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A scoping review of the ecological dynamics approach to skill learning in sport

A knowledge synthesis of empirical studies

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Abstract

Skill learning in sport is a relevant topic for researchers and sports practitioners and -pedagogues. Its been proposed that a sound theoretical model of the learner and the learning process could result in scientific and practical progress (Renshaw et al., 2009, p. 3). The theoretical perspective of ecological dynamics has been identified as a viable candidate for such modeling (Seifert et al., 2017). However, no comprehensive overview or knowledge synthesis of empirical research is available. The aim of this scoping review is to identify, summarize, and present all empirical research on skill learning in sports underpinned by an ecological dynamics rationale. For this purpose, a systematic literature search was conducted in four databases and looked at articles published from year 2000 to the date of the literature search (19.10.2021). The reviewing process followed PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews) (Tricco et al., 2018). 30 studies were included based on theoretical (i.e., ecological dynamics), contextual (sports context), and methodological (i.e., empirical, and investigation learning effects over time) inclusion criteria. Subsequent methodological assessment was done using MMAT (Mixed methods appraisal tool) (Hong et al., 2018). It was identified a highly heterogeneous collection of articles that differed in terms of basic line of inquiry and based on descriptive- and methodological variables. Furthermore, two pedagogical and practice design approaches, Constraints-led approach (CLA) (Button et al., 2020; Davids et al., 2008), and Differential learning (DL) (Schollhorn et al., 2012) were identified. Findings from the interventions indicate that self-organized forms of learning are at least a viable alternative to traditional approaches (i.e., prescriptive instruction, skill decomposition and corrective feedback) for skill learning in sport. Future research should continue the work of empirically investigating skill learning based on studies that are of high quality and commensurate with the theoretical perspective of ecological dynamics.

Keywords; sport, skill learning, ecological dynamics, practice design, sports pedagogy

Sammendrag

Ferdighetslæring i idrett er et aktuelt tema for idrettsforskere, idrettsutøvere og -pedagoger. Et solid teoretisk fundament er blitt trukket frem som vesentlig for videre vitenskapelig- og praktisk fremgang (Renshaw et al., 2009, s. 3). Det teoretiske perspektivet ecological dynamics har blitt identifisert som et slikt solid teoretisk fundament (Seifert et al., 2017). Likevel finnes det ingen kunnskapsoversikt av empirisk forskning på dette feltet. Målet med denne systematiske gjennomgangen (scoping review) er å identifisere, oppsummere og presentere all empirisk forskning gjort på ferdighetslæring i idrett fundert på ecological dynamics som teoretisk rammeverk. I den sammenheng ble det gjennomført et systematisk litteratursøk i fire databaser, der artikler publisert fra år 2000 til 19.10.2021 ble gjennomgått. Det systematiske litteratursøket fulgte PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyzes extension for Scoping Reviews) (Tricco et al., 2018). 30 studier ble inkludert basert på teoretiske (ecological dynamics), kontekstuelle (idrettslig kontekst) og metodiske (empiriske, og undersøker læringseffecter over tid) kriterier. Påfølgende metodologisk vurdering ble gjort ved hjelp av MMAT (Mixed methods appraisal tool) (Hong et al., 2018). Det ble identifisert en samling av studier som varierte betraktelig. Særlig med tanke på studiens formål, og deskriptive- og metodiske variabler. Videre ble det identifisert to pedagogiske tilnærminger, Constraints-led approach (CLA) (Button et al., 2020; Davids et al., 2008), og Differensial learning (DL) (Schollhorn et al., 2012). Funn fra de respektive studiene indikerer at selvorganiserte former for læring er fullgode alternativer til tradisjonelle pedagogiske tilnærminger til ferdighetslæring i idrett (dvs. bruk av instruksjon, trening på del-ferdigheter, og korrigerende tilbakemelding). Fremtidig forskning vil være tjent med å videreføre arbeidet med å styrke ecological dynamics som teoretisk rammeverk for ferdighetslæring i idrett. Dette bør gjøre ved bruk av empiriske studier av høy metodisk kvalitet.

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Bjørnar Berge

Table of content

List of figures

List of tables

1. Introduction

During the past decades a substantial body of research have examined skill learning of perceptual-motor skill in sports from the theoretical lens of ecological dynamics (Woods et al., 2020a, p. 1). This perspective entails distinct descriptions of what skill is, how the process of learning unfolds, and consequently, the functions of a learner, and the role of a sporting pedagogue. From this theoretical perspective, skill learning is understood as "adapting" or "attuning" to specific information in an environment (Araujo & Davids, 2011), and learning as the emergence of an adaptive, functional relationship between an organism and its environment, due to an increasingly effective information transaction (Kugler & Turvey, 1987, p. 12).

The application of ecological dynamics in research and applied settings is arguably a new practice. The majority of research literature is opinion based, rather than testing putting the theoretical tenets empirically to the test (Bergmann et al., 2021, p. 23). Moreover, Ramos et al. (2020b, p. 8) have proposed that empirical- and intervention-based research, based on ecological valid methodologies, can strengthen the conceptualization of skill learning. In turn, this could have practical implication not just for researchers, but for sports pedagogues interested in ensuring that time spent on preparation is utilised efficiently, effectively and resourcefully to provide maximal impact on the performance potential of individuals or teams (Renshaw et al., 2022, p. 1).

An extensive body of literature promoting an ecological dynamics approach to sports has been produced over that last couple of decades. Although not exclusively sports-related, the search conducted for this thesis provided over 6000 initial hits spread over four databases. In addition, multiple books such as: Button et al. (2020); Chow et al. (2015); Davids et al. (2008); Gray (2021); Renshaw et al. (2019) has contributed to furtherly develop the theoretical principles and constructs. In unison, this has led to a continuous audit of the theoretical perspective, as well as a suggestion of its practical application for researchers,

sports pedagogues and -practitioners. However, there exists no comprehensive overview or knowledge synthesis of empirical research underpinned by an ecological dynamics' approach to skill learning in sport[1].

The aim of this study has therefore been to identify, describe and summarise empirical research based on an ecological dynamics' conceptualisation of skill learning in sport. I conducted a literature search using predetermined inclusion criteria in the following databases: PsycINFO, PubMed, SPORTDiscus and Web of Science. The review looked at articles published from year 2000 to the date of the literature search (19.10.2021). I followed recommendations provided by PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews) (Tricco et al., 2018). The methodological assessment of the included articles was done using MMAT (Mixed methods appraisal tool) (Hong et al., 2018).

The target of this thesis was not to provide categorical "how-to"-answers regarding skill learning in sports, or to promote ecological dynamics as the answer to all sports-related research. In stead, the aim is to shed light on what the ecological dynamics' perspective has empirically "produced" on the topic of skill "adaptation" and learning in sports. Based on the accepted truth that "There is nothing so practical as a good theory" (Lewin, 1951, p. 388), one could argue that a sound theoretical model of the learner and the learning process could result in scientific and practical progress (Renshaw et al., 2009, p. 3). Without theoretical guidance, accompanied with appropriate tools, practitioners could be left at the mercy of often outdated practices, speculative information sources and their own intuition (Williams & Hodges, 2005, p. 637). Reversely, a sound and potentially impactful theory is dependant on empirical support.

[1] To date, there only exist some reviews with a more detailed focus: CLA-based practice design in soccer (Bergmann et al. (2021)); interceptive sports (Clark et al. (2019)); synergies in team sports (Ramos et al. (2020b)).

In sum, this thesis attempts to provide a summary of knowledge of the ecological dynamics approach to skill learning in sport, based on empirical research. I will start by presenting the distinct approaches to skill learning in sport before turning to the study at hand. I extensively focus on providing a comprehensive overview of ecological dynamics, presented as the "love child" of ecological psychology (i.e., Gibson, 1979; 1966) and a complexity outlook on movement coordination (Bernstein, 1967; Kelso, 1984; Newell, 1986). I will then describe the methods used before presenting the study results, including descriptive study characteristics and a synthesis of empirical findings. I then turn to discuss the relationship between theory, methodology and results, and end by discussing current issues and ways forward for research and practice.

2. A short overview of approaches to skill learning in sport

The history of motor learning research is well over a century long (Warren, 2006, p. 358). Most researchers agree that a considerable amount of practice or experience is required to improve skills to the point of expertise (Ericsson et al., 1993, p. 363). Motor learning has subsequently been defined as: "A set of processes associated with practice or experience leading to relatively permanent improvement in the capacity to perform" (Schmidt et al., 2018, p. 283). However, no consensus is found among researchers when it comes to what these processes are, and what effective practice consist of. As a consequence, what is hypothesized to be effective practice may differ depending on the scientific paradigm in which research and practice are situated (Anson et al., 2005, p. 217). One major reason for this is the way skillful behavior in sports, and the associated learning process, has been theoretically and ontologically defined. Research on learning in sports can be divided in two main research traditions: (i) the information-processing approach, based on cognitive psychology (see Adams, 1971; Fitts & Posner, 1967; Schmidt, 1975), and (ii) the ecological dynamics approach, based on ecological psychology and dynamical systems theory (see Davids et al., 1994; Handford, 1997). A simplified distinction between the ecological

dynamics approach and information processing approach is that the former proclaims that human behavior is fundamentally embedded within an environment, while the latter describes individuals as actors *upon* an environment, while the former proclaims that human behavior is fundamentally embedded *within* an environment.

Information processing approaches ascribes learning to a process of accumulating and refining internal representations (Schmidt, 1975). These representations, often called schemas (Schmidt, 1975), programs or plans, are thought to be stored as knowledge structures in the brain. From this perspective, skill is ontologically analogous to how software defines the function of a computer. The learning of skill is synonymous with an enhanced state, increasing amounts of knowledge stored in memory, or more sophisticated movement representations (Schmidt et al., 2018, p. 196). An information processing approach therefore holds that a sophisticated and comprehensive representation of an act, that resonates to the performance context, is the "something" being acquired in the process of learning. As argued by Handford and colleagues (1997, p. 622)., the something (i.e., representations) is operationalized in a dualistic manner, meaning that the mind is a "special" organ that translates objectivity (perceptually obtained "universal" properties of the physical world) into subjectivity (scaling the "universal" properties to individual capabilities). This computational process enables individuals to "realize" appropriate motor programs in a verity of situations.

The linear nature of perceiving objectivity, "subjective" computation and realizing the "correct" motor program, found in the information processing approach, has had profound consequences for how learning has been understood. Renshaw et al. (2022, p. 2) argues that the application of it information processing theories has led to a belief that skill learning is about deeply internalised rehearsal, a focus on error correction and a quest for universal movement optimums. Following a rationale where practice is about acquiring and enhancing internal models of the movement, an inference of desired automatization and repetitive consistency is logical. Derived from these beliefs are pedagogical practices that focus on

repetitive rehearsal, “route learning” and practice progressions from part to whole and isolated to contextual (Renshaw & Chow, 2019, p. 105). Gray (2020, p. 1) points to much used pedagogical tools such as prescriptive instructions and corrective feedback as effects of the information processing approach to learning in sports. Furthermore, this is seen as an effective way of educating learners about the most essential objective information “out there”. From this perspective, effective coaching is in no small part about communicating what effective skill is, how that looks, and tell an athlete what he/she must do to bride the gap between the current-, and “correct” movement. Importantly, the quality of such “cajoling” is based on being highly detailed, specific and concrete in the dissemination of knowledge (Williams & Hodges, 2005, pp. 640-645).

In summary, the information processing rationale holds that skill primarily stems from mental representations, and that learning is about “enriching” these through linear processes (i.e., part to whole, easy to difficult progression) and repetitious activities. Consequently, the function of a learner is mainly about effectuating predefined movements optimums, where quantity of practice is mostly emphasized. Such a belief is widely popularized through Ericsson’s (1993) “10 000 hour rule”. Following this, the role of a sports pedagogue is to indirectly (e.g., via feedback and instruction) transmit knowledge about what is “correct” movement, and thereby being a “solution provider” (Woods et al., 2021, pp. 2-3). The ecological dynamics rationale questions the ontological positioning of skillful behavior and the process of learning presented above (Davids et al., 1994; Handford, 1997). As we shall see next, the profoundly different operationalization of learning, leads to radically different outlook on what effective practice should include, both in terms of practice design, and pedagogical practices (Renshaw et al., 2022, p. 1).

The ecological dynamics approach could be seen as a response to the dualism found in motor learning research that follow the information processing approach (Newell, 1991, p. 214). This dualism is present in the conceptualization of perceptions and actions being both

an internally represented entity, and a physical reality that are conceptually divided. The criticism focuses on the limitations of their arguably reductionist and mechanistic descriptions (see Davids et al., 1994; Handford, 1997). Ecological dynamics challenges the computer analogy used to describe human behavior, such as skill learning in sports, at a philosophical, methodological and theoretical level (Handford, 1997, pp. 622-625). In this scientific debate, the ecological dynamics approach holds that holistic investigations of dynamic person-environment interactions (e.g., behavior in sport), is the appropriate unit of analysis (Davids & Araújo, 2010, p. 633). The main argument is that motor behavior generally do not appear in a vacuum, and that a theory of motor behavior needs to incorporate a sustained reference to the specific environmental context in which actions emerge (Renshaw et al., 2009, pp. 6-7).

The ecological dynamics rationale proposes that skillful behavior is best described as a self-organized formation of coordinative structures or synergies bound by a confluence of interacting constraints (Bernstein, 1967; Kelso, 1995; Newell, 1986). Perceptual information can be directly and unambiguously picked-up and used to tune or modulate action (Fajen et al., 2009; Gibson, 1979; Gibson & Carmichael, 1966). Thus, Warren (2006, p. 358) argues that skillful behavior in sport is more appropriately described as emergent, self-organized, and distributed over the agent–environment system. Controlled behavior is seen as an example of a biology capitalizing on the regularities of the entirety of the system. Components (often described as constraints) of this system is among others: the structure and physics of the environment, the biomechanics of the body, perceptual information about the state of the agent–environment system, and the demands of the task. Importantly, the systems behavior (person and environment) is an example of something being qualitatively different than the sum of its parts, hence the use of descriptions like intertwined, complex and nonlinear (Woods et al., 2020, p. 3). Skillful behavior, rather than being a product of pre-existing representations, could more aptly be defined as: “the emergence of an adaptive, functional relationship between an organism and its environment, founded on an effective information transaction” (Kugler & Turvey, 1987, p. 12).

Learning is in ecological dynamics portrayed as skill attunement or -adaptation, and is always seen in reference to-, and in an intertwined relation with, a specific environment (Araújo & Davids, 2011, p. 7). As a consequence, learning is said to arise most effectively from relevant performer-environment interactions, where inherent self-organizing tendencies are preserved (Davids et al., 2013, pp. 23-24). Under this notion, the sports practitioner s gets framed as an adaptive, self-governing problem-solvers, inferring that practice is about progressively deepening the knowledge *of* the environment (Gibson & Carmichael, 1966). Such knowledge is expressed through actions, perceptions, and skilled intentionality (Button et al., 2020). Knowledge *about* the environment (i.e., a verbalized from of knowledge) (Gibson, 1979), is given less value since action is seen as fundamentally emergent, and not deriving from mental processing of information (i.e., the information processing approach).

In turn, this means that a more effective approach for sports pedagogues is built on more "hands-of" approaches, or as eloquently put by McKay et al. (2021, p. 394):

"What this means for the coach is that, to foster the development of effective person-environment relationships, they need to guide the attention of the athlete toward important features of the environment. Athletes should be shown where to look, but not what to see."

In essence, this is done through carefully designed practice tasks that are built on clarifying environmental information of importance. Moreover, this entails that a behavior (e.g., sporting technique) is most effectively improved in a direct meeting with a relevant (i.e., competition-like) environmental niche. Appropriate practice is suggested to "nudge" an athlete by intentionally designing practice "landscapes" (Woods et al., 2020a, p. 5). A from of simplification, where relevant perception-action coupling is preserved, is suggested over practice decomposition (e.g., divide sport specific motor task into separate parts and practicing them in isolation) to meet the demands of the learner. In essence, the sports pedagogue gets framed not as a "provider of solutions", but a "designer of problems".

3. Theoretical framework

Ecological dynamics is based on ecological psychology, and a dynamical systems theory-perspective on movement coordination (Handford et al., 1997, p. 625). A definition of complex adaptive systems, and why this can be a fitting description of sports practitioners or -teams, will be presented first. This will be followed by a historic overview of the "dynamics" perspective, through Bernstein's (1967) ideas about coordination, and the ecological perspective, through Gibson's (1979; 1966) ideas of "direct" perception and affordances. This is partly to catch the chronological order of the affiliated theoretical perspective, and partly to map out the ecological dynamics perspective as clearly as possible. The search, synthesis, and summary of articles all refer to these seminal theoretical perspectives. Their complementary functions will be presented lastly, together with the pedagogical-/practice design approaches derived from them (Constraints-led approach (CLA), Nonlinear pedagogy (NLP) and Differential learning (DL).

3.1 Sport practitioners and -teams as complex adaptive systems

When defining sport practitioners or -teams as complex adaptive systems, a prerequisite is to view the systems components (individual or team and its environment) as co-existing in an open, dynamic, and nested way. Open systems, as opposed to closed systems, can exchange energy and information within their shares ecology (Vaughan et al., 2019, p. 5). As a function, complex systems are systems with many interacting components, all capable of affecting global system outcomes (Davids et al., 2014, p. 24). Adaptive systems are systems that evolve, develop and learn to negotiate with their environments by altering their behavior to emerging constraints (Davids et al., 2014, p. 4). Systems of this sort are found all around the world, with examples ranging from ant colonies, flock of birds, weather systems, and more importantly, individual players and teams in sport. The reorganization of systems like this are conceptualized as self-organized, and non-linear and non-proportionate in nature (Davids, 2014, p. 49). In sport, this could be exemplified by how individuals' transit between

patterns of movement (e.g., walking to running to sprinting), or how interpersonal interactions in team sports can synergize (Araujo & Davids, 2016).

A useful analogy can be to describe bird-flocking behavior as an example of complex adaptive systems. Flocking can be explained in two ways, either as a linear, closed system, or as a complex, open system. In the former, the behavior of the bird flock is seen as a function of a superior commander or "leader bird" organizing and leading the rest of the flock. This is considered a closed system since the interaction between degrees of freedom (individual birds) are limited to the commands of the leader bird. This way of explaining the flock's behavior is characterized as "top-down" since the control lies with the hieratically superior "leader" bird. Order (i.e., flocking behavior) is created based on the obedience of the flock, and the effectiveness of the leader bird's commands.

The complex adaptive system-modeling sees control as distributed over the entire flock. The same order (flocking behavior) is described as the individual bird's ability to keep an appropriate distance to the birds in its vicinity. In this way, a lower control law (individual birds keeping correct distance locally) can describe global behavior (flocking behavior as a whole) by extrapolation.

Let's see how bird flocking example could respond to a change in the environment, say a gust of wind. In the closed system-explanation, where the leader bird defines the function of the flock, this becomes problematic in especially two ways. Firstly, a delay in the system is expected. The leader bird must perceive and calculate an appropriate response and distribute this information to the rest of the flock. In everchanging and uncertain environments this could be problematic. Secondly, if the gust of wind hits the back of the flock, and the leader bird is in the front, one could expect that the coordinated flocking would fall apart since the leader has no way of perceiving the environmental change. In contrast, a complex adaptive system can handle these problems through self-organization and the extrapolation of following the lower control order (i.e., individual birds keeping correct

distance locally). This process is emergent and will therefore not have a problem with delay of information distribution, or the "direction" of the critical information (i.e., wind direction).

Two traits of complex adaptive systems have been proposed as especially important to model the behavior of such systems, namely *nonlinearity* and *non-proportionality* (Seifert et al., 2022, p. 2). In essence, and by using the bird-flocking analogy once more, theses characteristics proposes that a small perturbation in the system (e.g., meeting a predator) can result in a non-proportional response (chaos in the flock), and that this behavior is non-linear in the sense that hitting some critical value (being dangerously close to the predator) can force it to suddenly re-organize its behavior (flock entering a circling strategy for protection).

Multiple behavioral systems in sports have successfully been modeled as complex adaptive systems with self-organization properties. Examples ranging from simple oscillating hand movements (Kelso et al., 1981), inter-limb coordination in swimming (Seifert et al., 2010; Seifert et al., 2011) between-opponents synchronization in tennis (Palut & Zanone, 2005) and the formation of synergies between- and within sport teams such as football (Davids et al., 2005). The overall objective of this field of work is to principally and lawfully understand the dynamics of behavioral pattern formation in relation to changing constraints (Balague et al., 2013, p. 5). Self-organization and co-adaptation (see Kauffman, 1993) is a prominent example of such a lawful and principal description. In essence, human movement behavior, and its learning process, is explained as distributed over the entirety of the system, where emergent and self-organized processes are bound under interacting constraints (Vaughan et al., 2019, p. 4). Complex adaptive systems are best described in a holistic manner, under the notion that the whole is more (or qualitatively different) than the sum of its parts.

At this point, it could be clarifying to introduce two pioneers within the complexity paradigm to human movement behavior, namely Nicolai Bernstein and James Gibson. The

former is known for his complexity perspective on modelling motor coordination, and the latter is known for his description of perceptual obtainable information in the environment as sufficiently "rich" to guide action without the need for computation.

