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Is there place for assessment of procedural perceptual-motor learning in pediatric rehabilitation? A survey of French psychomotor and occupational therapists

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Abstract

The principles of motor learning have been applied in neurological rehabilitation for years. The underlying assumption is that these principles that have been identified in research on healthy individuals would also apply to those with neurological disorders, making them highly relevant for rehabilitation. However, there is currently no tool dedicated to evaluate procedural perceptual-motor

learning (PPML) abilities before rehabilitation. To address this gap, we created a new tool assessing PPML (EVAL_APP), based on two experimental tasks known to assess motor sequence learning and visuomotor adaptation. The study aimed to determine whether this tool is suitable for clinical practice and meets care needs by conducting a cross-sectional online survey of psychomotor and occupational therapists in France. The results show that professionals are interested in measuring PPML and over half of them indicated that they would use the tool. Participants who felt trained about PPML responded positively to the relevance of PPML assessment and to the future use of the EVAL_APP tool. While some parameters of the EVAL_APP tool are well adjusted, others may need improvement to be adapted for children with neurodevelopmental disorders, including Developmental Coordination Disorder. The results are encouraging for pursuing the conception of the new tool by considering the opinion of professionals specialized in pediatric rehabilitation.

Key-words: clinical evaluation, neurodevelopmental disorders, Developmental Coordination Disorder, pediatric rehabilitation, motor sequence learning, visuomotor adaptation, Serial Reaction Time Task, Target Jump Task

1. Introduction

For many years, motor learning principles have been implemented in neurological rehabilitation (Fisher et al., 2014; Hayes et al., 1999; Larin, 1998; Levac et al., 2009; Valvano, 2004; Zwicker & Harris, 2009). This recommendation is based on the idea that the principles of motor learning gleaned from research on healthy participants would be similar to those of patients with neurological disorders. On this basis, research targeting on rehabilitation interventions has grown

exponentially in recent years and shows that knowledge about motor learning has a direct impact on the patients' care (Fisher et al., 2014). This has been particularly apparent in the physical therapy management of adults with neurological disorders (e.g., Parkinson's disease and stroke) (Fisher et al., 2014; Hayes et al., 2015). However, according to Zwicker and Harris (2009), motor learning principles appear to be less commonly applied in pediatric rehabilitation. In addition, there is no tool assessing individuals' learning abilities as a prerequisite for rehabilitation.

Assessing motor difficulties of children with neurodevelopmental disorders, and in particular children with Developmental Coordination Disorder (DCD), is an important step before intervention, but assessing motor learning, that is the ability to progress with repeated practice, is also fundamental. Even if they are interdependent, motor performance and motor learning are two distinct concepts. Motor performance refers to the level of acquisition of a motor skill, whereas motor learning refers to the process of acquisition of a motor skill and to the capacity to adapt to environmental changes (Schmidt et al., 2018). The motor skill is acquired incrementally with practice, often implicitly, through repeated exposures to stimuli (Schmidt et al., 2018; Squire & Zola, 1996). More precisely, procedural perceptual-motor learning (PPML) integrates information into procedural memory (Eustache & Desgranges, 2008) and refers to two distinct processes with two distinct neuroanatomical substrates: motor sequence learning and sensori-motor / visuo-motor adaptation (Doyon & Benali, 2005).

Therapists and researchers in rehabilitation need standardized assessment tools to identify, classify and diagnose motor problems and to monitor the effects of interventions. Several psychometric evaluations are available to assess motor performance (e.g., Test of Gross Motor Development-2 (Ulrich, 2000), MABC-2 (Henderson et al., 2007), Bayley III (Bayley, 2006), see Griffiths et al., 2018);

however, no tool is yet available to assess motor learning. In other words, the available tests measure motor performance at one point in time, but they do not measure the dynamics with which a person acquires a new motor skill with repeated practice.

Measuring PPML abilities as an index of neural plasticity prior to intervention is essential to consider the possibilities of improvement during rehabilitation. Firstly, motor learning strategies can be used by therapists to structure the task and the learning environment during intervention sessions, in order to enhance the benefits of rehabilitation sessions and, thus, to support transfer and generalization of motor skills in real life (Larin, 1998; Levac et al., 2009; Zwicker & Harris, 2009). Several studies identify and describe the application of specific elements of motor learning strategies (motivation, feedback, practice, task type, learning stage) to different populations of children and adolescents with neurodevelopmental disorders (Larin, 1998; Levac et al., 2009). For instance, teaching principles regarding how to give instructions, provide feedback, and share knowledge can improve motor learning in children with DCD (see Niemeijer et al., 2003). Secondly, one goal of therapeutic interventions for children and youth with neurodevelopmental disorders is to improve PPML of useful motor skills in order to improve participation in the activities of daily living (e.g., Levac et al., 2009 ; Polatajko et al., 2001).

