study (right: $p < .001$, T0-T1: $d = 0.16$; T1-T2: $d = 0.26$; left: $p < .001$, T0-T1: $d = 0.25$, T1-T2: $d = 0.24$), whereas there was no significant difference in CF and TRAD, no significant difference between groups demonstrated. UEMOCOT demonstrated significant interaction time × group for the right ($F(2, 104) = 16.75$, $p < .001$, $\eta_p^2 = .24$) and left arm ($F(2, 104) = 5.76$, $p < .001$, $\eta_p^2 = .10$), and significant time effect (Figure 3) for the right ($F(2, 104) = 30.85$, $p < .001$, $\eta_p^2 = .23$) and left ($F(2,104) = 12.6$, $p < .001$, $\eta_p^2 = .10$) arm. Post-hoc test showed a significant increase for LM (right: $p < .001$; T0-T1: $d = 0.09$, T1-T2: $d = 0.18$; left: $p < .001$; T0-T1: $d = 0.13$, T1-T2: $d = 0.16$).

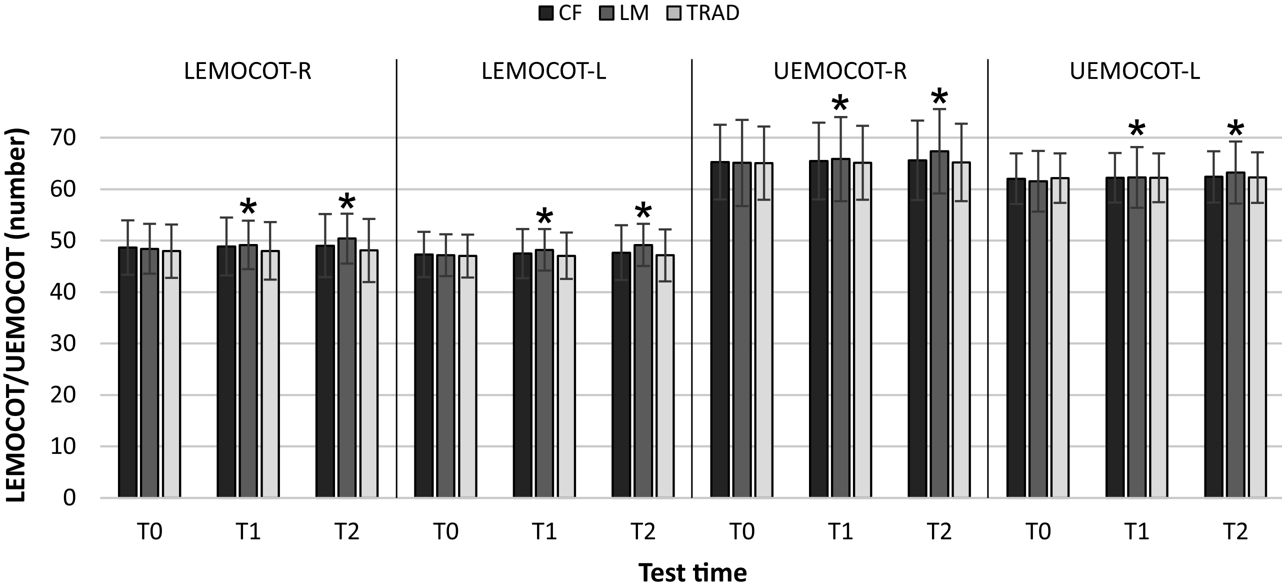
Agility results demonstrated significant interaction in time × group ($F(2, 104) = 258.9$, $p < .001$, $\eta_p^2 = .80$) and in time ($F(2,104) = 839.8$, $p < .001$, $\eta_p^2 = .90$). Bonferroni test demonstrated significant improvement for CF

Table 4 Means, standard deviations (in cm), and analysis of variance (ANOVA) for the Y Balance Test Upper Quarter

