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A games-based assessment in ecological dynamics for measuring physical literacy

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ABSTRACT

Ideas and concepts taken from ecological dynamics might provide an alternative perspective on physical literacy assessment. The aim of this paper was to pilot an assessment of physical literacy conceptualised in an ecological dynamics theoretical rationale. The assessment that was designed has a number of unique features: its scale of analysis is captured at an individual-environment interaction level during game play and it captures key affordances that a child is attuning to and how they are functionally playing the game. Data collection involved observing primary school children playing invasion games in physical education classes. Digital, video-based tagging (Dartfish Pro) of children's behaviours using the emergent game-based assessment tool was completed. Pilot data provided insights on the potential rich interpretations possible, such as readily differentiating between low and high physical literacy learners' behaviours when playing small-sided games. Greater knowledge *of* the performance environment was observed in children with higher physical literacy, noted through a greater capacity to favourably regulate their relative positioning between competing and cooperating players, adopting more varied offensive functionality, and exhibiting greater attunement to key affordances. Better understanding children's knowledge *of* the environment during games play, provides practitioners novel insight into how physical literacy reveals itself through embedded actions. This appreciation can help inform practice more holistically, contributing to richer learning environments and task design.

Introduction

In this paper, we considered how physical literacy can be assessed, leaning on an ecological dynamics conceptualisation to help us navigate the complexity of measuring something that is, in essence an embedded and embodied *process* (Rudd, 2021). Embodiment in the context of physical literacy, describes the potential individuals have to engage with their surrounds via movement (Whitehead, 2010). When movement learning is considered, embodiment means that perception and decision-making cannot be learnt independently from acting, as perceiving is already acting. Embedded cognition describes how individuals are shaped by, and can shape the (physical and socio-cultural) environments in which they reside (Araújo, Davids & Hristovski, 2006; Rudd, 2021). Linked to these notions, ecological dynamics has been acknowledged as contributing a well-developed empirical and theoretically informed perspective on how we comprehend movement skill, development and performance (Button et al., 2021). Central to this theory is the principle that movement is a self-organising phenomenon predicated on the interaction between an individual and their environment. On this basis, intentional action is viewed dynamically, with functional behavioural solutions arising from the continuous interactions of individual, task and environmental constraints (Newell, 1986; Seifert et al., 2018).

The earliest documented use of the term *physical literacy* was in reference to the quality of the movements of the indigenous people of America. Movement, for these people, was not formally taught, but rather embedded in the very fabric of their hunter-gatherer way of life, helping them navigate and 'wayfind' through the world (Maguire, 1884; Cariney et al., 2019; Woods et al., 2020b). Whitehead (2001, p131) reimagined the concept, producing her influential characterisation of physical literacy:

A physically literate individual moves with poise, economy and confidence in a wide variety of physically challenging situations. The indi-

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vidual is perceptive in 'reading' all aspects of the physical environment, anticipating movement needs or possibilities and responding appropriately to these, with intelligence and imagination. Physical literacy requires a holistic engagement that encompasses physical capacities embedded in perception, experience, memory, anticipation and decision-making.

Nowadays, commonly expressed themes within motor skill literature highlight that physical literacy involves the parallel consideration of movement competence, affective behaviours, knowledge, understanding, and the valuing of physical interactions with the environment (Whitehead 2013; Edwards et al., 2017).

Globally, only 20% of children and adolescents aged 11-17 years are considered to be sufficiently active to the point in which health gains can be achieved (Guthold et al., 2020). In part, this is due to fact that many children and young people in contemporary societies are often deprived of the opportunities that earlier generations had to develop their physical literacy, and as result, have been described as being part of a 'movement-supressed' society, whereby individuals are not getting enough physical activity to maintain their health (Keegan et al., 2013). Physical educators, through the use of different pedagogical models (e.g. Teaching Games for Understanding and Sport Education) are, thus, often tasked with the challenge of reshaping children's experiences of physical education in an attempt to improve both movement competencies and personal disposition towards physical activities. Such learning experiences are normally followed by assessments, which López-Pastor et al. (2013) suggested remains one of the most problematic issues facing physical educators. In team games research applications, there have been attempts to adopt more representative assessment strategies capturing skilled tactical problem solving (Oslin, Mitchell & Griffin 1998), and movement skills alongside individual and collective strategies in team sports (Gréhaigne, Godbout & Bouthier 1997). However, traditional assessments of physical literacy still tend to be reductionist, providing only knowledge *about* a child's performance within a specific physical literacy domain (physical, emotional and knowledge and understanding). Primarily there has been a focus on fundamental movement skills evaluation and the physical domain of physical literacy. This form of assessment typically breaks down movements into discrete and quantifiable outcomes – situated in de-contextualised settings (e.g. removed from game play contexts) where the skills will normally be performed (O'Sullivan et al., 2020). The collected data will be understood to be both reliable and valid under scientific methodologies oft-rooted in the dualistic worldview of Descartes, and opportunities for comparison between individuals and groups emerge. However, physical literacy is not founded, nor does it prescribe to Cartesian science and any attempt to overlap such assessment methods means that the embodied and embedded experience is lost (Whitehead, 2013; Rudd et al., 2021). An ecological dynamics perspective on physical literacy offers a solution to this problem by prescribing less emphasis on knowledge *about* performances. Instead, for us to understand and measure physical literacy it is it essential to focus on children's knowledge *of* the performance environment. This viewpoint draws on Gibson's (1979) insights on the distinction between knowledge *of* and knowledge *about* the environment, whereby knowledge *about* the environment is conceived by verbal descriptions, expressing idealised ways of doing or being (Woods et al., 2021). By contrast, knowledge *of* the environment is articulated through perception, action and skilled intentionality (Button et al., 2021).

