CONTEXTUAL INTERFERENCE: IS IT SUPPORTED ACROSS STUDIES?

by

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This meta-analysis examined the influence of the task, environment and learners characteristics during motor skill learning situations for varying organizations of task presentations (Contextual Interference). Types of tasks (open and closed skills) were evaluated based upon settings (laboratory and real world) with diverse populations (gender, age groups, and level of expertise). The strength of the CI effect was investigated based on whether the skill variation was a variation of the same or different Generalized Motor Program (GMP). Effect sizes were calculated subtracting low (blocked) from high (random/serial) contextual interference schedules of practice during acquisition, retention and transfer phases. Seventy-five published studies were found in the literature search. A total of 309 effect sizes were computed from 51 studies. The overall treatment effect supported contextual interference for blocked and random comparisons but not for blocked and serial comparisons. Another important finding was that contextual interference is most strongly supported for variation in GMP than for variation in parameter when comparing blocked and random schedules of practice. Furthermore, similar effect sizes were demonstrated for ecologically valid and non-ecologically valid settings, reinforcing the applicability of contextual interference theory in teaching motor skills in real world situations. Effect size differences among varied levels of amounts of practice, internal validity, and knowledge of results were not significantly different but pointed to directions that are worth of discussion.

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PREFACE

I dedicate this thesis to my wife for the support, love and friendship.

I thank my advisor Jere Gallagher who guided me through out the time it took me to complete this research and have generously given her time and expertise to better my work.

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1. BACKGROUND INFORMATION

1.1. INTRODUCTION

Physical education teachers, sport coaches and physical therapists often face the challenge of effectively teaching multiple motor skills during a single session. Motor learning researchers have long demonstrated that ordering of motor skills during practice affects immediate performance and posterior retention (Battig, 1979; Shea & Morgan, 1979). This empirical phenomenon was termed contextual interference (CI).

Controlling contextual interference means, therefore, manipulating schedules of practice to enhance learning. This manipulation dictates whether low or high interference is used in the learning situation. The practice schedules in CI studies are blocked in which skills are practiced one at a time, random which has an unpredictable order of tasks, and serial which is a sequential alternating schedule. As an example, Hall, Domingues and Cavazos (1994) tested contextual interference effects in an applied setting using skilled baseball players. Baseball players practiced batting three different types of pitches (fastballs, curveballs and change up) in either blocked or random order. The blocked group repeated the same task over and over until they complete all trials and then they would start a different task. The random group practiced batting in an unpredictable order. In a serial schedule, learners would repeat the task sequentially, so for each trial all tasks are repeated in the same order. While blocked order promotes low CI, random and serial schedules promote high CI.

Contextual interference is considered a performance paradox because increases in interference lead to degraded performance during practice, but to enhanced learning as measured in retention and transfer tests. If the main goal is to maximize learning, one would conclude the random practice condition is preferable over blocked practice condition. This statement, however, is not always true as many researchers have failed demonstrating contextual interference effects on motor learning (Del Rey, Wughalter & Carnes, 1987; Porreta, 1988; Brady, 1997; Jarus & Gutman, 2001).

Typical results of CI are not found in all learning situations (Magill & Hall, 1990). Among various factors that may affect contextual interference are the ecological validity of the experiments, age, gender, experience level of the learner, the type of skills, task difficulty, and the absence or presence of augmented feedback during the practice trials. There is not total agreement regarding contextual interference effects in these situations; therefore, there is a need for a deeper analysis of the literature by a meta-analysis. The purpose of this research is to provide a quantitative summary of the typical strengths and the limitations of the effect of contextual interference on motor learning.

Two theories have been presented and investigated to explain the empirical phenomenon of CI. These theoretical explanations are discussed next with the arguments that make each one a unique explanation for the contextual interference paradigm.

1.2. THEORETICAL/CONCEPTUAL FRAMEWORK

The elaboration distinctiveness hypothesis and the forgetting reconstruction hypothesis have been investigated and offered as an explanation to the CI effects. The elaboration hypothesis proposes that superior retention results during random practice are enhanced due to comparisons of multiple tasks in working memory (Shea & Morgan, 1979). In other words, in a high contextual interference condition, while a task is practiced, memory representations from the other tasks being practiced reside in working memory (Magill & Hall, 1990). These simultaneous memory representations increase the opportunity for comparisons among tasks. Furthermore, performing multiple tasks evoke various strategies for the task being learned. These features lead to a more distinctive memory representation explaining benefits on learning during retention and transfer.

An alternative explanation is the forgetting hypothesis which has been proposed by Lee and Magill (1985). This explanation is based on the premise that for each practiced skill an action plan is constructed before movement execution. Random practice schedules require more effortful processing than blocked practice schedules because interpolated tasks cause forgetting of information of previous encoded task information. Thus, for every practice trial, the learner must reconstruct all or at least part of the action plan before executing the forthcoming movement. This is not the case during blocked practice. Blocked practice subjects experience little if any practice in movement preparation process because the movement representation resides in the working memory.

Since a theoretical explanation should account for both acquisition and retention effects, Shea and Zimny (1983) presented a rationalization for the detrimental effects of high contextual interference during acquisition. The elaborative and distinctiveness model implies that blocked practice conditions foster subjects to engage in shallow cognitive processes restricted to one task (intratask) in working memory. In contrast, during random practice, learners are encouraged to take advantage of both intratask and intertask processing. The intertask processing allows the learner to incorporate new task information with existing knowledge and formulate a detailed task representation. The negative effects of random practice are usually expressed in laboratory experiments as longer latencies or larger error scores during acquisition (Wright, 1991; Wright, Li & Whitacre, 1992; Young, Cohen, & Husak, 1993).

The reconstruction explanation also received some support in the literature (Lee & Weeks, 1987; Immink & Wright, 1998). Lee and Weeks demonstrated that better retention results were found for a movement criterion when more forgetting rather than less forgetting had occurred. While researchers have not being able to identify which parts of the action plan are forgotten during intervening trials, they have been focusing on timing measure to allow action plan reconstruction during acquisition and its implications.

Immink and Wright (1998) proposed that the typically displayed acquisition differences between random and blocked practice participants are suggested to be a function of planning the movement ahead; therefore, if the learners are given additional planning time during random practice, differences in acquisition are reduced. They demonstrated that action plan reconstruction can take place before and after the onset of a movement when the preparation time is limited. However, when allowing for longer preparation time, acquisition differences were not found between blocked and random groups participants. Support for these results may be also found and explained on the basis of the elaborative processing (Wright, 1991).

Retention benefits without acquisition decrement are possible by engaging in appropriate amount of intertask processing. Subjects in a blocked group were able to outperform their counterparts when unrelated task information was presented between practice trials. These secondary task information allowed for multiple comparisons triggering the development of encoding strategies for the task being learned, which in turn lead to better retention. The lack of acquisition decrement was due to the differentiation of the intertask. Although other tasks were presented between practice trials, individuals only performed one task at a time.

Overall, the two theories may be complementary even though they present alternative explanations. The lack of research testing and contrasting these two theories is one reason for a meta-analysis. Although, the quantitative results from a meta-analysis would not account for differentiating the theories, it would suggest whether the effect sizes were greater for one theory compared to the other.

There is no doubt contextual interference is a robust learning phenomenon for simple laboratory tasks; although, attempts to extend the CI paradigm into applied settings with sport skills have produced mixed results. In the next section, two important components of CI research concerning environmental issues are discussed: ecological validity and type of skill.

1.3. ECOLOGICAL VALIDITY AND TYPE OF SKILL

Laboratory based research has consistently supported the CI effect while more ecologically valid studies have not had the same consistency. Two types of skills, open and closed, have been investigated in both laboratory and real world settings. Closed skills, in which the environmental condition is stable, have been widely used in laboratory based research. Open skills, in which the environmental conditions are often unpredictable, have more often been used in real world tasks type of studies, perhaps because open skills are largely practiced in sport settings and physical education classes.

Laboratory studies supported contextual interference for closed (Albaret & Thon, 1998; Proteau, Blandin, Alain & Dorion, 1994; Wright, Li & Coady, 1997) and open skills (Boyce & Del Rey, 1990; Brady, 1997). The laboratory conditions may contribute to these results since it is easier to control and measure variables accurately. Difficulty arises, however, with the application of these results to real life situations.

Ecologically valid studies using open skills have been at times consistent with the prediction of contextual interference (Hall, Domingues & Cavazos, 1994; Smith & Davies, 1995; Li & Lima, 2002), but reported no CI benefits other times (Landin, Hebert & Fairweather, 1993; Brady, 1997; Bortoli, Spagolla & Robazza, 2001; Meira & Tani, 2001). These results suggest CI is not a global learning phenomenon which can be generalized to all learning situations, indeed, researchers deal with great number of factors in trying to prove its applicability. Some of the factors that may influence applied studies, besides task characteristics, are individual differences.

1.4. INDIVIDUAL DIFFERENCES

1.4.1. Experience level

Novice, intermediate and experienced learners can benefit from contextual interference. Novice learners in general demonstrate the CI effects when practicing simple tasks, while experienced learners are tested with more complex tasks. Studies have supported the role of contextual interference for open skills with intermediate and experienced learners but not with novices. Skilled baseball players practicing batting three different pitches in a random group outperformed their counterparts in the blocked group during retention (Hall et al., 1994). Likewise, children with prior experience exhibited superior learning than inexperienced children when practicing racket striking (Wegman, 1999). Novice learners, however, do not take advantage of random practice early in learning situations when practicing open skills (Del Rey, Wughalter & Whitehurst, 1982; Hebert, Landin & Solmon, 1996).

According to these results one could hypothesize that high contextual interference overload the optimal amount of interference that enhances learning for novice subjects when learning open skills. Novices should be allowed to experience repeated attempts of a task under low interference conditions while experienced learners should practice open skills in an unpredictable order. This hypothesis should be investigated in children's motor skill learning since most of the children are usually novice learners.

1.4.2. Age

The amount of interference of a task practiced in a determined schedule is not the same for children and adults because young children are limited in the strategies available to process the information (Thomas, 1980). The question to be answered, though, is how should information be presented to children to facilitate multiple skills learning?

Studies in CI learning by children and early adolescents have given mixed results. While some findings supported the CI paradigm for 8 and 9-year-olds (Bortoli, Robazza, Durigon & Carra, 1992) and 14-year-olds (Bortoli et al., 2001) others did not for 5, 7 and 11-year-olds groups (Jarus & Goverover, 1999). A major weakness of these studies was the absence of an adult control group. In order to precisely attribute the interaction to age rather than to the task itself, adults and children need to perform the same task. Replicating CI typical results in a laboratory task, Pollock and Lee (1997) demonstrated that 7-year-olds children performed similarly to adults. Overall, these ambiguous results dictate further research in order to determine age differences in multiple motor skills learning.

1.4.3. Gender

An assumption that males have generally more experience in open skills than females leads to investigation of gender differences in CI research (Del Rey, Whitehurst & Wood, 1983; Smith & Rudisill, 1993). It was expected that males would outperform females during retention and transfer. However, no differences were found. A criticism about these studies is that gender differences could not be interpreted independently because of the interaction of other factors related to the task and environment. Even though, no data indicates gender differences will be found, it is worthy including in the meta-analysis.

Despite the fact that CI outcome is affected by individual characteristics, it cannot explain all results in CI research. Task characteristics may determine learning results as well. More specifically, the nature of the task variation seems to determine the amount of interference created during practice trials.

1.5. GMP AND PARAMETER LEARNING

The level of contextual interference may be established based on the theoretical view of movement representation proposed by Schmidt. A generalized motor program (GMP) is the memory representation for a class of actions that share certain invariant motor control characteristics such as relative timing, and relative force. Generating a movement requires a two stage process: First, selecting the appropriate generalized motor program for the goal, and second, implementing that program by specifying the parameters for movement such as selecting absolute time and force as well as which muscles to use (Lee, Wulf & Schmidt, 1992). An example will help clarify GMP and parameters difference. If a person throws a bean bag at a target and uses three different throwing patterns, underhand, overhand, and hook throwing, then three different motor programs are involved. However, if only one throwing pattern is used to throw at three different distances, force parameters of a single GMP must be modified to produce shorter and longer distance throwing.

The starting point of the discussion about GMP and parameter comparison is a review of literature by Magill and Hall (1990). They hypothesized that parameter modification of the same GMP does not create sufficient interference to require additional processing during acquisition which in turn facilitates retention. Moreover, variation in GMP should elicit GMP learning. Researchers found varied outcomes when testing these hypotheses, as seen in Table 1.

In general, results in GMP and parameter learning follow a pattern. Opposing what was first proposed by Magill and Hall (1990), GMP learning seems to be enhanced by low contextual interference schedules of practice whereas parameter learning appears to be enhanced by high contextual interference schedules of practice. This statement appears to be true for tasks requiring GMP variation and for tasks requiring parameter variation of the same GMP.