3.2 Bernstein's perspective on the coordination of movement

The Russian scientist Nicolai Bernstein aimed his scientific career at explaining how animals find and optimize solutions to motor problems (Bongaardt & Meijer, 2000, p. 57). His work can be described as highly influenced by practical, "real world" problems, something he shares with James J. Gibson, whom we'll return to later. Bernstein's research included studies on how metal workers coordinated their chisel and hammer, as well as analyzing the gait of Soviet citizens (p. 57). The purpose of his research was among other things to increase productivity in the national metal industry, and build optimal bridges in Soviet cities (p. 60). Bernstein developed a motion camera-technology called kymocyclography to analyze movement, a technology that enabled both a temporal- and spatial frame of reference when analyzing movement. As Bernstein (1927, p. 7) put is, it made it possible to "extract the maximal available amount of information about the process of coordinating movement."

Following this research, Bernstein formulated theories that focused on different aspects of the organization of movement. In sum, it's said that "more important than the answers he gave, were the questions he asked" (Bongaardt & Meijer, 2000, p. 57). Although his research dates to the early part of the 20th century, his complexity-perspective on coordination of movement is still relevant today. Particularly influential were his ideas about the «degrees of freedom problem» and «context conditioned variability» (Turvey, 1982). The former revolves around how the numerous degrees of freedom possible in the movement apparatus (the sum of potential compositions of muscle activation, joint positions, and timing of theses) is a case of redundancy and complexity. As an example, if you only consider det muscles involved in moving one's arm, the possible number of different configurations are highly numerous. The shoulder (n=10, excluding stabilators, biceps and triceps), elbow (n=6),

ulnoradial joint (n=4), and wrist (n=6) comes to a total of 26 degrees of freedom (Turvey, 1982, p. 242). If every muscle had to be individually controlled at any give moment, even the simplest movement becomes overwhelmingly complex. It is therefore questionable whether movement is a result of internal representations that specifies movement, since this would require an improbable number of representations. Additionally, it does not answer where these representations originate, at least in the case of learning new motor solutions. Bernstein consequently argued that motor control is “continuous”, and a case of a circular flux of information, as opposed to a top-down executive process (Bongaardt & Meijer, 2000, p. 63).

Context conditioned variability is about encompassing variability as a result of anatomical, mechanical and physiological variability (Fitch, 2014, pp. 246-251). Essentially, Bernstein saw the potential consequences of an equal activation of a "motor program" on different occasions, as something which would necessarily lead to different motion results. The reason being that a contextual replication of internal and external factors is practically impossible.

In essence, these ideas questioned whether motor control could be the result of an "open loop" process in which the initiation- and production of motion could be attributed to internal representations (Turvey, 1982, pp. 239-240). Instead, Bernstein (1967, p. 127) defined coordination as: «the process of mastering redundant degrees of freedom of the moving organ, in other words a conversion to a controllable system». The perspective on motor control is thereby shifted from a pursuit of universally optimal or correct motor solutions (i.e., acquiring and refine internal representations), to a focus on stabile flexibility. Bernstein argued that dexterity: the ability to find a motor solution to any external situation, that is, to adequately solve any emerging motor problem (Latash et al., 1996, p. 177), was a more fruitful way to frame and investigate, motor learning and -control. In essence, because anatomical-, mechanical- and physiological variables are ever-changing, so too must the motor output. This realization led Bernstein to put learning in a new light as well:

"*The process of practice towards the achievement of new motor habits essentially consists in the gradual success of a search for optimal motor solutions to the appropriate problems. Because of this, practice, when properly undertaken, does not consist in [simply] repeating the ... solution of a motor problem time after time, but [rather] in the process of solving the problem again and again by techniques which we changed and perfected from repetition to repetition. It is already apparent here that, in many cases, practise is a particular type of repetition without repetition, and that motor training, if the position is ignored, is merely mechanical repetition by rote, a method which has been discredited in pedagogy for some time*" (Bernstein, 1967, p. 134).

The goal of learning is to create an improved fit between the action capabilities of an organism, the task to be achieved, and the environmental niche in which it exists through self-organization (Woods et al., 2020b, p. 1). A prerequisite for such attunement or adaptation, is an effective interaction between afferent (incoming information about the internal state of the body and the external environment) and efferent (outgoing movement commands) information (Latash et al., 1996, p. 269).

A more specific account of how ecological dynamics describes motor control and learning, understood as effective information transaction between person and environment, can be found in the *ecological* side of ecological dynamics. Gibson's ideas of direct perception and affordances provides a viable theoretical platform to understand coordination-processes based on a mutual information transaction between an agent and his/her environment. As we shall see next, this form of information transaction provides answers to how a multi-agent systems such as the movement apparatus (conglomeration of e.g., joints and muscles) or teams (the interaction between teammates and opponents) can function effectively in dynamic and ever-changing environments (Woods et al., 2021, p. 4). In essence,

the ecological phycology's operationalization of information (the directly perceivable one) enables an operationalization of behavior as emergent and self-organized.

3.3 Gibson's ecological view on perception and action

James Gibson received his Ph.D. in 1928, published his last book (The Ecological Approach to Visual Perception) in 1979, meaning that he devoted over 50 years of his life to the psychological conundrum of perception (Reed, 1988, pp. 1-12). His research was identified as highly practical, exemplified in his assistance in the US Air Force's «Aviation Psychology Program» during WW2. His role in the war was to pick out the most promising pilots based on perceptual measurements. Despite his efforts in the war, is he perhaps best known for his academic work that followed, resulting in several books and academic publications dealing with perception (Gibson, 1979; Gibson, 1950; Gibson & Carmichael, 1966; Gibson & Gibson, 1955). Reed (1988, p. 313) summarizes Gibson's scientific influence by pointing out that he made the study of perception both scientific and realistic. Throughout his life, Gibson strongly thought of perception as a source of real or direct knowledge. This questioned long-held conceptualizations of perceptual senses as mere images or sensations of the world. In Gibson's eyes, perception's role in forming the richness of human motor behavior had to be more profoundly formative.

The contemporary theories about perception, and its relation to learning, were in the 1960's and 1970's mainly influenced by constructivism (how people make sense of their experience) (Caffarella & Merriam, 1999, p. 260). This theoretical paradigm henges on the idea that retinal images gets linked to mental models or specific representations based on a process of inference (Drayson, 2018, p. 3150). In relation to learning, popular constructivist views were cognitive constructivism and social constructivism. Kanselaar (2002, p. 1) describes the former as associated with the Swiss developmental psychologist Piaget (1977), whom described the inference-process as relating perceptual information to a mental model that is created through an individual's cognitive development. Humans are thought to make

sense of information, such as the visually obtained, by associating it with what is already known to the individual. That is, by trying to assimilate it into our existing knowledge (Amineh & Asl, 2015, p. 10). The second is connected to Vygotsky (1986), whom considered mental models as heavily mediated by community and culture, via modeling of others. His position is considered an anti-realist one, and states that the process of knowing is through relating oneself to others (Amineh & Asl, 2015, p. 10).

Gibson rejected the idea that inference or mediation of perceived information was needed, and proposed that humans (and other animals) passively and accurately perceives environmental information "directly" and unambiguously (Gibson, 1979). Based on this conviction, he set out to establish a framework that would capture the direct relation between a perceiving organism, and the objects of it's perceiving. In addition, Gibson sought to make his ideas about perception appropriate for scientific analysis (Turvey et al., 1981, pp. 239-240). Gibson's position on perception is a realist one, meaning that the visual field created by the retinal image contains the physical object itself, thus proposing that phenomenal object is identical to the physical one (Smythies & Ramachandran, 1997, p. 437). In essence, Gibson's ecological approach to perception proclaims that what we feel, hear or see are not just indirect interpretations of the physical world, it's a direct informational contact between an individual and its environment (Gibson, 1979, p. 3). Perception at the ecological scale defines the agent–environment system, and its holistic function. This is seen as a more informative scale of analysis, at least in relation to how it guides action (Gibson, 1979, p. 213). Gibson made this clear in how he described the control of locomotion and manipulation made by the human body:

"…control lies in the animal–environment system.... The rules that govern behavior are not like laws enforced by an authority or decisions made by a commander; behavior is regular without being regulated…the question is how can that be?" (Gibson, 1979, p. 225).

Gibson's theory of *direct* perception describes how an agent can use information from the surrounding energy (e.g., light, sound) as a foundation for action, without internal (e.g. mental or cognitive) processing or mediation (p. 80). Mediation can be in the from of retinal pictures, neural pictures, or mental pictures (Gibson, 1979, p. 147). Gibson argued that properties of the world (e.g., surfaces or textures) constitute rich, specifying information that can be used to guide action. The regular nature of how light reflects of surfaces, reveal environmental properties like surface layouts, objects, and events (Turvey & Shaw, 1999, p. 95).

Gibson (1979, p. 147) proclaims that (direct) perception, in the case of visual perception, includes "the activity of getting information from the ambient array of light." The fact that this array of information is ambient means that it encapsulates the agent completely. This information source is made invariant because of how it lawfully reflects off surfaces in the environment and hits the observer (Gibson, 1979, pp. 65-67). The combination of lawfulness and availability cuts to the core of Gibson's theory of direct perception. More specifically, it emphasizes that perception is not exclusively a sensory experience, it is also a process of actively obtaining information from the world, a psychosomatic act, consisting of motor action (Jordet, 2004, p. 19). In essence, the outlook on ambient energy arrays (light, sound, or smell) as directly informative, based on the relation between agent and object, encapsulates the reciprocity between perception and action. Put differently, a person's movement changes the perspective (i.e., the way energy arrays hit the observer), and the perspective informs the state of the person-environment system. Moving around and obtaining different perspectives is what relativizes the ambient energy available in the environment, translating the environment from something observable to inherently informative for action. It is therefore said that perceiving and acting is a case of circular causality (Warren, 2006, p. 359).

An important clarification at this point is that Gibson describes the process of looking *at* something and *for* something as distinctively different processes. The former could be to look at a painting, whilst the latter could be to look for action possibilities in a game of football in which you are participating. The latter form of perception is the only one where the previewed information can be acted on or be related to action opportunities or *affordances*. The ecological perspective on looking *for* something includes "a process of information pickup that involves the exploratory activity of looking around, getting around, and looking at things." (Gibson, 1979, p. 147).

Affordances encapsulates action because of directly perceived information, and at the same time relating this information to the individual (e.g., action capabilities). Gibson (1979, p. 127) originally defined an affordance as: "what it offers the animal, what it provides and furnishes, either for good or ill." In relation to acting, it can also be seen as: "Functionally significant properties of the environment that are perceived through active detection (perception and action) of information" (Kyttä, 2003, p. 45). Essentially, to perceive an affordance is to perceive an action opportunity under a particular set of environmental conditions. An affordance is therefore what connects a person's action capabilities (ability to kick a ball or walk a stair) to an environment which affords such an action (a ball at your feet or stairs in front of you). It is in this context that the Gibson's (1979, p. 129) somewhat soaring elaboration of affordances can make sense:

"An affordance is neither an objective property nor a subjective property; or it is both if you like. An affordance cuts across the dichotomy of subjective-objective and helps us to understand its inadequacy. It is equally a fact of the environment and a fact of behavior. It is both physical and psychical, yet neither. An affordance points both ways, to the environment and to the observer."

Importantly, an affordance does not isolate the environment as something objectively similar for all individuals (e.g., distance, size, or mass). Instead, it defines the environment in

relation to what it offers in terms of possible actions. An affordance informs a person about the “jumpability” of a barrier, the “kickability”, “catchability” or “throwability” of a ball, or the “pass-throughability” of a gap between two opponent defenders. Furthermore, affordances are thus understood as ‘emergent properties of the animal-environment systems’ (Fajen et al., 2009, p. 90).

Based on the description of direct perception and affordances, a distinct operationalization of learning can be made. Learning gets described as more functional coupling of perceptual- and action systems, based on increased task experience (see Gibson & Gibson, 1955). This process has been labeled information-movement- or perception-action coupling (Anson et al., 2005, p. 229). A substantial part of becoming increasingly skillful in sport is therefore to detect (i.e., exposing oneself to the most essential information) and realize (putting individual capabilities into action) affordances.

A learning situation were an individual or team engages with relevant situational properties, is the essence of affordance-driven learning. Learning is first and foremost guided by directly perceivable and unmediated information found in relevant person-environment interactions. This ensures that individual action capabilities are always considered and linked with relevant information sources in the environment. The relevance of affordances is highly dependant on representativeness. Moreover, the affordances which effectively guide behavior in competition, should also be present in practice to ensure learning transfer. This principle has been labeled “education of attention” (Gibson, 1966, p. 25). The basic idea is that a true individualized pedagogical approach should guide a person towards important aspects (affordances) of the environment but abstain from explicitly prescribing how to use this information. In practice, this implies that learning situations should be aimed at establishing functional relationships between a person and an environment through indirect “guidance” (Araujo & Davids, 2011, p. 13). A fruitful practice should include engagement with relevant objects (ball in football), surfaces (snow and ice for an alpinist), events (biased refereeing)

features (wind in the arena for a biathlete) and significant others (movement of teammates in team sport) (Button et al., 2020, pp. 9-10). The adequacy of such an approach is anchored in the belief that searching for vital environmental information, bound by the task at hand, is an appropriate and sufficient guide for action. Facilitating, amplification and guiding are seen as appropriate influence tools, but not to the extent that it breaks the self-organized and intertwined nature of effective perception and action coupling (Seifert et al., 2013, p. 169). As we shall see later, the focus on environmental specificity or representativeness is emphasized differently in the practice design- and pedagogical approaches found in this review (i.e., DL and CLA).

By taking such a stance, the focus shifts from the mechanism of internal structures, to understanding how each individual can perceive their performance environment (e.g. directly perceivable information), and their action capabilities in relation (Araujo & Davids, 2011, p. 16). Becoming more perceptually attuned to relevant properties of the environment, and utilizing its informational richness, is therefore seen as a vital part of becoming increasingly skillful in sports (p. 16). To clarify, learning from an ecological perspective is still interested in personal characteristics such as physical strength, psychological attributes, and social abilities, but that these constraints on behavior are fundamentally dependant on an individuals' ability to make use of them in specific environmental contexts. It is therefore said that skillful behavior in sports follows not just from knowledge *about* the environment (declarative knowledge), but also *of* the environment (see Gibson & Gibson, 1955).

To sum up so far, the ecological dynamics perspective includes especially two descriptions on motor behavior. Firstly, the complexity perspective, where learners are conceptualized as complex, neurobiological systems with inherent self-organization tendencies, and (ii), the ecological perspective, where reciprocal and intertwined interaction between vital factors such as intentions, perceptions, and actions, are described in unison. Put together, this operationalizes skill learning as a process of assembly, where each learner

creates functional movement solutions on the basis of the totality of the system (i.e., intrinsic dynamics and informational constraints) (Davids et al., 2013, p. 21).

3.4 Practice design and pedagogy in ecological dynamics

It is within fusion of ecological psychology and the complexity outlook on motor coordination that the empirical studies derived from the structured literature search finds common ground. A brief elaboration of identified approaches will be provided next, with an emphasis on the differences between them. However, it is important to remember that theoretically and ontologically speaking, these approaches share more commonalities than differences. In a nutshell, these approaches propose that skill learning in sports happens most effectively when a performer is allowed to come up with their own solutions through a process of self-organization (Anson et al., 2005, pp. 218-219). In essence, learning situations should allow performers to explore and create opportunities for action, embracing movement variability, rather than constraining them to predefined prescriptions of "ideal" technique (Woods et al., 2020a, pp. 3-4). What this implies for sport pedagogues is that practitioners must be allowed to explore different movement solutions that are both adaptable (i.e., different solutions for different task conditions) and individualized (functional based on individual characteristics) (Gray, 2020, p. 1).

The following are the pedagogical-/practice design approaches found: Constraints-led approach (CLA) (see Button et al., 2020; Davids et al., 2008), Nonlinear pedagogy (NLP) (see Chow, 2013; Chow et al., 2015; Chow et al., 2011) and Differential learning (DL) (see Schollhorn et al., 2012). Roughly speaking, the CLA and DL deals with the structuring and organization of practice, whilst NLP is more concerned with the pedagogical consequences of following a CLA to learning in sports. NLP and CLA are therefore seen as complementary (Lee et al., 2014, p. 1), while DL is conceived as a separate approach.

3.4.1 Constraints-led approach (CLA)

The Constraints-led approach articulates that a learner will self-organize in attempts to generate effective movement solutions on the basis of interacting with individual-, task- and environmental constraints (adopted from Newell, 1986; Renshaw & Chow, 2019, p. 103). This overarching framework can be used to describe, categorize and systemize behavioral processes such as skill learning in sport (see Glazier, 2017). Constraints have been defined as "boundary conditions, limitations, or design features that apply restrictions to the degrees of freedom of a system, thereby indicating the trajectories that the system may exhibit" (in Balague et al., 2019, p. 1; Kugler et al., 1980). Critically, the specific expression of behavior is always shaped by, but not defined, by the confluence of constraints.

Hodges and Williams (2020, p. 163) elaborates on the three constraints-categories by defining them thusly: (i) individual constraints as either structural (e.g., height, strength, and limb length), historical (e.g., development of resilience, experience) or functional (e.g., motivation, cognition, intention), (ii) task constraints as either tied to rules (e.g., laws of the game, boundary markings), task goals (winning and/or showing superior abilities) or instructional features (e.g., coach instruction or feedback from teammates) (iii) environmental constraints as either physical (e.g., weather, light, gravity) or sociocultural (e.g., values, cultural beliefs, peer support). By looking at the different constraints, it seems obvious that some are controllable or critical in the shaping of behavior. Another important consideration regarding the shaping effect of constraints, is that some work on relative short time-scales (e.g., accumulation of lactic acid in the muscles, being in a winning or loosing position in a game, or a sudden gust of wind), while others have a more profound effect on longer time-scales (e.g., growth and maturation, game models and principles of play, or cultural norms) (Balague et al., 2019).

By putting constraints into categories (task, environment or individual) it is possible to structure, organize and simplify the factors that lead to a movement coordination or

performance behavior. The main tool in a sport-pedagogues toolbox is therefore to manipulate- and alter key constraints, thereby indirectly creating behavioral change (i.e., learning). Critically, this is done by retaining much of the totality of the performance, and not resorting to decomposing of skill (Renshaw & Chow, 2019, p. 104). In other words, the critical factors (constraints) are not categorized for the purpose of working on these aspects in isolation (i.e., skill decomposition), but to integrate the "totality" of factors presented in a more integrative model.

The effectiveness of a constraints-manipulation is determined by their influence on exploration of movement solutions, combined with how well it reflects sports-specific performance factors (Correia et al., 2019, p. 122). Meaningful manipulation of constraints should lead to an amplification or utilization of inherent self-organizing tendencies, as well as guiding a performer in the search for more effective solutions. A sports pedagogue should therefore manipulate constraints not as an alternative prescription tool to verbal instruction or corrective feedback (i.e., specifically prescribing what to do), but use it as a way to "nudge" practitioners in a general direction (Woods et al., 2020a, p. 5). The ambition is not to direct a practitioner towards a predefined endpoint (i.e., optimal solution or correct technique), but to restrict particularly undesirable ones (Gray, 2020, pp. 1-2).

3.4.2 Nonlinear pedagogy (NLP)

Nonlinear pedagogy focuses on how pedagogues (e.g., teachers, coachers) can encourage the development of individualized movement behaviors through practice design (Chow et al., 2021, p. 4). In relation to the CLA, it is specifically aimed at giving sports pedagogues a practical tool box for how to design appropriate learning environments (Sullivan et al., 2021, p. 1216). Chow (2013, pp. 471-473) summarized key aspects of NLP by pointing to the following five: (i) the designing of representative learning environments (see Brunswik, 1956; Pinder et al., 2011), (ii) facilitation and creation of opportunities for learners to develop and adapt relevant information-movement couplings (affordance-driven learning) (see Gibson,

1979; Gibson & Gibson, 1955), (iii) manipulation of constraints, (iv) *repetition without repetition* (see Bernstein, 1967), and (v) the promotion of an external focus of attention (see Wulf & Prinz, 2001). Point v is not described in detail in this thesis, but is about the benefits, both for performance and learning, of attending to movement effects, and not the movement itself (see (Wulf & Prinz, 2001, p. 649). The remaining points have been presented earlier in the theory part.

Both CLA and NLP view the sport pedagogue as a meticulous *designer of learning environments* (Correia et al., 2019, p. 117). CLA and NLP will for that reason be described in unison for much of the thesis. Nuancing will be provided when appropriate. The role of sport pedagogues is to support, guide and facilitate functional learning, while preserving its emergent and self-organized nature. This viewpoint on learning proposes that effective pedagogical practice is through careful manipulation of constraints, and -affordance "landscapes" (Lee et al., 2014, p. 4; Woods et al., 2020b).

