Evaluating MoveLad, a Serious Exergame targeting Left-Right Confusion

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Abstract.* *Introduction: *Left-Right Confusion (LRC) is a difficulty that may persist into adulthood, yet it remains underexplored in the literature. Exergames present a promising approach, as left-right learning involves body awareness and motor response.* ***Objective***: *This paper presents the design, development, verification and utility evaluation of a serious exergame created to mitigate LRC.* ***Methodology or Steps***: *The game was designed using PEED and MOLDE methodologies, supported by a literature review, and involved the participation of 24 domain experts. The game was implemented in Unity and uses MediaPipe for motion capture. Utility was assessed with the SEU-Q v2 questionnaire.* ***Results***: *The game met all mandatory and most desirable requirements identified during the design process. In the utility evaluation, it achieved mean scores of 4.27/5 from the player perspective and 4.52/5 from the professional perspective, with an overall mean of 4.40/5. Qualitative data converged with quantitative findings. These results indicate that the game is perceived as useful, safe, and engaging, with potential to address LRC.*

Keywords: Psychomotricity; Left–Right Confusion; Laterality; Serious Game; Exergame.

1. Introduction

During childhood, concepts such as “up,” “down,” “front,” “inside,” and “outside” are learned [Nunes and Mamede 2021]. Such notions fall under the broader concept of psychomotricity and are acquired as children develop constructs such as spatial skills, time perception, laterality and lateral dominance, body awareness, and a sense of self [Meur and Staes 1989]. However, there are cases in which the concepts of “right” and “left” are not fully mastered, with such difficulty persisting into adulthood. This condition is known, among other terms, as Left–Right Confusion (LRC) [Souza e Hounsell 2024] and affects a substantial portion of the population, with estimates ranging from at least 10% of the general population [Yamashita 2022] to 15%–40%, depending on the group assessed [Ham, Dijkerman and Stralen 2021]. LRC is classified as a mild neurological symptom, defined as “subtle deficits in sensory integration, motor coordination and sequencing of complex acts” [Bachmann *et al.* 2014]. The problem can lead to practical difficulties, such as following GPS instructions in a timely manner, orienting oneself in the street, and finding one’s way home. It may also be associated with more severe conditions, such as dementia [Karaosmanoglu *et al.* 2021], Gerstmann syndrome [Altabakhi and Liang 2022], and schizophrenia [Viher *et al.* 2022]. To address this issue, we chose to employ games, particularly serious games.

Serious games represent an innovative approach, enabling new uses of media and concepts [Kokkalia, Economou and Choli 2017] and providing opportunities for developing and learning new concepts through novel methods. In early childhood education, for instance, serious games have been used to address sexual education and the prevention of child sexual abuse in schools [Jones *et al.* 2020], financial education [Torrens *et al.* 2021], children's nutrition education [Vlieger *et al.* 2021], among many others. Given the breadth of this field, we concluded that a serious game is a viable way of addressing LRC.

Because learning right and left involves body awareness and the dominant side [Bora, Cardoso and Toni 2021], a particular type of serious game, an exergame, appears especially suitable. Exergames are games that incorporate exercise or physical activity [Viana and Lira 2020], and they have been used successfully to target aspects of body control and posture [Estevan *et al.* 2023]. Therefore, to support therapists in mitigating LRC, we developed an exergame capable of transforming long and tedious exercises into a game, increasing the task's dynamism and appeal [Antunes *et al.* 2021]. According to Dutra *et al.* [2021], this approach is not only comparable in quality to traditional methods, but also more engaging and innovative.

This paper presents MoveLad, a game designed to support the mitigation of LRC. We first provide a literature review, followed by the game design process. Next, we report on the game development outcomes and the design verification process. Finally, we present the evaluation and the conclusions.

2. Related Work

One study targeted the physiotherapeutic rehabilitation of children with physical impairments [Antunes *et al.* 2021]. The software aimed to complement traditional therapy and included exercises focused on balance and motor education, assessing both gross and fine motor coordination. Among the benefits reported by the authors was an improved ability to differentiate right from left. This gain was associated with several other improvements, such as enhanced motor coordination.