Table 1

Supportive and non-supportive GMP/Parameter studies

Task variation	Variation in GMP		Variation in Parameters	
Authors / year	GMP learning	Parameter learning	GMP learning	Parameter learning
Lee and Magill (1990)	yes	no	no	no
Wulf and Lee (1993)	--	--	yes	no
Sekiya et al. (1994) – exp. 1and 2	no	yes	no	yes
Sekiya et al. (1996)	--	--	no	yes
* Lai and Shea (1998)	--	--	no	yes
** Shea et al. (2001)	--	--	no	yes

Issues may be raised about methodological differences present in these studies. Most studies did not have a random group as a high contextual interference condition (Sekiya et al., 1994; Sekiya et al., 1996; Lai and Shea, 1998; Shea et al., 2001). CI paradigm was supported sometimes on transfer results but not on retention results. Another problem is that only very simple laboratory tasks were used in these experiments. A meta-analysis will allow the observation of GMP and parameter learning in laboratory and real world experiments.

1.6. KNOWLEDGE OF RESULTS AND AMOUNT OF PRACTICE

Since presentation of knowledge of results (KR) and the amount of practice may influence learning, researchers investigated whether these two components would interact with contextual interference effects. Summary or reduced KR provided better learning outcome on retention than 100% frequency KR (Del Rey & Shewokis, 1993; Wulf, Schmidt & Deubel, 1993). The ideal frequency of presentation of KR is not well defined and may vary with the task (Shea et al., 2001; Lai & Shea, 1998).

It is generally expected that the higher the amount of practice the better learning results. Indeed, there seems to be a tendency in which the amount of practice positively correlates with random schedule (Shea et al., 1990; Proteau, Blandin, Alain & Dorion, 1994), yet there is also evidence suggesting no benefits for extended practice trials (Sekiya et al. 1996).

1.7. SUMMARY

Two theoretical explanations based on cognitive processing models have been proposed to explain the contextual interference effect. The elaboration distinctiveness hypothesis and the reconstruction hypothesis account for the comparisons between tasks in working memory and for reconstruction of action plans representing the movements.

Variables that moderate the CI outcome are related to the environment, the learner and the task. Contextual interference is more often supported in laboratory than in real world experiments due to the combination of a controllable environment for the task and a combination of the type of skill and schedule of practice. Experience level and gender may be also determining factors in CI outcome, but the extent of the benefits of CI for children at different stages of development is not well defined. Conflicting results in task characteristics point out that GMP and parameter learning are enhanced by different schedules of practice. These results are not conclusive and might be affected by the amount of practice and the schedule of KR.

Seeking the optimal learning situation, it is important to consider the task, environment and learner characteristics in combination with the CI manipulation. The next section will depict the procedures and methods used in for selecting, coding and analyzing 13 variables related to the CI effects.

2. METHODS

2.1. STUDY SELECTION

A search of studies published by October 2003 was conducted. Computer searches were conducted in Medline, PsycInfo, Sport Discuss and ERIC. The key terms used were “contextual interference, variable practice, random and blocked practice, motor skill learning, task variation, acquisition and retention”. In addition, references from key articles were cross-checked. Only published articles were included in the Meta analysis. A total of 75 articles was identified in the literature search.

2.2. CHARACTERISTICS CODED

Thirteen relevant characteristics were coded in the studies. The coded characteristics were year of publication, journal, age, gender, population health status, experience level, type of skill, task characteristic, internal validity, ecological validity, theoretical hypotheses, knowledge of results, and amount of practice. The selection of the coded characteristics was based on a priori decisions about critical factors.

The theoretical hypotheses were identified as the basis for explaining the study or testing a hypothesis. They were categorized as the forgetting/reconstruction hypothesis, the elaboration/distinctiveness hypothesis, both hypotheses, or no-hypothesis.

Individual characteristics such as age, gender, health status, and experience level were identified. Age was categorized into three main groups, children (10 and below), adolescents (11-17 years-of-age), and adults (18 and older). Gender of the groups were coded as males, females, mixed group of male and females, or not identified. Level of expertise was coded as novice, intermediate, expert, mixed, or not identified. Population status referred to whether the experiment was tested on typical or special-need individuals.

Type of skill was based upon whether the skills practiced and tested were open or closed skills. Open skills are tasks in which the environment is unpredictable while closed skills are tasks in which the environment is predictable. Task characteristic was categorized according to their proposed memory representation of the movement. They were classified into three categories: (GMP) Generalized Motor Program, a parameter of a GMP, or both, depending upon task variation during the acquisition phase.

Ecological validity was analyzed by the setting and task used in the experiment. They were classified as a real world setting and task, real world setting and artificial task, or both setting and task lacking real world features. For the analysis the first and last categories were used as real world and laboratory.

The amount of practice was classified and recoded into three categories according to the number of trials during acquisition, low amount of practice (1 to 50 trials), medium amount of practice (51 to 90 trials), and high amount of practice (91 trials and above). The amount of augmented feedback was coded as no-KR or frequent/summary KR.

Internal validity was coded into points from zero to five. A low internal validity was 2.5 and below, moderate internal validity was 3 to 3.5, and high internal validity was 4 and above. During data analysis low and moderate internal validity studies were collapsed and compared against high internal validity studies. Scores were determined by summing the points of the following questions:

1. Were the participants carefully described? (1)
2. Were subjects randomly assigned to groups? (1)
3. Are the various factors of contextual interference included? (.05)
4. Were the conditions clearly described? (.05)
5. Were all procedures carefully explained, appropriate, and followed? (1)
6. Was the statistical analysis properly described? (1)

Question 1 asked for specifications of subjects' age, gender, and experience level. Question two's criterion was met if the subjects were randomly assigned to the groups. Question 3 and 4 refer to whether the research included at least a low and a high contextual interference condition, and whether these conditions were explained in the procedure or methods section of the article. Number of repetitions, and the interval between practice and testing should be specified. Question 5 observed whether the tasks and the procedures match the outcome. In other worlds, was the task measuring what was proposed? In addition, it was expected that tasks that were unusual were described in more details. Question 6 related to whether essential statistics were reported. Each of these questions received either one or half point depending upon a pre-determined criterion.

2.3. CODING EFFECT SIZES

Studies were coded individually by the author and two PhD students. Each student coded half of the studies, which were randomly distributed between the two students. The researcher coded all studies. The researcher met with the student to compare results and all discrepancies were discussed and resolved prior to entering the data into the computer. Major points of disagreement related to internal validity, task characteristics and the primary variable to be chosen.

When multiple effect sizes were calculated for a study, only one effect size was used. The criterion for choosing the effect sizes was based upon the main hypothesis being tested in the manuscript. For example, when testing children throwing a bean bag the authors chose to use results for accuracy (performance score) rather than a measure of time. The authors believed learning was better reflected by the performance than by the timing measurement (Jarus & Gutman, 2001). Similarly, when practicing dissimilar and highly similar movement laboratory tasks, researchers decided to include ES for reaction time instead of ES for movement time. Indeed, RT seems to include cognitive processing activities, which were pertinent to the proposed objective of the study, which are not completely assessed by the movement time. (Wood & Ging, 1991).

A conservative approach for calculating effect sizes was chosen. The standardized mean differences were only calculated if there was a main effect between the control and experimental groups. When the results of the grouping effect were not significant, the effect sizes were reported as zero.

Two designs were used in the analysis. Effect sizes were calculated for within and across phase comparison. Within phase effect sizes represent differences between the means for low and high contextual interference groups in acquisition, retention and transfer. Across phase effect sizes represent differences between the same group means across acquisition and retention, or acquisition and transfer phases.

3. RESULTS

From the 75 studies gathered for the experiment in the literature search, 24 were excluded from the Meta analysis for the following reasons. First, one article was not located (Gabriele, Hall & Lee, 1989). Second, 10 articles were not relevant for the meta-analysis. Some tested only one condition, either random or blocked. Other studies tested specificities of contextual interference but did not provide essential information to compare the schedules of practice. The focuses of these studies were theoretical hypotheses, amount of feedback, and task characteristics. Third, 13 studies were excluded because they provided insufficient information to calculate an effect size (no Mean and Standard Deviation, or an F-ratio with 1 df).

3.1. EXCLUDED STUDIES

While reading and coding the 13 studies, which did not allow effect size calculation, it was observed that nine were published before 1994. The excluded studies investigated variables related to experience level, KR, amount of practice and theoretical hypotheses. Eight of those studies supported contextual interference paradigm whereas 4 studies did not support it. One study presented both results, supporting contextual interference for experienced learners while rejecting the benefits of contextual interference for novices.

3.2. INCLUDED STUDIES

From the 75 studies gathered for the meta-analysis, 51 provided enough information to calculate effect size. Effect sizes were calculated for within phase comparison and across phase comparison. For the within phase across groups comparison a total of 309 ESs were computed. In the blocked - random comparison there were 79 ESs for acquisition, 83 ESs for retention and 49 ESs for transfer. In the blocked - serial comparison there were 14 ESs for acquisition, 21 for retention and 16 for transfer. The remaining 47 ESs were not used in the analysis because they were distributed into other high CI groups such as alternating or mixed random - serial or in a different phase such as combined retention and transfer.

All non-significant results were reported as zero ES. The blocked – random comparison totaled 215 ESs, given that 93 were calculated and 122 were zero. The blocked – serial comparison reported 32 zero ESs and 19 calculated ESs totalizing 51 ESs (see Table 2).

Table 2

Number of Calculated ES Within Subjects Across Phases

Phases	Calculated ES	Not sig. reported as zero	Total
Blocked – Random	93	122	215
Blocked – Serial	19	32	51
Blocked – Other	17	26	43

For the across phase comparison, only 22 studies were included. Only those which provided means and standard deviation could be used in the analysis. A total of 146 effect sizes were calculated for the across phase comparison between acquisition and retention, and acquisition and transfer phases. The description of the analysis and the results of both within and across comparison are depicted in the next session.

3.3. EFFECT SIZE ANALYSIS

Effect sizes were computed differently for within and across phase comparisons. Within phase effect sizes were calculated as the difference between the means for high (random or serial) minus low (blocked) contextual interference groups divided by their pooled standard deviation for each phase (acquisition, retention, and transfer). Effect sizes may be biased estimators because studies with smaller sample sizes receive the same weighting as those with large sample sizes, resulting in an overestimation of the population of effect sizes (Hedges, 1981). This explains the need for the pooled SD (Thomas & Nelson, 2001).

Within phase effect sizes were also calculated using F-value with 1 df by the Equation 1 or by the simplified Equation 2 for equal subject groups:

$$ES = \frac{(\text{Sqrt } F) * (Nc + Ne)}{(\text{Sqrt error df}) * (\text{Sqrt } (Nc * Ne))} \qquad (1)$$

$$ES = \frac{2 * (\text{Sqrt } F)}{\text{Sqrt error df}} \tag{2}$$

Across phase effect sizes were calculated as the difference between the same group means across phases (ie. blocked acquisition minus blocked retention, or blocked acquisition minus blocked transfer) divided by their pooled standard deviation. The number of studies used for this comparisons were lower than the number of studies used to calculate effect sizes for between groups. Numbers for computations of effect sizes came from tables or reported means and standard deviations for the end of acquisition, retention and transfer.

When calculating across phase effect size for the blocked group, comparisons were made between acquisition pretest and retention, acquisition pretest and transfer, acquisition posttest and retention, and acquisition posttest and transfer. The acquisition pretest data consists of pretests results or the first block of acquisition. The acquisition posttest data consists of the last block of acquisition practice or the average of the results for the whole acquisition. This was determined by the data availability in the coded studies.

According to Hedges and Olkin (1985) effect sizes are positively biased in small samples, however a virtually unbiased estimate of the ES can be obtained by multiplying each ES by a correction factor. We approximately corrected for sample bias using the formula: $c = 1 – (3/4m – 9)$, where $(m = Ne + Nc – 2)$. Furthermore, each individual corrected ES was weighted by the reciprocal of its variance, giving greater weight to the more reliable (lower variance) estimated ES and thus yielding a truer estimate of population effect size (Hedges & Olkin, 1985). The individual variance Equation 3 is:

$$Var(ESi) = \frac{(Ne+Nc/Ne*Nc) + (ESi)^2}{2(Ne+Nc)} \tag{3}$$

After the calculation of corrected and weighted effect size, a test for a normal distribution was performed. The assumption for the normal distribution was met for skewness (-.063) and kurtosis (1.482) for the effect sizes representing blocked and random comparison, but not for the effect sizes representing blocked and serial comparison, kurtosis (2.058). Because the data for blocked and serial is not normally distributed, it should be ranked for statistical analysis as suggested by Thomas, Nelson and Thomas (1999). However, further analysis in blocked / serial data is not carried out because of the low number of comparisons available (N = 26).

Using Hedges (1981) model, effect size was used as an estimator of overall treatment effect. For each of the corrected and weighted effect sizes, overall means and a 95% confidence interval were calculated (see table 3). The corrected and weighted mean for random/blocked effect sizes during acquisition is -.31 with a CI -.40 to -.22 at alpha .05. Similarly, but with inverted signal retention had a mean of .31 with a CI .23 to .40. A negative signal means superior results of the blocked group, whereas a positive signal represents advantage of random group. For transfer, the corrected and weighted mean effect size is .23 with a CI from .12 to .34. A confidence interval that does not include zero indicates there is a significant difference in the level of learning between the different groups (ie. blocked and random). As expected, blocked and random group mean effect sizes are significantly different demonstrating that these practice schedules influence the outcome of learning measured in acquisition (ES M = -.37, SD = .69, N = 40), retention (ES M = .40, SD = .70, N = 48) and transfer (ES M = .23, SD = .58, N = 27) phases.

