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The Effect Of Contextual Interference On Motor Learning Among Healthy Adolescents: A Systematic Review

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Abstract: During the beginning of the 1990s, experimental research on the effect of contextual interference was widely carried out, which also brought significant of research profit. Considerable laboratory experiments supported the contextual interference-effect. However, the utility of laboratory-based research has been questioned, and no consistent conclusions were yielded in actual motor learning practices. This review aims to determine the effect of contextual interference (low, moderate, and high level) on actual motor learning under non-laboratory experiments among healthy adolescents. Four academic databases (Web of Science, PubMed, Scopus, and SPORT Discus) were searched systematically with predefined search terms. We selected studies through PICOS and conducted a systematic literature review according to the PRISMA guidelines. Thirteen studies were included, of which 12 were at low risk of bias, while only one was classified as high risk. In general, experience in participants has been shown to improve the contextual interference effect, and limited evidence was presented regarding their age. Results on experimental types (laboratory or non-laboratory) are mixed. Task variations from the different motor programs did not show an effect among children, probably because the task variations were too difficult and exceeded their ability. There is a limitation of high-quality evidence about the contextual interference effect on healthy adolescents under different practices schedules. The results are mainly inconsistent; several studies showed the CI effect, but this cannot be applied to the entire field of motor learning. Further independent studies of the parameters influencing the CI effect are required in future research.

Keywords: contextual interference, motor learning, practice schedule, sports performance, healthy adolescents

1 Introduction

In the field of motor learning, one prominent goal for all practitioners is to create effective environments that promote skills training during practice that will enhance participants' performance on later skill retention or transfer tests. There has been much debate about the relevancy and generality of the findings of basic motor learning research regarding practitioners [6,28]. Among these, a topic that has received a lot of attention is the contextual interference effect (CI effect). In 1966, Batting proposed the concept of contextual interference in the realm of verbal learning. Originally, contextual interference was defined as a functional interference in learning responsible for memory improvement. Batting (1979) conceptualized this effect as a consequence of adaptation processes that occur when the learner must respond to a variable input over an acquisition phase [2]. After that, Shea and Morgan (1979) attempted to introduce this theory into the field of motor learning and pioneered experimental research in this emerging field. Their results revealed the typical contextual interference effect whereby subjects who experienced a low contextual interference schedule had higher acquisition rates and lower retention and transfer scores, while the reverse was true for the group that practiced the task under high contextual interference conditions [6].

During the beginning of the 1990s, considerable laboratory experiments supported the contextual interference effect. The most widely used are multi-segment movement tasks, such as barrier knock-down and sequential button-pressing tasks. There also exist some propulsive tasks [18,49,50] and coincidence anticipation tasks [12,14,40]. Most results of the experiments were completed in laboratories and supported the CI effect, similar with those conducted by Shea and Morgan (1979). However, the results of these studies were not accepted by most researchers, and the validity of this conclusion in real-world environments has been questioned [35]. Goode stressed that because generality is the primary goal of science, before the practitioner can readily adopt the contextual interference hypothesis to real-world tasks, greater congruity must exist between laboratory and field-based research [19]. Stallings (1982) also suggested that the theoretical models of motor learning should be validated in practical settings by translating them into instructional procedures that apply to the practitioner [6].Since then, researchers have introduced the experiment of contextual interference effect into the actual training sessions to explore whether there is a contextual interference effect like laboratory experiments.

In general, the variability of the practice effect depends on several variables: practice order, intervention, subject characteristics, amount of training sessions, etc. According to the CI effect theory, a random structure of practice should create interference, thus enhancing future retention and transfer to tasks of the same response class [9]. Furthermore, this domain of research has experienced tremendous growth since the schema theory proposed by Schmidt (1975). The schema theory predicted more visible effects in children, for example, in a period of schema formation, than in adults [42]. However, this hypothesis was not supported by accumulated empirical evidence. Therefore, the optimal sequence of practice on motor learning among healthy adolescents remains inconclusive. Several reviews focus on the contextual interference effect [2,6,7,29,33], which summarizes the conclusion of previous studies and the author's own views and provides many references for this current review. Before this review, we assumed that the conclusion drawn from contextual interference studies conducted among adults can be directly applied to the adolescent's population. Therefore, the purpose of this review is to determine the effect of contextual interference (low, moderate and/or high level) on actual motor learning under non-laboratory experiments among healthy adolescents. The primary research question is as follows: What is the evidence concerning the contextual interference effect for healthy adolescents?

2. Materials and Methods

2.1 Inclusion and Exclusion Criteria

A systematic review was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement. Table 1 summarizes the inclusion criteria for this review, which are Population, Intervention, Comparison, Outcome, and Study Design (PICOS). In addition to the above screening criteria, studies were included if they satisfied the following criteria: (1) full-length, peer-reviewed journal articles; (2) healthy participants, excluding those with physical disability and/or brain lesions such as cerebral palsy; and (3) experiments focusing on sports skills training, excluding laboratory experiments (such as two-handed collaboration and goal-following experiments). We included motor learning studies examining the contextual interference effect with a progressive and/or random practice order group (Intervention), and at least one blocked practice order group (Control). Any outcome evaluating the acquisition, retention, and/or transfer of the learned skill (Outcome) was considered optional. To eliminate duplication, the considered studies were loaded into the reference management program in EndNote. One author led the search procedure. Secondly, the titles and abstracts were independently reviewed by the other two authors. Following that, pertinent full-text articles were selected for further in-depth investigation.

Table 1 (PICOS) Detail Screening Criteria

PICOS	Screening Criteria
Participant	Healthy teenagers or young adults (except obesity, frail, cancer, brain lesions and other diseases)
Intervention	Contextual interference, motor learning, practice order (blocked, random and/or progressive, serial)
Comparison	No exercise group or exercise group in the control group

Outcome	Skill performance (acquisition, transfer, retention)
Study Design	Randomized controlled trial，non-laboratory experiments

2.2 Data Sources and Search

A systematic search was undertaken on the existing literature on the impact of contextual interference on motor learning (skill acquisition, transfer and retention) among teenagers and young adults, published prior to March 2022. The study was designed and conducted in accordance with the PRISMA guideline [36]. The reference lists of research papers and systematic reviews were screened for further related studies. The primary search was performed in March 2022 (for the period between 1960 and March 2022) and updated in April 2022.