				ANOVA			
Variable	CF	LM	TRAD	Effect	*F*-ratio	*p*	η_p^2
Medial right							
T0	77.3 ± 12.5	78.8 ± 9.6	76.9 ± 12.7	G	0.23	.79	.004
T1	78.0 ± 12.3	79.0 ± 9.6	77.2 ± 12.7	T	65.59	< .001	.380
T2	80.5 ± 11.6	79.3 ± 9.8	77.7 ± 12.8	G × T	19.77	< .001	.270
Medial left							
T0	78.1 ± 9.0	78.4 ± 7.5	77.8 ± 8.8	G	0.22	.80	.004
T1	78.9 ± 8.7	78.6 ± 7.7	78.0 ± 8.9	T	65.49	< .001	.390
T2	81.3 ± 8.3	79.0 ± 8.0	78.6 ± 9.0	G × T	19.82	< .001	.270
Superolateral right							
T0	53.5 ± 15.5	53.4 ± 13.9	50.4 ± 15.1	G	0.71	.50	.010
T1	54.2 ± 15.6	53.4 ± 14.0	50.7 ± 15.0	T	68.48	< .001	.390
T2	56.6 ± 15.5	53.9 ± 14.3	51.2 ± 14.9	G × T	19.74	< .001	.270
Superolateral left							
T0	51.0 ± 8.5	50.9 ± 8.3	49.4 ± 8.6	G	0.90	.41	.020
T1	51.8 ± 8.7	51.0 ± 8.5	49.6 ± 8.2	T	66.55	< .001	.380
T2	54.2 ± 8.7	51.4 ± 8.6	50.2 ± 8.2	G × T	19.59	< .001	.260
Inferolateral right							
T0	68.8 ± 13.1	70.2 ± 12.7	68.4 ± 12.4	G	0.17	.84	.003
T1	69.6 ± 13.3	70.2 ± 12.8	68.7 ± 12.6	T	61.4	< .001	.370
T2	72.0 ± 12.8	70.7 ± 12.8	69.2 ± 12.8	G × T	20.03	< .001	.280
Inferolateral left							
T0	73.1 ± 10.6	72.5 ± 11.3	72.8 ± 10.5	G	0.24	.79	.005
T1	73.9 ± 10.8	72.6 ± 11.5	73.1 ± 10.6	T	60.19	< .001	.360
T2	76.3 ± 10.4	73.0 ± 11.7	73.5 ± 10.7	G × T	20.13	< .001	.270

Note. CF = CrossFit; LM = Les Mills; TRAD = traditional resistance training; T0 = tested before training; T1= tested after 8 weeks of training; T2 = tested after 16 weeks of training; G = group; T = time.

Figure 3 Results of the Lower Extremity Motor Coordination Test (LEMOCOT) and Upper Extremity Motor Coordination Test (UEMOCOT)



Note. CF = CrossFit; LM = Les Mills; TRAD = traditional resistance training; T0 = tested before training; T1 = tested after 8 weeks of training; T2 = tested after 16 weeks of training. *statistically significant within-group difference from the previous testing.

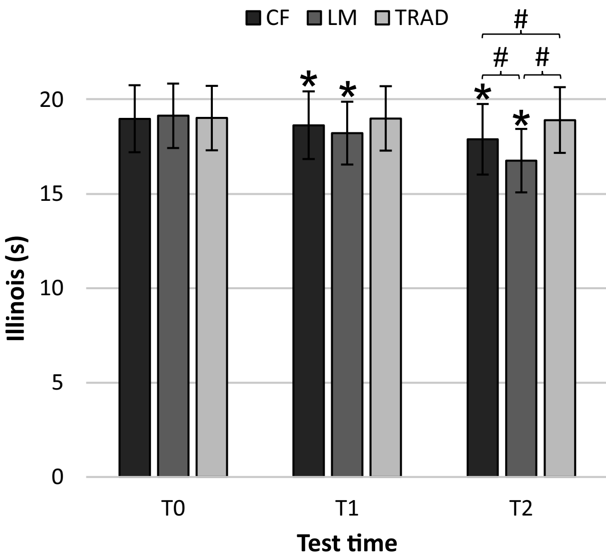
and LM ($p < .001$; CF T0-T1: $d = 0.20$, CF T1-T2: $d = 0.40$; LM T0-T1: $d = 0.55$, LM T1-T2: $d = 0.87$), while there was no significant change for TRAD (Figure 4). Post-hoc test showed significant increase in agility in LM compared to CF (16.76 ± 1.67 vs 17.9 ± 1.87, $p = .03$, $d = 0.64$) and TRAD (16.76 ± 1.67 vs 18.92 ± 1.74, $p < .001$, $d = 1.26$) and significant gain for CF compared to TRAD (17.9 ± 1.87 vs 18.92 ± 1.74, $p = .04$, $d = 0.56$) only in T2.

