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REVIEW ARTICLE

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Challenge Accepted: A Systematic Scoping Review of the Applications of the Challenge Point Framework

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ABSTRACT. The Challenge Point Framework (CPF) guides practice design for optimal motor skill learning. The CPF's use and prevalence has not been reported. This review's aims are to – (i) identify research areas that use the CPF, (ii) determine the CPF's prevalence across research areas and (iii) summarise applications of the CPF across research areas. A systematic scoping review, following modified PRISMA-ScR guidelines, was conducted. Papers referencing Guadagnoli and Lee's (2004) "Challenge Point Framework" paper were reviewed against inclusion/exclusion criteria. Data from 100 included papers were analysed for (1) numerical; (2) thematic; and (3) descriptive summaries. Four themes were identified and common CPF applications were identified within each theme. CPF use has been viewed favourably whilst its limitations have been acknowledged (e.g., lack of practical application research).

Keywords: training, skills, challenge point framework, learning

Introduction

Skill can be defined as the ability to achieve a well-defined goal with maximum certainty of success, while using the minimum amount of time, and physical- and mental-energy (Schmidt and Lee, 2019; Guthrie, 1960). The process of acquiring skills can be referred to as motor learning, which occurs as a direct result of practice (Krakauer, 2006). Practice is defined as a learning environment designed to develop skill proficiencies and capacities for the performance context (Haibach-Beach et al., 2018; Krakauer, 2006). Quality and quantity of practice are the main conditions for learning to acquire new skills. Quality of practice refers to various factors such as the practice design, equipment used, the task and its constraints, and the type and frequency of instruction and feedback (Wulf et al., 2016). Quantity of practice refers to time spent in practice i.e., length of practice session, number of skill task repetitions, and the frequency of practice (Haith & Krakauer, 2018). Optimizing the quantity and quality of practice has been suggested to make skill learning more efficient (Hodges & Lohse, 2022).

Purposefully and deliberately engaging in the optimal quantity and quality of practice will be associated with positive performance outcomes (Baker & Young, 2014, Ericsson, 2004; Ericsson & Harwell, 2019). However, finding the optimal quantity and quality of practice to maximize learning for an individual or group can be difficult (Hodges & Lohse, 2022). Furthermore, practicing skills is typically done under time constraints (Brydges et al., 2007; Gofton & Regehr, 2006). In view of these considerations, Guadagnoli and Lee (2004) proposed a conceptual framework known as the Challenge Point Framework (CPF) to help design practice for optimal motor skill learning and performance.

The CPF describes how the task difficulty (dependent on the skill level of the learner) and the potential available information to the learner (i.e., too much or too little information) interacts to represent the "challenge" of the practice environment. The interaction between task difficulty and potential available information can be used to set the "optimal challenge point" (OCP) for the learner (Guadagnoli & Lee, 2004). Optimally challenging practice may enhance skill learning and transfer (from practice to the performance environment) (Guadagnoli & Lee, 2004). The CPF outlines three main principles in understanding the learning of motor skills (Hodges & Lohse, 2022). The first principle is that practising a skill does not necessarily guarantee skill learning (Guadagnoli & Lee, 2004; Hodges & Lohse, 2022). In line with this first principle, increasing the challenge of the practice environment can temporarily reduce performance in practice, however, this decrease in performance may benefit skill learning in the long-term (Guadagnoli & Lee, 2004).

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The second principle discusses that each individual learner has an "optimal challenge point" (OCP) where practice performance and skill learning are equally optimized. Optimally challenging practice allows learners to develop skills that can withstand the stresses and variations of performance contexts (Guadagnoli & Aylsworth, 2013; Guadagnoli & Bertram, 2014; Wadden et al., 2019). The OCP is dependent on the skill level of the learner and the task difficulty relative to the skill level of the learner (i.e., functional task difficulty) (Guadagnoli & Aylsworth, 2013). Therefore, as the learner gains expertise and improves their skill level, the functional task difficulty needs to increase to maintain the optimal challenge point for the learner (Guadagnoli & Lee, 2004). This is linked to the third principle, which recommends the challenge of the practice environment be continually monitored and appropriately adapted as the learner increases their skill level or expertise to optimize training and increase learning opportunities (Hodges & Lohse, 2020).

Guadagnoli and Lee (2004) proposed the CPF as a theoretical framework to describe the effects of practice variables on motor learning. A theoretical framework is a structure that relies on a formal theory to guide research; that is, the framework is built by using an established, coherent theory (explanation) of certain relationships and phenomena (Kalkhoven, 2024). Researchers in various fields have applied the CPF in practical settings to better understand the effect of practice conditions on motor skill learning and retention, and how to optimize practice e.g., Hodges and Lohse (2022), Lotay et al. (2019), Guadagnoli et al. (2012), and Onla-Or and Winstein (2008). The CPF has further been used in sport to mimic high pressure competition situations, which has shown to translate to improved performances in competition e.g., Bertram et al. (2018). In medical education, the learning of surgical skills during medical students' training was optimized by applying the CPF e.g., Christancho et al. (2011b), Mema and Harris (2016), Sanli and Carnahan (2018). The CPF has also been particularly helpful in medical education research aimed at maximizing learning that takes place in medical students' limited training time e.g., Gofton and Regehr (2006).

In addition to maximizing training time, the CPF has been applied in clinical rehabilitation to help manage patients' feelings of frustration and motivation when (re)learning motor functions and skills e.g., Lotay et al., 2019. The CPF has also been applied and integrated in other theories, frameworks, and teaching tools in fields such as sport, with the goal of optimizing skill learning and training e.g., Andriella et al. (2023), Chow et al. (2016), Christancho et al. (2011), Farrow and Robertson (2017), Fitton Davies et al. (2023), Hendricks et al. (2019), Hodges and Lohse (2022); Maier et al. (2019); McIsaac et al. (2015). For example, Hodges and Lohse (2022) proposed the extended challenge-based framework for practice design in sports coaching.

The CPF was motivated by motor learning research and the distinction between short-term performance and long-term learning (Guadagnoli et al., 2012). Since its publication in 2004 (Guadagnoli & Lee, 2004), researchers in various fields beyond motor learning have applied the CPF. Identifying these research areas and assessing the prevalence of the CPF since its publication will establish the framework's breadth, adoption, and overall impact, thereby validating its value and versatility. Moreover, examining how the CPF has been tested and utilized across these domains, and in which populations, will demonstrate how researchers have innovated with the framework and adapted it to their specific contexts. Understanding how the framework has been applied across different domains and populations will not only highlight potential research gaps but also encourage cross-disciplinary approaches and underscore its practical implications. Considering this rationale, the aims of this review are threefold: (i) identify the specific areas of research that have used the CPF, (ii) assess the prevalence of CPF use across these areas, and (iii) summarize how the CPF has been tested and applied across the different research domains.

Materials and Methods

Study Design

A systematic scoping review was considered the best methodological approach to achieve this study's aims. Scoping reviews aim to draw conclusions about the overall state of research activity in a particular area and to address exploratory research questions by synthesizing, summarizing, and disseminating research on a topic (Arksey & O'Malley, 2005; Peterson et al., 2017). For scoping reviews, research is described, synthesized, and clarified by mapping key concepts, types of evidence, and gaps in literature (Aloraini et al., 2019; Griffin et al., 2021). Moreover, scoping reviews use a broader and less rigorous approach than traditional systematic reviews, allowing for a descriptive overview of a range of study designs and methodologies (Pham et al., 2014). This scoping review followed an adapted version of the PRISMA scoping review guidelines (see Appendix 1). To achieve the aims of this review, instead of creating search terms to identify relevant literature, all articles citing the Guadagnoli and Lee (2004) 'Challenge Point Framework' paper were identified (described below). Furthermore, Arksey and O'Malley's (2005) six-stage scoping review process, Levac et al. (2010) scoping review framework, and Peterson et al. (2017) updated methodological guidance for conducting scoping reviews were used to guide the review process and ensure methodological rigor. Each stage is outlined below, from identifying the research question (stage 1), to identifying relevant studies (stage 2), study selection (stage 3), charting data (stage 4), and collating, summarizing, and reporting (stage 5).