Even if the principles of motor learning are applied in rehabilitation intervention, acquisition of new skills is not always possible or more difficult for some patients with neurodevelopmental disorders (Clark et al., 2014; Clark & Lum, 2017). According to the model of Nicolson and Fawcett (2007), children with neurodevelopmental disorders present deficits in PPML. The deficit would depend on the type of neurodevelopmental disorder and more precisely on whether the

dysfunction originates in the cortico-striatal or cortico-cerebellar loops (Nicolson & Fawcett, 2007). In the case of a dysfunction of the cortico-striatal loop, the child would present a deficit in sequence learning, whereas in the case of a dysfunction of the cortico-cerebellar loop, the child would present a deficit in visuo-motor adaptation (Doyon & Benali, 2005). The model of Nicolson and Fawcett (2007) proposes that sequence learning and visuo-motor adaptation would be distinctively impaired in children with DCD, specific language impairment, attention deficit disorder with/without hyperactivity and developmental dyslexia. According to this model, motor sequence learning would be impaired in relation to a dysfunction of the cortico-striatal loop. Visuo-motor adaptation would be impaired in relation to a dysfunction of the cortico-cerebellar loop. However, recent findings are particularly inconsistent across studies. Results vary depending on the characteristics of tasks used to measure PPML (unimanual vs bimanual, number of exposures, etc.) and on the individual characteristics (IQ, age, severity of disease, etc.) (Martin et al., submitted; Martin et al., 2023). It follows that professionals should assess PPML abilities at an individual level rather than from a model stipulating deficit by pathology a priori.

In scientific research, PPML abilities are assessed with experimental tasks. Motor sequence learning is typically assessed with a Serial Reaction Time Task (SRTT) and visuomotor adaptation with a Target Jump Task (TJT). The SRTT is the most widely described experimental paradigm in the literature to measure PPML. It corresponds to the implicit learning of a motor sequence with repetition (Knopman & Nissen, 1987; Nissen and Bullemer, 1987). The TJT corresponds to adjusting movements to compensate the alteration of visual input (de Graaf et al., 1995). For both tasks, performance is measured in terms of reaction times and errors (Schmidt & Lee, 2014). The decrease of reaction times and errors during repeated

practice informs about general learning (SRTT: association between stimulus position and expected motor response; TJT: relationship between hand movements and the altered sensory input). An increase of reaction times and errors when a change is introduced (SRTT: randomized trials; TJT: not altered sensory input) informs about specific learning (Bo et al., 2008 ; Robertson, 2007). If SRTT and TJT are well described in the literature, there is currently no clinical tool to assess them. Indeed, we have adapted these tasks to evaluate PPML with a new tool assessing motor sequence learning and visuo-motor adaptation with the same parameters (input, output, instructions, feedback, effectors...) (<https://vimeo.com/651038688>). This tool, called EVAL_APP for "Evaluation de l'Apprentissage Procedural" in French, is currently being developed with the aim to identify a potential alteration in PPML by comparing the PPML of an individual with his/her age group. It also makes it possible to specify which type of PPML is impaired (motor sequence learning and/or visuo-motor adaptation) and, thus, to focus rehabilitation on activities implying motor sequence learning and/or visuo-motor adaptation.

The aim of the present study was to assess whether the EVAL_APP tool is appropriate for clinical practice and meet care needs. Inspired by the work of Bowen et al. (2009) who propose a guideline for conducting a feasibility study, we created a survey aimed to evaluate the appropriateness of using the EVAL_APP tool in the rehabilitation context. We selected this approach because (1) no previous study has considered the habits and knowledge of professionals who could assess the PPML and (2) professionals are the most directly relevant persons who can give advice to adjust the parameters of the tool.

On these bases, we conducted a national online survey addressed to French clinicians involved in the motor rehabilitation of children with neurodevelopmental

disorders: psychomotor therapists and occupational therapists. The aim of this survey was to: (1) evaluate if PPML assessment is relevant for professionals; (2) identify their opinions about the two tasks measuring PPML; and (3) adjust the parameters of these tasks according to the results. Study findings will allow us to adapt the EVAL_APP tool to assess PPML in line with clinical expectations.