The literature search was conducted using four prominent scholarly databases: PubMed, Web of Science, Scopus, and SPORT Discus. Each database was searched by title using a predefined combination of keywords: AB=("contextual interference" OR "intratask interference" OR "practice schedule" OR "practice order" OR "blocked" OR "progressive" OR "random") AND AB=("motor learning" OR "sports training" OR "motor performance" OR "motor development" OR "acquisition" OR "transfer" OR "retention") AND AB=("children" OR "child" OR "childhood" OR "adolescent" OR "youth" OR "teenager" OR "kids").Terms were joined with the use of logical operators that can be utilized by the database search engines.

2.3 Study Selection

One author conducted a search for articles and deleted duplicates. Two other authors independently selected studies based on their titles and abstracts. If this was unsuccessful, the papers were screened by reading the full text. The following information was extracted: (1) author/year, (2) design/sample/age/gender, (3) intervention/time/frequency/duration, and (4) major findings. We also excluded conference papers, studies of which only the abstracts were available, unpublished dissertations, and studies in a language other than English.

2.4 Methodological Quality Assessment

The PEDro scale was applied to assess the trials' methodological quality [11].The PEDro scale assesses four critical methodological features of a study: randomization, blinding, group comparison, and data analysis. This is based on a Delphi list developed by Verhaegen et al. [24], which includes the following 11 items: specified eligibility criteria, randomization, concealed allocation, baseline comparability, blinded subjects, blinded therapists, blinded assessors, adequate follow-up, intention-to-treat analysis, between-group comparisons, and point estimates and variability. The PEDro scale has a score range of 1 to 10, whereby a higher PEDro score indicates a higher-quality approach. To determine the methodological quality, the following criteria were used: A PEDro score <5 denotes poor quality, while a score ≥5 indicates excellent quality (Table 2) [30]

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Table 2 Summary of Methodological Quality Assessment Scores

References	Eligibility Criteria	Random Allocation	Allocation Concealment	Group Similar at Baseline	Blind Subject	Blind Therapist	Blind Assessor	Follow-up	Intention to Treat Analysis	Between Group Comparisons	Point Measure and Variability	Score
Shrutika et al.,2018	1	0	0	1	0	0	0	1	1	1	1	6
Landin et al.,2003	1	1	1	1	0	0	0	1	1	1	0	7
Bertollo et al.,2010	0	1	1	0	0	0	0	1	1	1	1	6
Kellie et al.,1994	1	1	1	1	0	0	0	1	1	1	0	7
Jarus et al.,2001	0	1	1	1	1	0	0	1	1	1	1	8
Buszard et al.,2017 study 2	1	0	0	1	0	0	0	1	1	1	1	6
Bortoli et al.,1992	0	1	1	1	0	0	0	1	1	1	1	7
Fialho et al.,2006	1	0	0	0	0	0	0	1	1	1	1	5
Meira & Tani,2003	0	0	0	1	0	0	0	1	1	1	0	4

Saemi et al.,2012	1	1	1	0	0	0	0	1	1	1	1	7
Meira & Tani,2001	0	1	1	0	0	0	0	1	1	1	0	5
Porter&Magill,2010	0	1	1	0	0	0	0	1	1	1	1	6
Aiken&Genter,2018	0	1	1	1	0	0	0	1	1	1	1	7
Total	6	9	9	8	1	0	0	13	13	13	9	

2.5 Data Extraction and Analysis

The author summarized relevant data using a standardized data extraction sheet. This comprises the type of study, participants (population, age, number per group), task, information regarding the acquisition, retention and transfer phases, including time points, duration, used outcome measures (e.g., anticipation timing task) and outcome parameters (e.g., variable and random error), as well as the results.

We planned to pool data when studies were comparable regarding populations, interventions, outcomes, and types of studies. The results of each study would be rated as significant (favoring blocked, progressive or random order), inconsistent or not significant [20]. Consistency of the results within one study would be given if 75% of the comparisons (e.g., measures, parameters, and tasks) would provide similar results (e.g., random was better than blocked for the retention). Then the evidence of the different tasks (several studies per task) was rated according to the suggestions in prior work [46]: Strong (consistent findings among multiple high quality randomized controlled trials (RCTs)), Moderate (consistent findings among multiple low quality RCTs and/or controlled clinical trials (CCTs) and/or one high quality RCT), Limited (one low quality RCT and/or CCT, Conflicting (inconsistent findings among multiple RCTs and/or CCTs; inconsistent findings among different parameters within one trial (if only one trial is available) or no evidence from trials (no RCTs or CCTs). Consistency among the studies assessing similar tasks would be given if more than 75% of the studies showed results in the same direction [46].

3. Results

The primary search in the databases resulted in 3,036 records (Fig 1), with 1,204 remaining after removing duplicates, conference papers, books and unpublished papers (1,832 in total). Then, a secondary screening was carried out. Among them, 1,116 papers had a theme that was not focused on the contextual interference effect, and 10 papers could not be found in full text form. Finally, the remaining 78 articles were read carefully and selected according to the PICOS criteria. Among them, 10 articles in total had participants that were not healthy adolescents (six participants with brain diseases, and four old adults). 25 experimental interventions were not in the order of practice. Papers in which the outcome did not focus on the skill acquisition, transfer or retention were excluded (12 in total). An additional 18 papers were excluded since the experimental design was not a randomized controlled trial, and laboratory experiments were also excluded. Finally, the remaining 13 papers were used as references for this study. Information on each study is presented in Table 3