Stage 1: Identifying the Research Questions

According to Arksey and O'Malley (2005), one of the main purposes for conducting a scoping review is 'to examine the extent, range and nature of research activity'. In line with this purpose, the following research questions were identified for this review:

- What are the specific areas of research that have used the CPF (range)?
- What is the prevalence of CPF use across these different areas (extent)?
- How was the CPF tested and applied across these areas of research (nature of research activity)?

Stage 2: Identifying Relevant Studies

Search Strategy. All papers citing the Guadagnoli and Lee (2004) paper were identified using four online databases - Scopus, Google Scholar, Web of Science Core Collection, and PubMed. This search strategy ensured that all research using and correctly acknowledging the CPF was captured. All papers published up to February 2024 were included in the search results. Results from all four databases were combined to provide the initial total ($n = 3635$).

Stage 3: Study Selection

Study selection consisted of two stages: Stage 1 involved full text eligibility screening of all papers that cited the Guadagnoli and Lee (2004) CPF paper (including book chapters) for reference to one or more of the terms "Challenge Point", "Challenge Point Framework", "Guadagnoli", "Guadagnoll", "CPF" or "optimal challenge point" or for citations of the Guadagnoli and Lee (2004) paper in the text. If the paper cited the Guadagnoli and Lee (2004) paper or one of the above search terms were in the text, then the paper was eligible and was included. If the CPF theory was not at all mentioned, used, applied, or discussed, then the paper was excluded. Foreign language papers were translated *via* Google Translate; book chapters were screened in a Google drive folder. Eligible papers were then reviewed in stage 2 first based on the exclusion and then based on the inclusion criteria (see Table 1). To be excluded, the paper had to meet one or more of the exclusion criteria. Papers had to meet one or more of the inclusion criteria to be included. Also, in stage 2 of the screening process, a second reviewer reviewed a random sample of 36 (4%) of the 1006 papers being reviewed against the inclusion/exclusion criteria. The second reviewer further determined the theme that the included papers should be placed in, and this was compared to the first author's thematic categorization of these papers. Both reviewers agreed on the inclusion/exclusion of 29 papers, while 7 required further discussion to reach consensus.

Stage 4: Charting the Data

For each paper, the following data were extracted: - (a) author(s) name(s), year published and title of study, (b) type of study, study purpose, (c) how the CPF was used in the study, (d) main findings of the study, (e) study sample, and (f) study design. Data were recorded in Microsoft Excel (2024) using a data extraction table based on discussions between authors (Supplementary 1). Furthermore, quality assessments were conducted on all experimental studies based on the applicable Joanna Briggs Institute (JBI) critical appraisal checklists (Supplementary 2).

Stage 5: Collating, Summarizing, and Reporting the Results

Data are reported in two-ways - numerically and thematically. Numerically, data are reported as totals with percentage frequencies (%) where appropriate. Numerical analyses were reported for the study selection process (see Figure 1) and for the following variables: by year of publication and by theme (Figure 2).

Data were thematically summarized in tables (Supplementary 1 and 2) and by mapping out key concepts and CPF applications within each theme. The inductive thematic analysis was based on Braun and Clarke (2006) framework which provides a step-by-step guide for conducting thematic analyses. In line with this framework, the author familiarized herself with the data by manually reading and extracting data from each paper to form codes. These codes were organized and reviewed to develop themes and subthemes. The themes were based on the primary context in which the CPF was applied, therefore no paper was included in more than one theme. For example, if the CPF was applied or used for research in a rehabilitation setting or context, then the paper was coded as "Rehabilitation". Synthesizing the data into themes helped identify the research areas and explore the nature of the research activity within the area.

Quality Assessment

The applicable Johanna Briggs Institute (JBI) critical appraisal checklists were used to assess the overall quality of the identified included original studies.

TABLE 1. Inclusion and Exclusion criteria for study selection.

Inclusion criteria	Exclusion criteria
Title of the paper (original study, review, textbook chapter, conference paper, pilot study, case-series) contains the term "challenge point" or "challenge point framework"	Paper is a thesis, study proposal, conference abstract or case study/report.
The CPF was used to guide the development of the study hypothesis.	Paper uses CPF only in discussion as an explanation of motor learning or to explain findings of the study (i.e., "this study found x, and this is in line with the CPF").
The CPF concept was reported to guide the design and methods of the study.	Paper only explains CPF theory in introduction/discussion but does not apply to study hypotheses, design or methods, or development of theory/framework.
CPF was used in the development of a theory or framework.	CPF was mentioned but not discussed or applied.
CPF concept was empirically tested.	
CPF was a central theme in a review paper.	
CPF was a central theme of the paper.	
Study applying or using the CPF had human participants.	

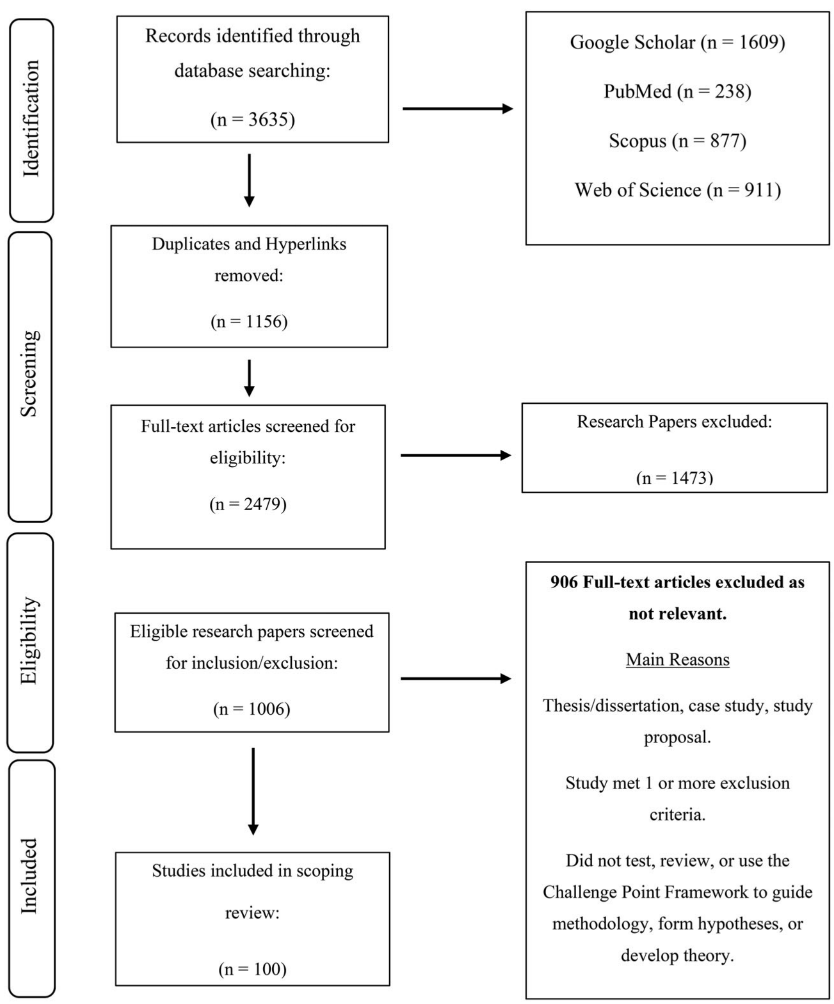

FIGURE 1. Literature selection process for the scoping review.