2. Material and methods

2.1. Study design

The online survey was hosted on the limesurvey-platform (Limesurvey Version 2.05, Build 160915) from 1st of February to 31th of July 2022. Ethical approval for the study was obtained by the ethics and research committee of the University of *blinded* (CER n° 2022-464). The compliance of this survey has been confirmed by the personal data protection department of the University *blinded*. Prior to completing the survey, all respondents completed an electronic informed consent form containing information about the purpose of the study, contact information of the researchers, voluntary nature of their participation and the collection, anonymous collection and storage and publication of the data.

2.2. Participants

Respondents were French psychomotor therapists and occupational therapists. They had to have a French state diploma. The survey was distributed via the "Association Nationale Française des Ergothérapeutes" and "Fédération Française des Psychomotriciens", Occitadys (a regional association of neurodevelopmental disorders professionals) and regional associations of professionals of psychomotor and occupational therapists. The survey was posted on social networks in various professional discussions.

2.3. Design and procedure

Two short instructional videos presented the definition of PPML and tasks measuring PPML. Pictures illustrated how instructions and feedback were to be given. The average time to complete the survey was approximately 10 minutes. The questionnaire was in French.

The online survey consisted of 26 questions and was organized into six subsections: (1) informed consent; (2) professional variables; (3) knowledge of PPML and interest in its assessment; (4) interest in the proposed tasks measuring PPML; (5) evaluation of tasks measuring PPML parameters; and (6) intention to use tasks measuring PPML. The complete survey is provided in English and French in the supplementary data.

Informed Consent: The participants were informed that the aim of the project was to create a new tool to assess PPML. The purpose of the survey was to gather the opinion of psychomotor therapists and occupational therapists about this tool and to adjust the parameters of the tasks according to the results obtained from the questions. They were also informed about the time to complete the questionnaire, the number of questions, and the topics to be addressed. In this first part, participants were asked to validate their consent.

Professionals variables: In this second part, participants were asked to indicate the year in which they graduated and with which state degree. They were also asked to indicate the type of institution in which they worked, as well as the age and type of clinical population with whom they worked.

Knowledge of the PPML and the interest of its assessment: In this section, participants watched a video that provided a definition of PPML (<https://vimeo.com/manage/videos/651034640>). Then they were asked to indicate their level of agreement with this definition and whether they had been taught about PPML during their initial or continuing education on a 5-point scale, ranging from not at all to a lot (Not at all, Very little, I don't remember, A little, A lot). They were asked if they felt sufficiently trained in this process (Not at all, Somewhat no, Neither yes nor no, Somewhat yes, Definitely) and if they felt it was pertinent to assess this process in their assessment (Not at all, Somewhat no, Don't know, Definitely yes). They were then asked if they were aware of a test that measures the PPML (yes/no). If they answered yes, they were asked to give the name of the test (free response). Finally, they were asked "How much do you think that a new tool measuring this process would be relevant in your clinical assessment?" The answer was given as a percentage.

Interest of the proposed tasks measuring PPML : They watched a second video in which the two learning tasks were presented (<https://vimeo.com/651038688>). They were asked to rate how much they think that this tool would be relevant in their assessment, as a percentage. If the score was less than 50%, they were then asked the next question "What are the reasons why you think this tool is not relevant?". They were invited to leave a free comment.

Evaluation of tasks measuring PPML parameters: In this section, participants were asked to evaluate the tool parameters. They were asked if they had easy access to a computer and a mouse; if the graphic environment, sound environment, use

of the mouse, duration of the task, instructions and feedback were adaptable to the intervention population (type of clinical population with whom they worked: psychiatric, neurodevelopmental, sensory, physiological disorders etc.; see section B in supplementary data), if the results in standard deviation were understandable to them (Not at all, Rather no, I don't know, Rather yes, Absolutely).

Intention to use tasks measuring PPML: In this last section, they were asked if this tool was offered as an open access tool, would they use it in their clinical assessment (Not at all, Somewhat no, Don't know, Somewhat yes, Absolutely).

2.4 Data analyses

Quantitative and open-ended questions analyses were carried out. For quantitative descriptive analyses, answers to one-choice questions were presented as percentages. For statistical analyses, Jamovi software was used (Jamovi, version 2.2, 2021). Subgroup analyses were conducted to test whether there was a difference between participants' responses according to their profession (psychomotor therapists or occupational therapists), their year of graduation, the age of the population of interest, and their feeling of being trained on PPML. U-Mann Whitney tests were used to compare subgroups and significance threshold was set at $p = .05$. Correlations were carried out using Spearman's rank correlations for categorical data. Values of $r = 0.1$ represent a small effect, $r = 0.3$ a medium effect and $r = 0.5$ is a large effect (Cohen, 1988). Results of correlation analyses were Bonferroni adjusted to control for alpha error accumulation (Bland & Altman, 1995).