Figure 1 PRISMA Flow Chart of the Study Selection Process

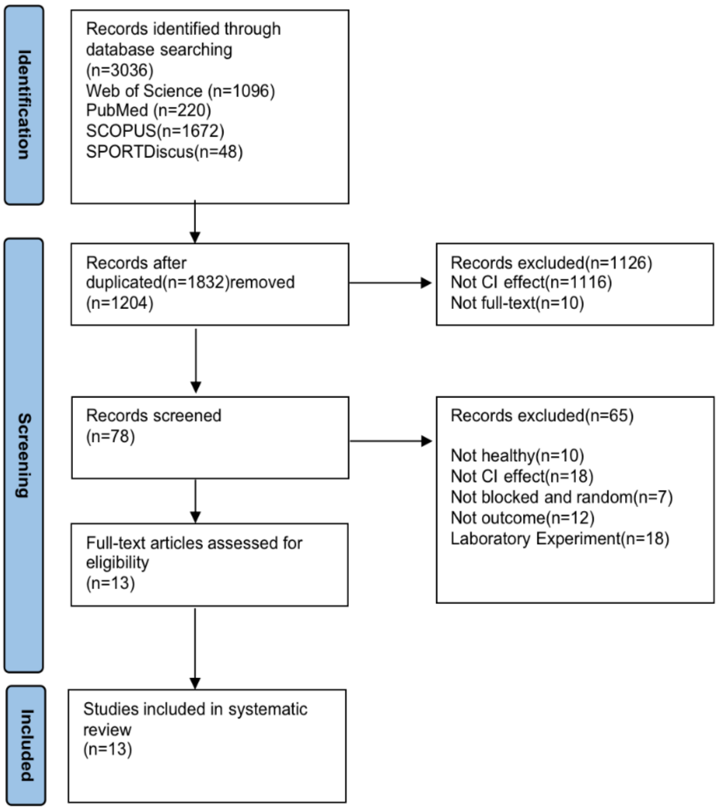

FIGURE 1 | PRISMA flflow chart of the study selection process

3.1 Methodological Quality

The PEDro scale has a range of values between 4 and 8 (mean=6.2, median=6, mode=7). One study received a score of <5, while the remaining 12 (n=12) received a score of five or higher, indicating a mix of high- and low-quality studies. The publication year did not influence the quality of the studies, since the low-quality study were published in 2006, while the high-quality studies were published between 1992 and 2018 (see Table 2). The mostly common criteria were followed up (n=13), intention to treat analysis (n=13), between group comparisons (n=13), point measure and variability (n=9), random allocation (n=9), allocation concealment (n=9), and group similar at baseline (n=8). The criteria blind subject, blind therapist and blind assessor did not satisfy any analysis. In terms of eligibility criteria, n=6 (Table 2).

3.2 Study Characteristics

The study characteristics included in this review are shown in Table 3. One paper presented two different experiments with different samples. This paper was handled as two separate studies in this review [39]. All studies were published between 1992 and 2018.The sample size ranged from 10 to 120 participants, and the mean age ranged from 8.5 to 21.5 years old. Regarding the participants, the studies included only male [22,25,41], female [3,31,39], or both sexes [1,4,8,15,23,32,37,39]. In terms of the characteristics of the subjects, three studies used skilled players in experiments [8,15,22], and all the remaining studies used novices as their participants. In terms of the skill test design in these studies, five studies performed three tests arrange skill acquisition, transfer, and retention [4,23,37,39]. Acquisition and retention tests were included in four articles [1,3,25,41], but skills transfer was investigated. Four articles included two tests, excluding skills retention tests [8,15,22,31]. In addition, one article tested the skills acquisition and transfer phases, but only gave the data of the transfer stage in the experimental results section [32].

Table 3 Summary of the Included Studies

NO.	Study	Description		Acquisition	Retention	Transfer	Results		
		Participants	Skill/Task	Time frame	Time frame	Time frame	Acquisition	Retention	Transfer
		n total		Outcome measure	Outcome measure	Outcome measure			
		n group		Outcome parameter	Outcome parameter	Outcome parameter			
1	Shrutika et al.,2018	Healthy children, novices at the task	Single leg hopping in three different patterns	6 sessions,72 trails,12 trails/session	Post 1 hour Post 24 hours Post 7 days	Post 7 days	Time variable: significant effect on age Age 8-10,10-12>Age 6-8 Error variable: significant effect on age Age 8-10,10-12>Age 6-8 Post hoc test: Age 6-8 more errors, No difference between age 8-10 and age 10-12	Time variable: Blocked>Random, significant effect on age: Age 8-10,10-12>Age 6-8 Error variable: Blocked>Random, significant effect on age: Age 8-10,10-12>Age 6-8 Post hoc test: Age 6-8 more errors, No difference between age 8-10 and age 10-12	Time variable: No effect-patterns, age and patterns, Effect-age Post hoc test: Age 6-8 take more time Error variable: Blocked group better, No effect-age, Effect-age and patterns Post hoc test: No difference
		total:120		Tasks themselves	Tasks themselves	modified in terms of size and patterns of blocks			

		6-8yrs=40(M=6.5,SD=0.7)blocked=20,random=20;8-10yrs=40(M=8.5,SD=0.7)blocked=20,random=20;10-12yrs=40(M=10.5,SD=0.07)blocked=20,random=20		Response time, number of errors (Losing balance, landing outside and hopping in same square twice)	Response time, number of errors (Losing balance, landing outside and hopping in same square twice)	Response time, number of errors (Losing balance, landing outside and hopping in same square twice)			
2	Landin et al.,2003	Right hand, male undergraduate student, novices at the task	Basic throws used in ultimate, the forehand and the backhand flick	2 days,100 trails/day (50 of each throw)	Post 1 day 60 trails	NA	Outcomes: Low CI-forehand improved Moderate/high CI-backhand improved Quadrants: Moderate CI-no biased Low/high CI-forehand improved	Outcomes: All CI-backhand better than forehand Quadrants: Alternating test-in high CI group, forehand better than backhand	NA
		Total:34 (N=34, M Age=20.25yrs, SD=1.40)		Tasks themselves	Tasks themselves				
		34 participants randomly assigned to one of 3 practice schedules: low, moderate or high CI		Outcomes: ring of the target Quadrants: performance bias.	Outcomes: ring of the target Quadrants: performance bias.				