Another study [Jiménez 2020] developed a game intended to improve left–right recognition in children with Down syndrome. The game used the Kinect camera to capture movement. Players were required to perform tasks such as "point to the left eye" or "show the right hand," as well as step on specific locations in an augmented-reality "whack-a-mole" activity. Difficulty was adjusted based on players' performance, allowing adaptation to individual cases. However, the study involved a limited number of participants (12). Comparisons to the present work are constrained because all participants had Down syndrome, whereas the present study focuses on children in general, without targeting any specific condition. In addition, [Jiménez 2020] presented movement in a mirrored view, which requires a less straightforward understanding of right and left.

A game designed specifically for autistic children, in which the goal is to control a robot along a path was also developed [Sampaio and Pereira 2025]. The robot moves forward automatically, and the player must shift it laterally (left, center, and right) to reach specific objectives. The game was validated by technology professionals, teachers, and parents of autistic children. The MEEGA+ questionnaire [Petri, Wangenheim and Borgatto 2019] was used for validation, and the software received positive evaluations, being described as easy to play, didactic, and fluid. The paper explicitly mentions teaching directions and laterality as a goal of the game, which makes it particularly relevant to the present research.

Overall, the topic remains underexplored, and the studies identified either do not address the problem in the specific manner proposed in this paper or rely on less widely available resources (e.g., Kinect cameras, robots).

3. Game Design

The project followed the PEED methodology [Rutes, Oliveira and Hounsell 2015], which provides guidelines specifically oriented toward the development of serious games. PEED requires consulting the literature to leverage existing ideas and concepts. This step was carried out through the conduction of a systematic mapping study (SMS) [Souza e Hounsell 2024].

Subsequently, PEED prescribes the involvement of three types of teams: (i) the Technical Development Team (TDT), composed of the game developers responsible for defining mechanics, gameplay, and programming; (ii) Domain-Expert End Users (DEUs), specialists from related areas needed for the game's development, who delimit the focus, content, and pedagogical aspects of the game; and (iii) Learner End Users (LEUs), the game's target audience, i.e., the final users.

The next step executed was meetings with the DEUs to establish the general guidelines to be followed during game development. The selected DEUs were individuals with expertise in related domains who were invited to support the design process. Invitations were made either in person to individuals known to the TDT or by email, based on a list of potential contributors who had previously collaborated on related projects. Ten meetings were held with twenty-four professionals, including psychologists, early childhood education and physical education teachers, game designers, among others. In total, 820 minutes of meetings took place. The information provided by the specialists was translated into requirements to be implemented in the game. Fifteen "mandatory requirements" were identified, conditions without which the game would not serve its intended purpose. They are: (1) use an in-game avatar for visualization; (2) identify crossed laterality and ambidexterity; (3) add audio/sound effects; (4) provide spoken instructions; (5) validate correctness regardless of movement amplitude; (6) provide cues to assist the player; (7) include time constraints for task execution; (8) avoid distracting elements and shrill sounds; (9) start levels on the player's dominant side; (10) gradually reduce hints as the player progresses; (11) save player progress; (12) require multiple correct responses to progress; (13) train upper limbs first, then lower limbs, then both; (14) use error animations and sounds that are not overly "fun"; (15) penalize players who move more than one limb (*e.g.*, both arms).

Seventeen "desirable requirements" were also listed, conditions that improve the game in some way but are not strictly necessary for the intended objective. They are: (1) provide auditory and visual feedback for errors and correct actions; (2) include a test mode; (3) include a relaxation mode; (4) include an achievements gallery; (5) unlock new phases as the player progresses; (6) include a life counter; (7) allow avatar selection; (8) deliver the game as a web application; (9) include combo mechanics; (10) show the avatar from the front in advanced levels; (11) allow narrator voice selection; (12) introduce adaptations for neurodivergent children; (13) show achievement descriptions on mouse hover; (14) record and display the achievement acquisition date; (15) adapt the game for children with visual impairment; (16) incorporate assessment of eye and ear dominance; and (17) adapt the game for wheelchair-users.