For analyses of four open-ended questions (1-“what is the type of population you work with the most ?” ; 2- “Do you know a tool that measures this process ? If yes, which tool(s) ?” ; 3- “Why don't you think this tool is relevant?” and 4- participants could leave a comment at the end of the survey), a frequency analysis was conducted to identify the occurrence of the different answers.

3. Results

3.1 Description of the respondents

In total, 428 professionals responded to the survey and 224 completed totally the survey. The response rate corresponds to the number of responses relative to the number of invitations, and the completion rate corresponds to the number of complete responses relative to the number of surveys opened (Eysenbach & Wyatt, 2002). Given that we shared the survey through social media, it is not possible to determine the final count of total survey invitations. Therefore, it is not possible to compute the response rate in our study. However, it is possible to compute the completion rate, which is 55.3% (224/428). Our rate could be higher if we had also included incomplete responses, as is the case in other surveys (Klein et al., 2023).

Of those who did not fully complete the survey (N=204), 15% (30/204) opened the survey but did not give their consent, 19% (37/204) stopped at subsection 2 when providing their professional variables, 43% (87/204, 58 psychomotor therapists and 29 occupational therapists) stopped at subsection 3 concerning their knowledge of the PPML and the interest of its assessment, 20% (41/204) stopped at subsection 4 when the test was presented, and 3% (7/204) stopped at subsection 5 when they were asked to evaluate the test parameters.

Among the respondents who completed totally the survey (N=224), there was 180 psychomotor therapists (80.3%) and 44 occupational therapists (19.6%). In France, 14185 psychomotor therapists and 14214 occupational therapists are registered in 2022 (ADELI- Drees directory, data as of January 1, 2022 <https://drees.shinyapps.io/demographie-ps/>). The rate of respondents was about 1.27% for psychomotor therapists and about 0.3% for occupational therapists. The majority of professionals graduated after 2002 (31.6% between 2002 and 2012; 43.7% between 2012 and 2022; see figure 1), worked in private practice (39.7% ; see figure 2A) with children from 6 to 12 years (64.7% ; see figure 2B) with neurodevelopmental disorders (72.3% ; see figure 2C).

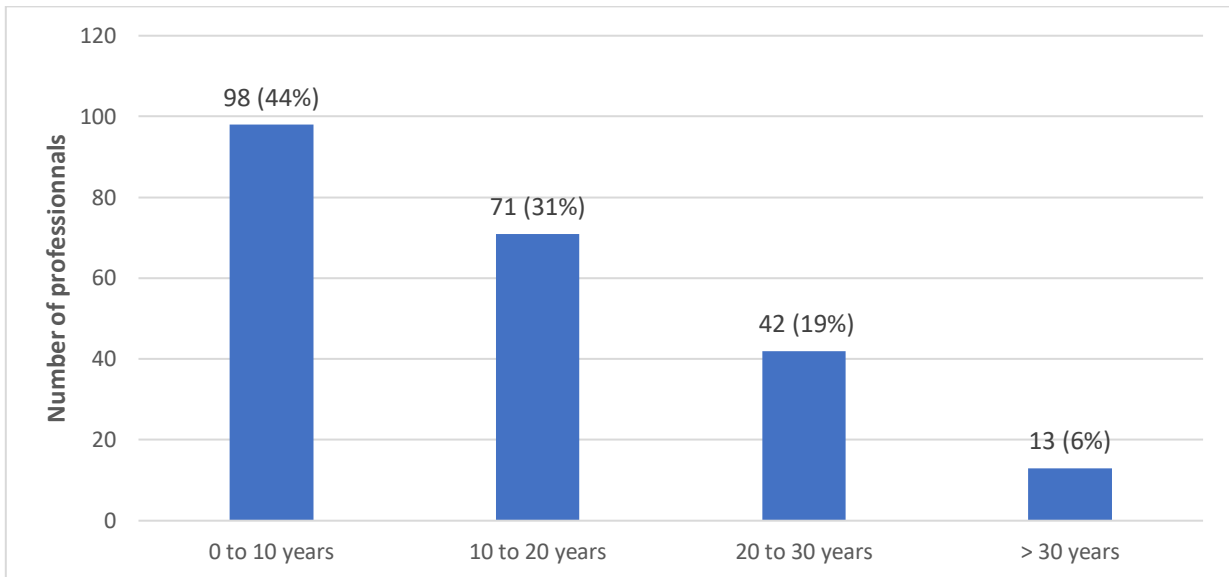


Figure 1 : Years since graduation of professionals who participated in the survey (N=224).