3	Bertollo et al.,2010	Female high school students (M age=15.8 yrs., SD=1.3 yrs.)	Dance step sequence (different sequences)	3weeks,2sessions/week(30mins each)	After 21 days	NA	Blocked>Random (p<0.01, d=0.90,95% CI=0.25-1.56)	No significant group difference	NA
		Total:40		Step sequence	Step sequence				
		Blocked:20 Random:20		Score of spatial and temporal accuracy	Score of spatial and temporal accuracy				
4	Kellie G.H et al.,1994	30male baseball players (age17-21, average 9.5 years' experience in competitive baseball)	Hitting three different types of pitches-fastballs, curveballs, and changeups	twice a week 6 weeks (12 sessions total)	NA	two separate transfer tests, each of 45 pitches,15 of each type of pitch	Significant improvement over the two sessions, no significant difference for condition and interaction	NA	Random>Blocked>Control
		Total:30		Tasks themselves		Tasks themselves			
		Control:10 Blocked:10 Random:10		The 5thand 8thsessions were recorded as acquisition data.		Random transfer test and Blocked transfer test			
5	Jarus & Gutman,2001	Children from public school, no cognitive and motor deficits (M_{age}=8.52 yrs., SD=0.61yrs.)	Throwing beanbags of different sizes to targets of different distances Simple task:	1 session,30 trials	After 1 day	After 1 day	Simple task: Total time: no significant group difference Accuracy score: not reported due	Simple task: Total time: no significant group difference Accuracy score: not reported due to lack of	Simple task: Total time: no significant group difference Accuracy score: not reported due

			different bag weights Complex task: different bag weights, sizes, different target order				to lack of significant results Complex task: Total time: blocked (Mean±SD= 10.83±3.1)> Random (Mean±SD= 14.94±4.34) Accuracy score: not reported due to lack of significant results	significant results Complex task: Total time: no significant group difference Accuracy score: not reported due to lack of significant results	to lack of significant results Complex task: Total time: no significant group difference Accuracy score: not reported due to lack of significant results
		Total:96		Tasks themselves	Tasks themselves	Same task, different bag (simple transfer), different bag and different target order (complex transfer)			
		Simple task condition(n=48): blocked=16, random=16, combine=16 Complex task condition(n=48): blocked=16, random=16, combine=16		Total time to complete each trial Accuracy score (not reported due to lack of significant results)	Total time to complete each trial Accuracy score (not reported due to lack of significant results)	Total time to complete each trial Accuracy score (not reported due to lack of significant results)			

6	Buszard et al.,2017 Study 2	Skilled youth tennis players (age 11-13) 8males (Mage=12.1, SD=0.4) 8 females (Mage=12.1, SD=0.9)	Serves down the T (target zone)	7 weeks,10 sessions (30 min each,40 serves)	NA	Two matches across two days	Low CI group>Moderate CI group, a significant interaction (Group*Time) effect on distance and speed	NA	No difference, No interaction effect (Group*Time)
		Total:16		Tasks themselves		Tasks themselves			
		Low CI=8 Moderate CI=8		Serves-in, Service displacement from the T, Service velocity		T Serves-in, Service displacement from the T, First service down the T			
7	Bortoli et al.,1992	9th grade students (Mage=14.6yrs., SD=0.7yrs.)	Volleyball skills (volley, bump, serve)	6 weeks 1 session/week	After 1 week	After 1 week	Blocked=Random(f<1.00)	No significant group difference	Long transfer: random>blocked ($F_{3,48}=2.97$, $p<0.05$, all 4 groups) Short transfer: not reported
		Total=52		Specified targets	Specified targets	Targets 1 meter (short transfer),1 meter behind (long transfer)			
		Blocked:13 Random:13 Serial Organization:13 Serial Organization (very high CI):13		Scores of accuracies	Scores of accuracies	Scores of accuracies			

8	Fialho et al.,2006	Skilled volleyball players (M_{age}=16.3$_{yrs}$, SD=0.67$_{yrs}$)	Volleyball skills (tennis serve, float serve)	4 days 1 session/day (46 trials each)	NA	After 10 mins After 24 hours (Retention of the transfer)	Mean Score: NA (between group result not reported) SD of the score: no significant group difference	NA	Mean Score: Transfer: NA (between group result not reported) Retention of the transfer: random>blocked (H10,1=3.6, $p<0.05$)for the first block of trails SD of the score: Transfer: no significant group difference Retention of the transfer: no significant group difference
		Total:10		Tasks themselves		Asian serve (transfer and retention of the transfer)			
		Blocked:5 Random:5		Accuracy scores of the serves (Means and SDs)		Accuracy scores of the serves (Means and SDs)			

9	Meira & Tani,2003	Female students, secondary school, Right-handed, Volleyball novices (Mage=12.7yrs, SD=NA)	Volleyball skills (underhand serve, overhand serve, Asian floater)	8 sessions(2/week),36 trials/session	NA	Immediately after: Transfer 1--3 sessions(2/week)28 trials/session 1 week after: Transfer 2--1 session,12 trials	Precision scores on target: no significant group difference Movement pattern quality scores: no significant group difference	NA	No significant group difference in neither transfer 1 nor 2, in neither of the parameters
		Total:36		Tasks themselves, with knowledge of result		Tasks themselves, with knowledge of result			
		Blocked:18 Random:18		Precision scores on target, Movement pattern quality scores		Precision scores on target, Movement pattern quality scores			
10	Saemi et al.,2012	Male elementary school students, low skilled in throwing task (Mage=10.47 yrs, SD=0.77yrs)	Throwing tennis ball from different starting positions to different targets	1 session 81 trials (27*3)	After 1 day (12 trials)	NA	Significant main effect for practice condition ($F_{2,33}$=4.19, p<0.024, η^2 =0.203) but no post-hoc pairwise comparison reported No significant practice	No significant group difference	NA

							condition*trial block interaction (F16,164=0.44, p=0.97)		
		Total:36		Task itself	Task itself				
		Blocked: NA Random: NA Increasing: NA		Scores (accuracy of the target)	Scores (accuracy of the target)				
11	Meira & Tani,2001	Undergraduate students aged between 18-30(Mage=21.5yrs, SD=NA)	Dart throwing skills with different grips and different distance	80 trials (20 trials/task)	NA	After the acquisition phase,40 trials	NA	NA	Main effect for block factor (F3,90= 12.56, p < 0.01) Blocked group: significant effect(p<0.01)
		Total:32(male-18, female-14)		Tasks themselves, with knowledge of result		Tasks themselves, with knowledge of result			
		Blocked:16 Random:16		Precision scores on target		Precision scores on target			