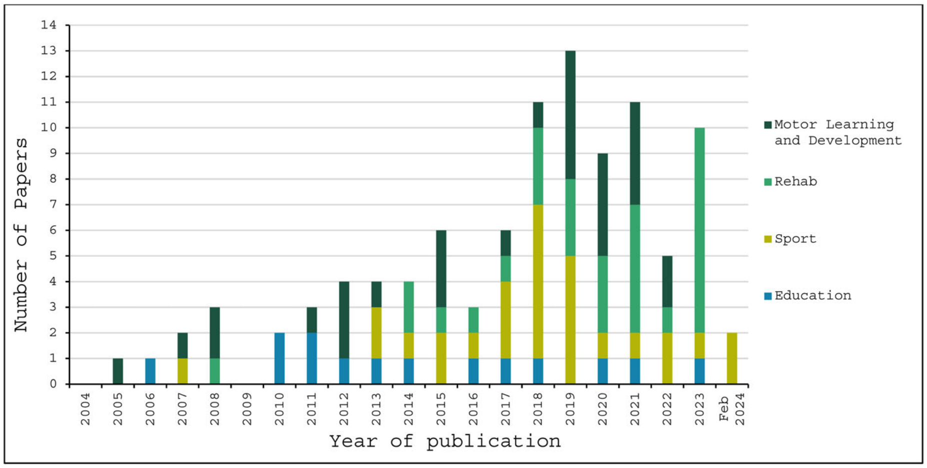

FIGURE 2. The number of papers within each theme by year.

Results

Numerical Analysis

The initial database search found 3635 research papers that cited the Guadagnoli and Lee (2004) paper. Following the removal of 1156 duplicates, 2479 papers remained for full-text eligibility screening. Following full-text eligibility screening, 1473 papers were removed because the paper only cited the 2004 "Challenge Point" paper and did not mention, discuss, use, or apply the CPF, and 1006 papers remained to be reviewed against the Inclusion/Exclusion criteria. Of the 1006 papers, 906 papers were excluded because they met one or more of the exclusion criteria, and 100 papers met one or more inclusion criteria and were therefore included in this review. The scoping review flowchart (Figure 1) details the search and study selection process. Supplementary 1 provides a summary table of the included papers in each theme. Forty-six percent of the included papers were reviews, book chapters, or conceptual studies which were theoretical in nature. The remaining 54% were original studies. Supplementary 2 provides a quality assessment of all experimental studies included in this review.

In education, the population samples across the 4 studies included online participants (Martin et al., 2018), first year trainees and faculty staff (Mema & Harris, 2016), medical students (Reinstein et al., 2021), and undergraduate medical students (mean age = 19,94 years old) (Yan et al., 2020). In motor learning and development, studies had sample populations of older adults, age range of 40 - 80 years old (Beik et al., 2020, 2021, 2022; Kaipa et al., 2017), of children, age range of 3 - 10 years old (Aadland et al., 2020; Balali et al., 2019; Hosseinirokh et al., 2018; Pesce et al., 2013; Saemi et al., 2012; Sidaway et al., 2012), and of young adults with an age range of 18 - 25 years old (Akizuki & Ohashi, 2015; Andrieux et al., 2016; Bootsma et al., 2018; Fitton Davies et al. 2023; Hodges & Lohse, 2020; Kaipa et al., 2023; Keetch & Lee, 2007; Marchal Crespo & Reinkensmeyer, 2008; Ollis et al., 2005; Ramezanzade et al., 2022; Sanli & Lee, 2015; Sullivan et al., 2008; Wadden et al., 2019). Furthermore, three studies made learning comparisons between groups of different skill levels (e.g., novice and experienced) (Kaipa et al., 2017; Ollis et al., 2005; Sullivan et al., 2008). In the rehabilitation field, a range of populations with different chronic conditions were studied. The chronic conditions studied included dementia/cognitive impairment (Andriella et al., 2023), Parkinson's Disease (Lau et al., 2022; Onla-Or & Winstein, 2008), Autism Spectrum Disorder (Clabaugh et al., 2019; Scassellati et al., 2018), lumbar spinal stenosis (Passmore et al., 2015), chronic stroke/post-stroke (Kraeutner et al., 2021; Lotay et al., 2019; Peters et al., 2020; Pollock et al., 2014), speech disorders (Matthews et al., 2021; Preston et al., 2014, 2018, 2020), and multiple sclerosis (Zahiri et al., 2020). Finally, study samples in sport included healthy participants aged 19–38 years old, with some being at university level (Gerig et al., 2017; Gutiérrez-Capote et al., 2024; Hendry et al., 2019; Jalalvand et al., 2019; Turakhia et al., 2021), and others being at either high school or post-university (Basalp et al., 2019; Gray, 2017; Hendry et al., 2019; Sheerin et al., 2020).

Chronology and Scope of Included Studies

Figure 2 shows the number of papers published in each theme by year since the CPF paper was first published. Fifty percent of papers were published in the last 5 years (i.e., between 2019 and February 2024).

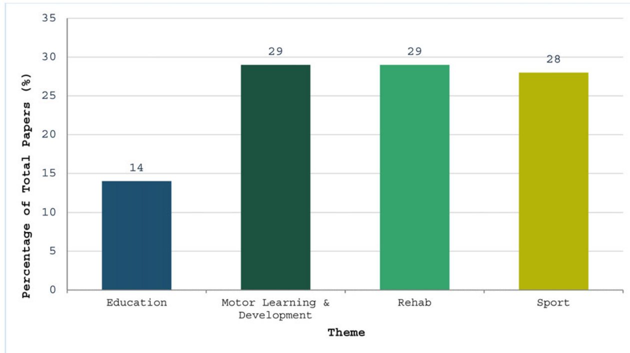

FIGURE 3. Bar graph showing the percentage of research papers included in each theme.

Thematic Analysis

The themes identified were 'Education', 'Motor Learning and Development', 'Rehabilitation', and 'Sport' (Figure 3). The themes were further reviewed and refined to determine subthemes where appropriate. The percentage contribution of each theme to the total can be seen in Figure 4. Below we report key findings for each theme and related subtheme, where appropriate.

Education

Within the education field, the CPF was applied to knowledge learning in academic education (Martin et al., 2018; Pesce et al., 2018; Yan et al., 2020) and was applied in two-ways in medical education - optimizing simulation-based training programs (Christancho et al., 2011a; 2011b; Cowan et al., 2010; Mema & Harris, 2016) and optimizing medical skill practice environments (Gofton & Regehr, 2006; Guadagnoli et al., 2012; Nelson & Eliasz, 2023; Reinstein et al., 2021; Roston, 2010; Sanli & Carnahan, 2018).

Academic Education. Martin et al. (2018) used the CPF to develop a framework that guided the design of massive open online courses (MOOCs)—online courses that encourage self-determination in academic learning - to ensure the course had an increased probability of optimally challenging learners. The authors used their framework to design a MOOC which was then tested by offering the course online and evaluating participants' participation in the course (Martin et al., 2018). The authors found that, based on self-reported data collected from a post-course survey, the 200 learners engaging with the MOOC had "strong" and "sustained activity" and "engagement" in the course (Martin et al., 2018). The post-course survey also revealed that learners felt positively toward the CPF-based MOOC and felt that their autonomy and competence needs were supported during the MOOC (Martin et al., 2018). However, because MOOCs by nature of being open and online have various uncontrolled variables, the retention and engagement results from this study cannot necessarily be attributed to the framework (Martin et al., 2018). In a neuroscience book chapter, the optimal challenge point (OCP) was suggested as a method to improve the quality of physical activity games for children to reap the largest cognitive and emotional development benefits (Pesce et al., 2018). Additionally, in an original study, aimed at determining the effects of different practice schedules on learning in university undergraduate students, the CPF-designed practice schedule group recalled significantly more words and were more efficient than uniform practice schedule groups (Yan et al., 2020).

Medical Education: optimizing Simulation-Based Training Programs. Four papers applied the CPF to the development of simulation-based training programs for different medical skills or procedures (Christancho et al., 2011a; 2011b; Cowan et al., 2010; Mema & Harris, 2016). Mema and Harris (2016) used the CPF to design the skill difficulty levels of simulation training for the Ultrasound Guided Central Venous Line (UGCVL) procedure. The skill difficulty levels were altered by varying the amount of guidance and feedback from the educators (Mema & Harris, 2016). Semi-structured interviews with seven novice pediatric intensive care unit fellows and six supervising faculty in a university-affiliated academic center, revealed that all students reported that they "felt the simulation training had been very useful" (Mema & Harris, 2016). Furthermore, the students reported that the "hands-on experience with different models" in the CPF-based simulation program helped them visualize the procedure and "acquire the visual spatial skills needed for effective performance" (Mema & Harris, 2016).