Discussion

For motor accuracy, none of the trainings studied developed motor precision based on the results of the MAT test. According to CrossFit and in their training guide (CrossFit., 2019), training with gymnastics-inspired movements and with Olympic weightlifting movements helps develop motor accuracy, however, there were no observed improvements following the 16 weeks of training. Similar to CF, LM and TRAD were inefficient, to the best of our knowledge, since LM is basically a HIIT training, previous work has only focused on the effect of an acute bout of HIIT, where a single session did not have a significant effect on aspects of motor accuracy (Swarbrick et al., 2020), despite the variety of techniques utilized in their choreographies, LM training did not show any improvement in motor accuracy. On the other hand, despite the variety of studies done on resistance training on different physical qualities, as far as we know this is the first study that investigated the effect of traditional resistance training on motor accuracy, as a result TRAD group did not show improvement even after 16 weeks of training.

Each group demonstrated time-dependent changes in both left and right legs, with significant improvements observed in T1 and T2 for CF and TRAD and only T2 for LM. When examining the upper limbs, improvements were mixed (Table 4), where CF improved in all three directions for all time points, while TRAD only observed improvements at T2, and LM failed to show any improvement. Anderson and Behm (2005) summarized from the literature that stable resistance training without integrating the balance factor has also a positive effect on the general balance of the body. Additionally, they cite the importance of the use of free weights to develop balance, which was greatly implemented in both CF and TRAD programming. The consistent improvement in balance seen in the CF

Figure 4 Results of the Illinois Agility Test



Note. CF = CrossFit; LM = Les Mills; TRAD = traditional resistance training; T0 = tested before training; T1 = tested after 8 weeks of training; T2 = tested after 16 weeks of training. *statistically significant within-group difference from the previous testing. #statistically significant between-group difference.

group every eight weeks for the upper and lower limbs can be attributed to the variety of complex Olympic and gymnastic movements as seen in their training guide (CrossFit, 2019), CF mentioned that the use of gymnastic techniques (handstand, pull-ups, squats, lunges, pistols) and Olympic weightlifting (snatch, clean and jerk) in their programs allows developing balance, which was demonstrated in the current study. According to the literature, Chaouachi et al. (2014) demonstrated that Olympic weightlifting techniques obviously help develop balance, in addition, Kochanowicz et al. (2017) and Bressel et al. (2007) demonstrated a positive effect of gymnastics training on proprioception and balance development. For LM training, the results of our study hardly showed a significant improvement in balance after 16 weeks of training and those only for the lower limbs, we believe that the execution of techniques of kicks inspired by taekwondo and karate during the Bodycombat™ class could have a great effect on this improvement of balance (Fong et al., 2012; Fong & Ng, 2011). According to Ageberg et al. (2005), anterior knee laxity, proprioception and muscle strength play a role in maintaining balance in a single limb, thereby, we can conclude that CF and TRAD training develops a balance of the body by improving the two parameters of perception and muscle strength.