3.4.3 Differential learning (DL)

Differential learning aims to amplify fluctuations in the movement apparatus, by constantly pushing the performer into varied movement solutions (Schollhorn et al., 2012, p. 102). This is done by constantly changing motor problems and tasks, while not resorting to explicit correction (Schollhorn et al., 2012, p. 102). In its most extreme version, DL is associated with the total absence of repetition, and augmented feedback. This is to allow a real (i.e., unmediated) form of self-organization, where no explicit guidance about errors or potential solutions are provided externally (Schöllhorn et al., 2022, p. 15). Unlike in CLA and NLP, where the manipulation of key task constraints are used "to facilitate the emergence of functional movement patterns and decision making behaviors" (Chow et al., 2007, p. 251), the differential learning approach does not identify key constraints. Instead, fluctuations in the learner's subsystems itself are exploited by forcing the performer to constantly instigate new coordination strategies. This practise is founded on the idea of stochastic resonance, which

Gray (2020, p. 8) describes thusly: the noisy, internal state of the performer resonates with the noisy signal from the environment, resulting in an amplification of signals. For an illustrative example of this phenomenon, see Dylov et al. (2011). The result of this greater confidence in motor destabilization, and subsequent self-organization, is that the maximation of motor variability is pursued. An example from association football can be to pre-plan an exercise to include x amount of left- and right foot finishes, in x amount of different circumstances (see Schollhorn et al., 2012, pp. 105-107).

In relation to a CLA and NLP, the promotion of behavior is seen as more prescriptive since the maximization of variability is based on explicit instruction about what to do, and not based on careful manipulation of different constraints. The promotion of perception-action coupling, by creating and manipulating affordance-landscapes, essential to CLA and NLP, are not shared in DL. Instead of deliberately displaying environmental traits of specific sport-related relevance (i.e., landscape of affordances), the focus is on displaying the entirety of a potential solution space (Gray, 2020, p. 2). Essentially, DL does not believe that any implicit "guidance" is needed to foster effective self-organization of motor coordination. It has therefore been argued that DL is more affected by the *complex adaptive system*-perspective than the ecological psychology-perspective (Bergmann et al., 2021, p. 3).

The aim thus far has been to theoretically and ontologically map out the ecological dynamics perspective, and its relation to skill learning in sports. A brief historical summary, consisting of the influential scientific work provided by Nikolai Bernstein and James J. Gibson has been emphasized. The reason behind this extensive mapping out of ecological dynamics, is to ensure a sound analysis of the empirical research review, with a particular focus on their associated pedagogical-/practice design approaches (CLA, NLP and DL). Based on the comprehensive historic, theoretical, and ontological review, a platform is made to interpret a wide range of factors associated with each included study. This could include independent variables (e.g., empirical actualization of DL- or CLA/NLP), contextualization of

research (e.g., laboratory or on-field research), characteristics of participants (e.g., influence of skill level or age), and perhaps most important, study findings. To this last point, how does one measure learning, defined as an improved, self-organized fit between person and environment?

4. Method

4.1 Design

The study was designed as a scoping that follows Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (see Page et al., 2021; Tricco et al., 2018), and was conducted on the 19th of October 2021. The following databases were used on the final search: PubMed, SPORTDiscus, Web of science, and PsychINFO. Mays and colleagues (2001, p. 191) describes scoping reviews as particularly useful in research areas that are either complex or have not yet been extensively reviewed. This highly inclusive approach makes it possible to pursue the aims of creating a systematic overview of a highly divergent body of research without being restricted to specific objectives, designs, or methods in the empirical research included (Sucharew & Macaluso, 2019, p. 416).

The scoping review consists of the following steps: (i) identify the research question, (ii) identify eligibility criteria and database selection (iii) conduct the search, (iv) chart the data, (v) critical appraise individual sources, and (vi) synthesize and summarize the results (Tricco et al., 2018). In the following, a detailed description of these steps will be presented with their relation to this scoping review.

4.1.2 Identifying the research question

The work on this thesis was initially about going from a field of interest (learning in sports and ecological dynamics) to a researchable format that could add something to the current field of research. Here, one of the academic supervisors (Christian Thue Bjørdal) provided

input. A form of the literature review was established as a fruitful direction, supported by an interpretation of the field of research as lacking in empirical research (Renshaw & Chow, 2019, pp. 104-105). The purpose of this scoping review became about summarizing research on skill learning in sports, which possessed three key characteristics: (i) Empirical and intervention-based research. This criterion was set so that only evidence-based-, and not opinion-based research material could be included. (ii) Research from a sporting context. This was established as a criterion to ensure that the scope of research was solely on learning and skill learning in sport. (iii) Based the research on an ecological dynamics rationale. As it turned out, the theory is often ill-defined in much of the research, and an interpretation of ontological premises for both learning as a concept, and its affiliated process was needed. A fundamental understanding of the ontological premises of the ecological dynamics theory, and a review of related pedagogical-/practice design approaches in the empirical research, resulted in the search terms used. The research question tries to encompass the considerations and reads as the following:

What characterizes empirical research on skill learning in sports from an ecological dynamics perspective, both descriptively and in terms of results?

4.1.3 Literature search

A literature search in the databases: Psycinfo, Pubmed, SPORTDiscus and Web of science was completed on the 19th of October 2021. The search included peer-reviewed academic articles written in English, published no earlier than 2000. Based on consultation with an academic supervisor (Christian Thue Bjørndal), the following terms and operators were used in each of the databases:

(sport*)

AND

("nonlinear pedagogy" OR "non-linear pedagogy" OR "constraints-led approach" OR "ecological dynamics" OR "ecological psychology" OR "ecological approach" OR "dynamical systems" OR "affordance*" OR "representative design")

Table 1.

Specification of the inclusion criteria based on theoretical-, methodological/design- or context-based criterion

Theoretical	Contextual	Methodological/design-based
- Is sufficiently in line with the ecological dynamics theory. This is reflected in the search terms.	- Sporting context, where the sport, and its context, is preserved in an inseparable and non-reductionist way. - Participants are characterized as sports practitioner s.	- Empirical. - Based on an (or several) intervention(s) that looks at effect over time (to distinguish learning from short term performance enhancement).

In the aftermath of the literature search, a mapping phase followed. This process consisted of a review of pedagogical-/practice design approaches and their connection to the ecological dynamics rationale. This was then discussed with one of the academic supervisors (Christian Thue Bjørndal), resulting in the inclusion criterion presented in table 1. The common thread was always to include only theoretically sound empirical approaches. This meant constant reviewing of both theoretical literature and the empirical research found, as well as discussions with the supervisors. In addition, the search process in the respective databases was supervised and reviewed by an academic supervisor (Jan Åge Kristensen) to ensure that the search process was conducted appropriately. The same supervisor helped oversee the use of automation tools.

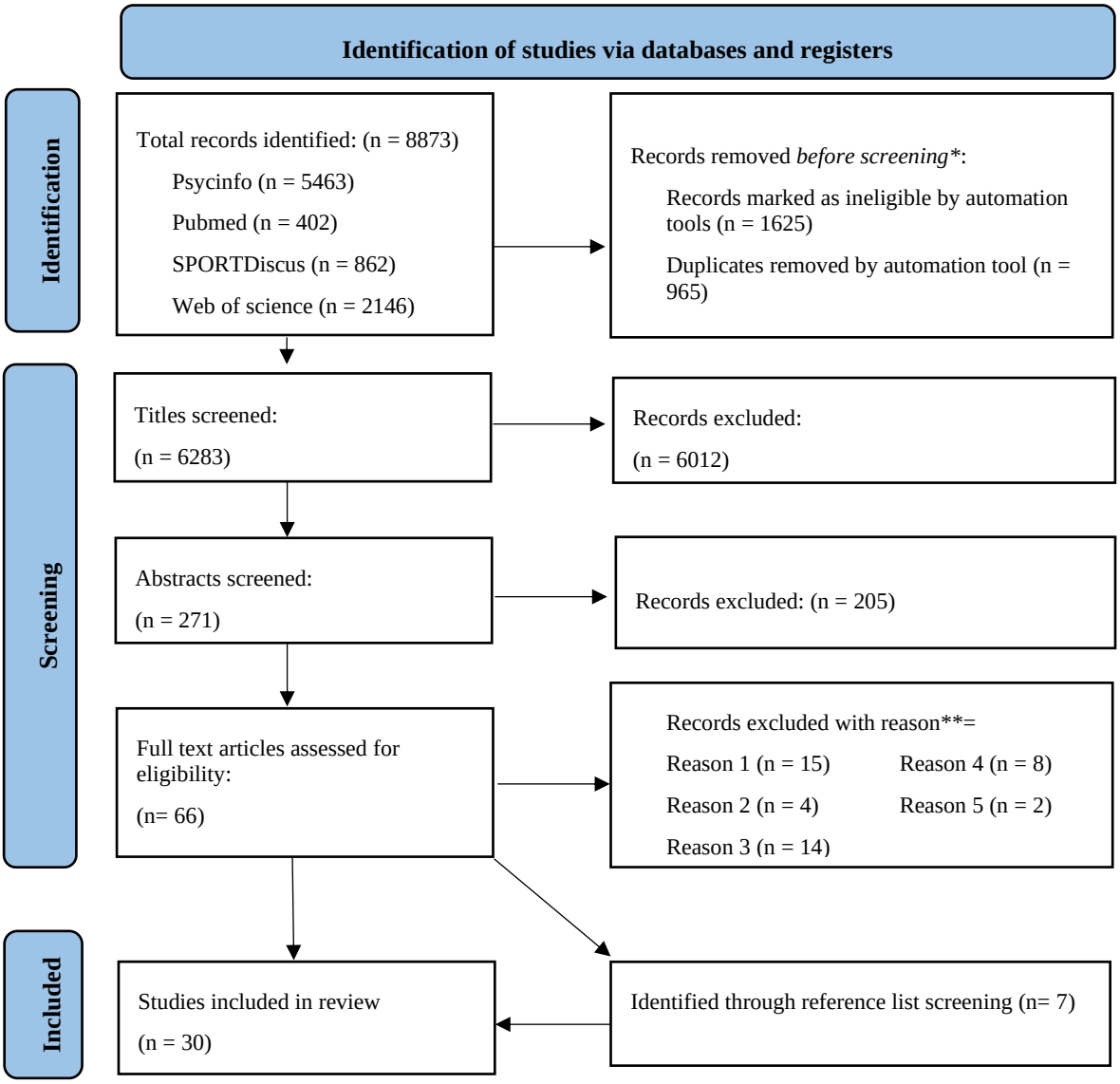
In sum, the academic supervisors oversaw the theoretical- and methodological sides of the search for articles, each having a respective field of expertise. Meetings between the three of us ensured compliance and a common direction for the process.

4.1.4 Selection of articles

After consolidating the search strategy, and with a more comprehensive overview of the pedagogical-/practice design approaches used in the empirical research, the process of selecting relevant articles could start. A schematic overview of this is presented in the flow chart in table 2, which follows the PRISMA standard (Page et al., 2021). An elaboration of the different parts of the selection and screening process will follow.

Table 2.

Prisma 2020 flow chart of the study selection process



*. Automation tools provided partly by databases software, and partly by EndNote X9 software.

** Numbered reasons for exclusion: 1: non-empirical intervention or non-sporting intervention. 2: non-sporting context (e.g., PE- or university context, "sports-like task") or outside applied settings. 3: Not looking at learning effects, at least two points

of observation needed. 4: Not based on an ecological dynamic's perspective, 5: Not published in academic journal, peer-reviewed or written in English.

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

The first step in the screening process was to apply automation tools where appropriate. This was in part via the respective databases (i.e., English language, from the year 2000 to present (19.10.2021), and peer reviewed (SPORTDiscus and PsycINFO only), and partly using EndNote (Version X9.3.1). Endnote was used to collect all articles from the respective databases in unison, and subsequently remove duplicates using an automation tool provided in the Endnote software. The remaining articles were exported from EndNote to Microsoft Excel (office 2016 version) for more accessible manual screening. The Excel file is found here: https://1drv.ms/x/s!AqH0Jyc-0PuYhSbU--63SouZNTNG?e=8U0iij. The preliminary screening step is to look through the headlines and exclude those that lack relevance to the research question. Excluding articles at this point was limited to context (e.g., explicitly stating a PE-context, or non-sporting research focus) or methodological/design-based (e.g., explicitly stating the article as a systematic review or discussion-article). Theoretical exclusion required a more thorough investigation of the theory applied for each separate article.

Next, the remaining articles were screened by reading through the abstracts. This gave additional information about context, methodology/design, and theory, which could be matched with the inclusion criteria. As a result, 66 articles passed through this screening process and were entirely read. These articles were also the subjects of a reference list screening, resulting in the addition of 7 extra articles: Farrow and Reid (2010); Hossner et al. (2016); Lee et al. (2014); Santos et al. (2018); Savelsbergh et al. (2010); Schollhorn et al. (2012); Schöllhorn et al. (2010).

The final part of the screening process consisted of matching the remaining articles with the inclusion criteria. In instances where inclusion was seen as challenging, the academic supervisors provided consultation. Most of of these cases were about theoretical considerations and interpretations. Based on these discussions with academic supervisor (Christian Thue Bjørndal) practices like “Teaching games for understanding”, “skill4genius” and solely explicit and implicit learning strategies (see Masters & Maxwell, 2008) were excluded. It was decided to include Differential learning, a Constraints-led approach and Nonlinear pedagogy. Mainly, the exclusions were based on their lack of overall compliance with the ecological dynamics rationale.

Some additional factors also needed contemplation and consultation with the supervisors. One factor was the length of intervention in relation to deeming something as learning or merely a short-term (performance) effect. At least two distinct, and time-separated points of observation were added as an inclusion criterion to capture learning effects only. Another was the characteristics of the participants. The use of sports practitioner s, and not for examples students or people in rehabilitation was set as an inclusion criterion. This was justified on the basis that for these participants, a more narrowed focus on learning could be inferred. Lastly, some articles measured variability in either movement output or in the practice design in isolation. In such cases the articles were excluded on the basis that this metric is not a consistent or reliable measurement of skill learning per se, at least without a reference to behavioral change over time and some sort of correlation to performance.

4.1.5 Charting results

This thesis aims to characterize an empirical body of research in a broad sense. Predetermined variables and subsequent categorization of these were not possible due to the novelty of this scoping review. As a start, descriptive metrics such as year of publication, study design, study context, sample specifications, type of sport, intervention specifications and theoretical

foundation were mapped out for all the articles. This provided a starting point to look for trends in the literature.

At this point it became apparent that two supplementary categorizations could provide clarity and make the charting more informative. The first categorization was to divide the articles into tactical/collective learning or learning on an individual technical skill-basis. Although overarching principles like constraints-led-, affordance driven- or self-organized learning was seen across studies irrespective of individual- or collective learning, the specification, operationalization, and measurements used were often different. As an example, the way organization of the movement apparatus on a climbing wall, and the organization of relational movement on a football field could both be seen as self-organized, but their operationalization as coordinative structures (see Kugler et al., 1980) or synergies (see Araujo & Davids, 2016) made common charting problematic. The categorization based on individual technical skill- and collective/tactical learning made sense as it helped describe how ecological dynamics has been applied in research, as well as being an effective backdrop for summarizing empirical results. The second categorization was tied to the research as either using a comparative or non-comparative design. The difference in research rationale, -design and -methodology is reflected in the qualitative appraisal tool used (MMAT) (Hong et al., 2018).

Using tables (see **Supplementary material 1** in appendix), relevant descriptive information was collected, categorized, and presented. Theoretical foundation or the pedagogical-/practice design approach (CLA, NLP or DL) is a common thread regardless of categorization and subsequent placement in the different tables. It should be noticed that these descriptive characterizations of the studies included are, one the one hand a product of the methodology used (PRISMA), and on the other hand a product of inference. Such a combination was needed since it was highly difficult to predict what sort of studies would derive from the structured literature search. All studies are present in two tables, reflecting

both collective/tactical learning or learning of individual technical skill, and comparative or non-comparative design (see **Supplementary material 1** in appendix).

4.1.6 Methodological quality assessment

A methodological quality assessment was done through the use of Mixed Methods Appraisal Tool (MMAT) developed by Hong et al. (2018). The MMAT permits methodological quality assessment of five study categories: qualitative research, randomized controlled trials, non-randomized studies, quantitative descriptive studies, and mixed methods studies (Hong et al., 2018, p. 1). The tool consists of two general questions and five design-specific questions. This leads to a score between 0 and 7. However, it is advised to provide a more detailed presentation of the ratings of each criterion, since this often leads to a more comprehensive quality assessment (Hong et al., 2018, p. 1). The ambition of the MMAT is not to provide or suggest the overall 'quality' of a research paper (e.g. quality of writing or conclusions), it's area of use is to indicate methodological quality based on pre-determined criteria (Gledhill et al., 2017, p. 103). MMAT was selected since it has been recognised as the most reliable appraisal tool for mixed methods research (Crowe & Sheppard, 2011). The details of the MMAT assessment are to be found in the results-part.

The methodological appraisal should be seen in relation to the overall quality assessment, whereby a discussion regarding the congruence between ontological description of skill and learning, and the ways this has been contextualized and measured, is central. The merging of theoretical and methodological assessment is perhaps unconventional but was seen as a necessity since a "proper" application of theory stands as vital in this review. The linking between theory and qualitative appraisal was furtherly practiced by not only categorizing and comparing studies of different methodological designs, but also categorizing and comparing the different approaches tied to the ecological dynamics perspective in general (DL, CLA, and comparison studies).

One vital weakness in relation to quality assessment, especially with regards to MMAT, is that it's advised to have at least two researchers independently appraising the material. This was not possible due to a lack of human resources. However, an academic supervisor guided and oversaw the appraisal process (Jan Åge Kristensen). In situations of uncertainty, specific articles and aspects of articles were explicitly discussed in person. Both supervisors looked over and verified the combined quality assessment (MMAT and examination of theoretical and empirical congruence).

4.1.7 Summary, synthesis, and analysis

The synthesizing of results resulted in four different tables, reflecting perspectives on learning (collective/tactical or individual) and overarching design/methodological approach (comparative or non-comparative). In these tables a wide range of descriptive factors are collected and systemized (see **Supplementary material 1** in appendix). The tables provide a condensed and clear overview of the research material. The affiliated approaches provide context, elaboration, and an analytical prism to interpret these metrics. The analysis aims to characterize the empirical research, as well as looking at how these characteristics have occurred through specific research practices. By taking such an approach, it is hopefully possible to excrete general characteristics from a complex, multi-facetted and varied body of empirical literature.

Taken together, the methodological approach in this scoping review finds methodological structure from the PRISMA guidelines and standardized quality assessment through MMAT. Other than that, a high degree of inference was needed to capture characterizations that reflects the intersection between theory, methodology and results. The focus in this thesis is to extract empirical manifestations of the ecological dynamics perspective in learning in sports. Consequently, the focus is more on descriptive variables than an in-depth validation of results from a statistical or methodological point of view.

5. Results

A decision was made to direct attention to two sides of the studies reviewed. Firstly, this includes a mapping out of relevant descriptive variables. This provides context for each study included. Some variables are given extra importance, and will be presented in figure 1, 2, 3 and 4 below. These study characteristics are: (i) pedagogical-/practice design approach (DL or CLA), (ii) contextual descriptive factors like type of sport, and individual differences such as skill level, gender, and age, and (iii) quality assessment (MMAT) and other methodological variables of importance.

A review of study results and findings will follow. Here, a form of synthesizing based on overall study objective will be provided. For clarity purposes, a downscaled and modified version of the tables will be presented. The main variables being looked at here are the independent- and outcome variables, as well as the contextualization of study. A full display of all variables collected are found in **Supplementary material 1** located in the appendix.

5.1 Review of descriptive variables

5.1.1 Pedagogical-/practice design approaches

Ecological dynamics-related pedagogical-/practice design approaches were categorized into either, Constraints-led approach, with or without an additional reference to Nonlinear pedagogy, or based on Differential learning. Studies that compared a CLA and DL in the same study will be commented separately.

All the DL studies used a comparative design. Two of the studies looked at collective behavior-based learning (Coutinho et al., 2018; Santos et al., 2018), and four studies looked at an individually based skill.

A range of different DL protocols were used in the studies included. Some examples are 40 different way to start in speed skating (Savelsbergh et al., 2010), different

specifications for arm-, knee-, trunk- or elbow position in hurdle running (Schöllhorn et al., 2010), or structured variations in ball kicking with references to supporting leg, kicking foot, trunk position, approach, kicking movement or the ball (Hossner et al., 2016; Schollhorn et al., 2012). Two last studies, Coutinho et al. (2018); Santos et al. (2018) used a DL-inspired intervention based on a form of Small Sided Games (SSG). The specifies of the DL protocol in these studies included variations of number of players on each team, pitch size, -turf, or -shape, type of ball, and playing rules. Additionally, visually perturbing glasses and physical barriers on the field got used. In sum, all variations found in the six studies were aimed at creating a non-repetitious protocol where participants could experience a wide range of possible solutions for a specific task. Importantly, none of the DL-studies gave any form of feedback on movement, but most of the DL studies promoted the movement variation by means of instruction (Hossner et al., 2016; Savelsbergh et al., 2010; Schollhorn et al., 2012; Schöllhorn et al., 2010).

Among the 21 studies based purely on a CLA protocol, nine of them used a non-comparative design, and 12 used a comparative design. Seven looked at a collective skill, while 14 studies investigated an individual technical skill.