In a conceptual study paper, Christancho et al. (2011b) used the CPF as one of the primary theoretical arguments

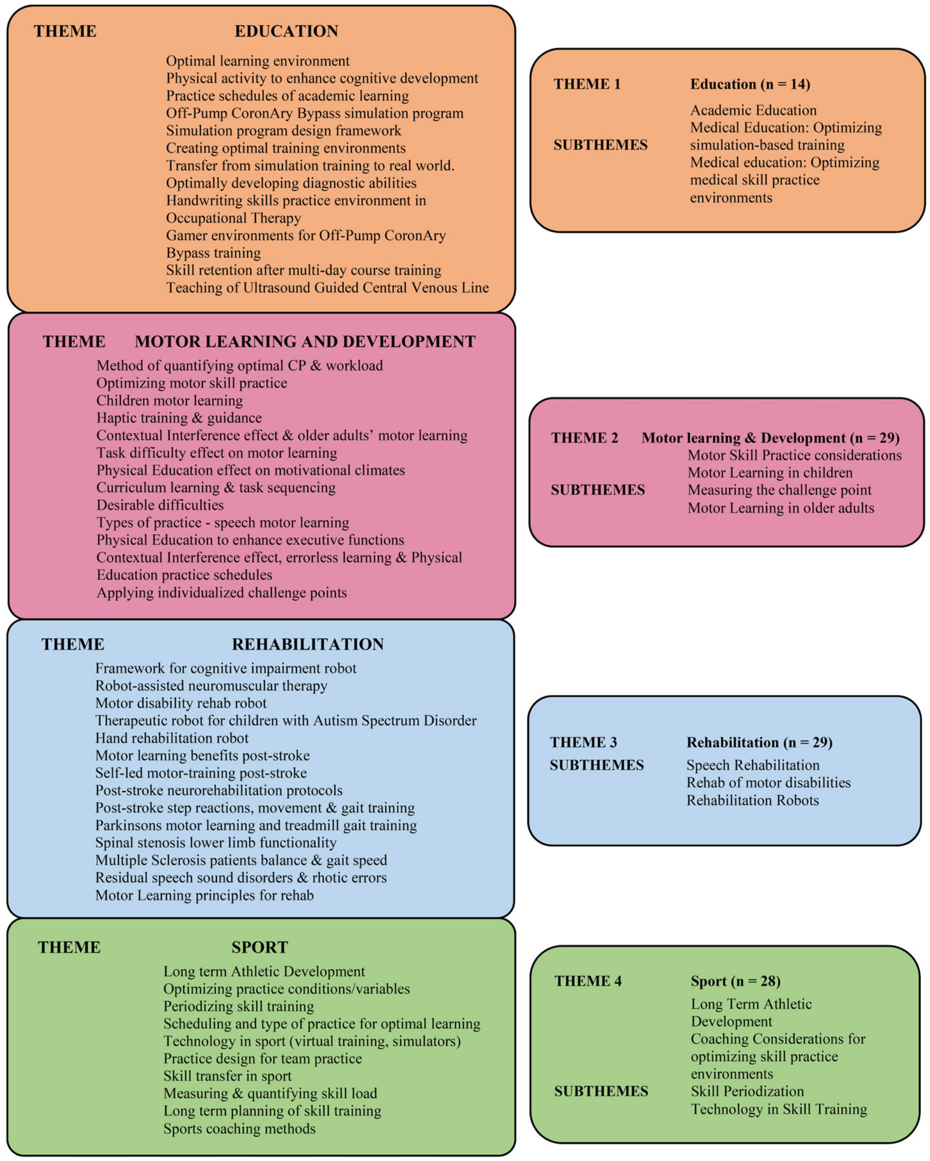

FIGURE 4. Thematic Analysis.

for the development of their surgical simulation design framework - the "Aim-Finetune-Follow through" framework. The "Aim-Finetune-FollowThrough" framework was created to provide simulation program designers with a systematic process for creating surgical simulation programs (Christancho et al., 2011b). The simulation framework consisted of a needs assessment, clearly outlining the type and amount of educator assistance required at each stage of skill learning (Christancho et al., 2011b). Thereafter, the design of learning activities and description of using the CPF to progressively challenge the learners were explained (Christancho et al., 2011b). The authors then further applied the "Aim-Finetune-FollowThrough" framework to develop an expert-guided and progressive simulation training program for the Off-Pump Coronary Artery Bypass (OPCAB) procedure (Christancho et al., 2011a).

Medical Education: optimizing Medical Skill Practice Environments. Five papers used the CPF for the design of medical training environments (Gofton & Regehr, 2006; Guadagnoli et al., 2012; Reinstein et al., 2021; Roston, 2010; Sanli & Carnahan, 2018). A textbook chapter created guidelines specifically for Occupational Therapists, providing them with recommendations of how to manipulate practice and task variables, to create an optimal zone of challenge when teaching handwriting to their rehabilitation patients (Roston, 2010).

Motor Skill Learning and Development

Motor Skill Practice Design. Fifteen papers investigated how practice is designed to enhance motor learning (Andrieux et al., 2016; Bootsma et al., 2018; Ghonasgi et al., 2020; Hodges et al., 2021; Hodges & Lohse, 2020; Kaipa et al., 2017; 2023; Keetch & Lee, 2007; Marchal Crespo & Reinkensmeyer, 2008; McIsaac et al., 2015; Ollis et al., 2005; Ramezanzade et al., 2022; Sanli & Lee, 2015; Wadden et al., 2019). In motor skill practice, the CPF has been used to guide the manipulation of practice variables according to the learner's skill level to maximize the learning potential of the practice. The identified practice variables that could be manipulated were task difficulty (Andrieux et al., 2016; Bootsma et al., 2018; Hodges & Lohse, 2020; Ollis et al., 2005; Ramezanzade et al., 2022), practice type and scheduling (Ghonasgi et al., 2020; Hodges et al., 2021; Kaipa et al., 2017; Keetch & Lee, 2007; McIsaac et al., 2015), and the frequency, amount and type of instruction and feedback provided (Basalp et al., 2021; Marchal Crespo & Reinkensmeyer, 2008). In a within-subjects experimental study, Wadden et al. (2019) investigated individualized-adapted practice schedules in 14 young adult participants and assessed whether a moderate or high degree of task challenge (contextual interference) was most beneficial for motor learning (measured by rate of response time). The authors found that the higher contextual interference practice condition led to faster response times in motor task retention compared to low and moderate levels of contextual interference (Wadden et al., 2019). The authors further concluded that using an individualized 'challenge point', that generates high contextual interference for the learner, optimizes challenge thereby enhancing motor learning (Wadden et al., 2019).

The CPF was also used to form study hypotheses and methodology in motor skill learning and development research e.g. Kaipa et al. (2017, 2023); Marchal Crespo and Reinkensmeyer (2008); Ollis et al. (2005); Ramezanzade et al. (2022). An experimental comparison study by Bootsma et al. (2018) aimed to determine the effects of functional task difficulty on motor skill acquisition, retention, and transfer. The authors measured the error percentage, moving time, and mental workload (using the NASA-TLX) of 36 young adult participants performing a skill task. The authors found that task difficulty did not affect the magnitude of visuomotor skill learning or motor learning and transfer, but it did affect motor performance (i.e., time to complete the task and errors made in performing the task) (Bootsma et al., 2018). For the groups that practiced the task at the medium and hard, but not at the low difficulty level, initial skill level correlated with the magnitude of learning (Bootsma et al., 2018). Other authors also found that partially allowing learners to control their own task difficulty promoted learning (measured by the accuracy of performing the task) (Andrieux et al., 2016). Hodges et al. (2021) in their experimental between-subjects study, investigated whether an uncertainty-based practice schedule was beneficial for learning a cursor-controlled reaching target task. The uncertainty-based practice schedule involved the exclusion of task difficulty levels where learners had consistent low error performances (defined by measuring number of errors in performance) (Hodges et al., 2021). The difficulty of the targets was altered based on the challenge-point framework. The authors found that the participants in the target exclusion group practiced the easy targets the least and the difficult targets the most, and they performed worse than the other groups in the retention test (Hodges et al., 2021). It was found that target exclusion was not an effective method for learning and that there were benefits, such as less errors in retention performances, from keeping easier/low error skills in practice (Hodges et al., 2021). Other studies additionally found that training with the appropriate amount of haptic guidance (touch-based sensations such as force or vibrations) based on the CPF was as effective in supporting learning of motor tasks as training with other feedback modalities (Basalp et al., 2021).