Level design was based on the MOLDE methodology [Farias *et al.* 2014]. In the game, the variables intended to shape the player experience were: the body limbs involved (arms, legs, or both); the number of hints provided (2, 1, or 0); the available reaction time (3, 2, 1.5, or 1.4 seconds); and the damage taken upon error (0, ¼, ½, or 1 heart). Three major groups (upper limbs, lower limbs, and both) were created and distributed across nine phases (one training phase, one main phase, and one "boss" phase for each major group), totaling 31 distinct difficulty levels.

As the game is an exergame, gestures are captured via a webcam, and movements are translated into in-game commands. For input configuration, we used MediaPipe, a free tool sufficiently robust to recognize sign language [Tayade and Halder 2021] and to track hand and finger movements [Boruah, Talukdar and Sarma 2021]. The game was developed using the Unity engine, which streamlines development by providing ready-made models and functions [Gazis and Katsiri 2023].

4. Game Overview

The main game features a dedicated training phase for each set of limbs required by the game (arms, legs, or both), totaling three preparatory phases, followed by three main phases [Souza e Hounsell 2025]. The arm and leg trainings provide tutorials on how to play.

Instructions for the expected commands are delivered audibly (e.g., "right arm"), and the initial levels include hints that reinforce the desired behavior. After receiving the command and the hints (which indicate the origin of an incoming attack), the player must move the corresponding limb (indicating a defense). The game supports both motion capture and keyboard input and was adapted for wheelchair users. The in-game avatar faces away from the player to avoid mirrored movement (in which the player's left arm would correspond to the avatar's right arm). The avatar's movements reflect the player's gestures. In addition, shields are generated when the player moves their limbs, making the registered input command visually explicit. Figure 1 illustrates the game tutorial and a training instance in which an attack targeted the right arm and was successfully blocked.

Figure 1. Training phase 1 instructions (left); Training phase 1 gameplay (right)

The training phases aim to teach both the target concepts and how to play. Two hints are displayed immediately before any command/attack (an enemy animation and a moving red exclamation mark). Progress within a training level requires a specified number of consecutive correct responses (3 or 5, depending on the phase's difficulty). Both correct actions and errors trigger visual and auditory feedback. A minimum accuracy of 60% is required to pass any training module. Higher performance yields gold or silver medals. The player's time and score are also reported.

The main phases are more challenging than the training phases. Each training phase has a corresponding main phase, which assesses what was taught in training. During main phases, the player has a finite health pool and mistakes result in damage. If the player's health reaches zero, the attempt restarts. Throughout each phase, incoming objects move towards the avatar, emphasizing which limb should be moved. In early levels, an on-screen exclamation mark provides an additional clue about the expected response. In later levels, visual clues are removed, and in the final levels only audible commands remain. Figure 2 shows main phase 1 scenario.

The environment changes as the player progresses through the phase. At the end of each main phase, the player faces the region's boss. The boss takes damage after every three consecutive correct responses. As the encounter progresses, the boss becomes faster and the penalty for mistakes increases. Figure 2 depicts the boss encounter, showing a different scenario from the main phase. Each panel displays the difficulty level and the player's total score at the top, while the player's remaining health is shown in the upper-left corner. The avatar remains centered as objects and attacks approach from both sides.

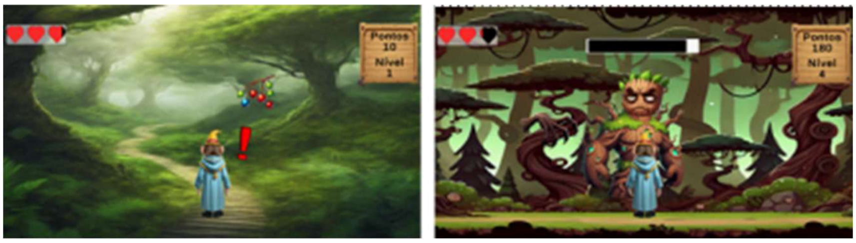

Figure 2. Main phase 1 scenario (left); Boss 1 scenario (right)

The game's theme is child-friendly and contains no weapons, blood, or explicit violence. Development also aimed to accommodate users who cannot read (given the target child audience). Menus include images intended to make their functions intuitive. Tests with volunteers indicated that the game can be played without written instructions, although text facilitates navigation.