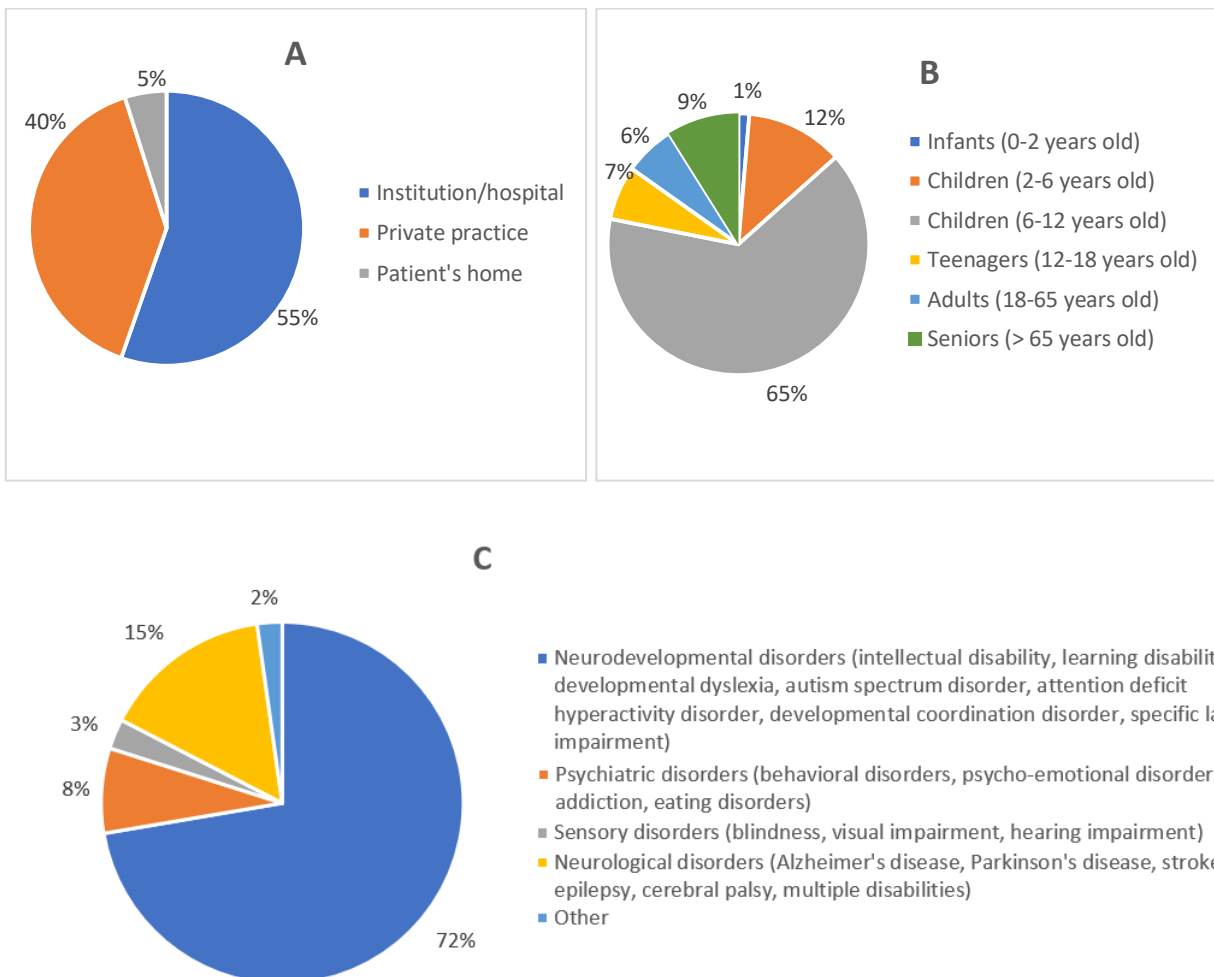


Figure 2: Distribution of health care institutions and population : A-Distribution of responses to the question: "What is your care setting ?" B- Distribution of responses to the question: "In this care setting, what is the age range of the population you work with the most?" C- Distribution of responses to the question: "In this care setting, what type of population do you work with the most?" (N=224).