For the blocked/serial comparison, the corrected and weighted means and confidence intervals for acquisition, retention and transfer were (ES M = -.21, CI = -.42 to .01), (ES M = .10, CI = -.10 to .29) and (ES M = .11, CI = -.09 to .31) respectively. Treatment effects for blocked and serial comparison indicate there is no difference between the two schedules of practice. Due to the lack of significance in the treatment effect and to a low sample size (acquisition N = 8, retention N = 10, transfer N = 8) blocked/serial comparisons were not included in further analysis.

Table 3

Means and Confidence Interval for Overall Treatment Effect

ES group	N	Corrected and weighted mean	95 % confidence interval
Random / blocked acquisition	40	-.31	-.40 to -.22
Random / blocked retention	48	.31	.23 to .40
Random / blocked transfer	27	.23	.12 to .34
Serial / blocked acquisition	8	-.21	-.42 to .01
Serial / blocked retention	10	.10	-.10 to .29
Serial / blocked transfer	8	.11	-.09 to .31

3.4. WITHIN PHASE ANALYSIS

The effect sizes calculated are independent; thus, not all effect sizes can be coded in all categories. Univariate ANOVAs were performed at the p = .05 level of significance whenever sample size was sufficient. Each of the following research questions were evaluated:

- In which of the two explanations is the majority of research based? Which theoretical explanation is most strongly supported?
- Is the contextual interference effect more strongly supported for ecologically valid settings? Is the contextual interference effect supported differently dependent upon type of skill? And is there an interaction between ecological validity and type of skill?
- Does the contextual interference effect differ in strength dependent upon the following factors: experience, gender or age?
- Does the contextual interference effect differ in strength for parameter learning and generalized motor program learning? Does the feedback schedule or the amount of practice influence the strength of contextual interference?
- Does the internal validity of the study influence the strength of the contextual interference effect?

3.4.1. Theoretical Explanation

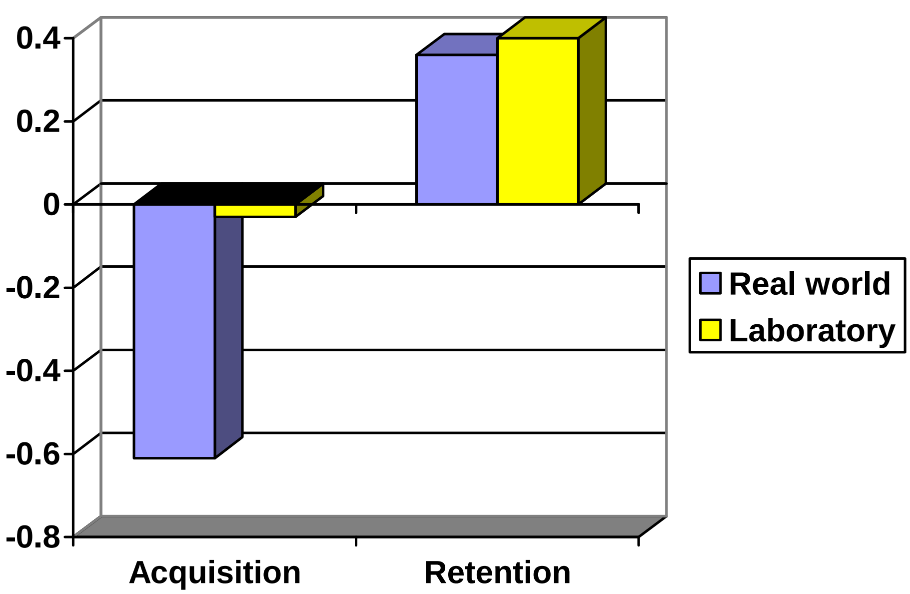
The elaboration and forgetting hypotheses were widely used to explain the contextual interference phenomenon. Both hypotheses were mutually used to justify the experiments in 18 studies. While 9 articles were explained only by the Forgetting/Reconstruction hypothesis, the Elaboration/Distinctiveness hypothesis was used in 5 articles. There were 19 studies that did not use any hypothesis to justify the experiments.

There were not enough studies testing the hypotheses to allow data analysis. From the 51 coded studies, there were only 4 effect sizes representing blocked and random practice comparison during retention for the forgetting hypothesis and 2 effect sizes for the elaboration hypothesis.

3.4.2. Ecological validity and type of skill

Acquisition results approached significance (p = .08) with the real world experiments demonstrating smaller negative means (ES M = -.03, SD = .63, N = 8) than the laboratory based experiments (ES M = -.61, SD = .76, N = 22). A mean of zero would denote no difference between blocked and random groups, thus, the real world task and setting result indicates that the random group performance was similar to blocked group performance during acquisition. For retention, experiments in the laboratory (ES M = .40, SD = .70, N = 28) had similar effect sizes (p = .65) to experiments in the real world (ES M = .36, SD = .50, N = 11) (see figure 1). Transfer results did not have a sufficient sample size (laboratory N = 4, real world N = 18). The analysis for type of skills was also limited by the low sample size for open skills (N = 4) in retention and (N = 7) transfer. Therefore, neither the analysis nor the interaction between type of skill and ecological validity was investigated.

Figure 1 ECOLOGICAL VALIDITY



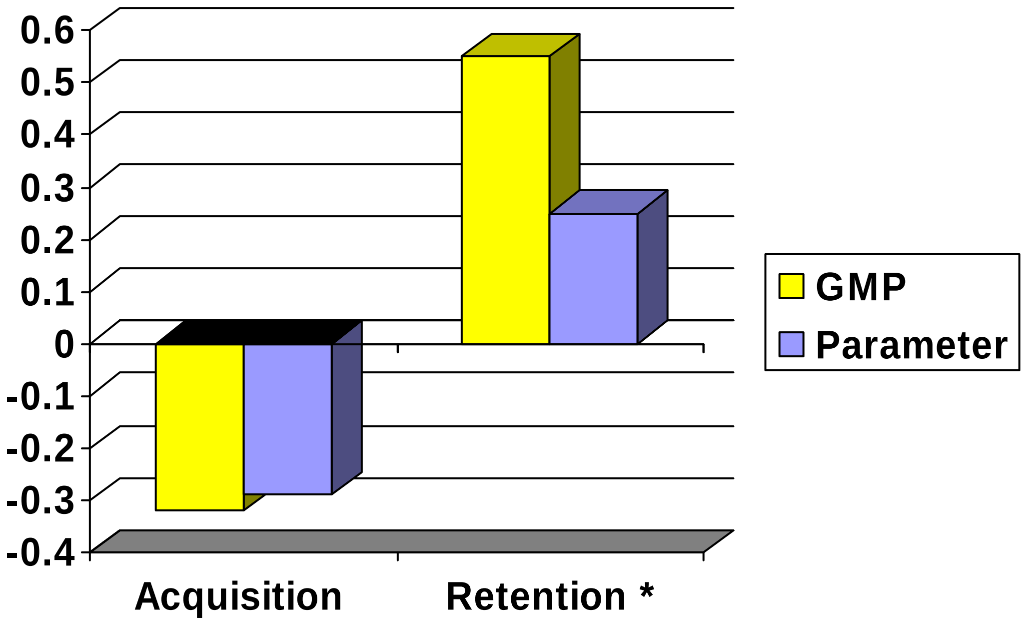
3.4.3. Experience, gender and age

None of these variables had sufficient sample sizes within each group for the three phases (acquisition, retention and transfer) to allow further statistical analysis. From the total effect sizes for blocked and random comparison, novices were 85 ES, experts 3 and intermediate learners none. Gender differences were not investigated because most of the studies did not specify gender (N = 56). While some studies had mixed groups (N = 44), others had only women (N = 16) and very few had only men (N = 3). Regarding age, it was clear that the majority of the studies investigated learning motor skills in adults (N = 93) rather than in adolescents (N = 9) or children (N = 12).

3.4.4. Task characteristic (GMP and parameter learning)

Acquisition results demonstrated there were no significant differences ($p = .60$) between task variations in generalized motor program (ES M = -.32, SD = .78, N = 14) and task variations in parameter (ES M = -.29, SD = .54, N = 22). However, studies with motor skill variation in GMP (ES M = .55, SD = .60, N = 17) were significantly different ($p = .04$) than studies with variation in parameter learning (ES M = .25, SD=.70, N = 23) for retention. A large difference in the number of effect sizes for GMP (N = 5) and parameter (N = 20) did not allow this comparison to be made for transfer phase (see figure 2).

Figure 2 TASK CHARACTERISTIC



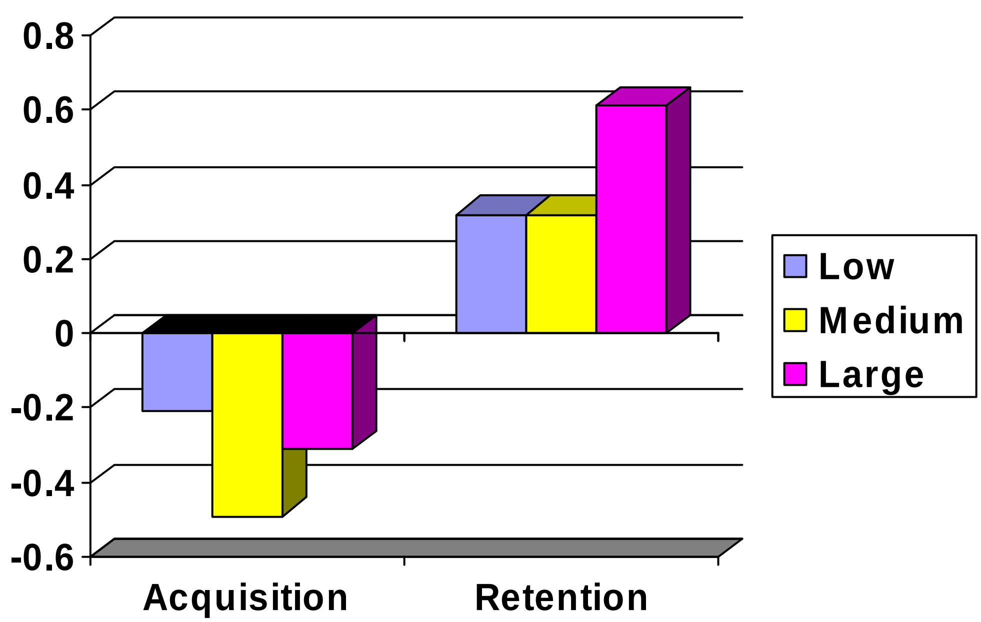
3.4.5. Knowledge of Results

The presence or absence of augmented feedback did not significantly influence effect sizes during acquisition (p = .16), retention (p = .66) or transfer (p = .55). Acquisition with no-KR (ES M = -.15, SD = .65, N = 13) favored blocked over random groups as well as acquisition with KR (ES M = -.47, SD = .70, N = 27). Even though effect size for KR was slightly higher than no-KR groups, the difference was not significant. During retention, the effect size for no-KR groups (ES M = .41, SD = .68, N = 16) and for presence of KR groups (ES M = .39, SD =.72, N = 32) were similar. Levels of KR were also not significantly different for the blocked-random comparison during transfer. Once again, studies with KR had slightly higher effect size means (M = .28, SD = .66, N = 20) than studies with no KR (M = .08, SD = .22, N = 7).

3.4.6. Amount of Practice

No differences were found for acquisition (p = .56) among the different amounts of practice. Effect size means were similar for low (ES M = -.21, SD = .61, N = 10), medium (ES M = -.49, SD = .74, N = 18) or large (ES M = -.31, SD = .71, N = 12) amounts of practice during acquisition. Parallel results were found for retention. There are no significant differences (p = .465) for low (ES M = .32, SD = .84, N = 9), medium (ES M = .32, SD = .55, N = 19) and large (ES M = .61, SD = .88, N = 14) amounts of practice. Sample size for amount of practice were small during transfer (low, N = 7; medium, N = 10; and large, N = 6) and did not allow statistical analysis (see figure 3).

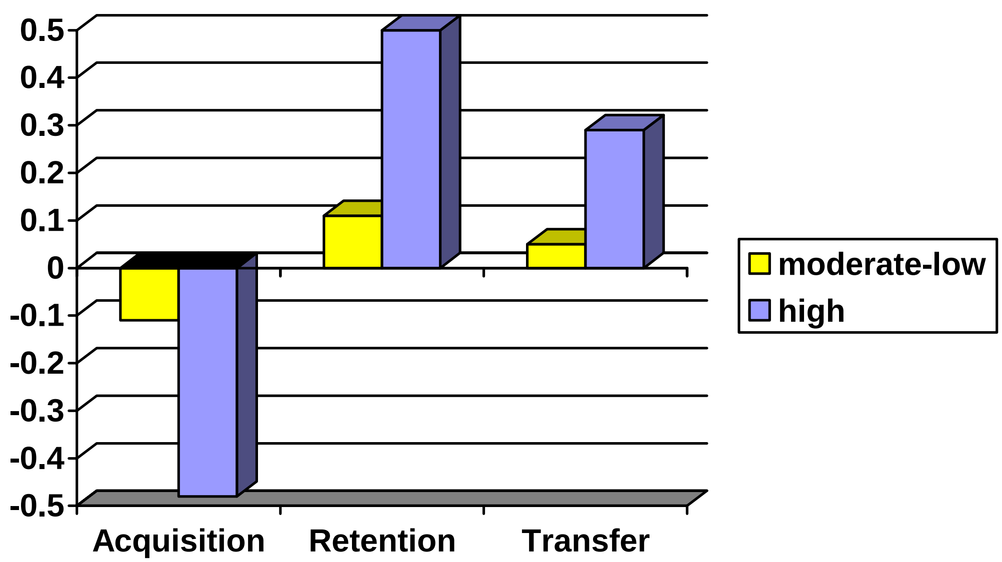
Figure 3 AMOUNT OF PRACTICE



3.4.7. Internal Validity

The data analysis revealed no significant differences for internal validity, but a trend in which highly controlled studies demonstrate stronger CI effects than less controlled studies (see figure 4). During acquisition high internal validity studies (ES M = -.48, SD = .79, N = 28) demonstrated larger effect size means than the moderate/low internal validity studies (ES M = -.11, SD = .27, N = 12), even though the difference between them was not significant (p = .155). Studies with strong internal validity (ES M = .50, SD = .77, N = 35) also had larger effect size means for retention than those with moderate/low internal validity (ES M = .11, SD = .34, N = 13). Once more, this difference fell short of significance (p = .096). Likewise, moderate/low internal validity studies (ES M = .05, SD = .48, N = 7) and high internal validity studies (ES M = .29, SD = .61, N = 20) did not differentiate significantly (p = .183) for transfer tests.