The aim of this paper was twofold: firstly, to propose an ecological dynamics conceptualisation of how physical literacy could be assessed – thereby preserving key information-movement couplings in representative contexts. Secondly, to use this theoretical rationale to design and pilot a games-based assessment tool of physical literacy. It is hoped that the preliminary insights gleaned here can support practitioners in the challenge to further explore how ideas of ecological dynamics could be harnessed to develop and assess physical literacy.

An ecological dynamics conceptualisation of physical literacy assessment

A central component of assessment informed by an ecological dynamics rationale is that it must faithfully preserve key person-environment relations. This is because ecological dynamics is based on the concept that perception is embedded in the environment and embodied in cognitions and actions (Araújo, Davids & Hristovski, 2006; Araújo et al., 2019). With a strong grounding in phenomenology, the definition of physical literacy proposed by Whitehead (2001 – noted earlier) acknowledges that the individual and the environment are inseparable, advocating the Monist dimension of being – viewing mind, body and environment as unitary. Assured interactions with the environment, intelligent, creative responses to stimuli and a mindfulness of embedded capability leading to fluent self-expression, are all key characteristics of the physically literate person (Whitehead, 2013). Ecological dynamics aligns well with Whitehead's interpretation of physical literacy, associated with the ideas that perception for movement is direct, and an external focus of attention is important to successfully accomplish intended goals. As a feasible framework for investigating behaviours when observing physical activity, physical education and conditioned games, ecological dynamics recognises the flexibility of neurobiological systems and their capacity to effectively and continually (re)organise themselves to use continuously evolving environmental affordances and satisfy interacting constraints (Button et al., 2021). The continuous coupling of actions and perception forms the basis of adaptive flexibility in realising functional movement solutions (Vilar et al., 2012; Chow et al., 2016).

Typically, research and practice in the field of physical literacy has focussed primarily upon the 'physical' dimension of the concept, and to a lesser extent on the affective and cognitive domains (Edwards et al., 2017). Such compromises are at the expense of concentrating upon the wider, more holistic meaning and understanding of the philosophy that encompasses the embodied dimension of being. However, research has typically focused its scale of analysis on the organism *per se*, viewed detached from the environment in which they inhabit. Resulting in artificial, decontextualised motor skill assessment, decoupled from the multiple nested movements typically observed when performed in context (Ng & Button, 2018). The execution of a standing overhand throw to determine throwing proficiency for example (Test of Gross Motor Development, Ulrich, 2013), is divorced from the reality of games play. The presence of competing and cooperating players results in the execution of an open, rather than closed-skill task, where the throw must be functionally appropriate to the external constraints influencing behaviour. Analysis of team sports performance informed by an ecological dynamics framework has attempted to help explain this more embodied-embedded aspect, exploring the interactions that exist between athletes and their environment (Vilar et al., 2012; Davids et al., 2013; Passos, 2020). Research has shown that, as a performer interacts with their environment, the prospect of action develops – meaning emerges, persists, and dissolves, continually shaped by informational constraints. The movements of defenders, distances to teammates, opportunities for distribution or travelling with the ball all enmesh to generate dynamic performance challenges and problems for individuals (Wilkie et al., 2021). This dynamic process, implied in the perception of affordances (Gibson 1979; defined as *opportunities for action*, discussed later), allows us to draw upon contemporary propositions of ecological dynamics that view the learning process as one of *wayfinding* – navigating *through* dynamic performance landscapes (Woods et al., 2020a).

Assessment of physical literacy, thus, needs to account for a performer's adaptability to context. An adaptable performer is able to selectively respond to the affordance landscape, attending to features that invite the successful completion of a task (Button et al., 2021; Chow et al., 2020b; O'Sullivan et al., 2020). Concepts in ecological dynamics provide a framework from which to explain these complex interactions in performance and learning. Thus, in the sections to come, we explore some key pillars of an ecological dynamics rationale which could help us design a novel games-based assessment tool of physical literacy.