12	Porter& Magill, 2010 Experiment 1	University students, novice golfers (Mage=NA, SD=NA)	Putting golf ball from different starting positions to target	1 session 81 trials (27 trials/distance)	After 1 day (20 trials)	Follow by retention test (20 trials)	Main effect for practice schedule ($F_{2,57}=5.62$, $p=0.0059$) and trial block ($F_{8,456}=8.50$, $p<0.0001$) but interaction was not significant Post-hoc analysis reported: Blocked and Increasing> Random (ES=0.123, ES=0.335, respectively)	Significant main effect for practice schedule ($F_{2,57}=5.80$, $p<0.05$) Post-hoc analysis reported: Increasing>Blocked and Random (ES=0.467, ES=0.475respectively)	Significant main effect for practice schedule ($F_{2,57}=3.37$, $p<0.05$) Post-hoc analysis reported: Increasing> Random (ES=0.432)
		Total:60(Male18, Female42)		Task itself	Task itself	Task itself			
		Blocked: NA Random: NA Increasing: NA		Scores (accuracy of the target)	Scores (accuracy of the target)	Scores (accuracy of the target)			

13	Porter& Magill, 2010 Experiment 2	Female students, novice basketball players (M_{age}=NA, SD=NA)	Passing basketball to target through three passing methods	1 session 81 trials (27 trials/distance)	After 1 day (20 trials)	Follow by retention test (20 trials)	Significant main effect for trial block (F8,744=72.74, p<0.0001) Post-hoc analysis reported: no significant main effect for Practice Schedule (F2,93=2.39, p=0.0969), no significant Practice Schedule*Trial Block (F16,744=1.47, p=0.1052)	Significant main effect for practice schedule (F2,93=36.27, p<0.0001) Post-hoc analysis reported: Increasing>Blocked and Random (ES=0.994, ES=0.417respectively)	Significant main effect for practice schedule (F2,93=56.58, p<0.0001) Post-hoc analysis reported: Increasing> Blocked and Random (ES=1.317, ES=0.666respectively)
		Total:96		Task itself	Task itself	Task itself			
		Blocked: NA Random: NA Increasing: NA		Scores (accuracy of the target)	Scores (accuracy of the target)	Scores (accuracy of the target)			

14	Aiken&Genter,2018	College students novice golfers (Mage=20.08, SD=NA)	Chipping golf ball from different ball lies ((uphill, downhill, and flat) to target	54 trials,9 blocks (6 trials/block)	After 5 minutes,2 retention tests Blocked (6 trials,2 trials/task) Random (6 trials,2 trials/task)	NA	main effect for trial block ($F_{8,176}=3.33$, $p<0.001$, $\eta^2=0.13$) Post-hoc analysis reported: no significant effect for Group ($F_{1,22}=0.04$, $p>0.05$), no significant Block*Group ($F_{8,176}=1.13$, $p>0.05$)	Main effect for group ($F_{1,22}=4.68$, $p<0.05$, $\eta^2=0.18$), significant Group*Test ($F_{1,22}=7.48$, $p=0.01$, $\eta^2=0.25$), no main effect for test ($F_{1,22}=1.42$, $p>0.05$)	NA
		Total:24(Male:10, Female:14)		Task itself	Task itself				
		Blocked: NA Random: NA		Scores (accuracy of the target)	Scores (accuracy of the target)				

Abbreviations: CI=Contextual Interference; m=meters; n=number; NA=not applicable; SD=standard deviation; yr./yrs.=year/years;> meaning "better than".

3.3 Best evidence synthesis

The best evidence synthesis (see Table 4) was conducted for all studies. We grouped the studies according to the tasks they evaluated and received seven task-specific groups. For most tasks, the evidence was conflicting or absent. Single tasks showed limited evidence supporting the contextual interference effect. Acquisition: there was limited evidence for the benefit of blocked practice over progressive practice for tennis serving [8]. Retention: there was limited evidence for the benefit of progressive practice over blocked and random practice for passing a basketball in three different ways [39]. Transfer: there was limited evidence for the benefit of random practice order over blocked practice and control group for baseball hitting [22]. Limited consistent evidence was found for the benefit of progressive practice order over blocked and random practice for basketball passing and putting a golf ball to a target [39]

Table 4 Best Evidence Synthesis

Area		*Subjects*	*Task*	*Study*	*Evidence Synthesis per Study*			*Evidence Synthesis Summary*		
					Acquisition	*Retention*	*Transfer*	*Acquisition*	*Retention*	*Transfer*
NLT	SMP	Novices	Throwing Task	Jarus & Gutman,2001	IC	NS	NS	X	-	X
				Saemi et al.,2012	NS	NS	NA			
				Meira & Tani,2001	NA	NA	SL			
			Step Sequence	Shrutika et al.,2018	NS	SL	IC	X	X	X
				Bertollo et al.,2010	SL	NS	NA			
			Golf	Porter&Magill , 2010 Experiment 1	SL	SM	SM	SL	SM	SM
		Skilled	Tennis Serving	Buszard et al.,2017 Study 2	SL	NA	NS	SL	NA	-
	DMP	Novices	Volleyball	Bortoli et al.,1992	NS	NS	IC	-	-	X
				Meira & Tani,2003	NS	NA	NS			
			Throwing Task	Landin et al.,2003	IC	NS	NA	X	-	-
			Basketball Passing	Porter&Magill , 2010 Experiment 2	NS	SM	SM	-	SM	SM
			Golf	Aiken&Genter ,2018	NS	NS	NA	-	-	-
		Skilled	Baseball Hitting	Kellie G.H et al.,1994	NS	NA	SH	-	-	SH
			Volleyball	Fialho et al.,2006	NS	NA	IC	-	-	X