Figure 4 INTERNAL VALIDITY



3.5. ACROSS PHASE ANALYSIS

A test for the normal distribution was performed. The assumption for the normal distribution was met for skewness (-.221) and kurtosis (1.046) for the effect sizes representing blocked, random, and serial groups across phases (acquisition-retention and acquisition-transfer). Since the data is normally distributed the statistical analysis will use the corrected and weighted effect size as the dependent measure. Data was analyzed with a repeated measures design at the .05 level of significance.

Across phase analysis paralleled overall results from within phase analysis. Overall group means were significantly different $F(2,35) = 3.77$, $p < .05$. Positive effect size means indicate increases in learning from acquisition to retention, or acquisition to transfer. Positive means were obtained by serial ($M = .45$) and random ($M = .35$) groups, while the blocked group obtained a negative ES mean ($M = -.54$). None of other comparisons are significant.

4. DISCUSSION

This meta-analysis investigated differences in strength of the contextual interference effect mediated by the subject's characteristics, the type of skill and the experimental setting. Questions associated with the theoretical explanations, gender, developmental learning differences, level of expertise and type of skill, could not be answered due to the low number of published studies examining these variables. Amount of practice, internal validity, ecological validity and KR yielded non-significant results but pointed to directions that are worthy of discussion. The primary findings in this study refer to the overall treatment effect and to the task characteristics regarding GMP and parameter learning.

The overall treatment effect supported contextual interference for blocked and random comparison as demonstrated by the mean of effect sizes for acquisition, retention and transfer. As it was typically demonstrated in previous research (Shea & Morgan, 1979; Gabriele, Hall & Lee, 1989) the blocked group outperformed random group for acquisition, yet, the random group was better for retention and transfer. Therefore, as expected this analysis supported the overall contextual interference effect.

Another important finding was generated by the overall treatment effect. Even though past research has supported contextual interference using blocked and serial schedules of practice (Lee & Magill, 1983), the meta-analysis reveals that retention and transfer results of serial practice schedules in average are not as strong as retention and transfer results of random practice schedules. In fact, serial groups do not differ from blocked groups. Therefore, contradicting some previous research, the meta-analysis does not support the serial schedule of practice as a high contextual interference condition.

Very few studies tried to test the hypotheses. Therefore, in this meta-analysis descriptive statistics was used to demonstrate that both hypotheses were widely used to explain or justify findings in contextual interference research. Studies combining the forgetting/reconstruction and elaboration/distinctiveness hypotheses were used to explain findings in 35% of the coded studies. For example, both hypotheses were complementary in explaining cognitive efforts and processes encouraged under different conditions (Gabriele, Hall & Lee, 1989; Bortoli, Spagolla & Robazza, 2001; Li & Lima, 2002). The forgetting/reconstruction alone was used in 17% and elaboration/distinctiveness in 10 % of the studies.

Ecological validity bordered significance for acquisition results, but was not significant for retention. These results are partially in line with studies advocating the use of contextual interference for teaching motor skills in real world settings (Boyce & Del Rey, 1990; Hall, Domingues & Cavazos, 1994). The difference in acquisition effect sizes, although not significant, suggested reduced decrement in acquisition performance for random practice learners when performing a real world task rather than a laboratory task. Both laboratory and real world experiments demonstrated similar retention results indicating that random groups in real world studies benefit from contextual interference as much as random groups in laboratory studies.

Type of skill was hypothesized to be a moderator in real world studies. Open skills are supposedly more difficult to perform than closed skills; thus, real world experiments with open skills were not expected to support contextual interference as well as real world experiments with closed skills. This hypothesis was not investigated due to low sample size for open skills; therefore, more research is needed to include this component in a meta-analysis.

Contextual interference is most strongly supported for variation in GMP than for variation in parameter when comparing blocked and random schedules of practice. Studies practicing variation in GMP had significantly larger means during retention than studies practicing variations in parameters of the same GMP. These results extended previous hypotheses by Magill and Hall (1990) and Sekiya et al. (1994). Magill and Hall hypothesized the contextual interference effect would be found when the task required variation in generalized motor programs, but not for parameter modifications. Sekiya et al. (1994) hypothesized that two or more parameters created more contextual interference effects than a single parameter modification. The present results demonstrated that modifications in the complete generalized motor program created stronger contextual interference effect compared to modifications of only parameters. Besides the present study, support for the CI paradigm in GMP variation can be found in several experiments (Gabriele, Hall & Buckolz, 1987; Painter, Inman, & Vincent, 1994; Pollatou, Kioumourtzoglou, Agelousis & Mavromatis, 1997). Similarly, transfer results lean towards the same direction with GMP learning having a .33 greater effect size than parameter learning, although, this is not significant.

The support for GMP learning demonstrated in this meta-analysis contradicts earlier studies (Sekiya et al. 1994; 1996; Lai & Shea, 1998; Shea et al. 2001). These studies reported parameter learning but not GMP learning benefits during retention or transfer for high contextual interference groups in contrast to low contextual interference groups. However, all of them used serial practice schedule as high contextual interference rather than a random schedule. As explained earlier, serial schedule was not supported as a high contextual interference condition;

nevertheless, it makes sense that no GMP learning was found. The serial practice condition does not provide as much contextual interference as does the random practice condition, and perhaps GMP variation requires higher contextual interference levels to demonstrate the typical learning benefits of CI.

Although the GMP was more strongly supported, it seems parameter learning demonstrates the contextual interference as well**.** The results of parameter learning in the present analysis depicted the typical contextual interference pattern with negative effect sizes for acquisition parameter learning, favoring blocked groups, and positive effect sizes for retention and transfer, favoring random groups. Therefore, parameter modification in motor skills appears to generate sufficient interference to elicit further retention.

The GMP and parameter learning in contextual interference research can be distinctively explained by the two theories. Let's suppose learners are practicing three basketball passes, chest pass, bounce pass and overhead pass. Let's also assume these motor skills differ not only on their GMPs but also in their parameters. Unlike laboratory based tasks; real world tasks with variations in GMP will usually require different parameters as well. The elaboration distinctiveness hypothesis argues that the motor skill representation remains in the working memory while the subject practices the subsequent motor skill allowing for comparison among the previous motor skill's GMPs. However, the elaboration hypothesis in its explanation does not account for the limited capacity of working memory. In this case, for example, the amount of information to be retained may overload the capacity of working memory causing a learning decrement. The forgetting reconstruction hypothesis seems to be a better fitted model for explaining the beneficial effects of CI during GMPs variation. The working memory in this model retains only the information related to the motor skill being executed because the learner must reconstruct all or at least part of the generalized motor plan at each trial. This effortful process of constructing action plan results in better retention.

On the other hand, when practicing basketball shooting from varied distances different parameters of the same GMP are being practiced. In this case, it would make sense that simultaneous memory representation of the force parameter would increase the opportunity for comparisons among tasks, evoking different strategies for the task being learned. Moreover, since the learners are varying only one parameter during practice, it is unlikely that the whole GMP will be forgotten between interpolated tasks. Therefore, the elaboration distinctiveness hypothesis completely explains variation in parameter learning.

Presence or absence of feedback during practice was thought to influence CI. The question to be answered is whether studies that present any frequency of augmented feedback differ from studies that do not present feedback during practice. No significant differences were found for acquisition, retention, and transfer for absence or presence of KR. Most interesting, though, would be investigating whether reduced/summary KR schedules support the contextual interference paradigm differently from frequent KR schedule. Unfortunately, lack of sample size did not allow the comparison between frequent and reduced KR schedules.

Analyzing past KR research it seems that neither 0 % nor 100 % frequency of KR are the best KR schedules to optimize learning. Lavery (1962) demonstrated that retention was advantageous for learners who received delayed summary KR after a set of trials in contrast to immediate KR after each trial when learning a single motor skill. In the same line, Schmidt et al. (1990) supported summary KR benefits in retention in contrast to immediate KR for a number of motor skills. These results were also evident in contextual interference research (Del Rey & Shewokis, 1993; Wulf & Lee, 1993). Most of the present KR groups incorporated in the analysis had 100 % frequency KR, which has been shown ineffective for learning, therefore, the difference in this analysis was not expected to be significant. Perhaps a comparison among frequent, reduced and no-KR, would lead to a different outcome. Further research with summary KR is needed to clarify this issue.

Contradicting prior research (Proteau et al., 1994; Shea et al. 1990), no advantage for learning was found when comparing different amounts of practice in the meta-analysis. Large amounts of practice demonstrated slightly better results for random groups compared to blocked groups. Moreover, higher amount of practice trials revealed slightly larger means than smaller amounts of practice. None of those differences were significant. It might be the case that amount of practice is specifically related to the task and learner, but based on these results it is not possible to draw conclusions.

Studies with stronger internal validity are expected to have larger effect sizes than studies with lower internal validity. Even though, mean effect sizes were not significantly different, they approached significance for retention. The results for acquisition, retention, and transfer demonstrated more robust effect sizes for studies where participants, task and the methodological procedures were tightly controlled.

Despite yielding considerable evidence that supported contextual interference, many related issues remain to be clarified or resolved. First, contextual interference was supported for random and blocked comparison but not for serial and blocked comparison. Second, variation in generalized motor programs seems to produce more interference and consequently superior retention than variation in parameters of a generalized motor program. Third, ecological validity and amount of practice results, even though not significant, pointed to directions that were in line with expectations based on prior research. Perhaps these analyses may have reached significant levels with sufficient sample sizes; thus, more research is needed to elucidate issues in those areas. The same holds true for frequency of KR, since the proposed analysis in the frequency of KR was not possible due lack of sample size. Internal validity demonstrated slightly higher significance supporting contextual interference for studies with stronger internal validity.

The number of ESs reported as zero might have influenced the results of this meta-analysis. The major findings in the meta-analysis were based on the comparison between blocked and random groups. There were 122 non-significant results which were reported as zero, and 93 significant results which were calculated ESs. Even with this large number of zero ESs in the analyses, strong results were found. Had all effect sizes been calculated results could have been even stronger and some non-significant results might have reached significant levels.

Future research in contextual interference should focus on knowledge of results, amount of practice and developmental individual differences. In order to elucidate the issue of KR in contextual interference, zero, reduced and 100% KR should be compared. Research in amount of practice needs to determine the minimum practice necessary to elicit retention benefits. Of course, both components amount of practice and frequency of KR may depend on other factors such as task characteristics. Studies with GMP variation should be preferred over parameter variation. Moreover, random practice must be used as high contextual interference effect. Ecologically valid studies should be preferred over laboratory studies since it was demonstrated that there are no differences between laboratory and real world results. Lastly, studies investigating the contextual interference effects in children are scarce; thus, they should be a priority for researchers in the field of motor learning.

The findings in this meta-analysis support the application of the contextual interference to a variety of situations in which motor skill’s learning is involved. The common sense of practicing a motor skill until it is mastered and then move on to the next one usually dictates the organization of the schedules or practice during physical education classes, sport practices and rehabilitation sessions. Teachers, coaches and therapists should promote learning situations with multiple tasks being practiced simultaneously. Furthermore, practitioners should understand the limitations of the contextual interference benefits.

It was observed that many studies in contextual interference do not report important information in the data analysis and methodology sections, which impacts the available sample sizes for the meta-analysis. Many authors do not report sufficient statistics to permit use of study results in secondary analyses. Others do not report them in sufficient detail to permit reanalysis by subgroups (i.e. boys and girls grouped together, level of experience not well defined) or provide insufficient detail in the methodology section to permit clear identification of the correct classification of the study (number of trials, description of skills practiced). As a minimum, authors should present descriptive statistics (i.e. mean, standard deviation) and ES for important outcome measures.