In the CLA-studies a large number of task-, individual- and environment related constraints-manipulations were used. Among the three categories, task-related constraints were most frequently used. Within this category, seven out of the 21 studies explicitly referenced Nonlinear pedagogy (NLP) as a pedagogical tool used in addition to a CLA. Naturally, these studies emphasized the role of the coach, and his/her influence on the learning outcome of practice. Lee et al. (2014), and six other studies (Pizarro et al., 2019; Pizarro et al., 2020; Práxedes et al., 2019; Praxedes et al., 2018b; Ramos et al., 2020a; Ramos et al., 2020c) investigated the effect of following NLP- or CLA-based pedagogical principles. The last six also used tactical- or game principles to guide their instructional- or other task-related constraints. Importantly, such an approach is highly dynamical in its specific

expression, since the overall principle is to account for the dynamical and non-linear nature of individuals and teams, and their learning process. Appropriate use of NLP is therefore defined in a case-by-case fashion. The makeup of each individual learner or team is a fundamental starting point as to "cater for individual complexities and dynamic learning environments" (Lee et al., 2014). It should be mentioned that all the aforementioned studies ensured compliance of CLA/NLP principles by either having a "CLA-expert" observing the intervention and/or educate the sports pedagogues prior to the intervention. The evaluation of compliance was subjective, and the CLA-expert were used more as a sparring partner than an external "quality assessor".

Five studies modified equipment as a constraints-manipulation. These came in the form of alternative field hockey stick or -ball, Brocken et al. (2021); Brocken et al. (2020), tennis racket (Lee et al., 2014), ball specifics (type or ball compression) (Farrow & Reid, 2010), or as part of non-sport specific modified games (Roberts et al., 2020). All of the climbing studies (n=4) modified the task by altering the orientation of grips (horizontal, vertical or both on the same hold). Gray (2018) virtually manipulated the baseball environment by putting up a barrier for the batters to hit over.

The level of opponent was manipulated in eight of the 21 CLA-studies. Krause et al. (2019) and Dicks et al. (2016) altered this by serving against an opponent or an empty court in tennis, or meeting one or three potential penalty takers in one penalty shoot, respectively. Six studies (Pizarro et al., 2019; Pizarro et al., 2020; Práxedes et al., 2019; Praxedes et al., 2018a; Praxedes et al., 2018b; Roberts et al., 2020) altered the level of opposition by putting the attackers in futsal or association football in numerical superiority.

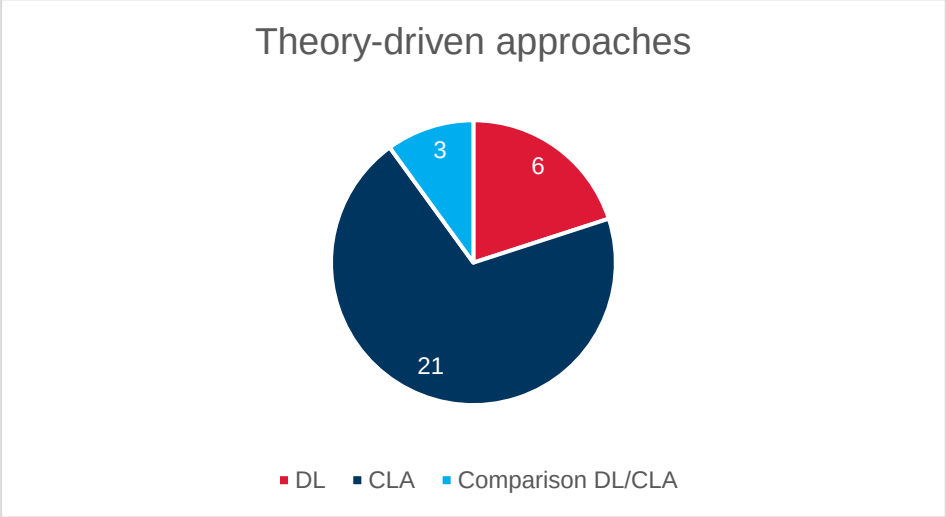
Lastly, a popular set of manipulations was to change the nature of the task. This came in the form of alternative task goals, -scoring format, -rules or -playing area. 10 studies explicitly used one or more of these manipulations. In addition to being guided by game/tactical- or CLA/NLP principles, these manipulations were often changed in reference

to the skill level of the participant(s) and the complexity of the behavior/skill being practiced. A concrete example can be found in Lee et al. (2014) who manipulated net height, target area, court size, and rules in accordance to both the nature of the skill (backhand vs forehand strokes) and the participant's individual skill level (based on performance score and technical "milestones").

In the studies comparing DL- and CLA protocols (Garcia-Herrero et al., 2016; Gray, 2020; Orangi et al., 2021), a comparative design was used. These studies looked at an individual technical skill within a team sport setting. The DL protocols in these studies consisted of a combination of variability stemming from body positions, bat position and the nature of the pitching (Gray, 2020, p. 5), or active prescription to maximize movement variability in technical practice exercises in association football (Orangi et al., 2021, p. 4). The CLA protocol consisted of a "swing path barrier", "stepping barrier" and a "connection ball" (see Gray, 2020, p. 4) or promoting movement through the use of unprescribed instruction/feedback and a variety of constraints manipulation (see Orangi et al., 2021, p. 4). Lastly, Garcia-Herrero et al. (2016) referenced DL and CLA, but ended up measuring the effect of repetitious- or induced variability protocols. According to Gray (2020); Orangi et al. (2021), this is not what differentiates the two approaches. Movement variability is promoted and encouraged in both DL and CLA, but the way this is created (prescribed before the execution (i.e., DL) or constraints/affordance-driven (i.e., CLA) is where the differences are found. Garcia-Herrero et al.'s (2016) study has still been included, but it should be noted that this difference in theoretical interpretation of DL exists among the three comparison-studies reviewed.

Figure 1.

An overview of the theoretical approaches used



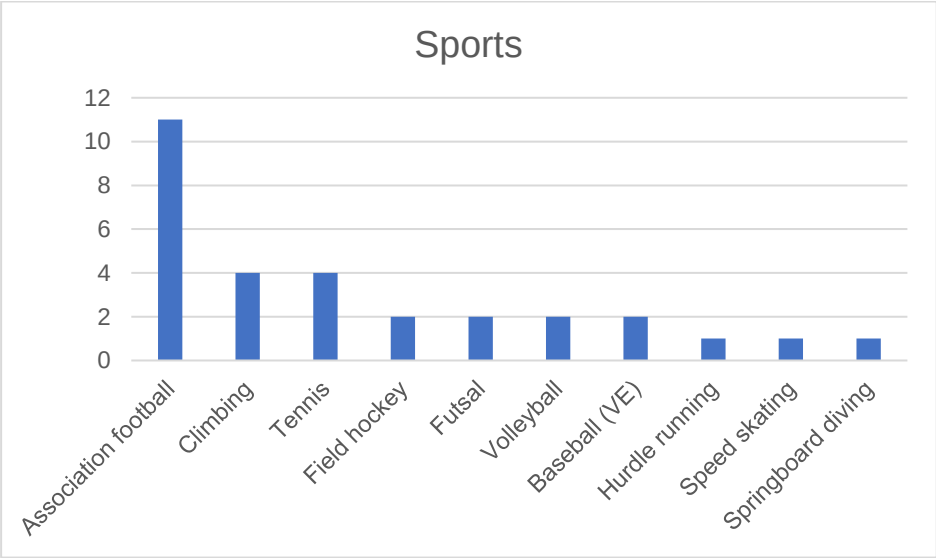
5.1.2 Types of sport

A total of 10 different sports were used in the 30 articles included. Association football (n=11) were most frequently used, followed by climbing (n=4) and tennis (n=4). Field hockey, futsal, volleyball, and baseball were used in two studies each, while hurdle running, speed skating and springboard diving were represented with a single study. As shown in tables found in the appendix (**Supplementary material 1)**, nine of the 30 studies looked at learning on a collective behavior scale and were therefore using team sports (association football (n=5), volleyball (n=2), futsal (n=2)). 10 additional studies within a team sport setting looked at skills that were framed as individual. These studies primarily focused on the learning of sport-specific techniques. 11 studies used an individual sports setting to conduct research on learning. Almost all studies conducted both the intervention and the testing in the respective sports "natural" setting (e.g., association football field, speed skating ice rink or indoor climbing wall). Two exceptions were identified in Gray (2018, 2020) who used a virtual environment-setting.

In the categorization of DL-, CLA- or studies comparing DL and CLA in the same study, we see that DL studies (n=6) used the context of association football in four studies, speed skating once and hurdle running once. Santos et al. (2018) looked at collective learning in the form of creative and tactical behavior, while Coutinho et al. (2018) looked at individual physical, technical and creative behaviors. The distribution of sports in CLA-studies was as follows: association football (n=5), baseball (n=1), as well as the totality of climbing-, tennis-, volleyball-, field hockey-, futsal- and springboard diving studies included. Four out of five association football studies, two out of two futsal studies and two out of two volleyball studies looked at a collective behavior that had either an offensive- or defensive team-based focus. The rest of the CLA-studies (n=13) looked at an individually based skill. The final category, comparison studies (DL versus CLA), used association football twice and baseball once. All these studies conceptualized their skill of interest as an individual technical skill.

Figure 2.

An overview of sports of study



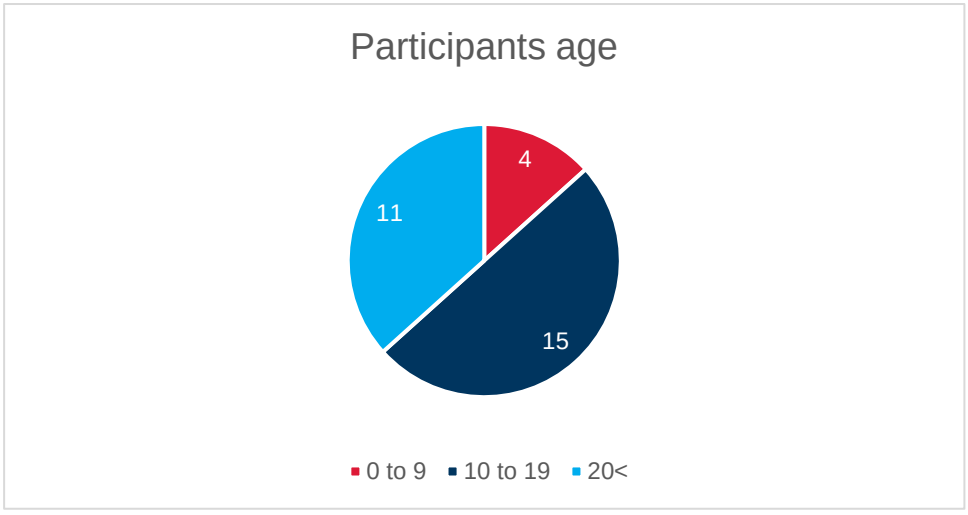
5.1.3 Age groups

The participant's age got categorized into three categories: (a) children (0-9 years of age), (b) older kids/adolescents (10-19 years of age) and (c) adults (20< years of age). Each study was classified based on the mean age of the participants. Almost all the studies used samples which differed no more than four years. Two exceptions were Savelsbergh et al. (2010), where the age range was 44,2±9,8, and Orth et al. (2018), where the novice group was 20,9±5,5 and the experienced group was 24,9±4,7. It can therefore be said that the age profile in the majority of the studies were highly homogenous. A total of four studies included children, 15 studies used participants in adolescence, while 11 studies used adults.

By relating age profile to pedagogical-/practice design approach, we see that all studies (n=4) using children (0-9 years) are CLA-studies. In the comparison studies, two out of three used adult participants, while the majority of DL- and CLA-studies used older kids/adolescent participants.

Figure 3.

An overview of age groups



Note. Numbers are based on mean age for each study.

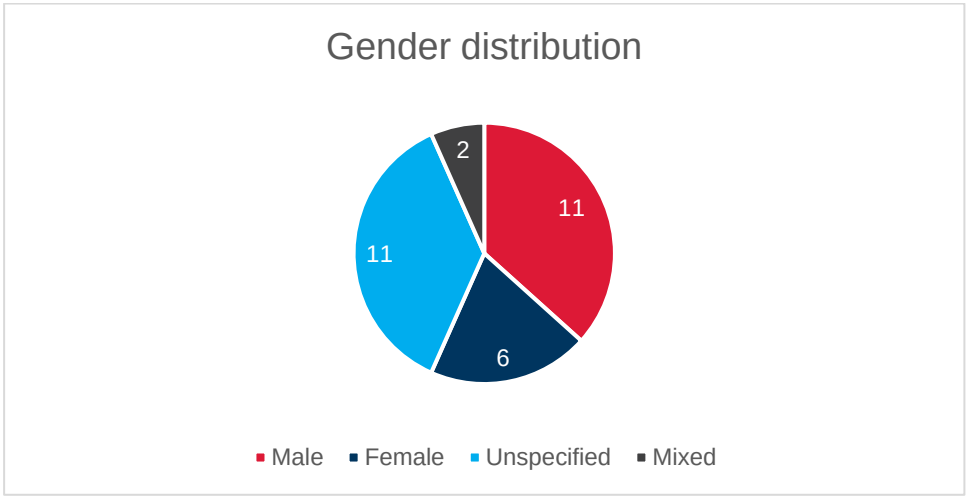
5.1.4 Gender

The distribution of gender used shows a tendency towards using male participants (n=11) over female participants (n=6). A total of 11 studies did not specify the gender of the participants, and two studies used a mixed sample.

If we look at the respective studies and their affiliation to DL, CLA or comparison between the two, we see that all studies using female or mixed participants are CLA-studies (n=6). Additionally, we see that irrespective of pedagogical-/practice design approach, a substantial number of studies do not specify the gender of their participants (DL (n=3), CLA (n=7) and comparison studies (n=1)).

Figure 4.

An overview of gender



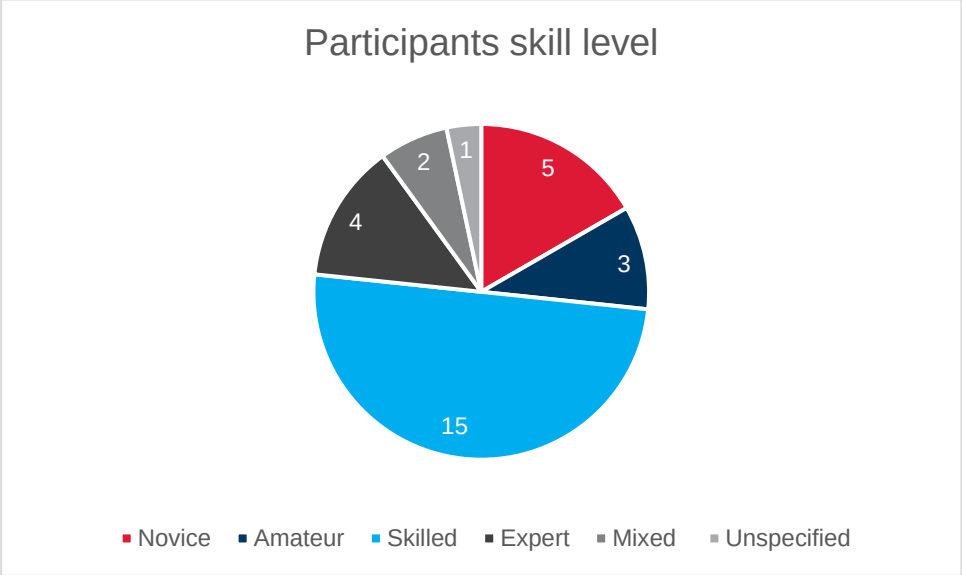
5.1.5 Skill level

The participants in the respective studies differed extensively in terms of skill level. Again, a general categorization was made. This time the categories were: novice (n=5), amateur (n=3), skilled (n=15), expert (n=4) or mixed (n=2). One additional study did not classify the skill level of the participants (Schöllhorn et al., 2010). It is important to remember that the categories used above are no more than indicative of the skill of the participants. Researchers rated skill level based on competition level, participant's experience, or subjective evaluation from researchers or external coaches. The evaluation of skill is therefore non-standardized and relativistic (e.g., age, competitiveness based on sport or geographic area). Four notable exceptions of this are the climbing studies (Orth et al., 2014; Orth et al., 2018; Seifert et al., 2015; Seifert et al., 2018) in which French Rating Scale of Difficulty (F-RSD) were used to estimate skill level of participants.

The skill level of the participants where evenly distributed over DL-, CLA-, and comparison studies. Some notable points are that three out of four studies using expert participants (the last was a comparison study), and all studies using participants of different skill level (n=2), were CLA-studies.

Figure 5.

An overview of participant's skill level



Note. A group-masked assessment of skill level was used in most studies.

To summarize the studies based on contextual factors characteristics (type of sport, gender-, age- and skill level of participants) and pedagogical-/practice design approach, it is apparent that the CLA-studies are the most diverse. This is reflected in the fact that they are alone in using female participants, using children, and having a mixed skill level within the same study. In addition, this category includes the largest number of different sports (n=8). A substantial part of this is that CLA-studies outnumber the other categories extensively (DL=6, CLA=21, comparison=3).

5.1.6 MMAT quality assessment

The MMAT enables a shared methodological assessment for five study categories (qualitative, qualitative randomized, quantitative non-randomized, quantitative descriptive and mixed methods). However, quantitative descriptive and mixed methods were excluded from the table since none of the studies included fit in these two categories. One study, Ramos

et al. (2020a) was qualitative, nine studies were quantitative randomized studies, while the rest (n=20), were non-randomized quantitative studies.

The qualitative study, Ramos et al. (2020a), fulfilled all requirements in the MMAT and was subsequently given a 100% score. This study applied a CLA in their intervention.

The nine quantitative randomized studies all fulfilled the criteria for point 2.1 (appropriate randomization) and 2.2 (comparable groups at baseline). Point 2.3 (completeness of outcome data) gave a total percentage of 77. This criterion was not met by Santos et al. (2018) and Schollhorn et al. (2012). The former analyzed under 1/3 of each session, and the latter had a drop out of 50%. Point 2.4 (blinding assessors) was only met by Lee et al. (2014), making it 11% of the total. In Lee et al. (2014), a trained research assistant conducted the analysis. For point 2.5 (participants adherence to intervention) was met by 88% of the studies, with the only exception being Santos et al. (2018) where drop-out information was not provided. The grand total for all the quantitative randomized studies is 75,5%, and the range was from 100% (Lee et al., 2014) to 40% (Santos et al., 2018).

Santos et al. (2018) and Schollhorn et al. (2012) were based on a DL approach, and fulfilled 50% of the criteria. All the studies comparing DL and a CLA (Garcia-Herrero et al., 2016; Gray, 2020; Orangi et al., 2021) were quantitative randomized studies, and produced a total of 80%. Four CLA-studies (Fitzpatrick et al., 2018; Gray, 2018; Lee et al., 2014; Roberts et al., 2020) fell into this category, and produced a grand total of 85%.

Among the quantitative non-randomized studies (n=20) criterion 3.1 (representativeness of participants towards target population), 3.2 (appropriateness of measurements) and 3.5 (intervention administered as intended) was met by all 20 studies. Point 3.3 (completeness of outcome data) gave a total of 70%. This criterion was not met by Schöllhorn et al. (2010) or Pizarro et al. (2020) who did not provide the relevant information. The same was true for Brocken et al. (2021); Brocken et al. (2020); Savelsbergh et al. (2010)

who had 19%, 21% and 21% drop out respectively, or Coutinho et al. (2018) who lost a recording (match) due to technical difficulties in combination with only analyzed parts of the matches or training sessions recorded. Point 3.4 (accounting for confounders in design and analysis) gave a total of 60%. Coutinho et al. (2018) did not met the criterion due to the intervention only being a marginal part of the total of practice volume, Pizarro et al. (2019); Pizarro et al. (2020); Práxedes et al. (2019); Praxedes et al. (2018a); Praxedes et al. (2018b); Ramos et al. (2020c) did not account for the level of opposition, and Praxedes et al. (2018a) additionally did not account for the fact that the groups were based on different training groups. The grand total for quantitative non-randomized studies is 86%. Five studies ended up with a score of 100%, and the lowest score was Pizarro et al. (2020) who was given 60%.

In relation to their theoretical backdrop, the four DL studies: Coutinho et al. (2018), Hossner et al. (2016), Savelsbergh et al. (2010) and Schöllhorn et al. (2010) gave to total of 85% and the CLA-studies (n=16) gave a total of 87,5%.

If we summarize alle the studies and categorized them based on DL-, CLA- or comparison studies, we see that DL studies (n=6) gives a total of 73,3%, CLA-studies (n=21) gives a total of 83,8% and comparison studies (n=3) gives a total of 80%.

Table 3.