Children's Motor Learning and Skill Development. Nine papers investigated using the CPF to enhance motor learning and skill development in children (Aadland et al., 2020; Balali et al., 2019; Fitton Davies et al., 2023; Hosseinirokh et al., 2018; Pesce et al., 2013; Saemi et al., 2012; Sidaway & Bates, 2012; Sproule et al., 2011; Sullivan et al., 2008). The CPF was applied to the development of optimal practice conditions for physical education (PE) environments in schools (Fitton Davies et al., 2023; Saemi et al., 2012; Sproule et al., 2011). Saemi et al. (2012) found that children practicing a fundamental skill during PE, based on a CPF practice schedule, showed significantly better retention (measured by accuracy of hitting a target) than other practice schedule groups. Research in this area has also used the CPF to set the challenge of physical activity interventions and motor skills tasks, and to develop games to promote play (Aadland et al., 2020; Balali et al., 2019; Hosseinirokh et al., 2018; Pesce et al., 2013; Saemi et al., 2012). Two studies have also shown that the CPF can be used to guide the amount and frequency of feedback, along with the knowledge of the task results (Sidaway et al., 2012; Sullivan et al., 2008).

Older Adults' Motor Learning and Skill Development. Three original studies applied the CPF to determine the best practice conditions for older adults to learn motor skills and to determine the effect of contextual interference on older adults' learning (Beik et al., 2020, 2021, 2022). The CPF was used to develop an algorithm for practice that considered the nominal task difficulty and the learner's practice performance (Beik et al., 2020, 2021, 2022). The CPF-based algorithm was then used to create the optimal challenge point for movement timing tasks. In all three studies, older adults in the CPF-based algorithm group performed better (had fewer errors) than the non-CPF groups and had increased activation of brain areas - measured using an electroencephalogram (EEG) - associated with motor learning compared to other groups (Beik et al., 2020, 2021, 2022).

Measuring the Optimal Challenge Point (OCP) for Motor Skill Learning and Development. Studies further sought to determine how the challenge point can be measured in motor tasks (Akizuki & Ohashi, 2015; Bryant & McLaughlin, 2012; Novak, 2018; Wadden et al., 2019). Wadden et al. (2019) in their quasi-experimental within-subjects design showed that optimal challenge points (OCPs) can be created by using individualized performance curves from the motor skill task practice. These individualized OCPs enhanced motor learning, determined by faster response times in retention tests, in 14 young adult participants. Additionally, two reviews highlighted that measuring a combination of factors (e.g., physical demand, cognitive demand, workload, stress, and performance) was a valid way of quantifying an individual's challenge point (Bryant & McLaughlin, 2012; Novak, 2018). A study by Akizuki and Ohashi (2015) evaluated the relationship between functional task difficulty and the OCP by measuring changes in salivary amylase levels (to measure the physiological response to challenge) and the NASA-TLX (representing perceptual measures of challenge) during a postural stability task. Using a quasi-random experimental design with four groups ranging from least to most stable, the authors found that there were substantial changes in salivary amylase levels in the least stable group compared to the other groups. The changes in salivary amylase levels were highly correlated with the NASA-TLX measures (Akizuki & Ohashi, 2015). Based on these findings, the authors concluded that salivary amylase and NASA-TLX can be used to quantify functional task difficulty.

Rehabilitation

Within rehabilitation settings, CPF was applied to speech rehabilitation (Matthews et al., 2021; Preston et al., 2014, 2018, 2020) and to the design of physical therapy sessions for various motor diseases or disabilities (Shumway-Cook, 2017). The various motor diseases and disabilities included Parkinson's disease (Lau et al., 2022; Onla-Or & Winstein, 2008), post-stroke disability (Aguirre-Ollinger & Yu, 2021; Kraeutner et al., 2021; Lotay et al., 2019; Maier et al., 2019; Peters et al., 2020; Pollock et al., 2014), lumbar spinal stenosis (Passmore et al., 2015), and multiple sclerosis (Zahiri et al., 2020). The CPF was also used to design and program rehabilitation robots (Andriella et al., 2023; Baur et al., 2018; Brown et al., 2016; Clabaugh et al., 2019; Nehrujee et al., 2021; Scassellati et al., 2018).

Speech Rehabilitation and Therapy. Creating speech task difficulty progressions was guided by the CPF to reduce the time spent in therapy (Matthews & Rvachew, 2021; Preston et al., 2014; 2018; 2020). For individuals with speech sound errors, applying the CPF to their speech therapy enhanced speech accuracy and learning (number of correct speech sounds produced) above pretreatment levels compared to other speech therapy treatment groups (Matthews et al., 2021; Preston et al., 2014, 2018, 2020). Moreover, Preston and colleagues (2020) used the CPF to create an open-source computer program called the 'Challenge Point Program' designed for speech rehabilitation. When individuals engaged in the 'Challenge Point Program', they increased their speech accuracy by over 30% above pretreatment levels and continued to improve their speech accuracy 2-months post-treatment (Preston et al., 2020).

Gait Training and Stepping Reactions. For individuals with motor disease and/or disability, such as Multiple Sclerosis, the CPF has been used to achieve the OCP during balance and gait mobility training (Zahiri et al., 2020). After completing four-weeks of balance and mobility training using OCPs, Multiple Sclerosis patients showed improvements in gait speed, balance, mobility, and gait stepping performance compared to the control group (Zahiri et al., 2020). Using the timing of steps, accuracy of step placement, and balance to change task difficulty, three descriptive case-series studies illustrated how using CPF-guided gait retraining improved and maximized patient mobility from baseline levels (Aguirre-Ollinger & Yu, 2021), improved walking balance, stepping length and initial step velocity with the paretic leg compared to baseline levels (Pollock et al., 2014), and reduced motor planning duration compared to baseline measurements (Peters et al., 2020). Aguirre-Ollinger and Yu (2021) further generated a CPF-based algorithm to develop an omnidirectional platform for gait training. In a randomized controlled pilot study by Lau et al. (2022), participants with Parkinson's disease showed improvements in walking gait measures, including increased gait speed during functional tasks, as well as cognitive measures such as the Montreal Cognitive Assessment (MoCA) and the Symbol Digit Modality Test (SDMT), from baseline to post-intervention (Lau et al., 2022).

Improving Motor Performance Outcomes in Neurorehabilitation. A meta-analysis concluded that using the CPF to personalize difficulty levels is a key principle for effective neurorehabilitation protocols post-stroke (Maier et al., 2019). When applying CPF-based adaptations to post-stroke motor skill training within a self-led training schedule, post-stroke participants had an average 22% higher improvement in tracking accuracy compared to healthy participants; however this was not significant when analyzed over all tasks (Lotay et al., 2019). Based on the accuracy and speed at which the goal movement was performed, participants with Parkinson Disease practicing a task at a CPF-based difficulty also demonstrated comparable learning (i.e., number of errors made when doing the motor task) compared to nondisabled participants (Onla-Or & Winstein, 2008). In this study, Parkinson Disease participants showed noticeable learning deficits (i.e., more errors) when nominal task difficulty was high (Onla-Or & Winstein, 2008).