Key pillars of an ecological dynamics approach to the design of a game-based assessment

The first step in developing an assessment tool was to enrich it with aspects of theory that could help researchers to understand the behaviours being observed. A significant assumption in adopting such an approach informed by ecological dynamics is that physically literate individuals would be more accomplished at recognising and taking advantage of (i.e., *attuning* to) information within their environment. What this information specifies is the affordances of one's surrounds, which performers can perceive and actualise to find their way through performance landscapes (i.e., use perception, cognition and action to achieve intended task goals). In doing so, the physically literate performer will functionally regulate their behaviours more appropriately than less literate individuals based upon task and environmental constraints. Building from earlier work considering the application of key ecological principles towards the manifestation of physical literacy in games play (Wilkie et al., 2021), potential performance indicators and their descriptions were introduced, discussed, trialled, and endorsed by the authorship team consisting of academic and technical experts within the field. During a four-month period, subsequent modifications and refinements were made, before agreement was established. As a consequence of this process the ecological conceptualisation, measurement variables, variable descriptions, and recommended reporting was finalised (Table 1), framed around the key ecological principles of 1) Wayfinding, 2) Affordances and Attunement, 3) Intentionality, and 4) functional movement skills.

Wayfinding

Wayfinding is a purposeful, intentional and self-regulated journey through various performance landscapes, guided by the perception and actualisation of affordances within the environment (Woods et al, 2020b). As an individual finds their way through a performance landscape, what they develop is their knowledge *of* the surrounds (Gibson, 1966), established through direct and unmediated interaction with the environment (Woods et al., 2020a). This is contrasted to knowledge *about* one's environment, which is indirect and mediated – by second hand information – through words, pictures, symbols or photographs (Gibson, 1966). Thus, if wayfinding is to be a central pillar of an assessment tool of physical literacy, it needs to centralise a performer's knowledge *of* (not *about*), their environment – emphasising the embedded-ness of the tool. Applied to a games-based context, wayfinding might reveal itself through the functionally effective solving of emergent, task-orientated movement challenges (Woods et al., 2020b). For example, successfully navigating through spaces emerging between opponents, finding ways of passing the ball to teammates in advantageous positions, or exploring ways of defending space when outnumbered by attackers, would be reflective of an individual's knowledge *of* the environment (Ribeiro et al., 2019). Wayfinding provides an anthropological grounding for the tool, subsequently informing the approach as a whole. Consequently, an ecologically dynamic assessment of physical literacy should capture the various ways in which children are able to adapt to the changing constraints of a performance environment as they find their way through the various ebbs and flows of a game. Physically literate children should be able to demonstrate more effective adaptation to novel performance situations, allowing adept, efficient interactions with the environment.

Affordances and attunement

Affordances are the action-relevant properties of the environment that can be exploited by performers (Gibson, 1979), while attunement describes the process of selection from relevant informational variables within the environment (Button et al, 2021). By integrating principles of affordances and attunement into the creation of the games-based assessment tool, it is possible to develop an ecological understanding of decision making. The notion of a symbiosis between an individual and the performance environment establishes the idea that individuals perceive the affordances of the environment in terms of their relevance and functionality (Davids et al., 2013). Individual action capabilities influence perception of affordances, guiding performance, and helping establish an understanding of what individuals learn and know, and how they choose to act (Araújo, Davids & Hristovski, 2006). So, while some affordances act as strong attractors, soliciting attention, individuals can choose to accept or reject these invitations for action by moderating the extent to which the system relaxes to particular attractors (stable states of system organisation), simultaneously ignoring alternatives (Araújo, Davids & Hristovski, 2006).

From a physical literacy perspective, the affordance landscape and attunement to picking out key information variables relevant to each individual reflects embedded knowledge and understanding of the environment in related or familiar tasks, as well as the ability to effectively adapt movements as required by the circumstances in novel settings. Physically literate children should be able to demonstrate more intuitive reading of the environment and attunement to key affordances offered resulting in greater responsivity to ongoing opportunities for action. Informed by ecological dynamics, variables (described fully in Table 1) such as *contested and uncontested distribution; signalling for the ball; off-ball movements to break or establish dyadic stability*; and *effectively tracking play* provide insight into a child's attunement to a game's affordances.

Intentionality

Intentionality, from an ecological dynamics perspective, describes an individual's capacity to self-regulate functional behaviour in the absence of external input (Chow et al., 2020b). By integrating principles of intentionality into the creation of the games-based assessment tool, it is possible to describe the realisation of value and meaning during movement. Intentionality is not only limited to cognition, but extends to a child's perception, action, comprehension, planning, self-organisation, decision making and motile effectivities as these qualities collectively work in concert to adapt to the dynamic environment and task constraints present in games play. Expressed through self-regulation and performance, a child's development and success are represented by the dynamic explorations of the environment, as a means of information-gathering in the service of action (Rudd, 2021).