3.2 Knowledge on the PPML and education about PPML

In the rest of the analysis, we were interested only in the responses of participants who work with children with neurodevelopmental disorders (N=162). We proposed the following definition of PPML: "Procedural perceptual-motor learning is the process that allows progressive memorization of procedures, i.e., know-how or skills, in order to automatize and retain them in the long term". Then, we asked participants at which percent they agreed with this definition. The vast majority of respondents (91.9%) answered that they agreed to at least 60% with this definition (figure 3).

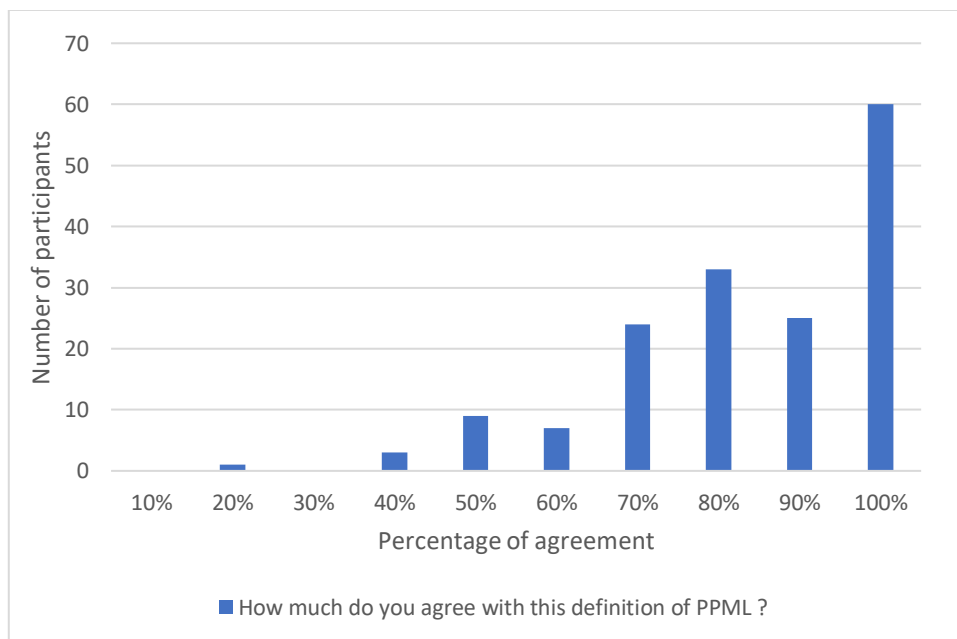


Figure 3: Distribution of answers to question "How much do you agree with this definition of Procedural Perceptual-Motor Learning ?" (N=162).

Participants felt they were insufficiently trained about PPML (11.1% "not at all", 45.0% "rather no"), although they found relevant to evaluate this process in their assessment (38.2% "absolutely", 50.0% "rather yes"). Most participants (88.3%) did not know a tool that measures this process. Only 11.7% of participants said that they knew tests that measured PPML, but they cited MABC-2 (Henderson et al., 2007), TGMD-2 (Ulrich, 2000), NEPSY subtest (Korkman et al., 2012), Charlop-

Atwell, (Albaret et al., 1994) and Purdue Pegboard (Tiffin et al., 1948). These tests aim to measure children's motor skills (global and fine motricity) at a specific point in time but not their ability to acquire a new motor skill.

Correlation analyses revealed that later date of graduation was significantly associated with being trained about PPML in their initial education ($r=0.36$, $p<0.001$). The more participants benefit of initial education in PPML, the more they agree with our definition ($r=0.34$, $p<0.001$) (Table 1).

3.3 Interest to assess PPML and interest in a new tool to assess PPML

The majority of participants (89.5%) answered to agree at least 60% a new tool measuring PPML would be relevant in their clinical assessment. After viewing the second video, 54.6% responded to agree at least 60% to think this tool would be relevant to their assessment (figure 4).