Rehabilitation Robots. The CPF has underpinned the frameworks and design of rehabilitation robots. The spectrum of these applications ranges from designing socially assistive robots for children with Autism Spectrum Disorder (Andriella et al., 2023; Clabaugh et al., 2019; Scassellati et al., 2018), creating hand rehabilitation robots (Nehrujee et al., 2021), and developing frameworks to guide the development of optimal challenge for users of these robots (Baur et al., 2018; Brown et al., 2016). The CPF-guided software for rehabilitation robots has also been developed to set the challenge of the task based on the user's skill level. To improve social skills and provide social assistance to children with Autism Spectrum Disorder, three studies specifically developed frameworks, adaptive robotic designs and learning content that personalized the challenge level and feedback (Andriella et al., 2023; Clabaugh et al., 2019; Scassellati et al., 2018). Using a pre-post study design, children with Autism Spectrum Disorder (aged 3–7 years old) showed an increase in focus and engagement, and a decrease in frustration over the course of a long-term, in-home interaction with a socially assistive robotics system based on the CPF (Clabaugh et al., 2019). Older children with Autism Spectrum Disorder (aged 6–12 years old) also showed improvements from baseline in their social and emotional understanding skills, perspective-taking abilities, and ordering and sequencing skills (Scassellati et al., 2018). In older adults affected by mild dementia and mild cognitive impairment, socially assistive robot therapists, that were developed based on the CPF, showed superiority in keeping participant performance constant compared to a human therapist, indicating that the CPF-based robot offered more appropriate assistance (Andriella et al., 2023).

A review compared 13 studies that used multiplayer games involving patients with cognitive and/or motor impairments to single player games, in the context of the CPF (Baur et al., 2018). The authors additionally used the CPF to develop a framework showing the relationship of game experience, and game performance, with conditional task difficulty (Baur et al., 2018). Based on theoretical evidence, the authors proposed that individualizing the difficulty of a game using to match the learner's skill level (as suggested by the CPF) may enhance the learners' perceived game experience and positively influence their performance compared to single player games (Baur et al., 2018). Furthermore, regarding game experience, modes selected specifically for the learner may result in more robust interventions (Baur et al., 2018). In their pilot questionnaire-based study, Nehrujee et al. (2021) reported high short-term usability and good experience ratings among patients, clinicians, and caregivers who used a hand neurorehabilitation robot (PLUTO) that used a game difficulty adaptation algorithm based on the CPF (Nehrujee et al., 2021). These findings were based on results from the System Usability Scale (SUS) - from which scores within a certain range correspond to the usability e.g., "a score above 70 corresponds to acceptable or good usability" (Nehrujee et al., 2021) - and from the User Experience Questionnaire (UEQ) which provides quantitative data about the participants' experience using the system (i.e., the PLUTO hand rehabilitation robot) (Nehrujee et al., 2021).

In a neurorehabilitation technology book chapter, the CPF was highlighted as an important design consideration when building rehabilitation robotics (Brown et al., 2016). Brown et al. (2016) in their book chapter selected the challenge level when using rehabilitation robots to maximize the degree of engagement so that, when used for neurological rehabilitation, it motivates patients to use their impaired limbs in unsupervised practice.

Sport

The CPF has been used extensively in sport. The CPF has been used to develop studies, theories, and frameworks for long term skill development (Guadagnoli & Bertram, 2014; Hendry et al., 2019; Hendry & Hodges, 2019; Malhotra et al., 2022; Pesce & Ben-Soussan, 2016; Williams, 2013), optimizing skill practice environments (Bertram et al., 2018; Chow et al., 2016; Goldberg et al., 2018; Guadagnoli & Aylsworth, 2013; Hendricks et al., 2019; Hendry et al., 2015; Hodges & Lohse, 2022; Jalalvand et al., 2019; Lindquist & Guadagnoli, 2007; Pill, 2018; Robertson & Farrow, 2018; Sheerin et al., 2020), skill periodization (Farrow & Robertson, 2017; Hendricks et al., 2018; Mujika et al., 2018), and sport technologies (Basalp et al., 2019; Gerig et al., 2017; Gray, 2017; Turakhia et al., 2021).

Long Term Skill Development. Some reviews suggested that, to promote long-term athletic development, athletes in their developmental years should engage in appropriately challenging sport-specific practice and play activities (e.g., small-sided soccer games) based on the CPF (Hendry et al., 2019). Hendry and Hodges (2019) assessed the developmental activities that defined elite players in female soccer by comparing national and varsity players' subjective ratings of challenge for practice, play, and competition across their childhood and adolescence. The authors found that national players participated in more play that they perceived to be more challenging and engaged in more moderate to high challenge practice compared to varsity players (Hendry & Hodges, 2019).

A review paper by Malhotra et al. (2022) developed a framework called "Skill Acquisition Framework for Youth Sport". This framework presents training guidelines for coaches on how to design, evaluate, and adjust task difficulty to achieve the OCP (Malhotra et al., 2022). The third principle of the CPF is that practice should be continually monitored (Guadagnoli & Lee, 2004). Therefore, other research proposed that coaches evaluate the quality of practice by measuring the technical difficulty perceived by the learner, using the "Rating of Perceived Challenge (RPC)" (Hendricks et al., 2019).

Coaching Considerations for Optimizing Skill Practice Environments. In a review on practice design in sport, the CPF was also used to describe the interactions between task difficulty, effort, and the underlying cognitive processes (Hodges & Lohse, 2022). From a theoretical perspective, it has been argued that creating the optimal challenge during skill practice maximizes learning efficiency and fosters stress-resistant skill acquisition - meaning that learned skills remain effective in times of high stress or pressure e.g. during competition (Guadagnoli & Aylsworth, 2013; Guadagnoli & Bertram, 2014). Additionally, the CPF has been used as the basis for theoretical recommendations on how the CPF principles can be applied in putting practice to enhance potential skill transfer from an anchored to a standard putter in a high-pressure performance setting with maximal efficiency (Guadagnoli & Aylsworth, 2013; Guadagnoli & Bertram, 2014). However, these arguments were conceptual in nature, and no empirical testing was provided to support their recommendations (Guadagnoli & Aylsworth, 2013; Guadagnoli & Bertram, 2014). Another study using a pre-post-test study design, showed that a real-time, haptic feedback gait retraining intervention based on the CPF was able to reduce resultant tibial acceleration (a measure of impact loading) in a sample of young adult runners (Sheerin et al., 2020).

In a review on long term athletic development in golf, Guadagnoli and Bertram (2014) argue that the CPF should be applied to athletes' motor skill practice when they are in their developmental years for them to become skilled/elite and to develop their decision-making. In a book chapter on optimizing the golf training environment, coaches were encouraged to understand the interaction between available information and task difficulty to better prescribe an OCP (Robertson & Farrow, 2018). Furthermore, reviews on skill learning and development have recommended using the CPF to structure skill training periodization (Hendricks et al., 2019; Robertson & Farrow, 2018). In line with the goal of skill monitoring, Hendricks et al. (2019) proposed "the rating of perceived challenge (RPC)" - a subjective internal load rating of perceived challenge that is based on the CPF. Hodges and Lohse (2022) recommend that practice specificity (i.e., how closely practice resembles the performance environment) and learner motivation be considered when designing practice sessions. When considering practice specificity and learner motivation, the difference between performance and learning becomes clearer and the motivational cost of increased errors in practice can be balanced (Hodges & Lohse, 2022).

Using Technology to Optimize Sport Skill Training. A rowing simulator was developed to provide automated feedback selection or adaptable task difficulty that matched the individual's skill level (Basalp et al., 2019). Participants that trained on the rowing simulator using CPF-based feedback showed improvement in kinematic performance metrics from baseline and demonstrated less error and variability than participants on a rowing simulator that used a fixed amount of feedback (i.e., did not adapt to participant skill level/performance) (Basalp et al., 2019; Gerig et al., 2017). A similar experiment was conducted in basketball, where an auto-adaptive basketball hoop (using a CPF-based adaptive algorithm) resulted in learners increasing their average performance score by more than 25% compared to performance using static and manually-adaptive basketball hoops (Turakhia et al., 2021). Additionally, in baseball, participants engaging in adaptive CPF-based training in a virtual environment showed improvements in 7 out of 8 batting performance assessments compared to only training in an virtual environment, regular batting practice and no extra batting practice (Gray, 2017). Moreover, participants in the adaptive CPF-based training group also showed superior batting statistics in their league and reached higher levels of baseball competition compared to individuals that did not engage with the CPF-VR training, and retained their batting performance assessment scores 1-year post-intervention compared to the other training groups (Gray, 2017).