The coactivation between the agonist and antagonist muscles is an essential element for the development of coordination, this coactivation increases the stability and rigidity of the joints (Duchateau & Baudry, 2010), thereby improving coordination. In the examined CF and LM modalities, the use of multi-joint complex plyometric movements heavily relies on coactivation and coordination of both the agonist and antagonist muscle groups, which, by reason would expect both groups to experience improvements in task control and muscle coordination. Interestingly, this was not the case in the current study, by which, only LM demonstrated improvements (T1 and T2). The improvement of the LM group can likely be explained by the nature of the exercise programming and modality. For instance, LM heavily relies on bodyweight resistance and in some variations (i.e., BODYPUMP) lighter weights are used. Furthermore, the rhythmic execution of alternating movements of martial arts and calisthenics engage both upper and lower limbs or a combination of them (Les Mills, 2019). Together, the modality of LM better reflects the conditions of the coordination tests, which examine unweighted upper and lower limb movement. Additionally, by trying to synchronize their movements to the rhythm of the music, an additional challenge for the participants may occur, which may tax the central nervous system and subsequently promote coordination adaptation (Johansson & Cole, 1992). Along with this, participants of LM have to synchronize movements in the RPM™ class, which is a cycling class that highly involves the lower limbs (Dorel et al., 2012).

Though CF provides many of the qualities that should promote improvements in coordination, it failed to elicit changes. This may be in part due to the style of muscle movement and engagement. The resistances of CF movements are generally much heavier than those of the LM modality, which would generate differences in muscle recruitment. For instance, commonly utilized movements such as the power clean, snatch, thruster, box jumps etc. are quick and explosive movements and are performed at the practitioner's own pace which can compromise coordination improvement (Duchateau & Baudry, 2010). Additionally, WODs are continuously varied, and exercises rapidly change, making it not uncommon for an individual to perform a continuous movement for no longer than a few repetitions. This force generation combined with the sporadic nature of the exercises may not be optimal for the translation to the coordination tests utilized in this study. Future research should utilize a multi-joint coordination test to evaluate the CF modality.

Similar to CF, the TRAD group did not show any improvement in coordination. This finding was expected due to the cadences prescribed to the participants (i.e., 2 s at each phase). Additionally, participants worked at a higher percentage of their 1RM, facilitating slow, controlled movements. Contrary to the findings of this study, Park et al. (2015) and Kauranen et al. (1998) found improvements in coordination respectively after six and ten weeks of a resistance training program. The difference in findings may be related to the use of specific single joint or upper extremity-only resistance programs, whereas the program of our study was a bodybuilding program dedicated to the whole body.

Time-dependent improvements in agility occurred in both CF and LM groups. These results are supported by previous studies (Howard & Stavrianeas, 2017; Taheri et al., 2014) which demonstrated an improvement in agility after 6 weeks of plyometric training and 10 weeks of HIIT, both of which are highly incorporated in CF and LM. Subsequently, agility improvement seen in CF and LM can be explained by plyometric muscle contractions during different exercises integrated into training (Baro & Sonowal, 2014). Contrary, TRAD training essentially relies on slow and relatively heavy execution of movements, therefore TRAD group did not improve in agility. According to Carter et al. (2018), agility is the ability to change directions efficiently and requires the integration of motor skills such as balance, strength, and reaction time. Despite the fact that TRAD improved balance, it was not enough to develop agility. Interestingly, LM did not develop balance despite having shown improvements in agility, along these lines we can infer that changes in reaction time may impact the development of agility.

Though this study was carefully developed, it was not without limitations. Participant training time was self-selected (mornings, afternoons or evenings) throughout the study period, creating a discrepancy between the training times. The resistance training protocol may have been over-prescribed for the population, and future studies should examine a periodization-based program to prevent this. It is important to note that group-based training and the support of the coaches contributed to the commitment of the participants. This relationship was not directly examined in this study and should be examined in future projects.

Conclusions

Among the studied programs, only LM demonstrated the ability to develop coordination, both LM and CF elicited developments in agility, while CF and TRAD improved balance, yet no effect on motor accuracy has been demonstrated in any group. As such, each program provides some level of improvement, and program selection should be made based on the most desired outcomes.

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Conflict of interest

The authors report no conflict of interest.