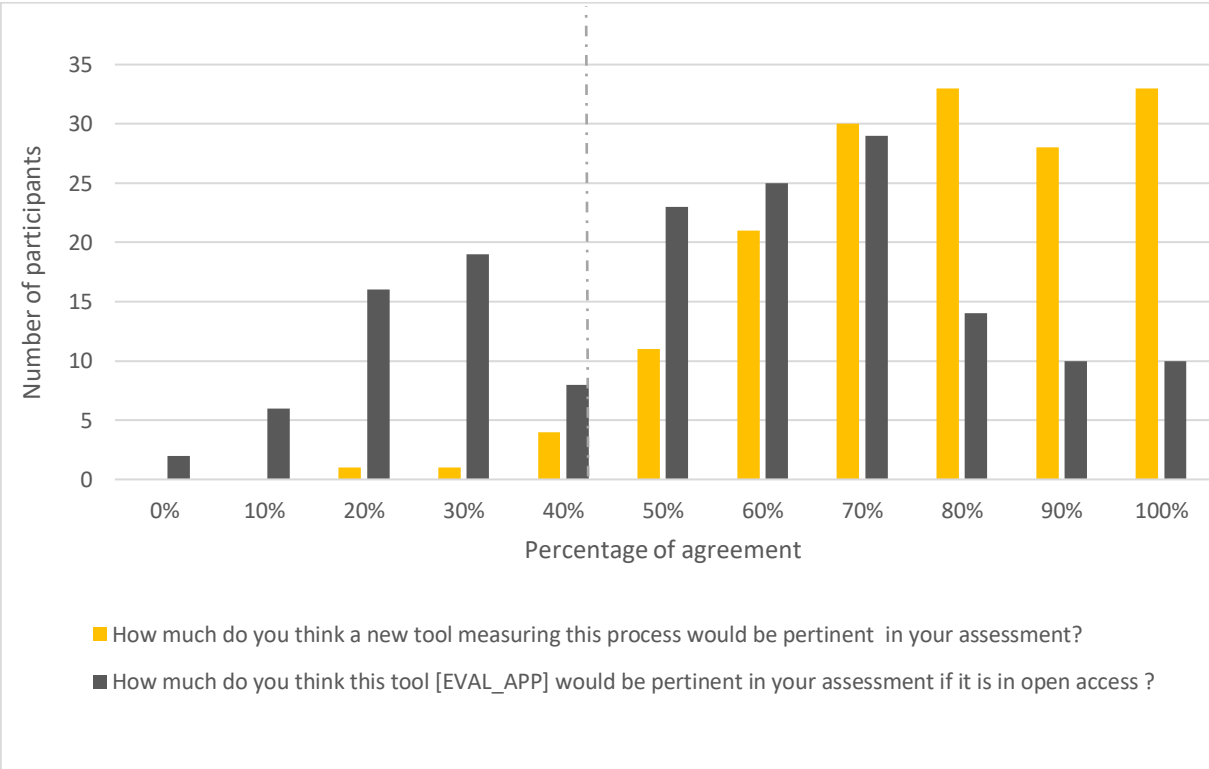


Figure 4: Percentage of agreement of participants working with children with neurodevelopmental disorders for 2 questions (Neurodevelopmental disorders = intellectual disability, learning disabilities, developmental dyslexia, autism spectrum disorder, attention deficit hyperactivity disorder, developmental coordination disorder, specific language impairment) (N=162).

The results of correlation analyses showed significant positive association between the year of graduation (variable 1) and teachings on procedural learning during initial education (variable 3) ($r=0.362$, $p<0.001$).

There were also positive correlations between the degree of agreement with our definition of PPML (variable 2) and the relevance of a new PPML tool (variable 7) ($r=0.31$, $p<0.001$), and the relevance of our tool (variable 8) ($r=0.25$, $p=0.001$). A higher the score for question "Do you feel it is relevant to evaluate this process in your assessment?" (variable 6) was associated with a higher score for question "Did you have any teachings on procedural learning during your continuing education?" (variable 4) ($r=0.33$, $p<0.001$). Higher scores for the question "Do you feel it is relevant to evaluate this process in your assessment?" (variable 6), were correlated with higher scores for the question "How much do you think a new tool measuring this process would be relevant in your clinical assessment?" (variable 7) ($r=0.54$, $p<0.001$), and the for the question "How relevant do you think this tool would be for your assessment?" (variable 8) ($r=0.24$, $p=0.002$) (Table 1).

The score obtained for the question "Did you receive any teachings on procedural learning during your continuing education?" (variable 4) was positively correlated with the score obtained for the question "Did you have any teachings on procedural learning during your initial education?" (variable 3) ($r=0.25$, $p=0.001$), and the score for the question "How much do you think a new tool measuring this process would be relevant in your clinical assessment?" (variable 7) ($r=0.26$, $p<0.001$).

Finally, the higher score of relevance of a new tool measuring PPML (variable 7), the higher score of relevance of our tool is (variable 8) ($r=0.40$, $p<0.001$).