Player behaviours in team sports are constrained by local organisational tendencies, with cooperative and competing environment interactions emerging as players regulate relative positioning to exploit opportunities when invading or defending space (Riley et al., 2011; Vilar et al., 2012). In practice, this process involves players moving with poise, economy and confidence that matches individual capabilities and self-regulation skills (Rudd, O' Callaghan, & Williams, 2019). A physically literate child will be well placed to demonstrate intentionality if they are able to adapt to the variable dynamic challenges that emerge in pursuit of achieving task and performance goals. Informed by ecological dynamics, variables (described fully in Table 1) such as *coadaptive network formation; moderation of defensive positioning to close down, overload or swarm the opposition;* and *effectively tracking play or players in offence and defence;* provide insight into how children demonstrate intentionality in games environments.

Functional movement skills

Functional Movement Skills refers to the qualities that allow individuals to negotiate their environment in the completion of intended task goals (Davids et al., 2012; Chow et al., 2020a). Rudd (2021) identifies functional movement skills as the only way practitioners can observe and appreciate all dimensions of a child's physical literacy. By integrating principles of functional movement skills into the creation of

Table 1
Theoretically informed framework for an emergent game-based assessment tool.

Ecological Conceptualisation	*Measurement Variable*	*Description of measurement variable*	*Recommended reporting*
Offensive Functionality (Distribution behaviours)	Attempted Passes	Number of attempted passes made by each child.	Total number of observed pass attempts
	Passing success	Behaviour results in successful distribution of ball to teammate.	Percentage of successful passes from total attempted passes
	Uncontested passes	Number of times distribution was to an unmarked teammate resulting in an unchallenged successful reception.	Percentage of unchallenged passes from total successful distributions
	Targeted player	Identifies the distribution target's physical literacy.	Percentage of distributions to higher and lower physical literacy targets
Invitations for Action (Length and direction of pass)	Hand off	Distribution of ball involves handing the ball to a teammate – there is no flight phase involved in the distribution action.	Percentage of total successful passes that were hand offs, short, medium or long passes
	Short pass	Distribution involves observed flight of ball between teammates of <1.5m.	
	Medium pass	Distribution involves observed flight of ball between teammates of 1.5m – 4.5m.	
	Long pass	Distribution involves observed flight of ball between teammates of >4.5m.	
	Penetrating pass	Distribution is of a penetrative (between 10 and 2 on a clock face), lateral (right lateral between 2 and 4, and left lateral between 8 and 10 on a clock face) or rearwards (between 4 and 8 on a clock face) orientation where 12 on the clock face indicates the direction of opposition goal).	Percentage of total successful passes that were penetrating, lateral or rearwards in direction
	Lateral pass		
	Rearwards pass		
Offensive Intentionality	Single off ball movement	Child undertakes one off ball locomotive action resulting in horizontal displacement of more than one step during offensive possession period.	Percentage of total offensive off ball periods where observed child completes a single locomotive action
	Multiple off ball movements	Child undertakes two or more off ball locomotive actions during offensive possession period.	Percentage of total offensive off ball periods where observed child completes more than one locomotive action
Offensive Spatial Temporal Interactions (in relation to eliminating dyadic system stability)	Remains stationary	Child remains stationary during offensive possession period.	Percentage of total offensive off ball periods where observed child does not move
	Moves into space	Child moves into space (no opposition player within 1.5m).	Percentage of total offensive off ball periods where observed child moves into an unoccupied court position
	Moves into contested space	Child moves in an area occupied by opposition player (one of more opposition players within 1.5m).	Percentage of total offensive off ball periods where observed child moves into an occupied court position
	Effectively tracks play	Head and body orientation of child allows for effective scanning behaviour - following play, observing the ball, and positions of competing and cooperating players.	Percentage of total offensive off ball periods where observed child tracks play

(*continued on next page*)

Table 1 (*continued*)