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APPENDIX A. TABLES

Table 4

Number and Reasons for the Excluded Studies

Number of Studies	Reason for exclusion	Support for CI
1	Not found	
2	Testing only one condition	
8	Not contrasting low and high CI	
4	Missing statistical data	No
1	Missing statistical data	Yes for experienced No for beginners
8	Missing statistical data	yes

Table 5

Included Studies in the Within Phase Analysis

Author / year	**Year**	**N**	**Number of ES**
Albaret et al.	1998	144	9
Bortoli et al.	1992	26	4
Bortoli et al.	2001	48	3
Boyce	1990	60	4
Brady	1997	36	1
Carnahan et al.	1990	24	6
Del Rey	1989	64	8
Del Rey et al.	1994	30	6
Del Rey et al.	1983	80	2
Edwards et al.	1986	40	6
French et al.	1990	92	2
Gabrielle et al.	1989	40	2
Giuffrida et al.	2002	72	8
Goodwin et al.	1996	30	18
Granda Vera et al.	2003	71	3
Hall et al.	1994	20	3
Hall et al.	1995	48	28
Heitman et al.	1989	20	2
Immink et al.	1998	30	12
Immink et al.	2001	30	12
Jarus et al.	1999	60	6
Jarus et al.	2001	64	6
Jarus et al.	1997	74	6
Landin et al.	1997	30	4
Li et al.	2002	38	2
Meira et al.	2001	32	2
Painter et al.	1994	48	4
Pollatou et al.	1997	63	12
Pollock et al.	1997	48	3
Porretta	1998	48	6
Porretta et al.	1991	48	6
Sekiya et al.	1996	24	2
Sekiya et al.	1994	36	9
Shea et al.	1990	72	2
Shea et al.	2001	30	12
Shea et al.	1979	72	9
Shewokis et al.	1998	54	4
Smith	1997	24	3
Smith	2002	20	2

Smith	2002	48	2
Smith et al.	2003	32	4
Smith et al.	1993	48	6
Tsutsui et al.	1998	18	5
Wegman	1999	54	12
Wood et al.	1991	48	6
Wright et al.	1997	46	3
Wright et al.	1992	60	4
Wright et al.	2001	48	6
Wrisberg	1991	52	3
Wulf et al.	1993	64	15
Young et al.	1993	66	4
51 studies		**2474**	**309**

Table 6

Number of calculated ES of random-blocked comparison for variables with not enough sample size for data analysis

Variable	Condition	Number of ES
Experience level	Novices	85
	Intermediate learners	0
	Experienced learners	3
Gender	Male	3
	Female	16
	Both	44
Age groups	Children	12
	Adolescents	9
	Adults	93
Type of Skill	Open	17
	Closed	93

Table 7

Mean Effect Sizes for variables with enough sample size for data analysis

Variable	Phase	Condition	n	Mean ES	SD
Ecological validity	Acquisition	Laboratory	22	-.03	.63
		Real world	8	-.61	.76
	Retention	Laboratory	28	.40	.70
		Real world	11	.36	.50
	Transfer	Laboratory	18	XXX	XXX
		Real world	4	XXX	XXX
Internal validity	Acquisition	Low - medium	12	-.11	.27
		High	28	-.48	.79
	Retention	Low - medium	13	.11	.34
		High	35	.50	.77
	Transfer	Low - medium	7	.05	.48
		High	20	.29	.61
Task Characteristics	Acquisition	GMP	14	.-32	.78
		Parameter	22	.-29	.54
	Retention	GMP	17	.55	.60
		Parameter	23	.25	.70
	Transfer	GMP	5	.48	.46
		Parameter	20	.15	.62
Knowledge of Results (KR)	Acquisition	No KR	13	-.15	.65
		Presence of KR	27	-.47	.70
	Retention	No KR	16	.41	.68
		Presence of KR	32	.39	.72
	Transfer	No KR	7	.08	.22
		Presence of KR	20	.28	.66
Amounts of practice	Acquisition	Low	10	-.21	.61
		Medium	18	-.49	.74
		Large	12	-.31	.71
	Retention	Low	9	.32	.84
		Medium	19	.32	.55
		Large	14	.61	.88
	Transfer	Low	7	XXX	XXX
		Medium	10	XXX	XXX
		Large	6	XXX	XXX

Table 8   ANOVA Summary tables - Ecological Validity

Within phase comparison – Ecological validity
Acquisition

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	184.831(b)	1	184.831	3.296	.080	3.296	.418
Intercept	196.459	1	196.459	3.504	.072	3.504	.440
ecological	184.831	1	184.831	3.296	.080	3.296	.418
Error	1569.988	28	56.071				
Total	2284.802	30					
Corrected Total	1754.820	29					

a Computed using alpha = .05
b R Squared = .105 (Adjusted R Squared = .073)
Dependent Variable: corrected and weighted ES for blocked and random

Retention

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	8.482(b)	1	8.482	.213	.647	.213	.073
Intercept	417.346	1	417.346	10.479	.003	10.479	.883
ecological	8.482	1	8.482	.213	.647	.213	.073
Error	1473.595	37	39.827				
Total	2063.349	39					
Corrected Total	1482.077	38					

a Computed using alpha = .05
b R Squared = .006 (Adjusted R Squared = -.021)
Dependent Variable: corrected and weighted ES for blocked and random

Table 9 ANOVA Summary tables - Task characteristics

Within phase comparison – Task characteristics
Acquisition

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	12.851(b)	1	12.851	.284	.598	.284	.081
Intercept	278.708	1	278.708	6.159	.018	6.159	.674
GMParam	12.851	1	12.851	.284	.598	.284	.081
Error	1538.641	34	45.254				
Total	1873.327	36					
Corrected Total	1551.492	35					

a Computed using alpha = .05
b R Squared = .008 (Adjusted R Squared = -.021)
Dependent Variable: corrected and weighted ES for blocked and random

Retention

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	149.175(b)	1	149.175	4.513	.040	4.513	.544
Intercept	547.042	1	547.042	16.550	.000	16.550	.977
GMParam	149.175	1	149.175	4.513	.040	4.513	.544
Error	1256.061	38	33.054				
Total	1880.632	40					
Corrected Total	1405.237	39					

a Computed using alpha = .05
b R Squared = .106 (Adjusted R Squared = .083)
Dependent Variable: corrected and weighted ES for blocked and random

Table 10 ANOVA Summary tables - Knowledge of results

Within phase comparison – knowledge of results
Acquisition

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	99.925(b)	1	99.925	2.062	.159	2.062	.288
Intercept	284.212	1	284.212	5.865	.020	5.865	.656
k_results	99.925	1	99.925	2.062	.159	2.062	.288
Error	1841.452	38	48.459				
Total	2413.649	40					
Corrected Total	1941.377	39					

a Computed using alpha = .05
b R Squared = .051 (Adjusted R Squared = .027)
Dependent Variable: corrected and weighted ES for blocked and random

Retention

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	7.543(b)	1	7.543	.202	.656	.202	.072
Intercept	472.336	1	472.336	12.623	.001	12.623	.935
K_results	7.543	1	7.543	.202	.656	.202	.072
Error	1721.222	46	37.418				
Total	2305.854	48					
Corrected Total	1728.766	47					

a Computed using alpha = .05
b R Squared = .004 (Adjusted R Squared = -.017)
Dependent Variable: corrected and weighted ES for blocked and random

Transfer

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	19.020(b)	1	19.020	.368	.549	.368	.090
Intercept	114.614	1	114.614	2.219	.149	2.219	.299
k_results	19.020	1	19.020	.368	.549	.368	.090
Error	1291.403	25	51.656				
Total	1523.896	27					
Corrected Total	1310.423	26					

a Computed using alpha = .05
b R Squared = .015 (Adjusted R Squared = -.025)
Dependent Variable: corrected and weighted ES for blocked and random

Table 11 ANOVA Summary tables - Amount of practice

Within phase comparison – Amount of practice
Acquisition

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	60.263(b)	2	30.131	.593	.558	1.185	.141
Intercept	369.364	1	369.364	7.265	.011	7.265	.747
practice_trials	60.263	2	30.131	.593	.558	1.185	.141
Error	1881.114	37	50.841				
Total	2413.649	40					
Corrected Total	1941.377	39					

a Computed using alpha = .05
b R Squared = .031 (Adjusted R Squared = -.021)
Dependent Variable: corrected and weighted ES for blocked and random

Retention

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	63.111(b)	2	31.556	.780	.465	1.561	.173
Intercept	417.726	1	417.726	10.332	.003	10.332	.880
practice_trials	63.111	2	31.556	.780	.465	1.561	.173
Error	1576.774	39	40.430				
Total	2179.870	42					
Corrected Total	1639.885	41					

a Computed using alpha = .05
b R Squared = .038 (Adjusted R Squared = -.011)
Dependent Variable: corrected and weighted ES for blocked and random

Table 12 ANOVA Summary tables - Internal Validity

Within phase comparison – Internal validity
Acquisition

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	102.146(b)	1	102.146	2.110	.155	2.110	.294
Intercept	252.011	1	252.011	5.207	.028	5.207	.604
internalval	102.146	1	102.146	2.110	.155	2.110	.294
Error	1839.231	38	48.401				
Total	2413.649	40					
Corrected Total	1941.377	39					

a Computed using alpha = .05
b R Squared = .053 (Adjusted R Squared = .028)
Dependent Variable: corrected and weighted ES for blocked and random

Retention

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	101.834(b)	1	101.834	2.879	.096	2.879	.383
Intercept	279.749	1	279.749	7.910	.007	7.910	.786
internalval	101.834	1	101.834	2.879	.096	2.879	.383
Error	1626.931	46	35.368				
Total	2305.854	48					
Corrected Total	1728.766	47					

a Computed using alpha = .05
b R Squared = .059 (Adjusted R Squared = .038)
Dependent Variable: corrected and weighted ES for blocked and random

Transfer

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	91.298(b)	1	91.298	1.872	.183	1.872	.260
Intercept	67.323	1	67.323	1.381	.251	1.381	.204
internalval	91.298	1	91.298	1.872	.183	1.872	.260
Error	1219.125	25	48.765				
Total	1523.896	27					
Corrected Total	1310.423	26					

a Computed using alpha = .05
b R Squared = .070 (Adjusted R Squared = .032)
Dependent Variable: corrected and weighted ES for blocked and random

APPENDIX B. EXTENDED BACKGROUND INFORMATION

On a daily basis physical education teachers and coaches face the challenge of effectively teaching multiple motor skills during a class or practice period. When instructors are teaching various motor skills, they have to establish the order of practicing the skills. The organization of practice sessions determine the amount of interference created between two or more tasks practiced simultaneously. Researchers studying verbal learning referred to the relative amount of interference created when practicing multiple skills as contextual interference. It was established that the organization of the practice session was directly related to the amount of contextual interference created and to learning (Battig, 1979).

The different schedules of practice are blocked, serial and random. In blocked practice schedules learners would repeat the same task over and over until they complete all trials and then they would start a different task. In a serial schedule of practice learners repeat the tasks sequentially, so for each trial all tasks are repeated in the same order. Finally, in a random schedule of practice the order of the tasks is unpredictable.

The manipulation of schedules of practice dictates whether the researcher wants to apply low, or high contextual interference in the learning situation. If learners practice skills under blocked condition, low contextual interference is produced. Conversely, high contextual interference is produced if random practice is used. Initial studies in the motor domain indicated indeed that there is a correlation between the amount of contextual interference and learning (Shea and Morgan, 1979; Lee & Magill, 1983; Gabrielle, Hall & Buckolz, 1987).

Since the initial demonstration of contextual interference by Shea and Morgan (1979) the phenomenon of contextual interference in the motor learning domain has demonstrated a similar trend. Randomizing the order of the presentation of tasks during acquisition produces superior retention when compared to blocked practice schedule. It also has been shown that high contextual interference during acquisition phase may hinder acquisition performance whereas facilitating learning as assessed by retention and transfer performance. In other words, temporary performance gains are sacrificed for long term benefits in learning.

If the main goal is to maximize learning, one would conclude the random practice condition is preferable over blocked practice condition. This statement, however, is not always true. Typical results are not found in all learning situations where multiple task variations are to-be-learned (Magill & Hall, 1990).

Researchers have investigated the interaction of contextual interference with different variables such as task characteristics and individual differences. To date, there are still conflicting results; therefore, it is hard to draw conclusive statements regarding the motor domain and the phenomenon of contextual interference. Among various factors that may influence contextual interference effect are the ecological validity of the experiments, age, gender, experience level of the learner, the type and characteristics of the skills, and the absence or presence of feedback during the practice trials.

Even though researchers have looked upon these issues, there is no total agreement regarding the contextual interference effects in these situations. This explains the need for a deeper analysis in the literature by a meta-analysis. The purpose of this research, therefore, is to provide quantitative summary of the typical strengths and the limitations of the effect of contextual interference on motor learning. The theoretical explanations, which have been studied for over 20 years, have been investigated and supported; however, to date, there is no agreement on the most complete and more reasonable explanation. The two theories are discussed next with the arguments that make each one a rational unique explanation for the contextual interference effect.

Theoretical/Conceptual Framework

Two theories have been presented to explain the findings of contextual interference. The elaboration distinctiveness view was first proposed by Shea and Morgan (1979). It assumes retention results are enhanced by random practice due to comparisons of multiple tasks in working memory. The other feasible explanation, the forgetting/reconstruction hypothesis, was presented by Lee and Magill (1985). It suggests the random practice condition promotes forgetting between repetitions, thus a new or at least part of an action plan has to be reconstructed before each trial. This action plan reconstruction develops stronger memory representation of the task and therefore retention and transfer benefits exist. Since these two theories (elaboration and reconstruction) have been proposed many researchers have addressed their strengths and weaknesses.