Abbreviations: NLT=non-laboratory tasks; SL=significant, favoring low CI effect (blocked practice order); SM=significant, favoring moderate CI effect (progressive practice order); SH=significant, favoring high CI effect (random practice order); IC=inconsistent; NA=not applicable, no study evaluated the according aspect; NR=not reported; NS=not significant.
Evaluation of the studies: Results of the single studies were evaluated taking in account all parameters and tasks into account. Results with ≥ 75% of the comparison favoring one practice order were evaluated as consistent evidence within one study.
Evaluation of the tasks: Results of the according studies were merged if ≥ 75% of the studies of one task showed the same result, evidence was rated as consistent.
Strength of the evidence (adapted from Tulder et al. [24]):
*** =Strong—consistent findings among multiple high quality randomized controlled trials (RCTs)
** =Moderate—consistent findings among multiple low quality RCTs and/or controlled clinical trials (CCTs) and/or one high quality RCT
* =Limited—one low quality RCT and/or CCT
X =Conflicting—inconsistent findings among multiple trials (RCTs and/or CCTs); inconsistent findings among different parameters within one trial (if only one trial is available)
- =No evidence from trials—no RCTs or CCTs

4. Discussion

In order to generalize the contextual interference effect to all motor skill learning situations, it must prove the generality of this effect first. Shea and Morgan (1979) also assumed that this effect can be applicable to a wide range of skill training, and they have thus attempted this in their early experiments. To explore the generality of the effect, at least two sections must be considered. The first involves the subject's characteristics. We need to consider whether different individual characteristics such as age, intelligence and experience for target skills, affect the degree of the generality of the contextual interference effect. The second involves the characteristics of the task. The type, complexity and variations of the different tasks may also influence the factors for the appearance of this effect.

Regarding the characteristics of the subjects, in this article, we selected only healthy adolescents as participants in the experiments. Subjects with physical and/or intellectual disabilities and other diseases were excluded. We only discussed whether differences in their age and previous experience affect the generality of the contextual interference effect. As mentioned in the rule of inclusion and exclusion criteria, all laboratory experiments were excluded, so when we discuss the types of experiments, we compare the conclusions with those laboratory experiments.

4.1 Subject Characteristics

4.1.1 The Influence of Experience on Contextual Interference Effect

Among all the articles we selected, only three chose experienced players as participants, and the remaining 11 experiments used novices as the subjects. The three articles selected baseball, tennis and volleyball players to participate in the experiments. Three articles show similar results and conclusions to most laboratory research. Overall, the group under high contextual interference outperformed the group that received low contextual interference in skill transfer and retention tests. However, there was no significant difference in the acquisition phases, which only have a negligible effect in some parameters, where the blocked group performed better than the random group, because all subjects have varying levels of experience in corresponding skills ($M=9.5_{yrs}$ in Kellie et al.1994, $M=4.1_{yrs}$, $SD=2.7_{yrs}$ in Fialho et al.2006). In the research by Buszard et al. (2017), participants were the top 50 players for their age group. According to the results, Kellie et al. suggested that high contextual interference (random practice order) can help athletes respond quickly and correctly in actual competitions, which is extremely important for them. In the skill transfer and retention phases, there was a superiority of the random practice over the blocked practice, but the advantage was eliminated with time, supporting the hypothesis of Ugrinowitsch and Manoel (2005), that random practice can help a temporary adaptation to new situations for skilled subjects.

According to the Challenge-Point framework (Guadagnoli & Lee, 2004), learning is heightened when contextual interference is matched to the performer's skill level for a given task [38]. For participants with a higher level, the complexity of the task should be continuously adjusted during the practice process, which may lead to better overall performance. The remaining 11 articles that selected novices as participants cannot provide consistent results. In skill acquisition, most results showed that different practice order did not result in a significant difference, and two experiments proved that the performance of the low contextual interference group was better than that of the high contextual interference group. At the skill retention phase, the results were broadly similar, with most experiments showing no significant difference between the blocked and other groups, with the high contextual interference group performing better in this stage. In the skill transfer stage, apart from four articles that were not reported in the skill transfer stage, the results of the remaining experiments were also inconsistent. According to these experimental results, it is not possible to draw a consistent conclusion to prove the effect of the contextual interference on motor learning among healthy adolescents in actual training environments.

Since high contextual interference practice conditions are more difficult than low conditions, it seems reasonable that high contextual interference conditions early in practice may pose a learning problem for beginners and that only after some degree of expertise or prior experience with related skills has been achieved would a high contextual interference practice situation be beneficial [29]. From this perspective, at least for an open skill, the degree of experience a person has may be an interactive variable to consider in determining whether high contextual interference benefits learning [29]. It may be important that a basic movement pattern is established initially, as Gentile (1972) proposed, before variations of that pattern or environmental conditions are experienced [16]. Alternatively, it may be, as Del Rey demonstrated, that knowledge on the perceptual demands of the task must be developed before variations of the perceptual characteristics of the task should be introduced [12].

4.1.2 The Influence of Age on Contextual Interference Effect

The majority of studies investigating the contextual interference effect have used college students as participants [29]. From among the 13 selected articles, and six selected experiment participants who were college students, three experiments were conducted with middle school students, and the remainder were children. All selected articles have manipulated variables other than age, and have not compared different age groups [29], except for a research conducted by Shrutika (2018). This article discussed the influence of random and blocked practice schedule on motor learning among children in the age range of 6 and 12, which provides a reference for this part of the study [37].