Ecological Conceptualisation	*Measurement Variable*	*Description of measurement variable*	*Recommended reporting*
	Proximity to ball on offence	Offensive positioning results in the child being ‘close to the ball’ (<1.5m away from player in possession), ‘near the ball’ (1.5m – 4.5m away from player in possession), or ‘distant to the ball’ (>4.5m away from player in possession).	Percentage of total offensive off ball periods where observed child is close, near or distant to the player in possession.
Coadaptive Network formation to achieve task goals	Calls or signals for ball	Child provides a visual or verbal indication that they are wanting to be the target of a pass	Percentage of total offensive off ball periods where observed child calls for ball
	Target for pass	Child is the target of distribution from a teammate	Percentage of total offensive off ball periods where observed child becomes the target of teammate’s distribution
	Attractor recognition ratio	The ratio of signals for the ball to the number of times the child becomes the target for distribution	Calculated ratio of calls for ball and becoming the target of distribution
Defensive Intentionality	Single movement	Child undertakes one off ball locomotive action resulting in horizontal displacement of more than one step during defensive possession period.	Percentage of total defensive off ball periods where observed child completes a single locomotive action
	Multiple Movements	Child undertakes two or more off ball locomotive actions during defensive possession period.	Percentage of total defensive off ball periods where observed child completes more than one locomotive action
Defensive Spatial Temporal Interactions (in relation to forming or retaining dyadic system stability)	Closes down ball	Child moves towards the player with the ball and affects ease of opposition player’s subsequent actions.	Percentage of total defensive off ball periods where observed child moves closes down or swarms the ball.
	Swarms ball	Child moves towards the player with the ball and affects ease of opposition player’s subsequent actions but is not the first person to close down the ball.	
	Marks opposition player	Child purposefully moves towards and subsequently occupies contested space attempting to mirror the movements of opposition player without the ball.	Percentage of total defensive off ball periods where observed child moves into contested court position
	No marking	Child moves into unoccupied space (no opposition player within 1.5m).	Percentage of total defensive off ball periods where observed child moves into an unoccupied court position.
	Effectively tracks play	Head and body orientation of child allows for effective scanning behaviour - following play, observing the ball, and positions of competing and cooperating players.	Percentage of total defensive off ball periods where observed child tracks play
	Proximity to ball on Defence	Defensive positioning results in the child being ‘close to the ball’ (<1.5m away from player in possession), ‘near the ball’ (1.5m – 4.5m away from player in possession), or ‘distant to the ball’ (>4.5m away from player in possession).	Percentage of total defensive off ball periods where observed child is close, near or distant to the player in possession
Defensive Functionality (Interactions with ball)	No attempted object interaction	Child makes no attempt to effect ball flight during distribution or shooting actions.	Percentage of total defensive off ball periods where observed child interacts with the ball
	Unsuccessful block or interception	Child unsuccessfully attempts to effect ball flight during distribution or shooting actions	
	Successful block or interception	Child successfully effects ball flight through contacting the ball during opposition possession	

the games-based assessment tool it is possible to describe the mixture of adaptive behaviours an individual possesses and is capable of implementing. The adjustment in perspective from conceptualising 'fundamental' movement and changing explanations of its role in physical literacy to 'functional', challenges the prevalent reductionist operationalisation and interpretation of this domain typically observed. Consequently, shifting the orientation of athlete and practitioner towards interactions and functional relationships between the child-environment system (Renshaw & Chow, 2019). Action results in the continuous delivery of new affordances for opponents, teammates and the individual themselves. Effective interaction with this dynamic landscape of affordances requires holistic engagement that is adaptive and flexible to reflect the interactions between competing and cooperating players.

Observing functional movement behaviours during games allows practitioners to establish the prominence of certain attractors amongst available distribution targets, while also providing insight to favoured functional movement solutions in pursuit of intended goals. The physically literate child will be able to demonstrate a fuller repertoire of emergent behaviours in pursuit of achieving task and performance goals, where cognition, perception and action comprise the articulated functional movement. Informed by ecological dynamics, variables (described fully in Table 1) such as *heterogeneous or homogenous ball distribution*; and *range and directions of passing,* provide insight into how children reveal functional movement skills in games environments.

Bringing a theoretical framework into practice

To better understand an individual's physical literacy when embedded in a games-based approach, researchers should observe the performer's movement skill in context. Such an approach would enable us to appreciate the information sources children attune to, the opportunities for action available, and how they might use such affordances to successfully negotiate task outcomes (Wilkie et al., 2021). Such an approach to observing physical literacy necessitates an ecological epistemology, recognising the mutual relationship between a child and their environment. Table 1 introduces a theoretically informed framework for an emergent, game-based assessment grounded in ecological dynamics, identifying variables measured and their definitions.

Case example – piloting the theoretically-informed framework for emergent, game-based assessment

Approach

For the purposes of this paper, a smaller, indicative sample of participant behaviour is included to provide insight to the potential the emergent game-based assessment tool has as a novel approach to games-based physical literacy assessment. With this in mind, the analysis presented is a representative, convenience sample taken from a larger research project, resulting in 10 primary school children (Age: 10.48 ± 0.25 yrs.) being selected. Baseline assessment using previously validated assessment tools capturing knowledge *about* physical literacy was undertaken prior to the emergent games-based assessment being performed. A composite physical literacy score for each child was obtained through the evaluation of Working Memory (McClelland et al., 2014), Game Play Perception (Miller et al., 2019), and an assessment of fundamental movement skills using the Dragon Challenge (Stratton et al., 2015). To determine similarities between individual participants, a *kmeans* cluster approach was utilised (R Core Team 2019) to detect and organise data into a number of groups via the elbow method. This analysis enabled subsequent grouping of individuals with similar levels of physical literacy into higher and lower-physical literacy categories. This categorisation informed the creation of balanced (mixed physical literacy) teams and was used for the purpose of identifying performers during the gameplay observations.