Overview of questions from Mixed Methods Appraisal Tool (MMAT) (Hong et al., 2018)

Screening questions (for all types)	**Qualitative**	**Quantitative randomized controlled trials**	**Quantitative non-randomized**	**Quantitative descriptive**	**Mixed methods**
S1. Are there clear research questions?	1.1. Is the qualitative approach appropriate to answer the research question?	2.1. Is randomization appropriately performed?	3.1. Are the participants representative of the target population?	4.1. Is the sampling strategy relevant to address the research question?	5.1. Is there an adequate rationale for using a mixed methods design to address the research question?
S2. Do the collected data allow to address the research questions?	1.2. Are the qualitative data collection methods adequate to address the research question?	2.2. Are the groups comparable at baseline?	3.2. Are measurements appropriate regarding both the outcome and intervention (or exposure)?	4.2. Is the sample representative of the target population?	5.2. Are the different components of the study effectively integrated to answer the research question?
	1.3. Are the findings adequately derived from the data?	2.3. Are there complete outcome data?	3.3. Are there complete outcome data?	4.3. Are the measurements appropriate?	5.3. Are the outputs of the integration of qualitative and quantitative components adequately interpreted?
	1.4. Is the interpretation of results sufficiently substantiated by data?	2.4. Are outcome assessors blinded to the intervention provided?	3.4. Are the confounders accounted for in the design and analysis?	4.4. Is the risk of nonresponse bias low?	5.4. Are divergences and inconsistencies between quantitative and qualitative results adequately addressed?
	1.5. Is there coherence between qualitative data sources, collection, analysis, and interpretation?	2.5 Did the participants adhere to the assigned intervention?	3.5. During the study period, is the intervention administered (or exposure occurred) as intended?	4.5. Is the statistical analysis appropriate to answer the research question?	5.5. Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?

From: Hong QN, Pluye P, Fàbregues S, Bartlett G, Boardman F, Cargo M, Dagenais P, Gagnon M-P, Griffiths F, Nicolau B, O'Cathain A, Rousseau M-C, Vedel I. Mixed Methods Appraisal Tool (MMAT), version 2018. Registration of Copyright (#1148552), Canadian Intellectual Property Office, Industry Canada.

Table 4.

Methodological quality assessment based on Mixed Methods Appraisal Tool, version 2018

Study	Screening questions		Qualitative studies					Quantitative randomized controlled trials					Quantitative non-Randomized					Over all quali	Quality score (%)
	S1	S2	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5		
(Barris et al., 2014)	✓	✓											✓	✓	✓	✓	✓	5	100%
(Brocken et al., 2021)	✓	✓											✓	✓		✓	✓	4	80%
(Brocken et al., 2020)	✓	✓											✓	✓		✓	✓	4	80%
(Coutinho et al., 2018)	✓	✓											✓	✓			✓	3	60%
(Dicks et al., 2016)	✓	✓											✓	✓	✓	✓	✓	5	100%
(Farrow & Reid, 2010)	✓	✓											✓	✓	✓	✓	✓	5	100%
(Fitzpatrick et al., 2018)	✓	✓						✓	✓	✓		✓						4	80%
(Garcia-Herrero et al., 2016)	✓	✓						✓	✓	✓		✓						4	80%
(Gray, 2018)	✓	✓						✓	✓	✓		✓						4	80%
(Gray, 2020)	✓	✓						✓	✓	✓		✓						4	80%
(Hossner et al., 2016)	✓	✓											✓	✓	✓	✓	✓	5	100%
(Krause et al., 2019)	✓	✓											✓	✓	✓	✓	✓	5	100%
(Lee et al., 2014)	✓	✓						✓	✓	✓	✓	✓						5	100%
(Orangi et al., 2021)	✓	✓						✓	✓	✓		✓						4	80%
(Orth et al., 2014)	✓	✓											✓	✓	✓	✓	✓	5	100%

Study	Screening questions		Qualitative studies					Quantitative randomized controlled trials					Quantitative non-Randomized					Over all quali	Quality score (%)
(Orth et al., 2018)	✓	✓											✓	✓	✓	✓	✓	5	100%
(Pizarro et al., 2020)	✓	✓											✓	✓			✓	3	60%
(Pizarro et al., 2019)	✓	✓											✓	✓	✓		✓	4	80%
(Práxedes et al., 2019)	✓	✓											✓	✓	✓		✓	4	80%
(Praxedes et al., 2018a)	✓	✓											✓	✓	✓		✓	4	80%
(Praxedes et al., 2018b)	✓	✓											✓	✓	✓		✓	4	80%
(Ramos et al., 2020a)	✓	✓	✓	✓	✓	✓	✓												
(Ramos et al., 2020c)	✓	✓											✓	✓	✓		✓	4	80%
(Roberts et al., 2020)	✓	✓						✓	✓	✓		✓						4	80%
(Santos et al., 2018)	✓	✓						✓	✓									2	40%
(Savelsbergh et al., 2010)	✓	✓											✓	✓		✓	✓	4	80%
(Schöllhorn et al., 2010)	✓	✓											✓	✓		✓	✓	4	80%
(Schollhorn et al., 2012)	✓	✓						✓	✓			✓						3	60%
(Seifert et al., 2015)	✓	✓											✓	✓	✓	✓	✓	5	100%
(Seifert et al., 2018)	✓	✓											✓	✓	✓	✓	✓	5	100%
Percentage of studies that met relevant criteria	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	77 %	11 %	88 %	100 %	100 %	70 %	65 %	100 %		

Note. Questions from group 4 (Quantitative descriptive studies) and group 5 (Mixed methods studies) excluded. No studies of these characteristics included in this review. Table content and structure inspired by Hong et al. (2018).

5.1.7 Additional Methodological characteristics

Among the 30 studies it was identified that nine studies used a single group design. The mean number of participants for the comparative studies were 34,9, whilst the same number for non-comparative studies were 10,4. The range of number of participants was from four participants in Barris et al. (2014), to 129 (102 for the analysis) in Brocken et al. (2020). 10 out of 30 (all comparative studies) used a randomization strategy when assigning to intervention group(s) or control group, meaning that 11 studies used a from of convenience selection (e.g., using already existing teams or groups or dividing based on skill level/age).

21 studies used a comparative design where two (n=11), three (n=6) or four (n=4) groups were used. Eight of the studies using a comparative design, applied some form of retention test (Brocken et al., 2021; Garcia-Herrero et al., 2016; Gray, 2018, 2020; Hossner et al., 2016; Lee et al., 2014; Práxedes et al., 2019; Schollhorn et al., 2012). The intervention in various control group varied extensively, and further information about this is provided in the tables in the **Supplementary material 1** found in the appendix. It should be noted however that only Savelsbergh et al. (2010) and Gray (2020) included a non-training control group, and that only Gray (2018, 2020); Hossner et al. (2016); Orangi et al. (2021); Roberts et al. (2020) explicitly stated the control group's theoretical foundation. In all instances this was tied to the information processing approach (see *introduction*) or external/internal focus of attention (Gray, 2018) The rest of the studies that used a comparative design defined the control group(s) as "traditional" or conceiving participants as linear systems (for an example, see Lee et al., 2014).

Seen as a whole, it was identified that 14 studies incorporated the intervention within an already existing training group (Dicks et al., 2016; Farrow & Reid, 2010; Fitzpatrick et al., 2018; Gray, 2018, 2020; Hossner et al., 2016; Lee et al., 2014; Orangi et al., 2021; Orth et al., 2014; Orth et al., 2018; Savelsbergh et al., 2010; Schöllhorn et al., 2010; Seifert et al., 2015; Seifert et al., 2018), while the rest of the studies established the training group/context for the

sole purpose of the study (n=16). A consequence of being incorporated into an already existing training regime was that participants in these studies often had considerable amount of practice outside the study intervention, which in all instances was not controlled for. Exception of this was found in seven studies that incorporated their intervention in all the participant's practice activities (Barris et al., 2014; Pizarro et al., 2019; Pizarro et al., 2020; Práxedes et al., 2019; Praxedes et al., 2018b; Ramos et al., 2020a; Ramos et al., 2020c). In the wake of these different intervention practices, it is noteworthy that the magnitude of the intervention ranged from 12 distinct attempts at a climbing route in Orth et al. (2014); Orth et al. (2018); Seifert et al. (2015), to a total of 148 practices sessions (120 minutes each) and 32 competitive league games in Ramos et al. (2020a); Ramos et al. (2020c). Number of sessions, session length and total intervention duration varied extensively.

The outcome variable used to measure learning varied considerably. In this thesis, they have been categorized as either "direct" (performance) or "indirectly" (a variable that is proposed to be indicative of an effective learning process, but is not related to performance pr se). The specific variable used for each study is found in **Supplementary material 1** provided in the appendix. The direct measurements included among others: time spent on skill course or hurdle running/speed skating sprint, different types of accuracy scores for technical execution, counting successful actions (e.g., pass being received by team mate, shoot leading to goal), testing physical variables (e.g., sprint speed, vertical jump) and counting number of fails (e.g., falling off climbing wall or loosing the ball in association football or futsal). Indirect variables included among others: counting creative actions, movement variability often as kinematically described, exploratory actions in climbing, interpersonal distances between team mates and opponents, and tactical awareness expressed through behavior or verbally.

The different ways to obtain the outcome variables (learning metrics) included the use of constructed skill tests (n= 10), systematic observation in practice or competition (n= 17), a

combination of the two aforementioned (Fitzpatrick et al., 2018; Krause et al., 2019), or semi-structured interviews (Ramos et al., 2020a). This is furtherly presented in table 5, 6 and 7 and in **Supplementary material 1** found in the appendix. Notable with regards to the systematic observations is that the studies from Praxedes and collogues and Pizarro and collogues used Game Performance Evaluation Tool (GPET) (García López et al., 2013). Farrow and Reid (2010); Fitzpatrick et al. (2018); Lee et al. (2014) used the experimental knowledge of one or several qualified coach(es) to evaluate match-play or technical proficiency. Ramos et al. (2020c) used a cluster-phase method adopted from Ribeiro et al. (2019). Coutinho et al. (2018); Santos et al. (2018) used Creative Behavior Assessment in Team Sports (CBATS) adopted from Santos et al. (2017), while Orangi et al. (2021) used a similar approach, but used Caso and van der Kamp (2020)'s operationalization of creative actions. Barris et al. (2014); Orth et al. (2014); Orth et al. (2018); Seifert et al. (2015) was mainly interested in movement variability. Here, the data collection consisted of collecting different kinematic variables and different "types" of behavior (e.g., "explanatory" of "performatory"). Seven studies did the observations in a competitive setting (Pizarro et al., 2019; Pizarro et al., 2020; Práxedes et al., 2019; Praxedes et al., 2018a; Praxedes et al., 2018b; Ramos et al., 2020a; Ramos et al., 2020c), while the rest of the studies constructed a context that tried to replicate the dynamic nature or the sports competitive form (e.g., Orangi et al., 2021), or used more or less decontextualized skill tests (e.g., Brocken et al., 2021; Brocken et al., 2020).

5.2 Review of study results and findings

In addition to the presentation of various descriptive variables, a presentation of study results is appropriate. Main results are narratively presented in table 5, 6 and 7 and more comprehensively in the tables named **Supplementary material 1** located in the appendix. In the process of summarizing results, it was realized that the 30 studies followed one out of three lines of inquiry. Specifically, it was found that 15 studies investigated the effect of predetermined practice design protocols that were either DL- or CLA/NLP-based. 10 studies

investigated the effect of coaching behavior that were guided by different CLA or NLP-based pedagogical- or practice design principles, with or without the guidance of sport-specific tactical principles. The last five studies were mostly interested in investigating the *process* of learning. Table 5, 6 and 7 is provided to reflect the studies respective "line of inquiry". For context, it was deemed appropriate to provide the following information about the studies: (i) theoretical framework in the form of DL- or a CLA affiliation, and the derived practice design- or pedagogical principles used, (ii) the content or "nature" of the intervention, which consists of information about environmental context used in both the intervention and the testing situation, and (iii) the variables used to measure learning (direct or indirect). It should be noted that because of the divergence found among the studies, an overall presentation has its limits and must be interpreted with a certain degree of reservation. The synthesizing done should be interpreted as a gross overview of research practices.

5.2.1 Effects of a predetermined practice design protocol

Table 5 includes 15 studies, in which six are DL studies (all DL studies included), seven are CLA-studies, and two studies are comparing DL and CLA protocols. All these studies are empirically testing a predetermined practice design protocol.

Among the DL studies, four studies completed a "traditional" DL intervention that consisted of drill-based practice: Hossner et al. (2016); Schollhorn et al. (2012); Schöllhorn et al. (2010) and Savelsbergh et al. (2010). The last two studies, Coutinho et al. (2018); Santos et al. (2018), contextualized DL protocols within a Small-Sided Games. A significant positive improvement (in all or some of the variables investigated) compared to control group was found in all studies, with the exception of Hossner et al. (2016). Savelsbergh et al. (2010), Schöllhorn et al. (2010) and Schollhorn et al. (2012) all identified that the participants were novices or lesser skilled, and that a generalization to more experienced individuals could not be made. Coutinho et al. (2018); Santos et al. (2018) found that younger participants (U15

over U17 and U13 over U15, respectively) responded positively in more of the variables, and with larger magnitude, compared to their older counterparts.

The seven CLA-studies included in table 5 manipulated one or several of constraint that could all be described as task constraints (Newell, 1986). Specifically, Brocken et al. (2021); Brocken et al. (2020) manipulated field hockey equipment (stick and ball, respectively), Krause et al. (2019) and Dicks et al. (2016) manipulated the task by altering representativeness and environmental complexity in tennis serving and association football penalty kicks, respectively. Gray (2018) used a virtual barrier that baseball hitters had to hit over as a constraint-manipulation, while Fitzpatrick et al. (2018) and Farrow and Reid (2010) used a combination of manipulations. More specifically, the manipulations consisted of regulating internal court dimensions, introducing a "recovery box", altering the scoring format, or manipulating the ball compression and/or the court size, respectively.

Significant positive improvements using direct measurements were found in Brocken et al. (2021); Brocken et al. (2020); Gray (2018); Fitzpatrick et al. (2018) and Dicks et al. (2016), while Farrow and Reid (2010) and Krause et al. (2019) did not find such effects. Despite the lack of clear performance improvements, the interventions could show to improved engagement, stroke opportunities and -success (Farrow & Reid, 2010), and signs of more tactically functional and varied serving (Krause et al., 2019). Additional positive effects measured by indirect measurements were found in Gray (2018) who identified increased movement variability in the CLA group in comparison to two other groups (internal- and external focus of attention group).

The two comparison studies, Garcia-Herrero et al. (2016) and Gray (2020) compared DL- and CLA-inspried practice protocols by altering degrees of variability in an association football kicking task, and comparing a DL protocol to a combination of three task manipulations (stepping- and swing path barrier and connection ball), respectively.

In Garcia-Herrero et al. (2016) skill was measured by looking at ball speed and accuracy scores in a skill test. No significant differences were found between the two groups. The study from Gray (2020) compared prescriptive instruction (PI), Differential learning (DL) and the Constraints-led approach (CLA), and looked at their effect on the promotion of opposite field hits in a virtual baseball environment. Results from this study showed that both DL- and CLA-groups produced better results compared to both the PI group and the non-active control group. Interestingly, a small significant difference between DL- and CLA-group was identified in favor of the CLA-group.

Table 5.

Results from studies investigating predetermined practice design protocol

Study	DL or CLA	Intervention context and form	Testing context and form	Practice design protocol (i.e., independent variable)	Results direct variable (i.e., outcome variable)	Results indirect variables (i.e., outcome variable)
Brocken et al. (2021)	CLA	Incorporated intervention practicing "basic technical exercises"	Constructed skill test	Equipment manipulation (stick)	CLA group improved significantly more on time spent on skill course. This effect was also found in retention test.	
Brocken et al. (2020)	CLA	Incorporated intervention practicing "basic technical exercises"	Constructed skill test	Equipment manipulation (ball)	CLA group improved significantly more on skill test measuring ball control and shooting.	
Garcia-Herrero et al. (2016)	DL vs. CLA	Study-exclusive intervention practicing goal-shot exercises	Constructed skill test	Form of variability; DL or CLA inspired	No significant difference found in accuracy and ball speed. Results were the same in retention test.	
Hossner et al. (2016)	DL	Study-exclusive intervention	Constructed skill test	DL protocol	No significant difference between either of the tree groups were found for shooting accuracy.	

Study	DL or CLA	Intervention context and form	Testing context and form	Practice design protocol (i.e., independent variable)	Results direct variable (i.e., outcome variable)	Results indirect variables (i.e., outcome variable)
		practicing goal-shot exercises				
Savelsbergh et al. (2010)	DL	Study-exclusive intervention practicing speed skating starts	Timed sprint (50m) (constructed skill test)	DL protocol	Significantly largest improvements found in DL group, both groups outperformed control group on time spent on sprint.	
Schollhorn et al. (2012)	DL	Incorporated intervention practicing goal shot- and ball control exercises	Constructed skill test	DL protocol	Significantly largest improvements found in DL group for shooting accuracy. In the retention test the effects were amplified.	
Schöllhorn et al. (2010)	DL	Study-exclusive intervention practicing hurdle running exercises	Timed sprint (60m) (constructed skill test)	DL protocol	Significantly largest improvements found in DL group for time spent on sprint.	
Coutinho et al. (2018)	DL	Incorporated intervention using Small-Sided Games	Systematic observation in Small-Sided Games	DL protocol	DL U15 improved all technical variables and RCOD DL U17 improved shooting and	DL U15 improved 2/3 creativity variables (for elaborate results, see tables in appendix).

Study	DL or CLA	Intervention context and form	Testing context and form	Practice design protocol (i.e., independent variable)	Results direct variable (i.e., outcome variable)	Results indirect variables (i.e., outcome variable)
					vertical jump (for elaborate results, see tables in appendix).	
Santos et al. (2018)	DL	Incorporated intervention using Small-Sided Games	Systematic observation in Small-Sided Games	DL protocol	Fewer fails for DL group, larger effect for U13 compared to U15.	DL group improved significantly more in creativity variables and positional regularity. Larger effect for U13 compared to U15.
Dicks et al. (2016)	CLA	Study-exclusive intervention practicing penalty kicks	Constructed penalty kick context (skill test)	"Reduces usefulness", identified as task constraint	Significantly better anticipation ability for intervention group.	
Farrow and Reid (2010)	CLA	Study-exclusive intervention using game-based tennis practice	Systematic observation playing against tennis coach	Equipment and rule manipulation (ball compression and court size)	No significant improvements on performance.	Improved engagement, stroke opportunities and -successes found for CLA group.
Fitzpatrick et al. (2018)	CLA	Study-exclusive intervention using game-based tennis practice	Constructed skill test and systematic observation/e	Combination of manipulations; court dimensions, "recovery box"	Significantly improvements in backhand success for CLA group.	More degeneracy found for CLA group.

Study	DL or CLA	Intervention context and form	Testing context and form	Practice design protocol (i.e., independent variable)	Results direct variable (i.e., outcome variable)	Results indirect variables (i.e., outcome variable)
			valuation of match play	and scoring format		
Gray (2018)	CLA	Study-exclusive intervention based in virtual batting environment	Constructed virtual batting environment-test	Task constraint; virtual barrier	CLA group produced significantly more “fly balls”. Results got solidified in retention test.	Increased movement variability (degeneracy), batt speed and launch angle for CLA group.
Gray (2020)	DL vs. CLA	Study-exclusive intervention based in virtual batting environment	Constructed virtual batting environment-test	DL protocol and task manipulation (stepping- and swing path barrier, connection ball)	Significantly better results for DL and CLA measured in Outer field – inside-and pull hits. CLA significantly (small effect) better than DL. Retention test amplified the advantageous effect for CLA over DL	Improved functional variability for CLA group (degeneracy).
Krause et al. (2019)	CLA	Study-exclusive intervention practicing serving exercises	Constructed skill test and systematic observation/evaluation of match play	Task manipulation (serving representativeness)	No difference found for points won.	Group of highest representativeness showed the most “strategic” serving.

5.2.2 Effects of following pedagogical- and tactical principles

10 studies were identified as investigating the effect of principally led coaching behavior that was either CLA- or NLP-based (see table 6). As a category, these studies were identified as following pedagogical-, practice design- and tactical principles. In these studies, the role of the sports pedagogue was to oversee, manipulate and adjust the practice so that is fit the learners in the intervention. This necessitated a dynamic sort of intervention where the pedagogue was free to carefully (i.e., in line with the proposed principles) manipulate task- individual- and environmental constraints. Among these studies, Pizarro et al. (2019); Pizarro et al. (2020); Práxedes et al. (2019); Praxedes et al. (2018a); Praxedes et al. (2018b) applied NLP- and offensive/defensive tactical principles and measured tactical and technical behavior. Ramos et al. (2020a); Ramos et al. (2020c) used CLA- and Step-game principles and measured tactical behavior. Lee et al. (2014) based the intervention on NLP principles, and measured the tennis forehand stroke in terms of performance (accuracy scores), subjective movement criterion evaluation, and kinematic data. Lastly, Roberts et al. (2020) used NLP principles and measured individual learning objectives (ILO's) that were based around technical execution and decision-making. The two studies mentioned lastly investigated individual technical skill and is by that not using any tactical principles for guidance.

A mapping out of NLP principles are found in the theory part, as well as being presented in Chow (2013, pp. 471-473). The CLA-principles used in Ramos et al.'s studies (2020a; 2020c) were manipulation of constraints, affordances-driven learning, co-adaptation (cooperation with teammates), representativeness (of the competitive performance environment), configurations of play (tactical principles of play) and complexity (practice involved solving tactical problems). The Step-game framework got described as "a player-centred approach, didactically conceived for non-invasive sports, in which players are presented with step-by-step, tactical game-problems that constrain emergence of functional technical-tactical game-related behaviours" (Mesquita et al., 2005; in Ramos et al., 2020c, p.