Discussion

The purpose of this review was to identify the specific areas of research that have used the CPF, assess the prevalence of CPF use across these areas, and summarize how the CPF has been tested and applied across the different research domains.

Whilst the CPF was published as a broad framework for motor learning and development, other research areas that have used the CPF include 'Education', 'Rehabilitation', and 'Sport'. Fifty percent of the papers included in this review were published in the last 5 years (2019—2024), with 29% of all papers in rehabilitation and 29% in motor learning and development.

Although practice design and progression complement each other, and the ultimate goal of applying the CPF is to enhance learning and transfer to practical settings (e.g., a sports coach making changes to a skill training drill in real-time), the study designs and research approaches across the various research areas emphasized the use of the CPF at different stages of the practice-progress-learn-transfer pathway. For the purpose of this discussion, we will summarize the work along practice-progress-learn-transfer pathway and provide examples where the primary focus was either designing practice variables, task difficulty progression, or skill transfer and retention.

Identifying the Quality Practice Variables to Design Practice

Across all themes, the CPF was used to design optimally challenging practice sessions. Optimally challenging practice sessions were designed by altering different practice variables to set the OCP. Throughout the papers, practice variables were identified that could be altered to set the OCP. These variables included task difficulty (Novak, 2018; Robertson & Farrow, 2018), feedback amount and type (Gerig et al., 2017; Jalalvand et al., 2019; Sullivan et al., 2008), haptic guidance (Basalp et al., 2021), practice types (e.g., retrieval practice) (Nelson & Eliasz, 2023) and practice schedules (Ghonasgi et al., 2020; Keetch & Lee, 2007; Saemi et al., 2012). When altering practice variables, it is recommended that practitioners should account for individual skill level and adjust variables based on the learner's response to the challenge (Aguirre-Ollinger & Yu, 2021; Beik et al., 2021; Ghonasgi et al., 2020; Jalalvand et al., 2019, Nehrujee et al., 2021, Wadden et al., 2019). For instance, when teaching motor skills for children's physical and cognitive development in physical education, it has been suggested that teachers learn to identify the child's OCP to be able to continually alter the activity to be optimally challenging (Cowan et al., 2010; Yan et al., 2020). Furthermore, scheduling of skill tasks in practice should be carefully considered in learning and acquiring motor skills (Hodges et al., 2021; Yan et al., 2020). It was found, in a study by Hodges et al. (2021), that excluding practice with low error (i.e., easier tasks) was detrimental to retention performance 24 h after practice (measured by the number of errors made) in 60 university students aged 18–24 years old. Subsequently, allowing participants to return to relatively easy components of a motor task was beneficial for later skill retention (Hodges et al., 2021).

Approaches to identify the OCP or to set the optimal challenge of practice sessions was investigated in several studies (Andrieux et al., 2016; Bootsma et al., 2016; Hendricks et al., 2019; Wadden et al., 2019). A study by Andrieux et al. (2016) partially allowed learners to control their own task difficulty during sessions and found that self-chosen task difficulty promoted the learning (measured by errors made during performance of a motor task) of complex tasks. Gutiérrez-Capote et al. (2024) further used the National Aeronautics and Space Administration-Task Load Index (NASA-TLX) in their study and found that it may be a feasible tool to use to determine the functional task difficulty in sport. However, in a study by Bootsma et al. (2018) that investigated the effects of functional task difficulty on motor skill acquisition, retention and transfer in twenty-one young adults (randomly assigned to 3 groups of differing task difficulties), the use of the NASA-TLX to identify the perceived mental workload revealed that the perceived mental workload did not differ between difficulty levels as expected (Bootsma et al., 2018). This indicated that the NASA-TLX may potentially not be representative of functional task difficulty, however it may still provide insights into the learner's experience of challenge which may be useful in inform difficulty progressions.

A study by Hendry and Hodges (2019) also measured perceptions of challenge and asked female national level and university level football players to recall their perceived challenge (based on a 5-point rating scale) of different practice activities that they had engaged in up to that point of their careers. Furthermore and building on the idea of being able to identify the optimal challenge point using monitoring tools, Hendricks et al. (2019), proposed a specific measure to optimize the challenge of practice - the rating of perceived challenge (RPC). The RPC is a 0–10 rating scale that is grounded on the CPF and is a function of the available information and task difficulty of a given practice session (Hendricks et al., 2019). The RPC originated in sport to quantify the technical and tactical demands of skill sessions and complement subjective ratings of perceived physical loads (Hendricks et al., 2019). Progressing practice variables to optimize skill learning and using subjective measures to inform how these variables are progressed may be important for managing levels of motivation and frustration that accompany the increase in error caused by more challenging tasks. For example, in a rehabilitation context, using the OCP to control the challenge of intensive and repetitive motor tasks helped regulate participants' feelings of frustration and motivation (Brown et al. 2016). Across the themes, all studies using the CPF to design practice found a positive association between practice variables and learning benefits. Based on these positive associations and considering the tools available to identify the optimal challenge, the use of CPF to design skill practice is highly recommended.

Progressively Adjusting Practice Variable to Increase Task Difficulty

After designing practice and setting the OCP, practice variables should be progressively adjusted to continue to enhance learning as the skill level of the learner changes. Adjusting practice variables, e.g., adding a time constraint to make the skill more challenging, ensures the challenge of practice continually matches the learner's OCP as their skill level increases (Jalalvand et al., 2019; Sanli & Lee, 2015, Onla-Or & Winstein, 2008). Progressing training is a key principle for positive adaptation in sports, thus, progressing practice variables to match the learner's OCP has been a key feature in several sport frameworks (Farrow & Robertson, 2017; Lindquist & Guadagnoli, 2007; Hendricks et al., 2018; Hodges & Lohse, 2022; Malhotra et al., 2022). For example, the Hendricks et al. (2019) rugby tackle periodization framework and the extended challenge-based framework for practice design in sports coaching by Hodges and Lohse (2022). Therefore, as suggested by Hodges and Lohse (2022), progressing the difficulty of sport skill practice is recommended to ensure the OCP changes as the skill level of the individual changes and the practice continues to be optimally challenging.

Furthermore, in sport, progressing the challenge of skill training may also assist in managing the overall load (travel, physical, mental) on the athlete (Farrow & Robertson, 2017; Hendricks et al., 2018). Generally, it is the practitioner who advances the practice variables. However, Jalalvand et al. (2019) found that allowing the learner (60 undergraduate students) to control practice variables resulted in enhanced learning (measured by the accuracy and movement pattern of a golf putting task) of more complex tasks. These findings are similar to the findings of Andrieux et al. (2016) discussed above. There have also been technology and software programs developed to ensure the OCP continues to match learner skill level in practice e.g., Basalp et al. (2019), Preston et al. (2020); Turakhia et al. (2021); Gray (2017); Wadden et al. (2019). For example, in rehabilitation, individuals with motor learning disorders have been able to use rehabilitative robots that have been specifically developed using the CPF to continually adjust the challenge of the skill task to match the learner's skill level (Andriella et al., 2023; Nehrujee et al., 2021; Scassellati et al., 2018). In a speech therapy study, the CPF was used to develop a computer software program called the "Challenge Point Program", in which stimulus complexity and the feedback given by the program to the learner were adaptive based on the learner's performance to help the learner improve their speech accuracy (Preston et al., 2020). In children aged 8–26 years old with acute auditory perception of rhotic sounds, using the "Challenge Point Program" was found to be able to predict treatment outcomes and facilitate gains in production of speech sounds compared to those with broader perceptual acuity pretreatment (Preston et al., 2020). Overall, adjusting practice variables to match the learner's skill level produces positive learning outcomes.