The elaboration hypothesis was proposed by Shea and colleagues, (Shea & Morgan, 1979; Shea & Zimny 1983). The explanation for contextual interference effects was that multiple processing strategies used by the random group during the acquisition phase led to better retention performance. The blocked group did not experience this greater elaboration of processing. In other words, the advantage during retention occurs because the actions to-be-learned underwent more elaborative and distinctive processing in the random group compared to the blocked group.

The elaborative and distinctiveness aspects of the hypothesis are explained by Magill and Hall (1990). First, distinctiveness is due to multiple comparisons in working memory. In a high contextual interference condition, while a task is practiced, multiple tasks reside in working memory simultaneously. It increases the opportunity for comparison between tasks leading to a more distinctive memory representation. Second, performing multiple tasks evokes different strategies for the task being learned. Various encoding strategies develop a more elaborate memory representation than a single encoding strategy. These features explain the benefits during retention and transfer but do not account for the acquisition effects.

Since a theoretical explanation for contextual interference should account for both acquisition and retention effects, Shea and Zimny (1983) presented a rationalization for the detrimental effects during acquisition for the elaborative hypothesis. The elaborative and distinctiveness model implies that blocked practice conditions foster subjects to engage in shallow cognitive processes restricted to working memory. Random practice condition subjects, on the other hand, are encouraged to rely on effortful working memory processes. The negative effects of random practice schedule during acquisition performance are usually expressed as longer latencies or larger error scores. Longer latencies on acquisition performance may be attributed to the multiple comparisons in working memory, while the larger error scores may be due to the adjustments from switching strategies.

Similarly convincing is the reconstruction hypothesis explanation of the detrimental effect on acquisition (Lee and Magill, 1985). If the “processing activities” involved in remembering a cognitive problem are not available in working memory at the time of a repetition of that problem, those processing activities have to be repeated.

Basically, the reconstruction hypothesis argues that conditions of practice, such as random or serial, which promote forgetting between trials, will depress acquisition performance yet promoting retention. Forgetting information during practice causes reconstruction of action plans. For each trial a new action plan needs to be constructed because at least some of the information, if not all, regarding the previously executed movement is no longer available in working memory. Reconstruction, therefore, strengthens retention and transfer performance. Practicing a skill under blocked conditions during the acquisition phase leads to very little or no recalling of the movement. Consequently, the performance of the individual during retention and transfer is poor.

There are no studies that tried to differentiate between specific proposals possibly because of the difficulty in contrasting hypothesis. The elaborative and distinctiveness hypothesis research studies focused on the inter-task and intra-task processing, while the forgetting and reconstruction hypothesis research studies were based on the time planning delays before and during the execution of the movements.

In an attempt to gain some insight into the underlying processes utilized by learners experiencing different levels of contextual interference, researchers investigating the elaboration hypothesis placed heavy emphasis on the task analyses that occurs during inter-trial interval. According to Shea and Zimny (1983) the elaboration hypothesis relies heavily on the existence of two distinct cognitive processing models: intratask and intertask processing.

Blocked and random practice differ in the use of inter and intratask processing. Blocked practice participants relay almost exclusively on intratask processing, which is very limited because it relies only on an individual task analysis. In contrast, during random practice, learners are encouraged to take advantage of both intratask and intertask processing. Intertask processing engages associative processing which enables the learner to incorporate new task information with existing knowledge. The intertask processing, therefore, is considered to be critical in allowing the learner to formulate a detailed task representation.

Wright (1991) investigated the role of intratask and intertask processing when acquiring motor skills in a low contextual interference practice condition. Additional processing during acquisition was enforced by verbalization of different movement patterns between trials. All groups practiced skills in blocked order. In the intertask practice condition, subjects were shown a diagram representing one of the two movement patterns that would be learned other than the one they were practicing. They were then asked to identify similarities. The supplemented intratask condition consisted of verbalization of the movement just performed. There was also a blocked control group, which had no manipulation during intertrial interval. As it was hypothesized, the condition supplemented with intertask processing exhibited superior retention performance relative to the intratask and control conditions, thus supporting the assumption that engaging in intertask processing aids retention. In contrast, supplemental intratask processing did little to enhance retention performance. It appears that providing supplementary processing already obligated by the inherent structure of the practice schedule is superfluous. Wright, Li, and Whitacre (1992) extended this statement by investigating the role of supplementary intertask and intratask information for random practice schedule.

Wright et al. (1992) stated that supplementing a high contextual interference condition with intertask activity was detrimental to both acquisition and retention. It was proposed that supplementing random practice with additional processing activity (intratask or intertask) should not facilitate retention performance beyond that exhibited by individuals merely exposed to random practice. As with the previous study, additional processing activity was achieved by verbalization of task information during the intertrial interval. The random group experiencing additional intertask processing information demonstrated that extra intertask activity promotes poorer retention and transfer performance. Both the random practice condition without additional processing and the random practice condition supplemented with intratask information outperformed the random group with intertask additional processing.

Parallel results were found for Young, Cohen and Husak, (1993). They pointed out that supplementary intratask activity is more advantageous than supplementary intertask activity for random practice. This study presented exemplar models between trials to manipulate the intratask and intertask processing activities associated with random practice. The supplemented intertask random group demonstrated significantly poorer retention performance than the random control group.

Retention benefits for random practice schedule seem to be dependent upon the amount of interference created by the intertask activity. Supplementary intertask activity in the random schedule may disrupt other processing activities inherent in this practice schedule. There may be a ceiling effect on retention performance due to the extent of intertask processing. Random practice, therefore, may result in reduced learning if the individual experiences intertask activity beyond the optimal level. Overall, not all findings are in accordance with the elaboration hypothesis view. Some results are difficult to explain by the elaboration explanation because of methodological aspects such as studies investigating time demands related to the preparation of executed movements. An alternative explanation is the reconstruction hypothesis.

A few studies were designed to directly investigate aspects related to the reconstruction explanation (Shea & Wright, 1991; Immink &Wright, 1998). First, Shea and Wright investigated whether similar or dissimilar interpolated tasks would cause different amounts of forgetting and retention performance. Second, Immink and Wright studied the temporal demands in planning a movement by blocked and random practice participants. Both aspects were important components of the forgetting reconstruction framework.

Motor retention is greater when forgetting during acquisition occurred as the result of a similar interpolated task rather than a dissimilar task (Shea & Wright, 1991). Four experimental groups with four exclusive interpolated distractor tasks were contrasted. The interpolated tasks consisted in no task, same task, similar task and dissimilar task. No task and same task groups had superior performance in acquisition compared to the similar and dissimilar groups. Thus, the amount of forgetting experienced by the similar and dissimilar groups was greater than the amount of forgetting experienced by the no task and same task groups. From the perspective of the reconstruction explanation, the task used to cause forgetting of the action plan should have little effect on retention. However, the dissimilar interpolated task group had significant inferior retention performance than all other groups. The other groups did not differ significantly from one another.

It is difficult to reconcile these findings with the reconstruction explanation. The reconstruction perspective would not predict these findings since the performance of the same task and no task groups demonstrated relatively less forgetting than the similar and dissimilar task groups in acquisition. In theory, less reconstructive processing and poorer retention performance should have occurred by the same task and no task groups.

These findings may be explained by components related to the elaboration view. It is possible that the no task and same task group engaged in intratask processing to increase the memorability of the task. It was already demonstrated that intratask processing can be beneficial for random practice schedule (Young et al. 1993). Also in accordance with the elaboration hypothesis is the significant better results of the similar task group over the dissimilar task group. A similar task in working memory seems to have provided the opportunity for the distinctive processing be performed resulting in a better retention outcome.

Another study was designed to investigate aspects of the reconstruction explanation (Immink & Wright, 1998). They addressed the viability of the reconstruction hypothesis by studying timing demands related to preparation and execution of the movements. In theory, an action plan reconstruction can proceed only after the subject becomes aware of the movement for which the plan must be reconstructed. An action plan reconstruction can take place not only during reaction time but also during movement time when preparation time is insufficient. Within this set Immink and Wright examined the temporal delays caused by skill manipulation prior to executing an upcoming movement.

Three temporal variables were measured and feedback was presented after the completion of the movements. The temporal variables were study time, reaction time and movement time. Study time refers to the temporal delay associated with planning the movement. It was measured by the time spent examining the display prior to initiating a response. The amount of study time was manipulated in the experiments. Reaction time and movement time were also recorded.

The temporal delay data of Immink and Wright (1998) is consistent with the predictions based on the reconstruction hypothesis. Researchers showed that under restrained study time conditions subjects using high contextual interference practice schedules increased movement time during acquisition when compared to their blocked counterparts. It seems that under this circumstance additional planning activity takes place after the onset of the movement. Regardless of whether the random practice individuals performed all the movement planning processes prior to movement initiation or entertained some of these processes during the initiation/implementation phases, typical contextual interference retention effects were observed.

Random practice participants spend more time planning a movement during acquisition than do blocked practice participants. With respect to the current theoretical accounts for the occurrence of CI effects, the increased random planning time may be explained as a result of additional reconstructive activity that random practice participants must engage in order to ready an appropriate action plan. Immink's study did not identify or verify any particular procedures that account for these temporal delays. Thus, further investigation is needed to describe more precisely the nature of the additional planning time taken by random practice participants.

Immink's study failed to reveal differences between random and blocked schedules during acquisition performance. The absence of an acquisition advantage for the blocked groups is in line with other studies (Wright, 1991; Pollock and Lee, 1997). Taken together these data suggest traditional benefits of random practice schedules may emerge even with the absence of acquisition decrement. Wright (1991) on the basis of elaborative processing demonstrated that it is possible to facilitate retention performance without compromising the acquisition performance by engaging in an appropriate amount of intertask processing. Immink and Wright (1998) propose that the typically displayed acquisition differences between random and blocked practice participants are suggested to be a function of planning the movement ahead; therefore, if the participants are given additional planning time during random practice, differences in acquisition are reduced.

Overall, it was demonstrated that both elaboration and reconstruction hypotheses account for the occurrence of contextual interference. Proposed by Shea and Morgan (1979) the elaborative and distinctiveness hypothesis has been supported by many researchers (Shea and Zimny, 1983; Wright, 1991; Wright, Li, and Whitacre, 1992). The forgetting reconstruction hypothesis was proposed by Lee and Magill (1985) and it has also been supported in recent research (Immink & Wright, 1998). Neither one of the hypotheses account for all findings in the literature, thus, future research is needed.

There are experimental data supporting both hypotheses accounting for the CI paradigm explanation. The elaboration hypothesis explanation is based on two distinct cognitive processing models, intratask and intertask. It also appears there is a limit on the amount that these processing activities may be beneficial for learning. It was demonstrated that supplementing a practice schedule that already engenders the cognitive processing activity may be superfluous or detrimental. Alternatively, the CI effects with the basis on the reconstruction of the action plan are linked to the temporal delays prior to the initiation of a movement.

The lack of research testing and contrasting these two theories is one reason that yields for a meta-analysis. Although, the quantitative results from a meta-analysis would not account for differentiating the theories, it would suggest whether the effect sizes are greater for one theory compared to the other.

Another issue regarding contextual interference is whether the results of the extensive research account for all learning situations or just for the ones the task and the environment are easily controlled. Inconsistent findings were found in non-laboratory settings such as physical education classes and sport practices. Research in school and sport settings are necessary because they reflect real life situations. Thus, in the next section, two important components of CI research concerning environmental issues are discussed: the ecological validity and the type of skills to-be-mastered.

Ecological Validity and Type of Skills

There is no doubt contextual interference is a robust learning phenomenon for simple laboratory controlled tasks; although, attempts to extend the CI paradigm into applied settings with sport skills have produced mixed results. Due to the importance of ecological validity and the direct implication of these studies, researchers have investigated the applicability of CI effects in applied settings with real life tasks. Laboratory based research has consistently supported the CI effect while more ecologically valid studies have not had the same consistency. Two types of skills have been investigated in both settings.

The motor skills used in contextual interference research are classified according to the environmental characteristics. Open skills are skills in which the environmental conditions are always changing, often unpredictably. Inversely, closed skills are skills in which the environment is stable and predictable. The initial set of studies investigated the effects of contextual interference using closed skills (Shea & Morgan, 1979; Lee & Magill, 1983; Gabriele, Hall & Buckolz, 1987); however, more recently open skills have become more commonly used in research because open skills are largely practiced in sport settings and physical education classes.

Laboratory studies typically test closed tasks such as button pushing (Sekiya et al., 1994; Shea, Lai, Wright, Immink and Black, 2001), knocking down barriers (Shea & Morgan, 1979; Proteau, Blandin, Alain & Dorion, 1994), key pressing (Wright, Li & Coady, 1994), and drawing patterns (Albaret & Thon, 1998). However, some closed tasks rifle shooting (Boyce & Del Rey, 1990) and golf putting (Brady, 1997) golf shots have been used in naturalistic settings. This closed context in laboratory research makes conditions more controllable and easier to measure accurately but difficulty arises with application to real life situations.