A deliberate effort to make the game equally appealing to boys and girls was made. Achievements avoid gendered terminology (e.g., "master" vs. "mistress") and instead use gender-neutral phrasing (e.g., "victory over the flames"). Similarly, the avatars are animals and plants. The goal is to make players feel the game was designed for them regardless of gender.

The hints provided to the player were progressively reduced following the prompt-fading technique from Applied Behavior Analysis (ABA) [Lear 2004]. Rooted in behaviorism, a scientific approach focused on reinforcing behaviors, this technique gradually removes prompts that indicate the target actions until the player can perform the desired behavior independently. Ultimately, the goal is to elicit correct limb selection with minimal reinforcement, relying only on the audible instruction. Automated control is also implemented: for example, the game does not register a correct response if the player moves both arms.

The game stores player information such as age, sex, and dominant hand and foot. This supports statistical analyses of LRC prevalence and helps identify which groups may benefit most from the game. All collected data is stored in a JSON file and can be accessed by the user and researchers. MoveLad requires only a Windows-based computer to work. A webcam can be used to enable motion-tracking features, but the game remains playable without one (the keyboard can be used for input).

The current Windows version of MoveLad, installation instructions and demonstration materials, is freely available through the Move2Learn website[1]. An application for software registration has been filed with the Brazilian National Institute of Industrial Property (INPI), under process No. 512026003041-2.

5. Verification

The prototype meets all 15 mandatory requirements and 11 of the 17 desirable requirements identified by the DEUs. The following desirable requirements were not implemented: delivering the game as a web application; adding combo mechanics; showing the avatar from the front in advanced levels; introducing adaptations for neurodivergent children; recording the achievement acquisition date; and incorporating the assessment of ocular and auditory laterality. The primary reason for not implementing these features was the research timeline, which required prioritizing higher-impact and/or more easily implementable functions over others.

Two questionnaires were used to verify the project. First, using MEEGA+ [Petri, Wangenheim and Borgatto 2019], the game was found to meet 29 of the 35 criteria, with 2 items deemed not applicable (as the game is not designed for use within a formal course or curriculum context). Of the 4 unmet criteria, 3 relate to social interaction (which is absent in the game, as there is no multiplayer mode, ranking, or similar features), and 1 concerns the possibility of the game becoming repetitive (which may occur). A second validation was conducted to assess whether the game complies with guidelines for the development of children's games [Valenza, Gasparini and Hounsell 2019]. Out of 40 total items, the game met 37. The three unmet items were: the game avoids differentiating left and right (which is evidently not the case); the game explores cooperative use (not included); and the game allows the player to correct their errors (not possible).

6. Utility Evaluation

To assess the usefulness of the game, we used the SEU-Q v2 questionnaire [Grimes, Schroeder and Hounsell 2019]. Approximately 1,250 potential participants were invited, including professionals from institutions involved in child education, professionals associated with serious game development, and other related experts. Invitations were

[1] https://udescmove2learn.wordpress.com/2025/04/05/movelad/

delivered in person, by email, and via WhatsApp. The evaluation collected both quantitative and qualitative data.

Responses were collected using a Google Forms survey. The form included a link to the game's website, enabling participants to download the software. It also embedded videos and images explaining the game's functioning, so that individuals who could not play the game could still complete the evaluation. A total of 54 individuals completed the questionnaire. However, nine respondents reported no familiarity with serious games and no knowledge of laterality and LRC. These responses were excluded. Therefore, 45 evaluations were retained, comprising 13 in-person and 32 remote assessments.