Data collection

In the analysed games, children were placed into mixed gender teams of five, consisting of individuals who had differing levels of physical literacy. Children then played a game of mat ball, which is a small-sided invasion game where the object is to score more points than the opposition. A point is scored by successfully distributing the ball to a teammate positioned in the scoring zone (a 2m x 1m gym mat with a player kneeling upon it). Games consisted of two competitive, five-minute periods of play with a short break between periods. Rules included: no physical contact, no running with or dribbling of the ball, and scoring was only possible by shooting from within the opposition half. The court dimensions were 18m x 12m with the gym mat placed centrally at either end of the court. Games were video recorded (GoPro Hero 9) from an elevated court side position allowing digital video-based tagging (Dartfish Pro) of the games to be completed.

Emergent game-based assessment coding

Post-event manual, electronic tagging was undertaken capturing child-environment interactions during team games play. The coding panel created for analysis used the theoretically informed framework highlighted in the emergent games-based analysis tool (Table 1). Discrete data (frequency counts) was coded by the lead author, using recorded video playback with frame-by-frame capabilities (1080hp, 60Hz frame rate). This allowed for accurate documentation of player action and behaviour. The scale of analysis was an individual child playing the game using event-based temporality for recorded observations. This approach defined the observed behaviours and interactions occurring between receipt of the ball by a player from another player and the conclusion of the subsequent distribution of the ball to another player as a temporal period. Coding typically took 40 – 50 minutes per player, resulting in an average of 899 data entry points being recorded per individual child during the game.

Descriptive analysis

Video tagging using the emergent games-based assessment tool, enabled a descriptive analysis to be undertaken, resulting in 98 temporal periods of play being recorded during the game (means per player: 11 'On Ball' periods, 39 'Offensive Off Ball' periods, and 48 'Defensive Off Ball' periods) over the duration of the game Table 2. Provides a summary of the descriptive analysis undertaken examining the behaviours of high-physical literacy learners (H-PL) and low-physical literacy learners (L-PL) during the game.

Results

Discussion

The aim of this paper was to conceptualise an ecological dynamics-inspired, game-based assessment tool to gain an embedded understanding of a child's physical literacy. Following this, we set out to pilot how such a tool could capture emergent child-environment interactions and how useful this information could be to help practitioners design programmes to support each child's ongoing development. This pilot study has provided initial evidence that an ecological dynamics informed games-based assessment has the potential to provide richer understanding of children's physical literacy.

The emergent gameplay behaviours forming the analysis highlight what information sources in the environment children are self-regulating their action to. Previous research has discussed how perception is embodied and embedded and how by directly studying behaviour or actions, it can reveal the performer's exploration, problem solving or reasoning (Araújo, Davids & Hristovski, 2006; Araújo et al. 2019). The tool helps guide a practitioner to focus on the ecological information

Table 2
Emergent game-based assessment tool of players behaviours during mat ball.

Ecological Conceptualisation	*Decisions 'expressed as actions'*	*L-PL learners*	*H-PL learners*	*Difference comparing H-PL to L-PL learners*
Offensive Functionality (Distribution behaviours)	Attempted Passes	29	47	More passes attempted
	Passing success	79.3%	78.7%	No difference
	Uncontested pass	86.9%	91.2%	More frequently passed to unmarked teammate
	Targeting L-PL player	31%	59.6%	H-PL demonstrated a more balanced distribution strategy. L-PL players typically demonstrate more mono-stable action couplings
	Targeting H-PL player	69%	40.4%	
Invitations for Action (Length and direction of pass)	Hand off	0%	8.5%	Technical interactions from H-PL players are more varied in the movement solution demonstrated
	Short	62%	51%	
	Medium	37.9%	36.2%	
	Long	0%	4.2%	
	Penetrating	41.4	44.7	H-PL players make penetrating and backward passes more frequently than L-PL players
	Lateral	44.8%	34.7%	
	Backwards	13.8%	19.1%	
Offensive Intentionality	Single movement	85.3%	90.4%	Less frequently demonstrates multiple movements
	Multiple Movements	14.8%	9.6%	
Offensive Spatial Temporal Interactions (in relation to eliminating dyadic system stability)	Remains stationary	34.6%	17.8%	Less likely to remain stationary during offensive periods
	Moves into space	43.6%	60.5%	Moves into unoccupied space more frequently potentially disturbing dyadic system stability
	Moves into contested space	21.8%	21.7%	No difference
	Effectively tracks play	91.6%	96.2%	More frequently demonstrates tracking of ball and critical play characteristics
	Close to ball (<1.5m away)	39.7%	31.8%	Less frequently close to teammates in possession
	Near to ball (1.5-4.5m way)	37.8%	51%	More frequently near to teammates in possession
	Distant to ball (>4.5m away)	22.4%	17.2%	Less frequently distant to teammates in possession
Coadaptive Network formation to achieve task goals	Calls or signals for ball	57.7%	34.4%	Less frequently indicates availability to receive pass
	Target for pass	22.4%	24.2%	Marginally more frequently targeted
	Attractor recognition ratio	2.57:1	1.42:1	More frequently acknowledged as a viable attractor (recipient of pass) when signalling for the ball
Defensive Intentionality	Single movement	89.7	82.5	Less likely to make only one locomotive action on defence
	Multiple Movements	10.3	17.4	More frequently adjusted position on defence
Defensive Spatial Temporal Interactions (in relation to forming or retaining dyadic system stability)	Closes down ball	24.6	29.6%	H-PL players More frequently observed trying to create dyadic system stability on defence by closing down opposition in and out of possession
	Swarms ball	11.8	15.9%	
	Marks opposition player (takes up contested space)	16.9	21.1%	
	No marking (takes up unoccupied space)	58.5	50.3%	
	Effectively tracks play	91.6%	96.2%	More frequently demonstrates tracking of ball and critical play characteristics
	Close to ball (<1.5m away)	33.3%	40.7%	More frequently close to the opposition player in possession
	Near to ball (1.5-4.5m way)	39%	39.2%	No difference
	Distant to ball (>4.5m away)	27.7%	20.1%	Less frequently distant to the opposition player in possession
Defensive Functionality (Interactions with ball)	No attempted object interaction	88.7%	75.1%	Less frequent
	Unsuccessful block or interception	9.2%	21.7%	More frequently attempted to block or intercept the ball
	Successful block or interception	2.1%	3.2%	Marginally more frequent