References

Ageberg, E., Roberts, D., Holmstrom, E., & Friden, T. (2005). Balance in single-limb stance in patients with anterior cruciate ligament injury: Relation to knee laxity, proprioception, muscle strength, and subjective function. *American Journal of Sports Medicine, 33*(10), 1527–1535. https://doi.org/10.1177/0363546505274934

Anderson, K., & Behm, D. G. (2005). The impact of instability resistance training on balance and stability. *Sports Medicine, 35*(1), 43–53. https://doi.org/10.2165/00007256-200535010-00004

Angleri, V., Ugrinowitsch, C., & Libardi, C. A. (2017). Crescent pyramid and drop-set systems do not promote greater strength gains, muscle hypertrophy, and changes on muscle architecture compared with traditional resistance training in well-trained men. *European Journal of Applied Physiology, 117*(2), 359–369. https://doi.org/10.1007/s00421-016-3529-1

Antosiak-Cyrak, K., Wiczyński, G., Podciechowska, K., & Rostkowska, E. (2015). Reliability of a new lower-extremity motor coordination test. *Polish Journal of Sport and Tourism, 22*(4), 219–223. https://doi.org/10.1515/pjst-2015-0029

Baro, M., & Sonowal, A. (2014). Effect of selected plyometric exercises on explosive strength, speed and agility. *International Journal of Science and Research, 3*(8), 877–878. https://www.ijsr.net/getabstract.php?paperid=2015506

Beckung, E., & Hagberg, G. (2002). Neuroimpairments, activity limitations, and participation restrictions in children with cerebral palsy. *Developmental Medicine & Child Neurology, 44*(5), 309–316. https://doi.org/10.1017/S0012162201002134

Bressel, E., Yonker, J. C., Kras, J., & Heath, E. M. (2007). Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. *Journal of Athletic Training, 42*(1), 42–46. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1896078/

Brzycki, M. (1993). Strength testing – Predicting a one-rep max from reps-to-fatigue. *Journal of Physical Education, Recreation & Dance, 64*(1), 88–90. https://doi.org/10.1080/07303084.1993.10606684

Carter, K., Sunderman, S., & Burnett, S. W. (2018). The effect of vestibular stimulation exercises on balance, coordination, and agility in children with Down syndrome. *American Journal of Psychiatry and Neuroscience, 6*(2), 28–32. https://doi.org/10.11648/j.ajpn.20180602.11

Chaouachi, A., Hammami, R., Kaabi, S., Chamari, K., Drinkwater, E. J., & Behm, D. G. (2014). Olympic weightlifting and plyometric training with children provides similar or greater performance improvements than traditional resistance training. *Journal of Strength & Conditioning Research, 28*(6), 1483–1496. https://doi.org/10.1519/JSC.0000000000000305

Claudino, J. G., Gabbett, T. J., Bourgeois, F., de Sá Souza, H., Miranda, R. C., Mezêncio, B., Soncin, R., Cardoso Filho, C. A., Bottaro, M., & Hernandez, A. J. (2018). CrossFit overview: Systematic review and meta-analysis. *Sports Medicine – Open, 4*(1), Article 11. https://doi.org/10.1186/s40798-018-0124-5

CrossFit. (2019). *Level 1 training guide.* https://journal.crossfit.com/article/training-guide-compiled

Diny, M. D., Kainz, D. L., Greenhalgh, N. P., & Klemp, A. S. (2015). The effect of induced stress on fine motor accuracy. *Journal of Advanced Student Sciences, 2015*. https://minds.wisconsin.edu/handle/1793/80218

Dorel, S., Guilhem, G., Couturier, A., & Hug, F. (2012). Adjustment of muscle coordination during an all-out sprint cycling task. *Medicine & Science in Sports & Exercise, 44*(11), 2154–2164. https://doi.org/10.1249/MSS.0b013e3182625423

Duchateau, J., & Baudry, S. (2010). Training adaptation of the neuromuscular system. In P. V. Komi (Ed.), *Neuromuscular aspects of sport performance* (pp. 216–253). Wiley-Blackwell. https://doi.org/10.1002/9781444324822.ch13