2612). The tactical principles of play used in Pizarro et al.'s and Práxedes et al.'s studies were: (i) recover the possession of the ball, (ii) prevent progression, and (iii) avoid the goal for the defensive phase of play, and (i) keep the ball possession, (ii) progression towards the goal, and (iii) shooting with the lowest level of opposition for the offensive phase of play (see Praxedes et al., 2018b, p. 5 for additional elaboration).

Results from these studies are quite ambivalent in nature. In terms of direct measurements, Pizarro et al. (2019); Pizarro et al. (2020); Práxedes et al. (2019); Praxedes et al. (2018a); Praxedes et al. (2018b) found positive improvements for some offensive (decision-making and execution of passing, dribbling and shooting) and defensive (marking, blocking and tackling) actions, but not all. Both execution and decision-making components were measured based on Game Performance Evaluation Tool (GPET) (García López et al., 2013). A typical finding was that more positive results were found for tactical skills (e.g., passing), compared to technical skills (e.g., dribbling) (for an example, see Praxedes et al., 2018a). Roberts et al. (2020) found performance improvements for 1v1 and decision-making (DM), but not for either foot finishing or time taken in skill course. Lee et al. (2014) found no performance improvements in their study.

When it comes to the indirect measurements, positive improvements were found in Lee et al. (2014), where degeneracy (functional variability) increased for the CLA (NLP) group. Ramos et al. (2020a); Ramos et al. (2020c) found increased tactical volleyball knowledge *of* (observed behavior) and *about* (based on declarative knowledge obtained from semi-structured interviews) the game. Ramos et al. (2020c) also found more complex and stable intra-team synchronization.

The last study in the principally-led category is Orangi et al. (2021), which compared linear pedagogy-, nonlinear pedagogy- and differential learning protocols for the promotion of

individual creative actions in association football. Operationalization of the different pedagogical-/practice design approaches are found in Orangi et al. (2021, p. 4).

Results in this study show that the CLA/NLP-group produced the larges number of different actions (i.e., variability), as well as the most original and creative ones. The DL-group followed closely on second place, whereas the LP-group (linear pedagogy) produced the lowest number of different-, original- and creative actions by some margin. The authors stated that the difference between DL- and NLP group was not as large as expected, and that movement repertoire per se, could be a better predictor for the emergence of creative actions, rather than the manner the enhanced movement repertoire was acquired (p. 6).

Table 6.

Results from studies following pedagogical- and tactical principles

Study	CLA or comparison study	Intervention context and -form	Testing form and -context	Pedagogical and/or tactical principles (i.e., independent variable)	Result direct variable (i.e., outcome variable)	Result indirect variable (i.e., outcome variable)
Lee et al. (2014)	CLA (NLP)	Study-exclusive intervention using game-based tennis practice	Constructed skill test including systematic observation/ evaluation	NLP principles	No difference for accuracy scores.	NLP group improved significantly more in movement degeneracy. Retention test show that learning was "preserved" more effectively in NLP group.
Orangi et al. (2021)	DL vs. CLA (NLP)	Study-exclusive intervention based on "skill practice exercises"	Systematic observation from constructed 11v11 match	DL protocol or NLP principles		NLP-group showed the most improvement of number of creative actions, followed by DL group.
Pizarro et al. (2020)	CLA (NLP)	Incorporated intervention using Small-Sided Conditioned Games	Systematic observation from competitive matches	NLP- and defensive game principles	Players improved DM and execution for marking, blocking and help coverage, not for interception or tackling.	

Study	CLA or comparison study	Intervention context and -form	Testing form and -context	Pedagogical and/or tactical principles (i.e., independent variable)	Result direct variable (i.e., outcome variable)	Result indirect variable (i.e., outcome variable)
Pizarro et al. (2019)	CLA (NLP)	Incorporated intervention using Small-Sided Conditioned Games	Systematic observation from competitive matches	NLP- and offensive game principles	Partly significant improvements for passing and dribbling, not for shooting (for elaborate results, see tables in appendix).	
(Práxedes et al., 2019)	CLA (NLP)	Incorporated intervention using Small-Sided Conditioned Games	Systematic observation from competitive matches	NLP- and tactical principle of play	Significant improvements for decision-making and execution of passing actions. Effects got preserved in retention test.	
Praxedes et al. (2018a)	CLA (NLP)	Incorporated intervention using modified games with numerical superiority	Systematic observation from competitive matches	NLP- and tactical principle of play	Significant improvements found for decision-making and execution for passing actions, but not for dribbling.	
Praxedes et al. (2018b)	CLA (NLP)	Incorporated intervention using modified games with numerical superiority	Systematic observation from competitive matches	NLP- and tactical principle of play	Average skill group improved significantly for decision-making and execution, low level group only improved execution.	

Study	CLA or comparison study	Intervention context and -form	Testing form and -context	Pedagogical and/or tactical principles (i.e., independent variable)	Result direct variable (i.e., outcome variable)	Result indirect variable (i.e., outcome variable)
Ramos et al. (2020a)	CLA	Incorporated intervention in "ecological representativeness"-sessions	Semi-structured focus-group interviews and observations from competitive matches	CLA- and Step-Game approach principles		Results indicate improvements for tactical knowledge *of* (behavior) and *about* (declarative knowledge based on interviews).
Ramos et al. (2020c)	CLA	Incorporated intervention in "ecological representativeness"-sessions	Systematic observation from competitive matches	CLA- and Step-Game approach principles		Results show increased intra-team synchrony (for elaboration, see tables in appendix).
Roberts et al. (2020)	CLA (NLP)	Incorporated intervention based on "pitch-based" technical/tactical training	Constructed skill test	NLP principles	Significant improvement for NLP group for decision-making and 1v1, but not for finishing or time used compared to LP group.	

5.2.3 Results from studies that investigate the *process* of learning

Five studies were identified as investigating the process of learning (see table 7). These studies perturbed the participants by instructing them not to balk (Barris et al., 2014), or manipulating climbing routes (horizontal, vertical or mixed grips) (Orth et al., 2014; Orth et al., 2018; Seifert et al., 2015; Seifert et al., 2018). The effects of the perturbations were measured based on: exploratory movements (holds not being used), performatory movements (holds being used), geometric index of entropy (GIE) of hip or/and hands, and inertial measurement units (IMU) for hip, feet and wrists (climbing studies), or kinematically measured variability in the preparatory phase of the diving-takeoff (Barris et al., 2014). These measurements are meant to concretizes how individuals explore through movement, and that this manifests itself as variability, either by comparing it across skill level (interindividual level) (Orth et al., 2018), or over time due to practice effects (intraindividual level) (Barris et al., 2014; Orth et al., 2014; Seifert et al., 2015; Seifert et al., 2018). Success was partly defined based on direct measurements (e.g., judge evaluation (Barris et al., 2014)), accent time and number of falls (climbing studies), or indirect measurements in the form of *meta-stability* (state of a person-environment system where competitive (less stable) and cooperative (more stable) coordination tendencies supports adaptation and emergence of new behaviors (Kelso, 2012, p. 913)) for the climbing studies, and functional variability/degeneracy in Barris et al. (2014).

Starting with the direct measurements, it was found that the scoring from a judge in Barris et al. (2014) did not improve in absolute terms, but became more consistent post intervention. The results are perhaps extra eye-catching since the participants were described as “world-class”. Seifert et al. (2018) and Seifert et al. (2015) found that induced meta-stability (mixed holds), and novel routes (transfer test) increased accent time and number of falls. The effect of transfer route was not supported in Orth et al. (2018), but was otherwise in line with the result from Seifert et al.’s studies. Seifert et al. (2018) and Seifert et al. (2015) found that practice had the opposite effect, meaning decreased accent time and fewer falls.

In terms of indirect measurements, results indicate that induced meta-stability, via the manipulation of climbing holds (horizontal, vertical or mixed), were promoting exploration, and by the same time allowing "safe" fall-back strategies (Seifert et al., 2015, p. 14). Orth et al. (2018) showed that the variability's specific expression (hand- or hip level) differed for novices and experts. experts only explored at the hip level (i.e., more variability) after a period of practice, while novices continued to explore with their hands. This indicates that some level of variability could serve to obtain the most important information about the task, and the state of the person-environment system (i.e., flexibility), whilst other sources of variability does not serve this purpose. These findings support the idea that variability can be "good" (functional) or "bad" (dysfunctional) in relation to learning (Woods et al., 2020a, p. 4). Seifert et al. (2018) found that the number of affordances (opportunities for action) alone was enough to induce meta-stability without an increase of route difficulty. Results in Orth et al. (2014) pointed to positive effects of being in meta-stable learning states for the transfer of learning (from practiced to novel route). Barris et al. (2014) found increased kinematic (movement) variability for all participants comparing post- to pre-intervention.

All in all, the studies support the notion that movement variability is an essential part of the process where learners identify, explore and exploit opportunities for action (i.e., affordances) (Woods et al., 2020a, pp. 3-4). The results with regards to transfer effects, also indicate that the process of improving the "fit" between the action capabilities of an individual, the task to be achieved, and the environmental niche in which it exists (i.e., learning) (Woods et al., 2020b, p. 1), is a highly specific one. Results produce a strong argument that the detection and realization of affordances are scaled to an individual's action capabilities (Orth et al., 2018). In turn, this infers that "guided" exploration (CLA/NLP), aimed at putting the learner in a meta-stable state (i.e., wrestling between mastery and failure at a given task), is more logical than the maximation of movement fluctuation or "variability for variability's sake" (DL approach) (Gray, 2020).

Table 7.

Findings from the studies investigating learning-processes

Study	Independent variable	Intervention form	Testing context	Principles of the learning process	Result direct variable (i.e., outcome variable)	Result indirect variable (i.e., outcome variable)
Barris et al. (2014)	Instructed not to balk	Monitoring 12 week of practice (10 session pr. Week). Incorporated intervention	Aquatic (natural) environment	Adaptive/functional variability (degeneracy) based on ecological dynamics perspective	More consistency in judge scoring, fewer balked attempts, but no improvements in the magnitude of judge scores.	Increased kinematic variability observed in all participants.
Orth et al. (2018)	Skill level of climbers; novice or experienced and hold design (horizontal, vertical, or mixed)	Monitoring learning and transfer over four practice sessions. Study-specific intervention.	Indoor climbing wall	Affordance-driven learning and meta-stability	Route design matched for difficulty did not affect number of falls.	Meta-stability induced exploration. Nature of exploration differed based on skill level. Route design affected learning differently based on skill level.
Orth et al. (2014)	Hold design complexity (horizontal, vertical, or mixed) and route novelty	Monitoring learning and transfer over four practice sessions. Study-specific intervention	Indoor climbing wall	Affordance-driven learning and meta-stability		Greater instability (higher Geometric Index of Entropy) induced learning most effectively. Transfer effects found.

Study	Independent variable	Intervention form	Testing context	Principles of the learning process	Result direct variable (i.e., outcome variable)	Result indirect variable (i.e., outcome variable)
Seifert et al. (2018)	Hold design (horizontal, vertical, or mixed)	Monitoring learning and transfer over four practice sessions. Study-specific intervention	Indoor climbing wall	Affordance-driven learning and transfer	Reduced accent time following practice. Effects reversed in novel transfer route and was smaller for complex route. Transfer from less- to more complex not found.	Decrease of both performatory and exploratory movements following practice. Route complexity effected affordance realization and degree of exploratory behavior.
Seifert et al. (2015)	Hold design (horizontal, vertical, or mixed)	Monitoring learning and transfer over four practice sessions. Study-specific intervention	Indoor climbing wall	Affordance-driven learning and meta-stability	Route design affected number of falls and accent time. Novelty (transfer route) had the same effect. Practice reduced both number of falls and accent duration	Decrease of both performatory and exploratory movements following practice. Route design was an effective way to achieve meta-stability, and more adaptive climbing.

The results from the 30 studies included in this review got categorized as following one of three “line of inquiry”. Further characterization was made based on theoretical affiliation (DL or CLA (NLP), contextualization of the intervention, and outcome variables used to measure learning. It should be acknowledged that this presentation is highly simplistic, and that a more elaborate and “complete” presentation is to be found in the **Supplementary material 1** found in the appendix. In line with Bergmann et al. (2021, p. 19), it seems logical to conclude that results from the studies must be interpreted based on fundamental theoretical framework, derived principles to practice design and pedagogical practices, as well as methodological characteristics and limitations. Furthermore, it must be acknowledged that results from the studies are likely to be highly affected by participant’s individual characteristics. These factors are inherently difficult to standardize, control for, and calculate. The mapping out of these variables should be interpreted in relation to the total makeup variables from each study.

6. Discussion

The aim of this scoping review has been to create a knowledge synthesis of empirical studies investigating skill learning conducted under the guidance of the ecological dynamics theoretical perspective. Based on a structured literature search, a highly divergent body of research was found. The variety is evident in two practice design and pedagogical approaches (the CLA /NLP and DL), 10 different sports, and multiple research designs and methodologies (comparative and non-comparative methodology, and qualitative-, quantitative randomized- or quantitative non-randomized designs). In addition, the studies included a variety of participants, differing in terms of age, skill level and gender. Further variation was found based on methodological assessment using Mixed Methods Appraisal Tool (MMAT) (Hong et al., 2018), and additional methodological characteristics. Lastly, the studies varied in terms of what the purpose of the study was, and what “type” of learning was investigated (i.e., collective behavior or individual technical skills). Specifically, three types of studies were identified: (i) testing effects of predetermined practice design protocols (collective/tactical learning; 2, individual technical skill; 14), (ii) testing effects of principally led interventions

(collective/tactical learning; 8, individual technical skill; 2) or (iii) investigating learning processes (individual technical skill only).

Based on the three distinct lines of inquiry, its fair to say that empirical expressions of the ecological dynamics perspective have been multi-faceted. The first line of inquiry, testing effects of predetermined practice design protocols, has concretized constraints and shown how these could be manipulated in a range of sports contexts. It has also shown how a DL protocol might take form. A strength in these studies is that the distinct practice design protocols, and their theoretical backdrop (e.g., stochastic resonance and perception-action coupling) are brought into fruition. The concretization of the independent variable (the predetermined practice design protocol), the standardization of outcome variables (e.g., standardized skill tests), and the use of tangible ways of obtaining outcome variables (e.g., time used, accuracy scores) makes it possible to compare results between studies that uses similar standardization. The replication of studies is also an opportunity. A weakness in these studies is their lack of individual customization or -analysis. This limits the investigation of an individuals improved fit with an environment. Additionally, because of the widespread use of decontextualized skill test, and a focus on isolated technical execution, the full spectrum of skill learning from an ecological dynamics perspective is arguably not tested. Essentially, actions are founded on constraints or affordances found in competition. In future studies it could be interesting to investigate a wider range of constraints manipulations, and not just task-constraints. The manipulation and/or exploration of individual- and environmental constrains could be give new insights to the effect of constraints manipulation in skill learning in sport. Another line of future studies could be to compare of effects of different constraints manipulations against each other. This was done in Farrow and Reid (2010), who investigating the effect of manipulating court dimensions against the manipulation of ball compression. More of such studies could give a general pointer about the potential for more- or less effective manipulation of constraints in different sports.

The second line of inquiry, testing effects of principally led interventions, clearly attempted to reflect the workings of a sports pedagogue as close to reality as possible. The use of already established training group, and the use of competitive matches as the context for measuring learning, clearly increased the ecological validity. This provides a concrete empirical example of how the ecological dynamics perspective could take form in practical settings. Further strengths in some of these studies where the use of standardized systematic observation tool in the form of Game Performance Evaluation Tool (GPET) (García López et al., 2013), and concrete and validated measurements of intra/inter-team synchronization, in the form of cluster-phase method adopted from Ribeiro et al. (2019) (Ramos et al., 2020c). In terms of limitations, its clear that the lack of standardized evaluation of appropriate application of pedagogical principles is a weakness. Additionally, few studies made specific accounts of how the principles were brought to life in form of actual practice design or pedagogical practices. Seen together with the multitude of interfering factors (e.g., performance of other players), its practically impossible to replicate or directly compare studies of this type. Future studies that choose to investigate the effect of pedagogical principles would benefit from investigating individual differences. Especially interesting could be to investigate the relationship between individual capabilities and tactical behavior. More specifically, this could shed light on how an individual's skill set effects the decision to dribble or pass. Other potential research avenues are to comparing a CLA/NLP approach to other approaches. This was done in Praxedes et al. (2018a), but the control group was not described in more detail than that a "direct instruction model" was used. Moreover, the results in this study revealed ambivalent results, in that tactical (pass), but not technical (dribble) seemed to benefit from the NLP-approach compared to the control group.

The third line of inquiry, investigating learning processes, focused on individual analysis. Their findings on different functions of variability, and the individualistic nature of affordance-realization, shed light on the importance of taking each individual learner's starting point into account when designing practice interventions. The use of a wide range of

direct and indirect measurements of learning provides a deep level of analysis in terms of the nuts and bolts of perceptual-motor learning. Furthermore, the concretization of affordances, through different orientation of climbing holds, is a unique example of how Gibson's ideas can be put into life. The linking between affordances and individual capabilities, seen in relation to the concept of meta-stability, seems to encompass the ecological dynamics perspective in an unparalleled way compared to the other studies in this review. Additional strengths were found in Barris et al. (2014), who analysed 120 practice sessions, and used "world class" athlethes. This gives a uniqe insight into the process of improving skills in elite athlethes. The general limitations in these studies where the use of small sample sizes, and short interventions (putting Barris (2014) asside). The other four studies used a total of 12 separate climbs, or four sessions of 60 minutes (Seifert et al., 2018). Although the focus in these studies where partly on immediate transfer effect between climbing routes, practice effects was also investigated. Taken the limited period of the intervention into account, its questionable whether the interventions led to learning, or acute performance effects. The lack of retention tests, besides the transfer test, prohibits further investigation of this. In sum, it seems like the five studies that followed line of inquiry (iii), can balance scientific rigour (the comprehensive measurement of learning), the ecological dynamics perspective ("catching" the coupling of individual capabilities and environmental information (i.e., affordances), and make it highly concrete (e.g., hold design in climbing). More research of this kind could help in the process of operationalizing the ecological dynamics perspective empirically.

As a whole, it is noteworthy that the duration of the interventions was generally short. This is arguably the most recurring weakness seen through the 30 studies. More specially, 11 studies used an intervention which consisted of less that five hours of practice, and only seven studies exceeded 20 hours of practice. Seen in relation to learning processes in the "real-world", which often takes years, its clear that more longitudinal studies are needed. Barris et al. (2014); Praxedes et al. (2018b) Ramos et al. (2020a); Ramos et al. (2020c) are some notable exceptions where parts of- or an entire season was used to investigate learning. The

findings substantiate the need to investigate learning over longer time horizons. For example, the results in Ramos et al. (2020a); Ramos et al. (2020c) reveal that learning, in the case of intra-team synergy formation in a volleyball team, was a highly non-linear process. Synchronization went through phases of reduced stability, followed by reorganization and re-establishment of stability. Without a longitudinal design, these observations would not be possible.

In relation to ecological dynamics more broadly, these studies are to be seen as new additions to an over 30-year process of putting the ecological dynamics perspective into fruition (see Davids et al., 1994; Handford et al., 1997). As argued by Araujo et al. (2021), the application of ecological dynamics is still "a work in progress", both for researchers and sports practitioners and -pedagogues. The challenge of applying the ecological dynamics perspective in empirical research is evident in many ways, and is probably a major reason behind the general lack of theory-driven- and high-quality studies (Bergmann et al., 2021, p. 2). The scarcity is also a consequence of being a new line of scientific investigation. Based on the studies included in this review, it was found that the oldest study was from 2010, and only 11 out of the 30 were published before 2018. This even though the structured literature search included studies from the year 2000, and that the establishment of the research direction was nearly 30 years ago. In sum, there has been identified a clear gulf between theoretical development, and empirical interventions, as well as "real-world" application (McKay et al., 2021, p. 394; Renshaw & Chow, 2019, p. 104). As pointed out by Ramos et al. (2020b, p. 8) empirical- and intervention-based research, based on ecological valid methodologies, can strengthen the conceptualization of skill learning. The 30 studies reviewed is to be seen as a substantial contribution on this part.

Based on this review, it becomes apparent that learning of perceptual-motor skills has been defined in multiple ways. Examples derived from the complexity outlook on movement coordination are: a "…gradual success of a search for optimal motor solutions to the

appropriate problems" (Bernstein, 1967, p. 134), or as distributed over the entirety of the system, where emergent and self-organized processes are bound under interacting constraints (Vaughan et al., 2019, p. 4). Ecological psychology has also contributed to a reframing of learning by conceptualizing it as a more functional coupling of perceptual- and action systems (Gibson & Gibson, 1955), or the emergence of an adaptive, functional relationship between an organism and its environment, due to an increasingly effective information transaction (Kugler & Turvey, 1987, p. 12). In sum, these descriptions have led to an outlook on learning processes as "adaptation" or "attunement", "coupling" or "assembly". Based on the two approaches identified, its proposed that skill learning could be promoted most effectively via a large number of random fluctuation, which leads to stochastic resonance (Schöllhorn et al., 2022, p. 15) (i.e., DL approach), or through meta-stability (state of a person-environment system where competitive (less stable) and cooperative (more stable) coordination tendencies supports adaptation and emergence of new behaviors (Kelso, 2012, p. 913) (i.e., CLA approach).