that is being picked up by the child. For example, through the use of the emergent game-based assessment tool, a practitioner is able to discern a child's responsiveness to affordances in the game.

Data from our pilot showed that passing success rates were almost identical between L-PL and H-PL children. On its own, this information provides some motivation to explore a wider, more holistic evaluation of performance that encompasses the child-environment interactions taking place as players attempt to effectively wayfind in pursuit of shared task goals. As a more readily accepted traditional performance measure, passing completion rates provide little insight to the 'how' and 'why' of observed performance. The rudimentary, but commonly held association between fundamental movement skills equating to physical literacy (Almond, 2013), leads to a much narrower realisation of the concept than for example Whitehead (2019) advocates. By framing the problem more holistically, drawing on individual movement skills and knowledge *of* the environment we are able to gain insight to how physical literacy better accounts for the qualities required for meaningful, embodied engagement in performance settings (Bailey, 2020a; Durden-Myers, Meloche & Dhillon, 2020). Passos et al. (2011.; 2020), for example, used an Adjacency Matrix to establish the networks formed through emergent coadaptive ball distribution behaviours in team sports, helping develop understanding of interpersonal interactions within social neurobiological systems. A similar approach was adopted in the emergent game-based assessment tool. A review of offensive performance functionality in passing reveals H-PL children adopted a more varied offensive functionality compared to L-PL children, who more typically demonstrated mono-stable action couplings. H-PL children were observed to make more uncontested, penetrating passes, over mixed distances, compared to their L-PL counterparts. L-PL children typically sought out higher literacy team mates for passes, attempting only short and medium range passes, predominantly in a lateral, rather than vertical, direction. The additional richness offered as a consequence of reviewing passing functionality in this manner, aligns well with the philosophical and ontological basis of physical literacy. Whereby, the interface between abilities, opportunities and circumstances, enmesh to affect an individual's navigation of their environment (Baily, 2020b; Whitehead, 2019).

H-PL children also demonstrated greater capacity to regulate their court position in relation to attempts to eliminate dyadic system stability between themselves and defenders. This performance feature resulted in participants more frequently finding space on the court, a willingness to remain in motion, and in their capacity to effectively track play and seek out the affordances offered within the games environment Davids et al. (2013) and Vilar et al. (2012) have highlighted how attackers engage in a process of symmetry breaking to destabilise attacker-defender stability and the organisational state of the game, while defenders try to maintain a stable dyadic system. H-PL players were able to demonstrate greater appreciation of making themselves available in regard to positioning themselves relative to the player in possession of the ball, by occupying space near, rather than right next to or distant to, the player in possession. Whitehead's (2001; 2010) original and more recent articulation of the core components of physical literacy identified the ability to read the situation and react appropriately through movement as key facets of becoming physically literate. The capacity to respond effectively to the formation and dissolution of attacker-defender stability was a feature of H-PL individual gameplay. Attractor recognition ratios (defined as the ratio of signals for the ball to the number of times the child becomes the target for distribution) were much better in H-PL children who appeared more discerning in when they signalled for the ball compared to L-PL children, who signalled almost twice as often, yet became the target of distribution less frequently. Observing invitations for action and functional behaviours in passing behaviour allows practitioners to establish dominant attractors in terms of other players that systems typically relax to as targets for distribution, while also providing insight to the functionally successful movement skills adopted. Such observations provide insight to the transient, emerging, or decaying attractor states that reveal themselves through the game providing an understanding of how learners are evidencing confidence in their decision making as some functional movements might actually emerge as being repellers through child-environment interactions.