Fong, S. S., Fu, S.-n., & Ng, G. Y. (2012). Taekwondo training speeds up the development of balance and sensory functions in young adolescents. *Journal of Science and Medicine in Sport, 15*(1), 64–68. https://doi.org/10.1016/j.jsams.2011.06.001

Fong, S. S., & Ng, G. Y. (2011). Does Taekwondo training improve physical fitness? *Physical Therapy in Sport, 12*(2), 100–106. https://doi.org/10.1016/j.ptsp.2010.07.001

Gorman, P. P., Butler, R. J., Plisky, P. J., & Kiesel, K. B. (2012). Upper Quarter Y Balance Test: Reliability and performance comparison between genders in active adults. *Journal of Strength & Conditioning Research, 26*(11), 3043–3048. https://doi.org/10.1519/JSC.0b013e3182472fdb

Halttunen, M., & Närhi, E. (2013). *The profile of music consumption in exercise environment – Music's impact on exercise enjoyment and motivation* [Bachelor's thesis, JAMK University of Applied Sciences]. Theseus. https://urn.fi/URN:NBN:fi:amk-2013121821762

Han, A., Fu, A., Cobley, S., & Sanders, R. H. (2018). Effectiveness of exercise intervention on improving fundamental movement skills and motor coordination in overweight/obese children and adolescents: A systematic review. *Journal of Science and Medicine in Sport, 21*(1), 89–102. https://doi.org/10.1016/j.jsams.2017.07.001

Hands, B. (2008). Changes in motor skill and fitness measures among children with high and low motor competence: A five-year longitudinal study. *Journal of Science and Medicine in Sport, 11*(2), 155-162. https://doi.org/10.1016/j.jsams.2007.02.012

Howard, N., & Stavrianeas, S. (2017). In-season high-intensity interval training improves conditioning in high school soccer players. *International Journal of Exercise Science, 10*(5), 713–720. https://digitalcommons.wku.edu/ijes/vol10/iss5/7

Johansson, R. S., & Cole, K. J. (1992). Sensory-motor coordination during grasping and manipulative actions. *Current Opinion in Neurobiology, 2*(6), 815–823. https://doi.org/10.1016/0959-4388(92)90139-C

Kauranen, K., & Vanharanta, H. (1996). Influences of aging, gender, and handedness on motor performance of upper and lower extremities. *Perceptual and Motor Skills, 82*(2), 515–525. https://doi.org/10.2466/pms.1996.82.2.515

Kauranen, K. J., Siira, P. T., & Vanharanta, H. V. (1998). A 10-week strength training program: Effect on the motor performance of an unimpaired upper extremity. *Archives of Physical Medicine and Rehabilitation, 79*(8), 925–930. https://doi.org/10.1016/S0003-9993(98)90089-2

Kochanowicz, A., Kochanowicz, K., Niespodziński, B., Mieszkowski, J., & Sawicki, P. (2017). Effects of systematic gymnastic training on postural control in young and adult men. *Science of Gymnastics Journal, 9*(1), 5–15. https://www.fsp.uni-lj.si/mma/-/20170301063843/?m=1488346723

Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of resistance training: Progression and exercise prescription. *Medicine & Science in Sports & Exercise, 36*(4), 674–688. https://doi.org/10.1249/01.mss.0000121945.36635.61

León-Quismondo, J., García-Unanue, J., & Burillo, P. (2020). Best practices for fitness center business sustainability: A qualitative vision. *Sustainability, 12*(12), Article 5067. https://doi.org/10.3390/su12125067

Les Mills. (2019). *Les Mills workouts*. https://www.lesmills.com/workouts/all/

Nazarenko, L. D. (2015). *The concept of classification of motor coordinations.* http://www.teoriya.ru/ru/node/3514

Orr, R., Raymond, J., & Singh, M. F. (2008). Efficacy of progressive resistance training on balance performance in older adults. *Sports Medicine, 38*(4), 317–343. https://doi.org/10.2165/00007256-200838040-00004

Park, J., Han, D.-W., & Shim, J. K. (2015). Effect of resistance training of the wrist joint muscles on multi-digit coordination. *Perceptual and Motor Skills, 120*(3), 816–840. https://doi.org/10.2466/25.26.PMS.120v16x9