While laboratory studies have mostly used closed skills, ecologically valid studies have often used open sport skills to assess contextual interference. The non-laboratory experimental research using open skills yield contradictory results. Consistent with the prediction of contextual interference, ecologically valid research such as Hall, Domingues and Cavazos (1994), Smith and Davies (1995), Li and Lima (2002) with baseball, pawlata roll and soccer skills respectively, have demonstrated a higher learning outcome when practicing the skills in random order. Conversely, Landin, Hebert and Fairweather (1993), Brady (1997), Bortoli, Spagolla and Robazza (2001), Meira and Tani (2001) reported no advantage at retention with varied practice in their field studies.

The inconsistency of the results of CI studies in ecologically valid settings suggests it may not be a global learning phenomenon which can be generalized to all leaning situations. In trying to prove its applicability to varied situations, researchers deal with great number of factors. Thus, the supportive or divergent results for the CI paradigm can usually be attributed to variables other than the setting and the type of skill, such as individual differences (experience level, age, gender, and cognitive capacity of the learner). These factors are discussed in the next section.

Individual Differences

Contextual interference is a broad phenomenon which has been tested in varied populations. Among the tested populations in CI research, experimenters evaluated the learning paradigm for experts and novices (Del Rey, Wughalter & Whitehurst, 1982; Hall, Domingues & Cavazos, 1994; Hebert, Landin & Solmon,1996; Wegman, 1999), children and adults (Polkis, 1990; Pollock & Lee, 1997; Jarus & Goverover, 1999; Bortoli, Spagolla & Robazza, 2001), boys and girls (Del Rey, Whitehurst & Wood, 1983; Smith & Rudisill, 1993), mentally challenged and control individuals (Porreta & O'Brien, 1991). The results for most of these studies are not as clear as one would like (high interference, superior retention – low interference, poorer retention). Experience level and age are factors that may limit the CI effect, although not all research has been consistent in the extent of these limitations. The few studies with mentally challenged individuals partially supported the CI paradigm. In addition, the studies contrasting gender usually include other factors in the design of the study, which make it difficult to attribute the results to gender. These factors are covered next.

Experience level. Past research has shown an interaction between the type of skill and the experience level of the subjects when different practice schedules are used during acquisition. Studies have supported the role of contextual interference for open skills with intermediate and experienced learners (Hall et al., 1994; Wegman, 1999) but not with novices (Del Rey et al., 1982; Hebert et al., 1996).

The learning benefits of contextual interference have been frequently demonstrated using novice learners yet experts may benefit as well. Hall et al. (1994) supported the CI effects for experts. Skilled baseball players were tested in random and blocked order in a batting task. The groups practiced batting against three different pitches, fastballs, curveballs and change-ups. The random group outperformed the blocked group during a transfer task. Parallel results for intermediate learners were found by Wegman (1999). Elementary school children with prior experience exhibited superior learning when practicing fundamental motor skills under random conditions. It seems learners at different levels of experience may benefit from contextual interference when learning open skills. There is not total agreement, though, that novices take advantage of the random practice early in learning situations.

Learning open skills with a high contextual interference schedule seems to overload the "optimal" amount of interference that enhances learning for novice subjects. As expected, experienced subjects who underwent acquisition under high contextual interference practice schedules for a coincidence anticipation task outperformed their novice counterparts. In addition, the experienced random group was superior to the experienced blocked group during transfer. Conversely, novices in low CI groups outperformed their inexperienced counterparts using high CI during transfer (Del Rey et al., 1982) and retention (Hebert et al., 1996). These findings indicated learning multiple open skills under a random schedule of practice is beneficial only for experienced learners.

One could hypothesize that high contextual interference practice conditions are counterproductive during the early stages of motor skill learning and favorable for the advanced learner when learning an open skill. Novices should be allowed to experience repeated attempts of a task under low interference conditions while experienced learners should practice open skills in an unpredictable fashion. This hypothesis should be investigated as well in children's motor skill learning since most of the children are usually novice learners.

Age. One of the earlier CI studies involving children demonstrated somewhat similar results compared to the novices CI literature with open skills (Del Rey et al., 1983). Del Rey and colleagues found that experienced and inexperienced 8-year-old children demonstrated better transfer results practicing open skills in blocked order compared to those practicing in random order. In this case, experts and novices had similar results; thus, opposing findings listed above where experts were better in the random practice condition.

An explanation for these results is that young children differ from adults in the way they process information. The amount of interference of a task practiced in a determined schedule is not the same for children and adults because young children are limited in the strategies available to process the information (Thomas, 1980). The question to be answered by researchers, therefore, is how should information be presented to children to facilitate multiple skills learning?

Studies designed to investigate CI effect in learning motor skills by children have given mixed results. Some findings supported the benefits of high vs. low contextual interference (Bortoli, Robazza, Durigon & Carra, 1992; Bortoli, Spagolla & Robazza, 2001), while other findings did not (Wegman, 1999; Jarus & Goverover, 1999). Studies with typical and mentally handicapped children partially supported the CI paradigm demonstrating the learning benefits during retention and transfer without the decrement during acquisition (Porreta & O'Brien, 1991; Painter, Inman & Vincent, 1994; Pollock & Lee, 1997).

Beneficial effects of contextual interference were found for 8- and 9-year-old children during retention (Bortoli et al., 2001) and for 14-year-olds during transfer (Bortoli et al., 1992). One potential weakness of these studies is the absence of an adult control group. In order to precisely attribute the interaction with the contextual interference effects to age rather than to the task itself, adults and children need to perform the same task. Pollock and Lee (1997) designed a study in which a 7-year-old group and an adult group performed the same laboratory task. Results demonstrated that children performed similar to adults, given that both had superior retention performance when acquisition practice was done randomly. This result unfortunately was not replicated in other studies.

A set of studies in CI research in children did not parallel the pattern of results often demonstrated in adults. Wegman (1999) demonstrated no significant difference in retention when third graders practiced closed motor skills under blocked and random schedules. Similarly, Jarus and Goverover (1999) failed in demonstrating CI effects in children performing a closed skill. The only significant differences were between the two conditions (high and low CI) for the 7-year-old groups, and yet the low contextual interference group exhibited greater retention performance than the high contextual interference group. The 5- and 11-year-old groups had similar results to their counterparts during retention and transfer independently of the practice schedule used during acquisition. As it was suggested earlier for children learning open skills, it appears blocked practice schedule were more beneficial for inexperienced learners performing closed skills.

Two child based studies included mild mentally handicapped individuals (Porreta & O'Brien, 1991; Painter et al. 1994). The outcome of these studies revealed that they may also benefit from CI. Both studies supported CI effects on retention, but did not replicate the entire CI paradigm. The mentally handicapped children seem to benefit from random practice during retention without the decrement during acquisition performance. The absence of changes in performance during acquisition is also demonstrated in Pollock and Lee (1997), which suggests decrement in early practice is not necessary to enhance retention.

Gender. Research studies on contextual interference also investigated whether the learning phenomenon differ by gender. Del Rey et al. (1983) investigated gender differences in a study that included also age and level of expertise as factors. Typical results were not replicated; transfer results were advantageous for the groups that learned under low contextual interference schedule. Although boys were significantly more accurate than girls during acquisition, no gender differences were found during transfer. Smith and Rudisill (1993) found similar results. This study examined the interaction between contextual interference, gender and proficiency level. Boys outperformed girls during acquisition practice trials, yet none of the random groups exhibited the degradation during acquisition performance. Boys and girls did not differ significantly from each other during transfer result.

Overall, the gender differences could not be interpreted independently because of the interaction with other factors. It was proposed that females only differed from males because they typically possessed less experience at open skills. It is possible that previous experience of open skills may account for the gender differences, yet this is purely assumption. Certainly further investigation is needed in this topic.

Although some issues regarding experience level have been partially clarified by previous research, it is still quite difficult to reach a consensus on defining the level of experience in which high CI conditions will be advantageous. However, the results of novices as well as young children practicing open skills are quite consistent. It seems less experienced subjects benefit more from blocked practice than from random practice when learning open skills.

Children's research on contextual interference has revealed ambiguous results compared to the typical ones presented in the adult population. While some studies show the beneficial effects of contextual interference in closed skills, other research contradicts adult findings.

The findings of CI can be extended to the mentally challenged population, yet the research studies do not show the same pattern of results. Unexpected acquisition results appear to be a constant, diminishing the decrement of random practice compared to blocked practice.

Gender has also not been explored raising many relevant questions. The few research studies that included gender comparisons also include other factors thus there is great difficulty in drawing specific conclusions. Perhaps the lack of research in this topic is because there is nothing that indicates that there should be differences between genders.

Despite the fact that CI outcome is affected by individual characteristics, it cannot explain all results in CI research. Task characteristics may determine learning results as well. More specifically, the nature of the task variation seems to determine the amount of interference created during practice trials.

GMP and Parameter Learning

A generalized motor program (GMP) is a memory representation for a class of movements that have certain invariant characteristics, such as relative timing and relative force, but which differ in the movement parameters, such as absolute time, absolute force, and muscle groups involved (Schmidt, 1988). Task characteristics determine if the same or different GMP is required and are used to determine the specific parameters of the GMP.

In a review of CI literature, Magill and Hall (1990) proposed that the CI effect would be found only when task variations to-be-learned are governed by different GMPs but not for specifying parameters within a GMP. They hypothesized that parameter modifications of the same GMP does not create sufficient interference to require additional processing during acquisition which in turn facilitates retention. A line of CI research targeting GMP and parameter learning examined their hypothesis.

Contextual interference researchers have devoted a great deal of effort to distinguish how movement characteristics correlate with task manipulation. Some research supported the hypothesis that high levels of contextual interference (random and serial) promote GMP learning but not parameter learning (Wulf & Lee, 1993). Other research studies demonstrated that random and serial schedules are more effective in enhancing parameter learning (Sekiya, Magill, Sidaway & Anderson, 1994; Sekiya, Magill & Anderson, 1996; Shea, et al. 2001).

Researchers studied the CI paradigm for GMP and parameter learning by partitioning movement errors into components attributable to the relative (GMP) and absolute dimensions (parameter) of the movement. Accuracy of the relative (GMP learning) and absolute timing (parameter learning) were analyzed. Three measurement times (overall error measure, relative timing performance and absolute timing performance) were typically included. Overall error included both absolute and relative timing. Relative timing measured accuracy of the GMP while absolute timing measured parameter learning.

Wulf and Lee (1993) tested the hypothesis that GMP learning occurs even in a situation that requires the learning of movements with the same relative timing (GMP). The relative timing or proportion of the goal segment times was the same across all versions while the absolute durations were different. There were no significant random/blocked differences during acquisition, yet relative timing was enhanced in the random group during delayed retention and transfer. Results of absolute timing for the random group, on the other hand, were degraded relatively to blocked practice. These results provided evidence for Magill and Hall's (1990) hypothesis that typical CI effects are evident in GMP but not parameter learning. However, more recent studies (Sekiya et al., 1994, 1996; Shea et al., 2001) contradicted these results.

Sekiya et al. (1994) tested a modification of the hypothesis of GMP and parameter learning proposed by Magill and Hall. Their findings contradicted those reported by previous research. Two predictions were studied. First, when task variations are governed by different GMPs, the contextual interference effects should be found in both GMP learning and parameter learning. Second, when task variations are governed by the same GMP but different parameters, the contextual interference effects should not occur in either GMP or parameter learning. The rationale explaining these hypotheses is that when GMPs are reconstructed, parameters added to them also need to be modified. Thus, the CI effect in GMP construction leads to the CI effect in parameter modifications.

When variation of practice was controlled by different GMPs, the CI effect was found for parameter learning but not for GMP learning. The difference between this study and Wulf and Lee (1993) was that each variation had a different relative timing (GMP) and a different overall duration (parameter). Relative timing which predicts GMP learning did not show a statistically significant difference between serial and blocked groups during retention. Overall duration, conversely, demonstrated marked CI effects.

In experiment two the CI effect was not found for GMP learning, but it was found for parameter learning. The task apparatus, procedures and dependent measures were the same as experiment one. The three movements learned had the same relative time of the goal movement times but different absolute goals movement times. They were described as fast, medium and slow speed. The expected findings according to the Magill and Hall’s (1990) prediction were that no significance would be found for either relative timing or overall duration. While the relative timing results were in agreement with the prediction, overall duration opposed it by demonstrating CI effects favoring the serial group over the blocked group on retention. Thus, parameter learning was enhanced for task variations that were governed by the same GMP but different parameters.

Overall, it was found that CI effects were enhanced for parameter learning, but not GMP learning, regardless of whether skill variations were controlled by the same or different GMPs. By studying the dissociated aspects of GMP and parameter learning, Sekiya and colleagues (1994) concluded parameter modifications alone produce enough interference to create the CI effect. This finding was replicated by Sekiya, Magill and Anderson (1996).

Sekiya et al. (1996) investigated whether practicing variations of the overall force parameter would enhance the CI effect. The task was to produce spatial-temporal movement patterns on a computer screen by moving a computer mouse with the preferred hand. The three variations of the goal pattern represented small, medium and large amplitudes. The three goal pattern shared the same relative amplitude patterns (GMP) but had different absolute amplitudes (parameter).

The general performance replicated typical CI findings by showing that better performance during retention was enhanced by high levels of contextual interference during acquisition. Further examination demonstrated that the locus of CI effect was on parameter learning rather than GMP learning. The accuracy of the overall force parameter created sufficient interference to facilitate retention performance. Thus, concerning force characteristics, the results showed that parameter learning enhanced the CI paradigm.