The use of representative designs seems of paramount importance in the process of investigating learning as a process of "adaptation", "attunement", "coupling" or "assembly" between an organism and its environment. Brunswik stated that behavior should "… *be sampled from the organism's typical environment so as to be representative of the environmental stimuli from which they have been adapted, and to which behavior is intended to be generalized*" (Brunswik, 1956 in; Pinder et al., 2011, p. 148). In relation to skill, it is proposed that the constraints used in practice need to adequately replicate the ones found in the performance environment. This design principle seems to be highly commensurate with the ecological dynamics perspective's description of skill learning as specific relationship between in individual and a sport-specific environment. In turn, this relationship is founded on an improved ability to detect and realize affordances (i.e., opportunities for actions), that are tied to the specific constraints found in each sport (Woods et al., 2020b, p. 2). The use of representative (learning) design seems to be a functional and effective principle to follow for

both sports practitioners, -pedagogues and researchers that wants to put the ecological dynamics perspective into fruition.

A consequence of reduced representativeness is that transfer of learning, or study results, are less certain. A basic adopted truth is that for transfer to occur, specificity is of paramount importance. The basic assumption is that learning is highly restricted to the specific problem-solving practiced. Schmidt et al. (2018, p. 513) argued that: "One point that consistently emerges (in discussions about transfer) is that motor transfer is generally low unless two tasks are so similar as to be practically identical". The argument made by many custodians of the ecological dynamics approach, especially in relation to the "Gibsonian" perspective, is that the need for fidelity also applies to the environmental context (i.e., sports-specific constraints and a representative landscape of affordances). As seen in table 5 and 6, its notable that a range of studies did not use interventions- or skill tests that replicated the demands of competition or the basic nature of the sport. This principle seems to be more actively used in the CLA, where the purposeful guidance, founded on different types of constraints manipulations, is aimed at differentiating functional- from dysfunctional movement, and important- (i.e., key affordances) from less important information (Gray, 2020). The violating of the principle of representativeness was only found in studies that investigated the learning of individual technical skills. A sole focus on isolated and decontextualized technical skills seems to miss the theoretical contribution from ecological dynamics that perceptual-motor skills are fundamentally distributed over the person-environment system (Warren, 2006).

Vaughan et al. (2019, p. 2) argued that skill learning in sports should be viewed as a *wicked* scientific problem. Such problems are characterized by being complex and interrelated, which rarely results in straightforward and categorical answers. Solutions to such questions are a holistic, deeply contextualized understanding of the questions at hand, as well as a realization that solution generation is of secondary concern (p. 2). The application of a

holistic scientific paradigm (i.e., ecological dynamics) to the study of skill learning in sports, it therefore warranted. Moreover, the divergent nature found among the included studies is in some sense a strength. Ecological dynamics as a theoretical perspective and skill learning in sport as a concept got investigated from a range of perspectives, arguably leading to a more comprehensive understanding of the two.

6.1 Practical implications

In a field of research where appropriate practical application is arguable the most important, it is incumbent that theory transcends into usable tools for sports practitioners and -pedagogues. Theory should counteract practices that are based on the mercy of often outdated practices, speculative information sources, or practitioners/pedagogues own intuition (Williams & Hodges, 2005, p. 637). The most concrete "tools" for sports practitioners and -pedagogues found in the research reviewed, is DL and the CLA.

Pol et al. (2020, p. 2) has argued that the ecological dynamics perspective can lead to "more efficient interventions across all sports, ages, and levels of expertise". Based on the approaches identified (DL and CLA/NLP), and their overall findings, its fair to say that this is generally supported. The Differential learning- and Constraint-led approach finds common ground in that the exploration of different movement solutions is at the heart of effective practice (Gray, 2020, p. 1), and is therefore an overall effective way to promote learning. The shared goal in these practice design- or pedagogical approaches is to increase functionality, not strive for universal movement optimums. Behavioral signs of improved "fit" between person and environment (i.e., learning) is in the degree of adaptability (i.e., actions are appropriate to the task at hand) and individualization (i.e., actions are in line with the individual characteristics of the performer) (Gray, 2020, p. 1). Moreover, their distinct differences have led to different empirical investigations. Primarily, the DL approach has focused on novices in the learning of individual technical skills, and divergent forms of collective/tactical behavior in the form of creativity. The CLA rationale has been applied in a

wider range of circumstances in relation to individual technical skills (e.g., different skill level, age, gender and type of sport), and in convergent forms of collective/tactical behavior (i.e., decision-making as successful or unsuccessful and actions as inline with tactical principles of play or not). The general research findings indicate that DL and CLA could serve different purposes dependant on the aim of practice.

DL promotes a large motor solution space and continuously confronts learners with their potential performance limits (Schollhorn et al., 2012, p. 102). The notion of "not leaving any stone unturned" for motor solutions could ensure that potential functional motor solutions are not "missed". It seems logical that this could be beneficial especially when learning a new skill. This was tested in Schöllhorn et al. (2010); Orangi et al. (2021) and Savelsbergh et al. (2010), who all used lesser skilled participants. The positive results found indicate that "fundamental technical skills" could effectively be learned without any form of guidance, either explicitly or implicitly. More support of DL's supperior effectiveness for lesser skilled individuals were found in Coutinho et al. (2018) and Santos et al. (2018). Findings indicate that DL is more effective for younger individuals compared to older ones (U15/U17 and U13/U15, respectively). Both studies pointed to the fact that younger individuals were more of a "clean slate", and therefore more open to the malleable effect of DL protocols. The two studies did however disagree on the role DL could serve for older or more experienced individuals. Santos et al. (2018, p. 12) argued that the differential-learning approach is especially relevant for the development of young players (or perhaps less experienced older individuals), while Coutinho et al. (2018) argued that it is just as effective for older or more experienced individuals, but that even more perturbation is needed to account for highly stabilized movement patterns. Other DL-studies in this review, Schollhorn et al. (2012) and Hossner et al. (2016), found ambigous results in their studies based on participants of a higher skill level. In sum, the findings indicate that DL protocols are perhaps best served in early stage of learning technical skill in sport and spots practitioners and -pedagogues should take this into account when designing practice protocols.

Another field of application for the DL approach were divergents tactical behavior. More specifically, Coutinho et al. (2018); Santos et al. (2018) and Orangi et al. (2021) measured tactical behavior in the form of creativity: "…*players' disposition of movement and attunement outside the box under the guidance of the environment and their ability to solve specific game problems in a novel, feasible, unexpected, and original way by starting a single act or flowing in a collective action that will lead to their team's success"* (Santos et al., 2018, p. 11). The divergent sides of behavior was measured by looking at "outside the box" actions. The logic behind using DL protocols for the promotion of creatvity seems obvious. In an approach where the maximation of movement variability is at the core of the rationale, and with an outcome variable that measures such behavorial characteristics (i.e., counting different action solutions, see Orangi et al. (2021, p. 5)), its perhaps unsurprising that all three studies showed significant positive results compared with more traditional practice approaches. Orangi et al. (2021, p. 6) concluded that a large movement repertoire per se (core of the DL-rationale), could be the best predictor for the emergence of creative actions, regardless of how the movement repertoire was acquired. The findings in these three studies indicate that the DL could be fitting approach for the promotion of creative individual motor actions in association football, and possibly other sports as well.

The CLA rationale proclaims that self-organized learning is fostered most effectively within certain boundaries. The use of indirect forms of "nudging" and "guidance" is largely done by showing individuals "where to look, but not what to see" (McKay et al., 2021, p. 394). The idea is to continuously "bridge" current abilities and future states being strived for (i.e., performance improvements) by means of simplification (e.g., reducing number of opponents in association football or slowing the bounce of a tennis ball) and amplification (e.g., designing a landscape of affordances that specifies key environmental information). Essential to the process of learning is the specific coupling of perception and action (Seifert et al., 2017).

A handful of CLA-studies investigated the effect of CLA-protocols for participants of different skill level. Praxedes et al. (2018b) used a skilled- and an amateur group, Brocken et al. (2020) looked at the relationship between field hockey experience and potential learning benefits from using a modified ball, and Orth et al. (2018) investigated differences between novice- and skilled climber's response to practice effects in climbing and their ability to transfer climbing skills. In Praxedes et al. (2018b), it was concluded that the superior effectiveness found for the group of a higher skill level is based on a better balance between current abilities and the task at hand (i.e., decision-making and execution of passing actions in association football) Brocken et al. (2020) found that the lack of challenge for both groups (skilled and lesser skilled) prohibited a clear distinction between the two. It was therefore concluded that a more appropriate level of challenge could be beneficial, especially for the group of a higher skill level. In Orth et al. (2018), the role of skill level was investigated for both learning- and transfer effects. In sum, the results show that for effective learning, understood as putting a climber in a meta-stable state (i.e., state of a person-environment system where competitive (less stable) and cooperative (more stable) coordination tendencies supports adaptation and emergence of new behaviors (Kelso, 2012, p. 913), the climbing task needs to match the skill level of the climber. Conversely, for immediate transfer for occur (from one climbing route to a similar one), a stabilized movement pattern is needed. What is suggested here, is that effects on learning (i.e., longer time horizon) and effect on acute performance could be dichotomous. Taken together, the practical take-home is that practices should cater individual's current abilities and use this at a starting point for eventual manipulation of constraints.

The investigation of collective and tactical behavior was investigated in a range of CLA studies. It's form of expression was decision-making (i.e., successful or unsuccessful) in some studies (Pizarro et al., 2019; Pizarro et al., 2020; Práxedes et al., 2019; Praxedes et al., 2018a; Praxedes et al., 2018b; Roberts et al., 2020), interpreted based on declarative knowledge in another (Ramos et al., 2020c), and inferred based collective synergetic behavior

(Ramos et al., 2020a) in an additional one. The basic assumption in all these studies was that a CLA could be used to "nudge" individuals- or teams towards a convergent form of tactical behavior. This meant establishing some overarching principles of tactical play, which is used to define actions in terms of appropriateness. An overview of this is found in section 5.2.2. Overall, the findings in theses studies are ambivalent, and points to the effects of constraints manipulation as highly specific. An example of this is found in Praxedes et al. (2018a) who argues that the nature of the "technical-tactical action" in contention should define the organization of practice. In this study, it was found that more "tactical" actions (e.g., passing), as opposed to "technical" action (e.g., dribbling), were more fitting for a CLA-based intervention founded on numerical superiority. It should be noted that this study was the only one that compared the intervention to a control group, in this case, a "traditional" pedagogical approach. In Ramos et al. (2020a) it was stated that the increased intra-team synchrony was due to a combination of guided self-organization (CLA) and a more prescriptive approach through the Step-Game approach (SGA) (used cues and explicitly stating tactical strategies and game plans). Lastly, it should be mentioned that one DL study, Santos et al. (2018), investigated a convergent form of tactical behavior. In this study, it was found that the DL-protocol increased the dyadic positional regularity of the team in relation to both team's goals. In sum, it appears unclear to what extent guidance is needed for convergent tactical behavior, and whether or not some degree of explicit guidance (conveying knowledge *about* verbally) is functional. Nevertheless, a clear indication of the effectiveness of a CLA for convergent tactical behavior, is the fact that many studies measured the practice effects in competitive matches (Pizarro et al., 2019; Pizarro et al., 2020; Práxedes et al., 2019; Praxedes et al., 2018a; Praxedes et al., 2018b; Ramos et al., 2020a; Ramos et al., 2020c). This shows that learning promoted by such pedagogical means can transfer effectively form practice to competition.

In sum, the CLA-studies above emphasized that the most effective interventions are based on an appropriate bridging between current abilities and the future state being stived

for. A mix of unknown (less stable) and known (more stable) coordination tendencies (i.e., meta-stability) is recommended. It is here emphasized that a targeted manipulation, where the person-environment system is deliberately "nudged" in a specific direction is most effective. This effect of deliberate nudging seems to be at least partly applicable to collective- and tactical behaviors as well. Conversely, the focus in DL is to move away from current coordinative tendencies for the sake of expanding the movement solution space. A real and unmediated self-organization is rooted for. The studies reviewed (n=6) suggest that this approach is perhaps most applicable in the process of learning new skills, or divergent forms of tactical behavior. It should be noted that few other lines of inquiry have been used for the DL-approach. Despite their differences, the results indicate that self-organized forms of learning are at least a viable alternative to traditional approaches (i.e., prescriptive instruction, skill decomposition and corrective feedback) in many forms of learning. The optimal form of self-organization is however still a topic of debate, especially in relation to skill level of the learner, and for convergent- and divergent tactical behavior.

7. Concluding thoughts

This scoping review has revealed a highly varied body of research. The divergence is evident in a range of descriptive variables, methodological practices, and lines of inquiry. In total, the studies reviewed gives new insights as to how the ecological dynamics perspective on skill learning in sports has been expressed empirically. This knowledge synthesis discusses central issues in the research direction as a whole, with an extra focus on how theoretical- and methodological aspects can merge effectively. Moreover, the challenge of empirically pinpointing the ecological dynamics perspective on learning is still a work in progress (Araujo et al., 2021).

The results derived for the 30 studies reviewed questions traditional pedagogical practices, and subsequent ways to design practice. An approach to skill learning in sport where individual's self-organization is at the core of practice is argued for. This entails

engagement with appropriate problems, in appropriate contexts, and with an appropriate degree of variability. What “appropriate” means is however highly contingent on whether a Differential learning-, or a Constraints-led approach is put forth. The argument made by Pol et al. (2020, p. 2) that the ecological dynamics rationale could revolutionize the efficiency of interventions across all sports, ages, and levels of expertise, could not be discarded based on findings from the 30 studies reviewed. However, the claim seems to lack sufficient empirical support to be verified. More empirical- and intervention-based research, based on ecological valid methodologies, could serve as useful in that regard (Ramos et al., 2020b, p. 8).

8. Limitations

In this current review a number of limitations should be mentioned. Firstly, the process of conducting a scoping review, doing a systematic literature search, and methodologically assessing a pool of research of this scope is traditionally the workings a team of researchers. The academic supervisors provided assistance in terms of overall guidance, but a complete review of each step of the review was not practically feasible. Especially in relation to the literature search, selection of articles (screening over 6200 articles for title), and the MMAT-process, its highly likely that the lack of previous experience on my part has led to human mistakes and inconsistencies.

In addition to the extent of this scoping review, the fact that a similar review was not found in the literature, meant that the methodological process in this review included some degree of trail and error. For example, it could be argued that the MMAT was not totally fit for purpose since the adding of other methodological variables was deemed necessary.

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Appendix

Supplementary material 1

Table 8.

Descriptive characteristics of studies investigating learning of collective/tactical behavior.

Author	Sport	Study context	Participants				Study design	Theoretical foundation	Study description
			N (groups)	Age	Gender	Participant level			
(Coutinho et al., 2018)	Association football	Training	30 (4)	U15 and U17	Male	Skilled	NRS	DL	A Differential learning program aimed to enrich and improve technical skills and creativity in attacking players was compared to usual care CG. DL consisted of physical literacy, technical exercises and SSGs.
(Pizarro et al., 2020)	Futsal	Training, competition analysis	8	U16	Male	Skilled	NRS	CLA (NLP)	The indirect effect of an NLP program based on SSCGs on defensive actions (decision-making and execution) was measured pre- and post intervention using a quasi- experimental methodology and an intragroup design.
(Pizarro et al., 2019)	Futsal	Training, competition analysis	8	U16	Male	Skilled	NRS	CLA (NLP)	The study analysed the effect of an intervention program, based on NLP, on the decision-making and execution of different actions (pass, dribbling and shooting) in futsal.

Author	Sport	Study context	Participants				Study design	Theoretical foundation	Study description
			N (groups)	Age	Gender	Participant level			
(Práxedes et al., 2019)	Association football	Training, competition analysis	19	U12	Unspecified	Amateur	NRS	CLA (NLP)	The study analysed the effect of an NLP-based training intervention. Three phases; baseline (direct instruction), intervention (NLP) and retention were used to measure passing DM and -performance over time (13 matches).
(Praxedes et al., 2018a)	Association football	Training, competition analysis	19 (2)	U12	Male	Skilled	NRS	CLA (NLP)	The study used a between-group comparison (NLP- or direct instruction group) measuring passing and dribbling DM and execution in competitive games after 14 session intervention.
(Praxedes et al., 2018b)	Association football	Training, competition analysis	19 (2)	U12	Unspecified	Amateur	NRS	CLA (NLP)	The study compared the effect of an NLP-based program using numerically imbalanced (phase 1) or balanced (phase 2) in SSCGs. Groups were divided based on skill level (average or low).
(Ramos et al., 2020a)	Volleyball	Training and competition	16 (15 players, 1 coach/researcher)	14-15	Female	Coach: Expert players: Skilled	Qualitative	CLA and Step-game approach	An action-research approach using reflexive diary (coach) and semi-structured focus-group interviews investigated the effect of combining CLA and Step-game approach to develop youth volleyballers' tactical knowledge expressed through performance over a full competitive season.

Author	Sport	Study context	Participants				Study design	Theoretical foundation	Study description
			N (groups)	Age	Gender	Participant level			
(Ramos et al., 2020c)	Volleyball	Training and competition	16 (15 players, 1 coach/ researcher)	14-15	Female	Coach: Expert players: Skilled	NRS	CLA and Step-game approach	The intervention study looked at the impact of increased performance complexity on synchronisation of counterattacking tendencies in team players (laterally and longitudinally on court). Different set moments were also used as an independent variable. Three AR-cycles made up the progression of the study; (1) diagnosis of the team's current synchronisation tendencies, (2) increased tactical complexity and (3) work on team synchrony with increased tactical complexity system.
(Santos et al., 2018)	Association football	Training	40 (4)	U13 and U15	Unspecified	Skilled	RCT	DL	The study investigated the effect of a Differential learning program, based on SSCGs on the creative and tactical behavior of youth soccer players.

Note. PL = Player level, RL = regional level, NL = national level, AL = average level, DL = Differential learning, NLP = Nonlinear pedagogy, CLA = constraints-led approach, NRS = non-randomized study, RCT = randomized controlled trail, CG = control group, QDS = quantitative descriptive study SSGs = small-sided games, RLD = Representative learning design

Table 9.

Descriptive characteristics of studies investigating individual sports or individual technical skills in team sports.

Author	Sport	Study context	Participants				Study design	Theory-driven practical approach	Study description
			N (groups)	Age	Gender	Participant level			
(Barris et al., 2014)	Springboard diving	Training	4	20 ± 2.9	Female	Expert	NRS	CLA	The study investigated whether a sample of elite divers were able to adapt their movement patterns regardless of the perceived quality of their preparatory movements on the springboard. This was provoked by instructing divers to refrain from balking. Effect of this intention-based constraints was investigated over a 12-week training program.
(Brocken et al., 2021)	Field hockey	Training	68 (2)	9.58- 12.54	Female	Skilled	NRS	CLA	The study examined whether modified equipment (stick) can be utilized to capture the effect of cross-education in the form of interlimb transfer. This was tested using a cross-sectional design with young field hockey players.

Author	Sport	Study context	Participants				Study design	Theory-driven practical approach	Study description
			N (groups)	Age	Gender	Participant level			
(Brocken et al., 2020)	Field hockey	Training	129 (2)	8.54 ± 0.45	Female	Mixed	NRS	CLA	The study looked at the effect of modified hockey ball in relation to improvement on technical hockey skills compared to practice with a traditional hockey ball. A potential mediator effect based on experience was also tested. This was tested using a cross-sectional design with young female field hockey players.
(Dicks et al., 2016)	Association football	Training	18 goalkeepers, 5 penalty takers	20.89 + 0.96	Male	Novice	NRS	CLA	The study examined whether reduced usefulness training improved the anticipation performance of novice football goalkeepers for deceptive and nondeceptive penalty kicks.
(Farrow & Reid, 2010)	Tennis	Training	23 (4)	8.0 ± 0.4	Not specified	Novice	NRS	CLA	Based on four different constraints manipulation -groups (ball compression, court size), the study investigated the effect of these for skill learning, and task adherence and happiness

Author	Sport	Study context	Participants				Study design	Theory-driven practical approach	Study description
			N (groups)	Age	Gender	Participant level			
(Fitzpatrick et al., 2018)	Tennis	Training	16 (2)	7.2 ± 0.6/7.4 ± 0.4	Not specified	Skilled	RCT	CLA	The aim of the study was to investigate effects of constraints manipulations (internal court dimensions, recovery box location and scoring format) on children's match-play behaviours and tennis-specific skills test, with a focus on backhand stroke development.
(Garcia-Herrero et al., 2016)	Association football	Training	41 (2)	14.21 ± 0.89	Not specified	Skilled	RCT	CLA vs DL	The study compared induced variability and repetition practice and their effects on accuracy and ball speed in kicking a football.
(Gray, 2018)	Baseball	VE-training	30 (3)	21-23	Male	Expert	RCT	CLA	The study looked at the effect of instructing an internal or external focus of attention or using the CLA. The setting was baseball batting in a virtual environment, and the task involved batting with the intention to hit fly balls (typical home run hitting).