Preeti, Kalra, S., Yadav, J., & Pawaria, S. (2019). Effect of Pilates on lower limb strength, dynamic balance, agility and coordination skills in aspiring state level badminton players. *Journal of Clinical and Diagnostic Research, 13*(7), YC01–YC06. https://doi.org/10.7860/jcdr/2019/41713.12978

Preston, N., Magallon, S., Hill, L. J., Andrews, E., Ahern, S. M., & Mon-Williams, M. (2017). A systematic review of high quality randomized controlled trials investigating motor skill programmes for children with developmental coordination disorder. *Clinical Rehabilitation, 31*(7), 857–870. https://doi.org/10.1177/0269215516661014

Raya, M. A., Gailey, R. S., Gaunaurd, I. A., Jayne, D. M., Campbell, S. M., Gagne, E., Manrique, P. G., Muller, D. G., & Tucker, C. (2013). Comparison of three agility tests with male servicemembers: Edgren Side Step Test, T-Test, and Illinois Agility Test. *Journal of Rehabilitation Research and Development, 50*(7), 951–960. https://doi.org/10.1682/JRRD.2012.05.0096

Riseth, L., Nøst, T. H., Nilsen, T. I., & Steinsbekk, A. (2019). Long-term members' use of fitness centers: A qualitative study. *BMC Sports Science, Medicine and Rehabilitation, 11*, Article 2. https://doi.org/10.1186/s13102-019-0114-z

Shaffer, S. W., Teyhen, D. S., Lorenson, C. L., Warren, R. L., Koreerat, C. M., Straseske, C. A., & Childs, J. D. (2013). Y-balance test: A reliability study involving multiple raters. *Military Medicine, 178*(11), 1264–1270. https://doi.org/10.7205/MILMED-D-13-00222

Srimathveeravalli, G., & Thenkurussi, K. (2005). Motor skill training assistance using haptic attributes. In *First Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. World Haptics Conference* (pp. 452–457). IEEE Computer Society. https://doi.org/10.1109/WHC.2005.96

Stodden, D. F., Goodway, J. D., Langendorfer, S. J., Roberton, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008). A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest, 60*(2), 290–306. https://doi.org/10.1080/00336297.2008.10483582

Swarbrick, D., Kiss, A., Trehub, S., Tremblay, L., Alter, D., & Chen, J. L. (2020). HIIT the Road Jack: An exploratory study on the effects of an acute bout of cardiovascular high-intensity interval training on piano learning. *Frontiers in Psychology, 11,* Article 2154. https://doi.org/10.3389/fpsyg.2020.02154

Taheri, E., Nikseresht, A., & Khoshnam, E. (2014). The effect of 8 weeks of plyometric and resistance training on agility, speed and explosive power in soccer players. *European Journal of Experimental Biology, 4*(1), 383–386. https://www.primescholars.com/articles/the-effect-of-8-weeks-of-plyometric-and-resistance-training-on-agility-speed-and-explosive-power-in-soccer-players-91912.html

Tallent, J., Woodhead, A., Frazer, A. K., Hill, J., Kidgell, D. J., & Howatson, G. (2021). Corticospinal and spinal adaptations to motor skill and resistance training: Potential mechanisms and implications for motor rehabilitation and athletic development. *European Journal of Applied Physiology, 121*(3), 707–719. https://doi.org/10.1007/s00421-020-04584-2

Thompson, W. R. (2019). Worldwide Survey of Fitness Trends for 2020. *ACSM'S Health & Fitness Journal*, *23*(6), 10–18. https://doi.org/10.1249/fit.0000000000000526

Wulf, G. (2007). *Attention and motor skill learning*. Human Kinetics. https://doi.org/10.5040/9781492596844

Wulf, G., Shea, C., & Lewthwaite, R. (2010). Motor skill learning and performance: A review of influential factors. *Medical Education, 44*(1), 75–84. https://doi.org/10.1111/j.1365-2923.2009.03421.x