Lai and Shea (1998) also demonstrated the effects in relative and absolute timing learning created by constant and serial practice schedules. The proposed constant condition of practice rather than a blocked condition raised some methodological issues. The constant condition group practiced just one task during acquisition, thus, there are no contextual interference. Constant practice was significantly better than serial practice in GMP learning since it presented less relative timing errors for acquisition, retention and transfer. Serial practice, on the other hand, was advantageous for parameter learning for retention and transfer results.

Shea et al. (2001) extended previous findings by implementing four variable practice conditions to investigate the effect of relative and absolute timing in the CI paradigm. According to Shea and colleagues, the differences in previous research could be attributed to the schedules of practice utilized in the experiments. Wulf and Lee (1993) contrasted blocked and random practice schedules whereas Sekiya and colleagues (Sekiya et al. 1994, Sekiya et al. 1996) contrasted blocked and serial practice conditions and Lai and Shea (1998) contrasted constant and serial practice conditions. Thus, Shea's experiment included the following practice conditions: constant, blocked, serial and random. The constant practice group, which experienced only one task during acquisition, was added to the experiment to increase the range of practice conditions and contextual interference. Thus, it investigated GMP and parameter learning from the most constant practice condition to the most variable practice condition.

This study used a key press task on a computer keyboard. The task manipulated absolute timing while relative timing was held constant. The relative goal segments for all the tasks were the same (22.2%, 44.4% and 33.3%) while the goal movement times were 700ms, 900 ms and 1100ms. Dependent variables of interest were relative, variable and absolute timing errors.

It was hypothesized that increased movement consistency leads to enhanced relative timing learning and degraded absolute timing learning. In other words, Shea and colleagues proposed increased movement variability would degrade relative timing learning and enhance absolute timing learning. Generally, the results were in agreement with the hypotheses. Relative timing errors for constant and blocked groups were significantly smaller than relative timing errors for random group on retention and transfer. The serial group was not significantly different from the blocked and random groups but was higher than the constant group. Therefore, high variability of practice decreased GMP learning.

Parameter learning was demonstrated in the acquisition and transfer results. Absolute timing error was smaller for constant and blocked groups than for serial and random groups during acquisition. Although there were no differences in retention performance, transfer results yielded superior parameter learning. Absolute timing errors for serial and random groups were significantly smaller than absolute timing errors for blocked and constant groups.

Overall, results of Shea et al. (2001) contradicted those of Wulf and Lee (1993) but were consistent with Lai and Shea (1998), Sekiya et al. (1994) and Sekiya et al. (1996). Shea et al. (2001) demonstrated that random practice groups had greater relative timing errors than blocked practice groups in retention and transfer. Thus, GMP learning was not replicated. Results were consistent with Lai and Shea's (1998) results. Constant practice enhanced GMP learning when compared to serial practice. Finally, there were no significant differences between blocked and serial practice in relative timing errors during retention likewise Sekiya et al. (1994) and Sekiya et al. (1996).

In general, results in GMP and parameter learning follow a certain pattern. Opposing what was first proposed by Magill and Hall (1990), GMP learning seems to be enhanced by low contextual interference schedules of practice whereas parameter learning appears to be enhanced by high contextual interference schedules of practice. This statement appears to be true for task variations that require GMP variation and for task variations that require parameter variation of the same GMP.

Table 1 includes GMP and Parameter learning results

TASK VARIATION	**VARIATION IN GMP**		**VARIATION IN PARAMETER**	
Support of High CI	GMP learning	Parameter learning	GMP learning	Parameter learning
Lee and Magill hypothesis	yes	no	no	no
Wulf and Lee (1993)	--	--	yes	no
Sekiya et al. (1994) – experiments 1	no	yes	--	--
Sekiya et al. (1994) – experiment 2	--	--	no	yes
Sekiya et al. (1996)	--	--	no	yes
* Lai and Shea (1998)	--	--	no	yes
** Shea et al. (2001)	--	--	no	yes

* Only serial and constant conditions were present in the experiment
** Learning was demonstrated on transfer but not on retention results

There are possibly some factors that could have influenced these findings. These factors are feedback and amount of practice trials during acquisition. Both of these factors are included in most of the CI research studies, although their influence is under stressed by researchers. Next section presents a discussion in the knowledge of results.

Knowledge of Results

Knowledge of results (KR) may vary quantitatively or qualitatively in the way it is presented to the learner. KR may be presented after each trial (frequent), after a set trial (summary) or not presented at all. Another important component is the variation of information given by the feedback. These different features on feedback schedules are factors that determine results in CI studies. Frequency of KR was studied in the CI literature by Del Rey and Shewokis

(1993), Wulf, Schmidt and Deubel (1993), and Wulf and Lee (1993). The main question was whether the KR schedule would affect contextual interference outcome. The effect of reduced feedback on GMP and parameter learning is also of interest.

Del Rey and Shewokis (1993) demonstrated that summary KR rather than frequent KR is beneficial for random groups during transfer. Conversely, blocked groups benefited more from frequent than summary KR. The frequency of feedback was presented in three different conditions, 100 % KR (after each trial), KR5 (after 5 trials) and KR10 (after 10 trials). Even though there no significant differences in retention, transfer results demonstrated that the random KR10 group outperformed all other groups but did not differ significantly from the blocked KR10 group. Comparing the random groups, receiving KR after 10 trials was significantly better than receiving KR after each trial. In short, the blocked group benefited from high frequency KR while random group benefited from low frequency KR.

Wulf, Schmidt and Deubel (1993) determine that reduced KR group enhanced learning at GMP levels but not at parameter levels. This result was consistent in two experiments in which subjects were given either 100 % or 63 % KR frequencies. Reduced KR frequency degraded parameter learning but enhanced GMP learning during retention and transfer. These findings provided further evidence for the benefit of supplementing the schedules of practice with summary KR rather than frequent KR.

Not all studies testing summary KR, however, demonstrated the same effects on the schedules of practice. Del Rey & Shewokis, 1993 failed in demonstrating correlation between reduced KR5 group and the schedules of practice. Similarly, no interaction was found for KR and the order of practice trials in Wulf and Lee's (1993) study. Summary KR in this case was provided after three trials. In both studies, the reduced KR used may have been insufficient to produce the expected effects of reduced feedback. It might also be true that KR influences CI effect by other component than the frequency, such as the nature of the feedback.

Wulf and Lee (1993) found that random practice exerts beneficial effects at the level of GMP learning. In contrast, Shea et al. (2001) and Lai and Shea (1998) argued that high contextual interference is more beneficial at the level of parameter learning. Researchers have asked what factors may account for these discrepant findings. One important difference between those experiments is the type of information presented to the learner during acquisition by the feedback.

The nature of the feedback as the relative-timing dimension of the movement was demonstrated to be an important factor in mediating feedback and CI interaction (Shea et al. 2001). The nature of the feedback refers to whether it was expressed as a ratio of the total time such as in Lai and Shea (1998) or in absolute segment times such as in Wulf and Lee (1993). Ratio of the total time would be presented in percentages (22%, 44% and 33%) while absolute segment times would be presented in ms (200ms, 400ms and 300ms). Even though the numbers represent the same ratio, the way it is presented may affect the degree to which the learner's attention is drawn to the relative or absolute characteristics of the task.

Shea et al. (2001) contrasted ratio and segment time goals feedback in blocked and random practice schedules. As expected, dissimilar results were found for the two different conditions. The group that received segment ratio goal and segment ratio feedback performed similarly to the groups in Lai and Shea (1998). Blocked practice groups outperformed random practice groups during retention and transfer when contrasting relative timing errors. However, the groups that received segment time goals and segment time feedback produced different relative timing error results. As in Wulf and Lee (1993), random practice resulted in smaller relative timing error than blocked practice in retention and transfer. Therefore, just by switching the goal and the type of feedback the results in relative timing (GMP) learning were reversed.

The explanation for these findings is that ratio segment goal and feedback conditions can be disruptive for random practice. The presentation of ratio segment goals and feedback in a random practice schedule creates additional processing of information. The additional processing is added to the already high cognitive load presented by the random condition. Consequently, this added load may disrupt reconstruction of the action plan or interfere with the inter-item processing that has been proposed to enhance random practice.

As a summary, KR definitely influences the interaction with variation of practice schedules. Most interesting, then, is that both the frequency and the nature of KR may establish the direction of the correlation.

Summary KR benefits random practice conditions. However, the ideal frequency of presentation is not well defined and may vary with the task. Random groups demonstrated significantly greater results in GMP learning than blocked groups with summary KR after 10 trials but not with summary KR after 3 and 5 trials.

The nature of the presented goal movement and feedback determine the results on relative timing learning. The presentation of segment movement ratio benefits blocked practice schedule over random practice schedule during retention and transfer. The presentation of segment movement time benefits random practice schedules over blocked practice schedules.

Amount of Practice

Generally, it is accepted that the more an individual practices a motor skill, the higher the learning results. Within this set, CI researchers expected the benefits from contextual interference would increase as a function of the number of acquisition trials. Not all findings, though, demonstrate consistently increase in learning with increase in practice trials. Shea, Kohl and Indermill (1990) and Proteau, Blandin, Alain and Dorion (1994) revealled that the amount of practice influences the immediate acquisition performance and learning as measured in retention.

Shea et al. (1990) investigated the impact of increasing the number of acquisition trials on retention. Subjects performed 50, 200 or 400 practice trials during acquisition under blocked or random practice schedules. The subjects were then tested on retention in both blocked and random conditions. Acquisition performance under a random schedule was less accurate early in practice than performance under blocked conditions. As the amount of practice increased the difference decreased.

Positive effects of increasing the amount of practice were demonstrated in the retention phase by the random groups. When retention was measured under a random context, the random acquisition group performance was inferior to the blocked group early in 50 practice trials. As the number of practice trials increased the performance of the random group improved. With 400 practice trials the random group was significantly better than their blocked counterparts. Thus, increasing the amount of practice during acquisition has a positive effect in learning for random groups. Alternatively, increasing the amount of practice for the blocked groups during acquisition demonstrated no learning benefits. Blocked group participants performed poorer when given 400 trials versus fewer practice trials when retention was measured in random order.

Somewhat similar results were found in another study based on the amount of practice (Proteau et al., 1994). The study tested a hypothesis that contextual interference effects would increase as a function of the number of acquisition trials on GMP learning. There were three conditions of practice: random, blocked-repeated and blocked. Blocked-repeated consisted of two blocked conditions consecutively presented. Each group had three levels of practice trials during acquisition, 54, 108 or 216 trials. The detrimental effects of random practice were overcome when enough practice was available. Acquisition performance was superior for the blocked compared to the random group up to 54 trials but it was similar at the end of acquisition for the extended trial groups.

The results also indicated that increasing the number of acquisition trials performed under the random schedule favored learning as measured in a retention test. Even though the random group outperformed the blocked groups during retention, the blocked groups presented unexpected improvement. Both groups, the blocked and blocked repeated demonstrated significant improvement on retention whether they practiced 54 or 216 trials during acquisition.

Contradicting results in earlier CI studies, Sekiya et al. (1996) demonstrated no advantage for learning comparing two groups with different amount of practice. The absence of superior retention for the group with more practice could be due to methodological error in designing the study. The explanation is that Sekiya and colleagues compared two conditions with relatively large numbers of acquisition trials (270 and 540). Perhaps it may be necessary to involve groups with smaller amounts of practice to examine the correlation between amount of practice and CI effects.

In summary, the results in the amount of practice and the CI paradigm require further investigation. There seems to be a tendency in which the amount of practice positively correlates with random schedule, yet there is also evidence suggesting no benefits for extended practice trials. Moreover, extended practice trials during acquisition for blocked groups appear to diminish retention performance.

Overall Summary

Two theoretical explanations based on cognitive processing models have been proposed to explain the contextual interference effect. The elaboration distinctiveness hypothesis and the reconstruction hypothesis account for the comparisons between tasks in working memory and for construction of action plans representing the movements.

Variables that moderate the CI outcome are related to the environment, the learner and the task. Contextual interference is more often supported in laboratory than in real world experiments due to the combination of a controllable environment for the task and a combination of the type of skill and schedule of practice. Experience level and gender are also determining factors in CI outcome, but the extent of the benefits of CI for children at different stages of developmental are not well defined. Conflicting results in research about task characteristics point out that GMP and parameter learning are enhanced by different schedules of practice. These results are not conclusive and might be affected by feedback during acquisition and the amount of practice.

Research Questions

In light of the discrepant results among the studies that have reported contextual interference effects, it is important to investigate the variables that moderate this relationship. Thus, the research questions this meta-analysis is proposed to answer are:

Theoretical Explanation. In which of the two explanations is the majority of research based? Which theoretical explanation is most strongly supported?

Ecological Validity and Type of Skill. Is the contextual interference effect more strongly supported for ecologically valid settings? Is the contextual interference effect supported differently dependent upon type of skill? And is there an interaction between ecological validity and type of skill?

Individual Differences. Does the contextual interference effect differ in strength dependent upon the following factors: experience, gender and age?

Task Characteristics, Knowledge of Results and Amount of Practice. Does the contextual interference effect differ in strength for parameter learning and generalized motor program learning? Does the feedback schedule or the amount of practice influence the strength of contextual interference?

Internal Validity. Does the internal validity of the study influence the strength of the contextual interference effect?

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