The emergent game-based assessment tool also provides rich insight into defensive intentionality and spatial-temporal behaviours. Our tool highlighted that H-PL children demonstrated behaviours typically considered favourable in defensive gameplay situations. By being generally closer to the ball at all times, closing down or swarming the ball following distribution, and by marking players off the ball more frequently than L-PL children they were more readily able to form or preserve desirable defensive dyadic system stability. These observed attempts to maintain the organisational state of the game represent embedded moments of engagement incorporating physical capacities, perception and decision making. These H-PL child behaviours were combined with a greater willingness to change court position or defensive role during periods out of possession, in response to the affordances offered by the environment. Adaptation in games and sports contexts acknowledges the recurring reorganisation of the team, conceptualised as a complex system, to satisfy the ecological constraints of competition (Button et al., 2021). Although all players demonstrated similar capacity to track play when defending, the data suggests greater attunement to key affordances by H-PL children as a consequence of more frequently-reported attempts and successes blocking or intercepting passes. The evaluation of defensive spatial temporal interactions and functionality provided insight to children's wayfinding success and the ability to not only effectively read the situation, but to also anticipate the likelihood of certain actions manifesting themselves. This capacity to read, anticipate and react effectively through movement is something highlighted by Whitehead (2001; 2010), Jurbala (2015) and Shearer et al. (2018) as being characteristic of the physically literate individual. Button et al. (2021) indicates that an individual must perceive enough of their environment to achieve such task goals, while selecting only the most relevant information to facilitate successful intentional behaviour. The embedded functional capabilities of the performer manifest themselves in the continuous interactions between child and environment, allowing observations to be picked out that readily differentiate L-PL and H-PL child-environment interactions when playing games.

Limitations and future research

Through an ecological dynamics rationale, we explored the assessment of physical literacy in ways yet to be taken up in research and practice. This approach, however, is not without limitation that requires some brief mention. The analysis presented, was purposefully explorative, focussing on a smaller sample size for the initial presentation of data. A more substantive project recruiting children from across key stage two year groups is planned. This would allow for a more robust statistical analysis to be undertaken, greater fidelity and increased confidence in the generalisability of findings. Video tagging can be time consuming, due to the scale of analysis being at the individual-environment interaction level and perhaps it is unreasonable to expect a 'full' analysis to be completed by teachers in school settings. Further research is needed to explore the potential to employ the tool to evaluate discrete gameplay qualities such as 'attacking behaviours', 'defensive behaviours', or 'spatial awareness' by selectively employing measurement variables from the games-based assessment tool. A more streamlined evaluation could be undertaken, aligned to specific teaching intervention objectives and the design of learning episodes aimed at developing principles of attack and defence, or tactics and strategies to overcome opponents for example. Future research should also look to build on the game-based analysis tool's potential to navigate unexplored research territory in terms of dyadic system stability, networking and cognitive ecology in children's games.

As part of the iterative process of establishing the Key Pillars from ecological dynamics that provided a framework for assessment, we acknowledge that not all elements of the physically literacy construct have been equally accommodated. For example, the affective domain of physical literacy and the ecological principle of affective learning design is an important core concept that was beyond the scope of this particular study. But, considering how enjoyment, frustration, motivation, and confidence might manifest themselves during game play is a potential area of future investigation. Finally, there is the scope to build upon the Key pillars of an ecological dynamics approach identified in this paper and apply them to alternative sporting environments. We wanted, in the first instance to create a tool that could be deployed more broadly across the National Curriculum for Physical Education, and as a consequence there was an orientation towards the modified, small sided games typical of this environment.

Conclusion

Undertaking an assessment that measures gameplay interactions in the manner outlined enables researchers and practitioners insight into how children learn to perceive affordances within games-based environments. This analysis outlined a rationale for why an approach informed by ecological dynamics might offer a novel contribution to understanding and evaluating physical literacy. In particular, the sample data provides a flavour of the potentially rich interpretations possible when there is a willingness to move beyond reductionist, decontextualised assessment strategies and embrace a more holistic, embedded evaluation of physical literacy during performance. This is the first tool, of which we are aware, that frames physical literacy assessment and evaluation through an ecological dynamics rationale, evaluating emergent gameplay behaviours where decisions are expressed as actions. Tapping into children's knowledge *of* the environment – manifest through the perception of affordances, their intentionality, and how they functionally move to effectively wayfind through the challenges they are presented with – provides uniquely novel insight into how physical literacy reveals itself through embodied organism-environment interactions in naturalistic settings.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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