6.1. In-person vs. Remote assessment

The in-person assessment was conducted exclusively with professionals from domains related to the game (e.g., pedagogues, game designers, and early childhood education teachers). A total of 12 amongst the 13 interviewees held at least a completed postgraduate degree. Participants had a mean age of 42.23 years and 18.31 years of professional experience. Their educational backgrounds were distributed across four areas: education (n = 3), digital games (n = 3), health (n = 4), and technology (n = 3).

In contrast, the remote assessment was conducted with the general public and resulted in greater heterogeneity in both professional background and educational level. Among the 32 participants, 4 did not hold a college degree (having completed technical education instead), and seven did not hold a postgraduate degree. Educational backgrounds spanned five areas: education (n = 11), digital games (n = 6), health (n = 7), technology (n = 5), and other fields (n = 3). Table 1 summarizes the participant's self-reported familiarity with the research topics.

Table 1. Responses on familiarity

	In-Person responses Scale (1-10)				Remote responses Scale (1-10)			
	Mean	SD	Mode	Median	Mean	SD	Mode	Median
Self-reported familiarity with laterality and LRC	6.15	3.44	10	7	5.78	2.93	7	6,5
Self-reported familiarity with exergames	6.38	3.04	9	7	5.53	3.51	7	7
Self-reported familiarity with serious games	6.54	3.55	9	8	5.88	3.27	7	7
Self-reported familiarity with digital games	7.23	2.71	9	8	7.16	2.80	9	8

Even though in-person assessments yielded slightly different scores than remote assessments, the results were broadly convergent. Therefore, both sets of data are analyzed jointly in this paper. When relevant, results will be reported separately for each modality.

6.2. Quantitative assessment

The quantitative instrument captures two perspectives. Firstly, the evaluators rate the game from the player's perspective (LEU). Table 2 reports these results using combined in-person and remote data.

In the in-person LEU assessment, the lowest scores were for ease of completing the challenges (4.00) and ease of motion capture (4.31). These ratings likely reflected practical constraints, including limited availability of the required infrastructure (computer/webcam) and gesture-tracking sensitivity to bystanders and environmental conditions (e.g., shadows and clothing). The highest-scoring items (4.69) were sound effects, environment aesthetics, feedback, interest, and fun/engagement, suggesting high satisfaction with these aspects. Across all items, the standard deviation was ≤ 1.00, indicating relatively consistent responses.

In the remote LEU assessment, the lowest scores were again for ease of completing the challenges (3.66) and ease of motion capture (3.94). These ratings likely reflect technical limitations of the motion-tracking. The highest-rated item was sound effects (4.44), also mirroring the in-person results. The standard deviation was 1.11 for perceiving game benefit, and 1.05 for ease of completing the challenges. All others were equal or lower than 1.00 across all items.

Table 2. Evaluation of LEU's from the participant's perspective (N=45)

Player's perspective					
Focus	Assessed item	Scale (1-5)			
		Mean	SD	Mode	Median
Interaction	Ease of understanding the challenges	4.16	0.85	5	4
	Ease of completing challenges	3.76	0.88	4	4
	Ease of motion capture	4.04	1.00	5	4
	Overall (Interaction)	3.99	0.92	5	4
Feedback	Sound effects	4.51	0.76	5	5
	Environment/Setting	4.47	0.81	5	5
	Object perception	4.31	0.85	5	5
	Overall (Feedback)	4.43	0.81	5	5
Motivation	Perceived game benefit	4.24	1.03	5	5
	Interest	4.49	0.63	5	5
	Fun/Engagement	4.49	0.66	5	5
	Overall (Motivation)	4.41	0.79	5	5
Overall mean		4.27	0.87	5	5

Overall, in-person scores were slightly higher than remote ones (4.53 vs. 4.17), but the patterns were convergent. The combined weighted mean for both was 4.27. Secondly, evaluators rated the game from the perspective of professionals who would use the game therapeutically (DEU). Table 3 shows the results from this perspective, using combined in-person and remote data. In the in-person DEU perspective, the lowest-rated item was professional usefulness (4.23), possibly because some auxiliary features were seen as less essential or the workflow as overly complex. The highest-rated item was game safety (4.92), indicating that the game was perceived as safe. The standard deviation was equal or lower than 1.00 in all items, once again indicating consistent answers.