According to the results presented by Shrutika et al., there were differences in performance with random and blocked practice schedules across different age groups [37], which means that age may be an element affecting the existence of the contextual interference effect. More specifically, during the acquisition phase, participants from various age groups performed similarly on both blocked and random practice schedules, with no significant differences. There was no significant interaction between practice group and age. In the retention phase (immediate and delayed retention tests), the blocked group showed better performance than the random group, and there was a significant interaction between group and age, with the 8-10- and 10-12-years-old performing significantly better than 6-8-years-old subjects. However, in the transfer test, there was no significant difference in performance of the three age groups. The blocked practice group completed the task better than the random practice group, but the difference was statistically insignificant [37]. Based on the results in these phases, we can perform the following analysis. Barreiros et al. suggested that during early stages of motor learning, performance differences are not commonly observed [2]. In this experiment, subjects are children under 12 years old, and they were novices at single leg hopping. The random practice schedule, which represents the high contextual interference, possibly overwhelmed their ability. Taking into account the cognitive load theory, complex tasks in addition to a random practice schedule cause system overload during the early phase of learning with high attention, memory, and motor demands [17].Similar outcomes were achieved in other studies, indicating that blocked practice was beneficial for learning of multi-joint motor skills during the acquisition phase [5,44,45]. After the acquisition phase, we could consider the retention test as a specific measure of learning, and the transfer test demonstrates adaptability. The results of the retention and transfer tests indicate that children perform better with low contextual interference, and children aged 8–10 years and 10–12 years performed the task faster and with more accuracy as compared to 6–8-year-olds in both practice groups [37]. This result can be interpreted by the elaboration and reconstruction hypothesis.

In a random practice schedule, deeper processing and strategy formation is required, as an action plan prepared during the previous trial and must be forgotten and reconstructed with every preceding trial, since there was no repetition of the same pattern. But in blocked practice training, the action plan learned was directly applied to the next trial [33]. Intra-task and inter-task processing is required with random practice, while blocked practice requires only intra-task processing with only the task at hand in working memory [37]. As random practice requires more cognitive effort than blocked practice, it can be correlated to poor performance in children on a random practice schedule [10]. Considering complexity of the task in this study, learning may have been easier for older children, irrespective of practice group, as these children have better balance and strength abilities [34,48]. Furthermore, considering the challenge point framework, the random practice schedule possibly exceeded the level of challenge, resulting in an increased cognitive effort, thereby interfering with the learning benefits of a random practice schedule [21].

Therefore, some evidence suggests that the contextual interference effect may be age related. However, the exact nature of this relationship cannot be determined from the available research literature, and it seems possible that at least for children, initial blocked practice is required before introducing random practice trials [29]. Evidence from the experiment by Pigott and Shapiro directly supports this possibility [38], while the results of Del Rey and his colleagues indirectly support it [13]. Further research is needed to determine the degree to which the contextual interference effect is age-related.

4.2 Task Characteristics

4.2.1 Laboratory and Non-Laboratory Tasks

Magill and Hall have discussed that the generality of the contextual interference effect could be influenced by task characteristics like laboratory tasks, such as coincident anticipation timing tasks versus motor skill performance outside the laboratory or non-laboratory tasks, such as throwing beanbags [29]. Therefore, we discuss preferentially whether the type of experiment has an impact on the generality of the contextual interference effect in this section.

(1) Laboratory Tasks

Two types of tasks have predominated contextual interference research in laboratories [29], where one is a multi-segment movement task, and the other is a coincident anticipation timing task. Experiments using these different tasks generally demonstrated the existence of the contextual interference effect, under laboratory conditions.

In terms of the multi-segment movement task, the most valuable and widely imitated experiment has been the barrier knock-down task used by Shea and Morgan [43]. Versions of this task were designed to require arm movement through a specified multi-segment movement pattern and two types of goals need to be achieved. One goal involves moving as fast as possible through a prescribed movement pattern, and the other goal requires subjects to move through a prescribed movement pattern, but at a predetermined criterion movement time for either the entire pattern or for each pattern segment [43]. Depending on the different task goals, these research works came out with many kinds of conclusions. When multi-segment movement tasks have the goal to move as fast as possible, subjects are required to learn to move through different movement patterns. The results have consistently shown the benefit of random over blocked practice schedules for both retention [26] and transfer [43]. When multi-segment movement tasks have a criterion movement time for the complete pattern and different movement patterns must be learned[26], again, random practice schedules produced better retention performance.

These results provide evidence that the

contextual interference effect can be demonstrated for retention tests when the variations that must be learned require subjects to learn different patterns of movement, regardless of whether the goal is to move as fast as possible, or to move to a criterion movement time [29]. For transfer performance, the results from Shea and Morgan showed that when the task goal was to move as fast as possible and the practiced task variations involved moving through different multi-segment patterns, transfer to a novel pattern was better when practice was with a random schedule [43]. However, when the task goal involved learning different segment criterion movement times with the same pattern [27], novel transfer was enhanced by a random practice schedule when the transfer movement times exceeded the range of practiced movement times. There was no random vs. blocked practice schedule difference when the transfer movement times were within the range of practiced movement times. Such results led the researchers to suppose that the variations that must be learned are controlled by either the same or different motor programs. The anticipation timing task involved another widely used experiment to investigate the contextual interference effect; the task variations were created by varying the stimulus speeds to which subjects must respond [12-14,40]. The results based on this task are mixed.

(2) Non-Laboratory Tasks

Non-laboratory tasks are typically used in motor skill performance settings outside the laboratory [29], and relate to specific and actual sport skills, and have a disparity in both appearance time and the number of studies from laboratory experiments. From a developmental motor learning perspective, this change in research direction from laboratory to non-laboratory tasks is desired [20]. Learning laboratory tasks can reflect participants' coordination, reaction and judgment abilities, while learning non-laboratory tasks may be more similar as activities in their daily life and closer to the needs of actual sports programs, providing a new reference for training methods for athletes and novices. Practicing non-laboratory tasks might improve the translation to other daily life relevant tasks, as these tasks might appear to be more natural and are probably more frequently occur in the children’s daily routines than laboratory tasks [47]. In our review, we selected 13 articles containing 14 experiments that investigated non-laboratory tasks: three examined volleyball skills, four throwing tasks, one golf skills, and one step sequence training.

Further tasks were baseball hitting, tennis serving and basketball passing skills. In healthy adolescents, the evidence is mixed when practicing non-laboratory tasks. In our review, the best evidence synthesis shows limited to moderate support for the contextual interference effect in non-laboratory tasks (Table 3). Only in the tennis serving task, we find the contextual interference effect for skill acquisition, and in basketball passing training, we find the effect at the retention phase. However, in the skill transfer test, we find the contextual interference effect in three experiments, including golf chipping, baseball hitting and basketball passing.