Author	Sport	Study context	Participants				Study design	Theory-driven practical approach	Study description
			N (groups)	Age	Gender	Participant level			
(Gray, 2020)	Baseball	VE-training	40 (4)	19-22	Male	Expert	RCT	CLA vs DL	The study looked at the effect of prescriptive coaching, DL and CLA in comparison to control groups. The setting was baseball batting in a virtual environment, and the task involved both movement coordination and action selection components.
(Hossner et al., 2016) Exp. 1	Association football	Training	28 (3)	13.8, SD = 1.1	Male	Skilled	NRS	DL	The study compared traditional (instruction and easy to hard progression)-, differencial+feedback- and differencial learning using shot precision training in football. The aim was to test contextual interference theory (elaborateness of the abstracted representation) up against DL theory (exploitation of stochastic resonance).
(Krause et al., 2019)	Tennis	Training	33 (3)	15.4 ± 1.9	17 males, 16 females	Skilled	NRS	CLA	The study assessed the learning effect on serving in tennis with different degrees of representativeness (low, moderate, or high) measured with a Representative Practice Assessment Tool (RPAT).

Author	Sport	Study context	Participants				Study design	Theory-driven practical approach	Study description
			N (groups)	Age	Gender	Participant level			
(Lee et al., 2014)	Tennis	Training	24 (2)	9-10	Female	Novice	RCT	CLA (NLP)	The study was aimed at testing the effectiveness of a Nonlinear Pedagogy approach to learning a forehand stroke in tennis. The participants were tested for Performance accuracy scores, movement criterion scores and kinematic data using a pre-, post-, retention design.
(Orangi et al., 2021)	Association football	Training	66 (3)	27.49 ± 2.68	Male	Novice	RCT	Comparison study	The study compared LP, NLP and DL and their effect on developing adequacy, variability, originality, and creativity in football actions.
(Orth et al., 2014)	Climbing	Training	6	Mean = 23.6	Unspecified	Skilled (6a (F-RSD))	NRS	CLA	The main objective of the study was to investigate the effect of induced learning and meta-stability based on horizontal-, vertical, and mixed holds respectively. The geometric index of entropy (GIE) of the hip was used as a measure for both transfer and indication of meta-stability.

Author	Sport	Study context	Participants				Study design	Theory-driven practical approach	Study description
			N (groups)	Age	Gender	Participant level			
(Orth et al., 2018)	Climbing	Training	14 (2)	Novices: 20.9 ± 5.7 Experienced: 24.9 ± 4.7	Unspecified	Mixed	NRS	CLA	The study looked at the learning effect of practicing three different climbing routes (horizontal, vertical, and mixed grips) over 4 sessions. Experience was a key independent variable. Learning was measured by performance (falls), the total number of exploratory actions with the hands and geometric index of entropy at the hip.
(Roberts et al., 2020)	Association football	Training	22 (2)	U17	Unspecified	Expert	RCT	CLA (NLP)	The study compared the effects of LP and NLP using a cross over design on individual learning objectives. More specifically, 1v1, DM and both feet finishing measured with Loughborough Soccer Shooting Test (LSST).

Author	Sport	Study context	Participants				Study design	Theory-driven practical approach	Study description
			N (groups)	Age	Gender	Participant level			
(Savelsbergh et al., 2010)	Speed skating	Training	34 (3)	44.2 ± 9.8	Male	Novice	NRS	DL	The study looked at the effect of implementing a traditional (instruction)- or differential learning protocol on learning the start in speed skating. Pre- and post tests included 5-, 10-, 25- and 49-meters measurements and were compared to a control group (practiced, but not specifically on the start).
(Schöllhorn et al., 2010)	Hurdle running	Training	28 (2)	13.2 ± 1.7	Unspecified	Unspecified	RCT (but based on pre-test)	DL	The study tested the DL- and traditional learning (instructive) approach for 60m hurdle running for juvenile athletes. Improvements in running time was the main factor measured.

Author	Sport	Study context	Participants				Study design	Theory-driven practical approach	Study description
			N (groups)	Age	Gender	Participant level			
(Schollhorn et al., 2012)	Association football	Training	24 (3)	Control (23,8 ±3,9), Differential blocked (24,5 ± 2,1), Differential random (24,5 ± 2,1)	Unspecified	Skilled	RCT	DL	Participants were divided into three groups and trained under traditional-, differential blocked-, and differential random protocol. The pre-, post-, and retention test consisted of testing the ability to control the ball in minimum amount of space and shoot at goal with precision.
(Seifert et al., 2015)	Climbing	Training	9	21.9 ± 2.7	Male	Skilled (6a-6b (F-RSD))	NRS	CLA	The aim of our study was to investigate the role of constraints manipulation (i.e., vertical, horizontal, or mixed holds) in inducing meta-stability in learning to climb in a challenging environment (i.e., a climbing task). The number of exploratory (touched holds), the hip path, and for the double-edge route, the type of hand grasping patterns (vertical vs. horizontal-edge grasping) were used as measures for learning.

Author	Sport	Study context	Participants				Study design	Theory-driven practical approach	Study description
			N (groups)	Age	Gender	Participant level			
(Seifert et al., 2018)	Climbing	Training	8	21.0 ± 2.4	5 males, 3 females	Amateur (5c (F-RSD))	NRS	CLA	The aim of this study was to investigate how the affordances of an indoor climbing wall changed for intermediate climbers following a period of practice during which hold orientation was manipulated within a learning and transfer protocol.

Note. DL = Differential learning, LP = linear pedagogy, NLP = Nonlinear pedagogy, CLA = constraints-led approach, NRS = non-randomized study, RCT = randomized controlled trail.

Table 10.

Narrative synthesis of comparison-interventions and their effectiveness.

Author	Groups	Intervention duration		Manipulation for intervention group	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
(Brocken et al., 2021)	Modified stick first (n = 33) Traditional stick first (n = 35)	14 (15-20)	7	ASM REV3RSE hockey stick (switches left- and right-hand function)	Field hockey skills: (measured in time spent).	Both groups improved, but the improvements after using the modified stick were more systematic and significantly larger than with the regular hockey stick.
(Brocken et al., 2020)	Modified ball first-group (n = 51 (for analysis)) Regular ball first-group (n = 51 (for analysis))	14 (60)	7	Modified ball (asymmetrical mass distribution)	Field hockey skill test aimed at testing ball control and shooting skills.	A significant improvement of field hockey skills was found with the modified hockey ball compared to the regular hockey ball conditions. No mediator—effect was found based on experience.
(Coutinho et al., 2018)	DL U15 (n = 9) DL U17 (n = 6) CG U15 (n = 9) CG U17 (n = 6)	20 (25)	10	Differential learning and physical literacy program	In game: Technical performance (shots, dribbles, and goals) Creativity (fluency, attempts and versatility) Physical variables: Vertical jump test	In U15, greater improvements for DL compared to TL for all technical variables, fluency, and versatility, and RCOD. In U17, only achieved greater improvements in shooting and vertical jump test for DL group compared to TL.

Author	Groups	Intervention duration		Manipulation for intervention group	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
					30m sprint test Repeated change-of-direction test (RCOD)	
(Dicks et al., 2016)	One-player penalty shooting (traditional) (n = 9) Three-player penalty shooting(intervention) (n = 9)	4 (not specified)	Not specified	Three players making the run-up, forcing the keeper to rely on "later" information to base their anticipation on.	Anticipation for deceptive and non-deceptive penalty kicks.	Intervention group showed significant improvements for both deceptive and non-deceptive anticipation. This was not the case for control group. Results were backed in follow-up non-deceptive test were intervention group made significantly more saves, whilst control group did not.
(Farrow & Reid, 2010)	Standard ball/scaled court (n = 6) Modified ball/scaled court (n = 5) Standard ball/standard court (n = 6) Modified ball/standard court (n = 6)	5 (30)	5	Court size and ball compression	Stroke assessment (backhand and forehand); quantitative (balls kept in play) and qualitative (assessed by three tennis coaches) Number of strokes and number of successful strokes during the intervention period	Results show that standard ball and -court conditions resulted in poorer engagement, fewer stroke opportunities and fewer successful strokes. Scaled court gave larger effects on outcome variables compared to ball compression. Few conclusive pre/post test effects were found (learning effects).

Author	Groups	Intervention duration		Manipulation for intervention group	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
					Engagement rating after each session	
(Fitzpatrick et al., 2018)	CLA (n = 8) CG (n = 8)	8 (60)	8	Internal court dimensions, recovery box location and scoring format	Match play and tennis-specific skills testing (TSST); forehand and backhand distribution (%) and technical proficiency, respectively)	The experimental group showed less disparity between the percentage of forehands and backhands performed during match-play, greater backhand success rates, improved rally capacity when rallying with a coach, and enhanced technical proficiency.
(Garcia-Herrero et al., 2016)	Repetition group (n = 21) Induced variability group (n = 20)	10 (14 kicks, minutes not specified)	3-4	Induced variability (task-based, redundancy-promoting)	Ball speed (radar gun; km/h), accuracy (radial error)	Significant improvements were found for both groups, and with no significant differences between them. This is a fact of both variables.

Author	Groups	Intervention duration		Manipulation for intervention group	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
(Gray, 2018)	Internal focus (n = 10= External focus (n = 10) CLA (n = 10)	6 (60)	6	The two instructional approaches and the CLA (vertical barrier as constraint manipulation)	Launch angle (most home runs are hit with a 22-30° angel, participants had a mean of no more than 10° as an inclusion criterion) and exit velocity of the bat (most home runs are hit with >100 mph) and fly balls.	Results reveal that CLA, and EF (self-organizing approaches) were superior compared to IF for all three factors. Self-organizing approaches also created more movement variability. Interestingly, CLA also showed significantly better outcomes compared to EF.
(Gray, 2020)	Prescriptive instruction (PI) (n = 10) DL (n = 10) CLA (n = 10 Non-active control group (n =10)	6 (60)	6	PI: cues referring to an ideal technique DL: 6 sources of variability (extrinsic) with three different alternations for all 6 CLA: swing path barrier, connecting ball (ball between the biceps and forearm) and Stepping barrier	Outer field hits (gave 1 point), pull hits (gave -0,5 points), points (total of the two aforementioned) and inside hits (described as unwise hitting opportunities').	Pre/post test results show significantly more improvements for CLA and DL over control group and PI group for all variables except inside hits were CLA and PI gave significant improvement. A small significant difference between CLA and DL was also found in favor of the CLA.

Author	Groups	Intervention duration		Manipulation for intervention group	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
(Hossner et al., 2016)	Traditional learning (TL) (n = 9) DL+feedback (FB) (n = 9) DL (n = 10)	12 (30)	6	TL: Instruction on "sweet spot", inside and outside shooting. Easy to hard progression. DL: 13 sources of variation, introduced in isolation at first, and later combined DL+FB: same as DL, but with additional correctional feedback about every 3. trail.	Shooting accuracy test with 4 altering targets and 2 different finishing positions.	No significant differences between either of the three groups were found. However, the main hypothesis was to test the effect of FB in DL, and it could be inferred by the results that FB did not hinder learning.
(Krause et al., 2019)	Serve only (SO) (n = 10) Serve return (SR) (n = 11= Serve +3rd (S3) (n = 12)	12 (56 ± 6 serves per session)	6	SO: No opponent presented SR: An opponent returned the serve S3: An opponent returned, and the participant was required to hit at least one extra rally shot	Matchplay and Serving skill test (serve speed, serve placement, serve variability, positional advantage and points won on serve)	Key finding shows that when hitting a 2nd serve in match-play, participants in S3 appeared to strategically slow the speed of their serves to focus on placement. SO (as opposed to the S3) group served more variably on 2nd serve, while no changes in positional advantage were observed for any group post intervention. Non of the groups showed a significant increase or decrease in the number of points won/lost or ace/unreturned serves from pre- to post-test.

Author	Groups	Intervention duration		Manipulation for intervention group	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
						These findings were to some degree reversed in the skill test compared to match play.
(Lee et al., 2014)	NLP (n = 11) LP (n = 10)	8 (15)	4	NLP: manipulation of constraints (net height, target area, court size, and rules to achieve specific task goals) LP: prescriptive, repetitive drills	Performance accuracy scores, movement criterion scores and kinematic data	Both groups showed similar degree of performance improvements, but NLP group showed grater degeneracy (many ways to achieve the same outcome).
(Orangi et al., 2021)	LP (n = 22) NLP (n = 22) DL (n = 22)	24 (45)	12	LP: prescription and instruction NLP: constraints manipulation DL: instruction to maximize variability, no feedback.	Counting variability, adequacy, originality, and creativity of individual football actions with the ball.	Variability of different actions was highest in the NLP-group, followed by DL-group, whereas the LP-group showed the lowest number of different actions. Moreover, the NLP-group and DL-group showed more original and creative actions compare to the LP-group.

Author	Groups	Intervention duration		Manipulation for intervention group	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
(Orth et al., 2018)	Novice (n =7) Experienced (n =7)	4 (three routes climbed)	2	Three different routes: horizontal-, vertical- and mixed grips	Number of falls of the wall (performance), geometric index of entropy (GIE) of the hip, and exploratory actions (touches) with the hands	Behavioral exploration (GIE and exploratory actions) was largest under the metastable condition (mixed route). Data suggests that meta-stability induces exploratory behaviors in different way based on skill level. Less skilled individuals explore both hand and hip levels, whereas more experienced climbers explore only at the hip level.
(Praxedes et al., 2018a)	NLP (n = 10) CG (n = 9)	14 (60)	7	NLP	DM and execution measured for passing and dribbling actions using Game Performance Evaluation Tool (GPET).	Results show significant differences in favor of NLP-group for passing DM and execution, but not for dribbling DM and execution. This indicates that the nature of the skill (e.g., technical, or tactical) effects what is considered effective learning/training methodology.
Praxedes et al. (2018b)	Average skill level (n = 10) Low skill level (n = 9)	34 (60)	Approx. 18	NLP; numerical superiority or equality in SSCGs	DM and execution for passing actions using GPET.	Average skill group; significantly improved DM and execution of passing from Pre-intervention 1 to Intervention 1 phases, and between the Pre-intervention 1 and Pre-intervention 2 phases. Low level group only showed significant improvements for execution between Pre-intervention 1 and Intervention 2 phases.

Author	Groups	Intervention duration		Manipulation for intervention group	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
(Roberts et al., 2020)	NLP (n = 11) LP (n = 11)	16 (60)	8	NLP and constraints manipulation; guided by Individual learning objectives (OILs)	Both feet finishing, DM and 1v1 proficiency Loughborough Soccer Shooting Test (LSST)	The results showed significant differences between NLP and LP in 1v1 and DM in favour of NLP. However, there were no significant differences for either strong- or weak foot finishing, or time taken.
(Santos et al., 2018)	DL U13 (n = 10) DL U15 (n = 10) CG U13 (n = 10) CG U15 (n = 10)	40 (30)	Approx. 13	DL based SSCGs	Technical (pass, dribble and shot) and collective (interpersonal distance between pair of teammates) behavior measured for attempts, fluency, versatility and originality, and dyadic regularity, distance to own- and opponents target, respectively.	Differential learning produces favorable results for attempts, versatility, and originality. A lower level of fails war also measured. Moreover, results show more positional regularity (dyadic and distance to own- and opponents target). Larger effects in U13 compared to U15 was found.

Author	Groups	Intervention duration		Manipulation for intervention group	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
(Savelsbergh et al., 2010)	- 27 distributed over the three groups, not specified further	3 (60)	1	Differential learning protocol, traditional instruction-based protocol, and control group	Timing at 5, 10, 25 and 49 meters. Video analysis of technique.	The results show that both traditional- and DL group improved more than control group. Interestingly, the DL group outperformed the traditional group despite the difference in instructional guidance and feedback.
(Schöllhorn et al., 2010)	-DL (not specified) -Traditional group (n = not specified=	24 (30)	6	Differential learning protocol, traditional instruction-based protocol	Time spent on 60m hurdle race.	Based on the results, the DL group improved significantly more (mean = 0.64 sec) than the traditional group (mean = 0.33 sec).

Author	Groups	Intervention duration		Manipulation for intervention group	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
(Schollhorn et al., 2012)	-CG (n = 4 -Differential blocked (n = 4) -Differential random (n = 4)	8 (25)	4	Differential learning protocol (blocked and random, respectively), traditional instruction-based protocol	Ball control with chest and feet and shooting from 16m in 7 different situations at a goal without a goalkeeper.	The results reveal that the two DL groups improved significantly more than CG for shooting accuracy and ball control. A significant difference in favour of random DL was found in the retention test for shooting accuracy.

Note. TL = traditional learning, CG = control group DL = Differential learning, LP = linear pedagogy, NLP = Nonlinear pedagogy, CLA = constraints-led approach, DM = decision-making, FB = feedback, EF = external focus (of attention)

Table 11.

Narrative synthesis of non-comparative interventions.

Author	Groups	Intervention duration		Manipulation	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
(Barris et al., 2014)	1 (single group design)	120 (unspecified)	12	Instructed not to balk (terminating the takeoff)	Completed or balked dives, and movement variability	Results suggested that on completion of training, athletes could produce fewer incidents of balking, more varied preparatory phase before the take off, and at the same time producing more stable performance outcomes. These results are interpreted

Author	Groups	Intervention duration		Manipulation	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
						as an increasement of movement functionality because of improved movement flexibility.
(Orth et al., 2014)	Individual assessment (n = 6)	4 (3 ascends)	4 days	Horizontal-, Vertical- or mixed grips	geometric index of entropy (GIE)	The data shows that by representing meta-stability through designing hand holds, learning can be induced and transfer of climbing fluency in route finding can be facilitated.
(Pizarro et al., 2020)	1 (single group design)	12 (60 min), plus matches (not specified how many)	6	SSCGs based on NLP- and defensive game principles.	First defender; marking, blocking, and tackling others; marking, interception and help coverage. DM and execution of these actions was evaluated as successful or unsuccessful.	In sum, players improved DM and execution in marking and blocking and help coverage. There were no significant results for interception- or tackling actions. This could be tied to the usage of numerical superiority for the attacking team.
(Pizarro et al., 2019)	1 (single group design)	12 (60), plus 6 games	6	SSCGs based on NPL- and offensive game principles.	Measuring DM and execution using Game Performance Evaluation Tool (GPET) to score for	Principle 1(keep the ball possession); passing significantly improved Principle 2 (progression towards the goal); passing and dribbling significantly improved Principle 3 (shooting at goal with the lowest level of

Author	Groups	Intervention duration		Manipulation	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
					passing-, dribbling- and shooting actions.	opposition); dribbling significantly improved. No significant results for shooting actions. Results suggest that task design and tactical principle should be considered when trying to improve tactical behavior.
(Práxedes et al., 2019)	1 (single group design)	14 (60) (only intervention phase), plus 13 matches	13	SSCGs based on NLP principles and session objectives	DM and performance of passing actions using Game Performance Evaluation Tool (GPET)	Results show significant improvement in values for DM and execution (performance) in passing actions in intermediate- and retention measurements compared to pre-intervention measurement.
(Ramos et al., 2020a)	1 (single group design)	143 (120), plus 32 matches	Sept to June	CLA and SGA principles	Three components of tactical knowledge; tactical awareness, emerging understanding, and playing tactically	Results indicate that the development of players' tactical knowledge benefited from a mutual integration of different, yet complementary, pedagogical approaches (SGA and CLA). The use of ecological and meaningful contexts seemingly helped players develop a deeper knowledge *of* a performance environment, which could transpire to positive effects on tactical knowledge.
(Ramos et al., 2020c)	1 (single group design)	143 (120), plus 32 matches	Sept to June	CLA and SGA principles, as well as tactical problems in counterattacking	Team synchronization (cluster amplitude as a function of set	Results showed reductions in intra-team synchrony when tactical complexity of counterattacking play increased (second AR-cycle). Intra-team synchrony (re)emerged between the first and third AR-cycles. Final set moments proved to be a significant

Author	Groups	Intervention duration		Manipulation	Outcome variables	Main results
		Session (min pr. Session)	Weeks			
				phase that had to be resolved (based on reflection and identification)	moments and court directions)	environmental constraint, but its impact was progressively reduced over the cycles due to CLA and SGA intervention.
(Seifert et al., 2015)	Individual assessment (n = 9)	4 (3 ascends on three different routes)	10 days	Horizontal-, Vertical- or mixed grips	Neck and hip rolling motion, neck-hip coordination, number of exploratory and performatory movements, ascent duration and geometric index of entropy (hip trajectory).	In terms of learning, practice led to significantly fewer exploratory and performatory movements being observed and reduced ascent-times over sessions, but no change in geometric index of entropy (i.e., climbing fluency) was observed. In sum, the data suggest that individuals learn to search and explore the perceptual motor workspace during practice in a "safe" way; meaning that meta-stable region of performance offers both exploration and opportunities to use fall-back strategies (pre-existing behavioral repertoire).
(Seifert et al., 2018)	Individual assessment (n = 8)	4 (60)	10 days	Horizontal-, Vertical- or mixed grips	Four states of behavior: stationary, hold exploration, hip movement and global motion measured based on four inertial measurement units (IMU).	Results showed that with practice, the learners can decrease the relative duration of hold exploration and the number of performatory movements. The participants' climbing efficacy improved as a function of practice and that the benefits of manipulating task constraints, improved affordance perception. In sum this promotes safe exploration during learning,

Author	Groups	Intervention duration		Manipulation	Outcome variables	Main results
		Session (min pr. Session)	Weeks			

Note. SSCG = Small-Sided Conditioned Games, DM = decision-making, NLP = Nonlinear pedagogy, CLA Constraints-led approach, SGA = Step-Game Approach