In the remote DEU assessment, the lowest-rated items were child acceptance (4.13) and ease of professional use (4.13). The acceptance score likely reflects concerns about implementing the game with groups (e.g., in classroom settings), where adapting the activity may not always be easy or feasible. The lower rating for professional-use ease may similarly relate to limited access to appropriate equipment, particularly in Brazilian public schools, and to constraints in collective use, as motion capture may inadvertently track bystanders. Accordingly, the game's necessarily individual use was perceived as a limiting factor. Standard deviations were ≤ 1.00 across all items.

Table 3. Evaluation of DEU's from the participant's perspective (N=45)

Player's perspective					
Focus	Assessed item	Scale (1-5)			
		Mean	SD	Mode	Median
Therapeutic	Usefulness for a child audience	4.71	0.59	5	4
	Usefulness of the generated data	4.69	0.56	5	4
	Usefulness for professional use	4.38	0.78	5	4
	Overall (Therapeutic)	4.59	0.66	5	4
Acceptance	Child acceptance	4.24	0.77	5	5
	Suitability for professional use	4.24	0.77	5	5
	Game safety	4.64	0.57	5	5
	Overall (Acceptance)	4.38	0.73	5	5
Motivation	Perceived seriousness of the objective	4.80	0.40	5	5
	Ease of professional use	4.22	0.82	5	5
	Benefits for professional use	4.73	0.50	5	5
	Overall (Motivation)	4.59	0.65	5	5
Overall mean		4.52	0.69	5	5

In this round, some remote scores exceeded the in-person scores, such as perceived seriousness of the objective (4.81 vs. 4.77) and usefulness for professional use (4.44 vs. 4.23). Nevertheless, overall, in-person scores remained slightly higher than remote scores (4.65 vs. 4.47). Once again, the patterns were broadly convergent. The weighted mean across both groups was 4.52. Considering both LEU and DEU scores, in-person mean was 4.59, and remote mean was 4.32. The overall weighted mean for the quantitative assessment was 4.40.

Qualitative comments were broadly consistent with the quantitative findings. Participants highlighted the game's engagement, clarity of feedback, and perceived usefulness for left–right learning. The main concerns involved motion-capture limitations, environmental sensitivity, and practical constraints for group or classroom use. The most frequently reported suggestions involved adding a new functionality such as a new game mode, combo mechanics or special moves.

7. Conclusions

Although LRC affects a substantial portion of the population, it remains underexplored. Few serious games address this issue, and most do so only tangentially. This paper presented the game design process that resulted in the serious exergame entitled MoveLad. The game provides a resource specifically designed to address LRC and is the result of literature analysis and the involvement of 24 experts across more than 13 hours of discussion. It includes multiple configuration options to improve accessibility for diverse audiences. The game is expected to be most useful for children under professional supervision; however, it may also be used freely by other users. This paper indicates that the proposed exergame was positively perceived by experts and evaluators and shows potential as a supportive tool for left–right learning. The results suggest that it may help professionals and users in activities related to LRC.

Future work includes evaluations by professionals who may use the game in practice with Learner End Users (LEUs). Additionally, future developments include delivering the game as a web-based application, as well as adapting motion capture to run on mobile devices (e.g., smartphones). Another possible extension would be to add levels in which the avatar faces the player, thereby teaching not only the player's own left–right concepts, but also left–right discrimination for a third person facing them.

Generative AI (ChatGPT, OpenAI) was used primarily to translate portions of the manuscript from Portuguese to English and to support language editing (grammar, clarity, and conciseness). The authors reviewed, edited, and verified all AI-assisted text and take full responsibility for the final content. No generative AI tool was used to produce research data, produce codes, run analyses, or generate results.

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