In conclusion, the existing research results cannot directly support the effect of contextual interference on actual motor learning among healthy adolescents, whether in laboratory or non-laboratory experiments, and further research needs to be conducted in the future.

4.2.2 Task Variations from the Same and Different Motor Programs

As mentioned in the last section, it cannot demonstrate that the contextual interference effect applies to all types of learning tasks based on whether the type of experiment is a laboratory or a non-laboratory one. Thus, in this section, we expend this point by analyzing tasks in relation to motor programs. According to the definition of the contextual interference effect, the essential characteristic of this effect is the learning of different variations of a given skill. Given this characteristic, it is possible that the amount of interference created by practice trials of the skill variations being learned is related to the relationship of the variations [29].Thus, we investigate whether the variations are influenced by the same motor program or by different motor programs. In this review, we adopted the theoretical view of the motor program proposed by Schmidt (1975, 1988), which has achieved a broad range of acceptance. The view of the motor program, which Schmidt argues should be called a generalized motor program, is that it serves as the memory representation for a movement class rather than for any one particular action or movement [42].

A movement class is defined by the invariant characteristics of actions. When a variety of actions have common invariant characteristics, they are considered to be in the same movement class and are thus represented in and controlled by the same generalized motor program [42]. Several different movement characteristics have been proposed to be the invariant features of a motor program. For example, Schmidt (1988) suggested movement characteristics such as the relative timing (i.e., phasing) of the components of the action, the relative force produced by the components of the action, and the sequence of events involved in the action [42]. As in this review, variations of a skill were assumed to be under the control of the same motor program if the relative timing, sequence of events, and/or spatial configurations remained constant across the skill variations that were practiced [29]. Therefore, tasks practiced in a contextual interference experiment required parameter modifications, which included movement characteristics such as overall duration, overall force, size of the spatial configuration, and muscle groups used to perform the skill. On the other hand, variations of a skill are considered to be controlled by different motor programs if relative timing, sequence of events, and/or spatial configurations differed across the practiced variations [29]. In this review, the task variations from the same and different motor programs are shown in Table 4.

From this, we proposed two assumptions. First, when the skill variations to be learned require different motor programs, different levels of contextual interference are created by practice schedule manipulations, which in turn lead to different retention and transfer effects. That is, higher levels of contextual interference such as a random practice schedule lead to superior retention and novel task transfer performance, compared to lower levels of contextual interference, such as a blocked schedule [29]. In the selected articles, when we divided the participants into two categories (novice and experienced) and divided the task types into the same and different motor programs, the results were inconsistent after comparison. Overall, the results were mixed, with no consistent conclusion that groups under high interference outperformed than groups received low interference at the retention and transfer phases. But in the second experiment conducted by Porter and Magill, in which novice participants were required to passing a basketball to the target through three different passing methods, the increasing group (practice under a mixed schedule of blocked and random) performed better than either a blocked only or random only practice schedule at skill retention and transfer tests.

Secondly, when the skill variations involved parameter modifications of the same motor program, the contextual interference effect was not found. According to the results conducted by experiments in same motor program but modified parameters, whether the subjects were novice or not, some presented the contextual interference effect. The most representative experiment was also conducted by Porter and Magill (2010). In this experiment, subjects were required to put a golf ball from different starting positions to the target. In the skill acquisition phase, the blocked group and increasing group showed better performance than the random group. However, at the retention and transfer tests, the group under mixed practice schedule outperformed than both blocked and random groups, like the results in different motor programs. To a certain degree, the results conducted by Porter and Magill in their two different experiments supports the challenge point hypothesis, but still need more research to prove this in the future.

Batting (1979) noted that the degree of the contextual interference effect could be a function of the difficulty of the task, with more difficulty leading to greater amounts of contextual interference [1]. Thus, different motor program variations may be a more difficult learning task than the same motor program variation situation. When task variations controlled by different motor programs must be learned, a more difficult learning situation is established [29]. Thus, higher levels of contextual interference during practice of these tasks are created, thereby establishing a more difficult processing situation than when the task variations are parameter modifications of the same program. As for our results, all participants were adolescents with lower levels of experience and comprehension than adults. Therefore, under the same motor program, by modifying the parameters for practice, better performance of skill retention and transfer can be obtained. Practice with different motor programs may be too difficult for them to facilitate skill learning.

4.3 Study Limitations

The results of our literature search were limited. There are several independent studies on parameters (participant experience, age, task types, etc.) affecting the contextual interference effect, and the results obtained in the reviews cannot be generally applied to the entire field of motor learning by adolescents. Therefore, further research is required to demonstrate the generality of the conclusions. The selected studies did not evaluate the effect of contextual interference according to long-term or short-term study periods, and there were not enough comparable studies to discuss.

4.4 Recommendations

We presume that the practice order in both novice and skilled children can influence the contextual interference effect in the corresponding population. Therefore, we could recommend designing such research and include children of various ages and skill development levels. A careful selection of the motor task to be studied is crucial, and this should be necessary to distinguish between the same or different motor programs to explore the influence of the different motor program on the contextual interference effect. Finally, the studies should be designed, and the results reported in accordance with the various internationally accepted checklists to ensure high study quality and low bias.

5. Conclusion

In summary, there is a persistent demand for increasing our knowledge about the contextual interference effect on motor learning among healthy adolescents, especially in children with no prior experience, as the number of existing studies is small, and the methodological quality of the studies is relatively low. For certain tasks, we found limited evidence supporting the contextual interference effect in skilled children. However, we would be cautious in generalizing these results to novices. To advance motor learning in children and improve their performance in skills practice, there is an urgent need to increase our overall understanding of the contextual interference effect among adolescents.

6. Data Availability Statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

7. Acknowledgements

The literature search, selection of studies, and study quality assessment was performed by XW. Following an initial screen of titles and abstracts, full scrutiny of potentially eligible studies was independently screened by XW using the specific inclusion criteria. BA and SS arbitrated any disagreements in study inclusion. XW and SS arbitrated any disagreements in assessment study quality. All authors contributed to manuscript revision, read, and approved the submitted version.

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