Has Learning Occurred? And Will That Learning Transfer?

The main goal of learning new skills and/or training acquired ones is to proficiently execute the skill(s) in the performance environment with consistency. Researchers have tested whether optimizing the challenge (setting the OCP) in a training session can result in skill learning that can be retained and transferred to performance contexts (Pesce et al., 2013; Sheerin et al., 2020; Wadden et al., 2019). Skill retention is defined and observed when the skill being taught is remembered long after the completion of practice - indicating skill learning (Sidaway et al., 2012). Skill transfer is the task proficiency gained or lost in performance settings as a result of practice, or experience, of a different task (Bootsma et al., 2018). The OCP has also been used to develop new skill learning strategies such as stress-resistant learning, i.e., learning skills in a way that they can withstand the stresses and pressures of the contextual performance environment (Guadagnoli et al., 2012; Guadagnoli & Bertram, 2014). Guadagnoli and Bertram (2014), in their review, proposed a theoretical argument that implementing the CPF into golf practice may result in better performance under pressure, an important characteristic of being a successful golfer. The authors further argued that using the OCP may contribute to improving the speed and accuracy of executing skills in the performance context (Guadagnoli & Bertram, 2014). In two separate papers, based on the CPF theory, Guadagnoli and Aylsworth (2013) and Guadagnoli and Bertram (2014) outline specific steps to guide the implementation of the OCP to maximize the efficiency of transfer from one type of golf putting task to another. Furthermore, in the context of learning skills, Guadagnoli et al. (2012) proposed that using OCPs promotes short-term stress and failure which may facilitate reduced time spent learning whilst also increasing the potential for skill transfer to the performance environment. Although these recommendations were theoretical, the authors do cite an original study by Wadden et al. (2019) which used high contextual interference and individualizing the 'challenge point' to optimize task challenge, to support their argument (Wadden et al., 2019).

In medical education, the "Aim-FineTune-FollowThrough" framework, developed by Christancho et al. (2011b), supported the use of OCPs and integrated OCPs into the needs assessment and 'Followthrough' stages of the framework to optimize learning and increase transfer potential (Christancho et al., 2011b). The framework recommended identifying OCPs based on the learner's skill level by outlining the design of practice variables, such as type and amount of assistance required (Christancho et al., 2011b). Mema and Harris (2016) study also found benefits of applying the CPF to create OCPs in simulation-based training. The authors used the CPF to guide the development of the different difficulty levels in a simulation training program for the Ultrasound-Guided Central Venous Line procedure. From qualitative interviews conducted with participants who engaged in the simulation training program, it was established that the participants felt that the step-by-step approach of practicing one step of the procedure before moving onto more challenging steps/practice conditions and being able to practice different complexity scenarios facilitated their skill transfer from practice to performance environments (i.e., at the bedside) (Mema & Harris, 2016).

The majority of studies that have used the OCP to increase the potential skill retention and transfer to the performance environment were conducted over relatively short periods. Across the studies, retention testing varied between doing testing 1, 2 or 3 days after the training intervention session (Gerig et al., 2017; Jalalvand et al., 2019; Lotay et al., 2019; Matthews et al., 2021) or testing 4–6 weeks after the intervention (Matthews et al., 2021). In one long-term study, Gray (2017) determined baseball batting skill retention by following players' performances over 5 years following their engagement in a CPF-based virtual environment training intervention. Gray (2017) found that the group that engaged in the CPF-based training had superior batting statistics in the league and reached higher competition levels compared to the groups that were not exposed to the adaptive virtual environments (Gray, 2017). To strengthen the value of the CPF, both short term and long-term skill retention and transfer studies are required.

Limitations of the CPF

The concept of the challenge and how it relates to the skill level of the individual, and by extension how the challenge can be optimized to enhance learning and performance, appear to be critical features of the CPF - regardless of how and when it is being used. These critical features are arguably what makes the CPF so versatile across fields. Despite the benefits shown from engaging in CPF-based skill practice, researchers have also highlighted its limitations. One such limitation, argued by Thompson et al. (2019), was that the mental fatigue induced by practicing skills was a contributing factor to how the challenge of the skill is experienced. Bootsma et al. (2018) however found that mental workload (measured using the NASA-TLX) was not affected by the task difficulty (Bootsma et al., 2018). Bootsma et al. (2018) further concluded that the CPF may not fully capture how the different task variables interact to create the challenge experienced when performing skilled tasks (Bootsma et al., 2018). The role of mental and physical fatigue, and how challenging tasks are perceived, and their relationship to skill learning is required in future research.

Furthermore, although Hodges and Lohse (2022) supported the CPF and used it to develop the "extended challenge-based framework for practice design in high performance sports coaching", they acknowledged that the CPF alone may not fully explain task demands. In addressing these limitations, the authors argued that the aim of practice is not always to learn and consequently, added in field-specific elements to their "extended challenge-based framework" (Hodges & Lohse, 2022). The authors described three distinct goals of practice; "practice-to-learn", "practice-to-maintain", and "practice-to-transfer" (Hodges & Lohse, 2022). Considering these different practice goals is important for how practice is designed (Hodges & Lohse, 2022). Practical examples of how the framework can inform coaching practice were also provided in the extended challenge-based framework e.g., "Assigning players different coloured pinnies and requiring that every other pass is made to a green shirt" (Hodges & Lohse, 2022). Furthermore, the CPF did not necessarily account for the increase in number of errors associated with increases in task difficulty, which may have motivational costs (Hodges & Lohse, 2022). As a result, steps to promote motivation are needed when athletes are performing in the optimal challenge zone (Hodges & Lohse, 2022). Additionally, in sports there has been a lack of testing of the CPF in practical settings (Mujika et al., 2018), however it has been used to develop skill periodization plans (Farrow & Robertson, 2017; Hendricks et al., 2018).

Strengths and Limitations of This Scoping Review

This review set out to analyze the use and applications of the CPF across various fields of research. To be comprehensive, we used a scoping review approach and included all forms of literature. While using a scoping review format can be seen as a strength, it can also be viewed as a limitation. Forty-four percent of the included papers were reviews or book chapters, which were theoretical in nature. The remaining 56% were original studies which were then subject to a quality assessment.

Conclusion

In 2004, Guadagnoli and Lee offered a conceptual framework to explain how adapting practice variables (task difficulty and available information) to create the 'optimal challenge' for individuals will maximize the potential learning and performance benefits. In the concluding remarks of the paper, the authors note the following—"Whether or not the present framework turns out to be largely correct or mostly incorrect, we will consider it a success if research is conducted that advances our knowledge regarding the role of practice variables in motor learning".

Based on the current review, we would argue Guadagnoli and Lee were 'largely correct.' The framework can be considered a success as the research conducted has not only advanced our knowledge of the role of practice variables in motor learning, but also of how practice variables can be designed and progressed to optimize learning in a range of motor skill learning and performance environments. Such environments include medical and academic education, rehabilitation, and sport. In medical education, CPF has been integrated into simulation programs for surgical procedures like the Off-Pump Coronary Artery Bypass (OPCAB), providing a valuable tool for developing and refining clinical procedural skills in medicine. In rehabilitation, the CPF supports technological innovations such as speech-learning software for speech therapy and the design of rehabilitation robots to help individuals with disabilities. In sport, the CPF has been applied to long-term athletic development models, skill periodization, and coaching frameworks to enhance skill training.

Overall, the CPF was viewed favorably within these applications, however, it was acknowledged that the CPF alone may not fully capture the task demands of motor skills. Introducing the use of monitoring tools (e.g., NASA-TLX, RPC) in conjunction with the use of the CPF could give a more comprehensive idea of the task demands and of the learner's internal response to the task demands. Monitoring can help the teacher/coach/practitioner to adjust the practice as needed to ensure the learner is achieving the goals of the practice session (e.g. practice to learn) (Hodges & Lohse, 2022). Additionally, the application of the CPF in other occupational settings was only done in one study. Therefore, other occupations where learning skills efficiently and effectively is an important part of the profession (e.g., military training) should consider applying the CPF to their training.

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