Table 1 : Correlation between items measuring education and interest in Procedural Perceptual-Motor Learning (PPML) measuring, in new PPML tool, in our PPML tool

Variables	M	SD	2.	3.	4.	5.	6.	7.	8.
	2009	9.41	0.08	0.36***	-0,07	0,05	0.13	0.06	0.08
1. In what year did you graduate?	14 years ago	5 to 23 years ago	($p=0,30$)	($p<0,001$)	($p=0,37$)	($p=0,52$)	($p=0,08$)	$p=0,44$	($p=0,30$)
2. How much do you agree with this definition? (%)	83,8	16.9	-	0,34***	0.08	0,024	0.21	0.31***	0,25***
				($p<0,001$)	($p=0,27$)	($p=0,76$)	($p=0,07$)	($p<.001$)	($p=0,001$)
3. Did you have any teachings on procedural learning during your initial education? (out of 5)	2,91	1.38	-	-	0,25***	0.17	0.17	0.09	0.12
					($p=0,001$)	($p=0,02$)	($p=0,02$)	($p=0,22$)	($p=0,12$)
4. Did you have any teachings on procedural learning during your continuing education? (out of 5)	2,82	1.43	-	-	-	0.10	0.33***	0.26***	0,14
						($p=0,18$)	($p<.001$)	($p<.001$)	$p=0,063$
5. Do you feel adequately informed about this process? (out of 5)	2,55	0.95	-	-	-	-	-0.08	-0,01	0.01
							$p=0,29$	$p=0,92$	$p=0,82$
6. Do you feel it relevant to evaluate this process in your assessment? (out of 5)	4,26	0.67	-	-	-	-	-	0.54***	0.24***
								($p<.001$)	($p=0,002$)
7. How much do you think that a new tool measuring this process would be relevant in your clinical assessment? (%)	77,7	17.4	-	-	-	-	-	-	0.40***
									($p<.001$)
8. How relevant do you think this tool would be relevant to your assessment? (%)	55,4	25.0	-	-	-	-	-	-	-

All correlation coefficients are based on Spearman Correlation Analyses. Results of correlation analyses are Bonferroni adjusted with $p < 0.007$ ($0.05/7$). Stars (***)= represent significant results).

3.4. Intention to use the tasks two PPML

Just over half of participants (55%) would use this tool in their assessment, 11% wouldn't use it and 34% don't know (figure 5). There were no significant differences between participants' responses based on their profession (occupational therapist or psychomotor therapist), their year of graduation, the age of intervention population.

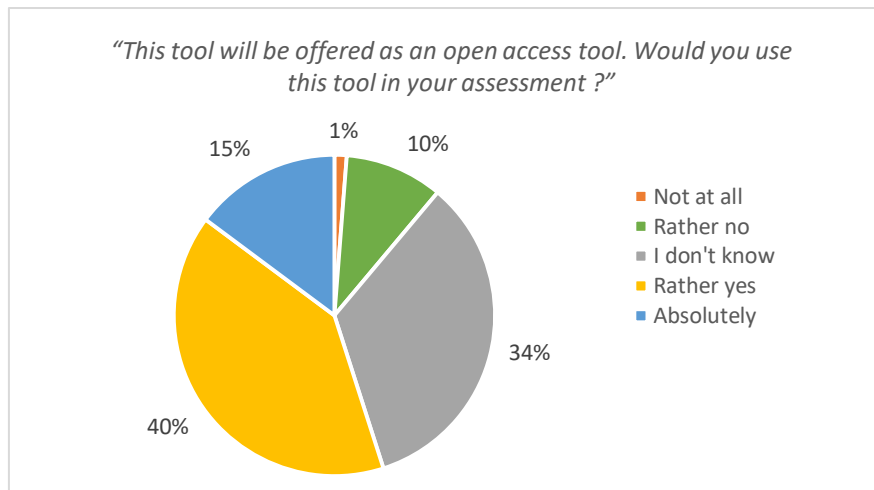


Figure 5 : Answers of participants working with children with neurodevelopmental disorders to question "This tool will be offered as an open access tool. Would you use this tool in your assessment ?" (N=162).

Statistically significant differences were found in participants who reported having benefited from a training in the process of PPML ("not at all", "rather no" versus "rather yes", "absolutely"). The group that felt insufficiently trained on PPML [Mean (SD)=3.46 (0.75)] had a significantly lower score compared to those who felt sufficiently informed on PPML [Mean (SD)=3.86 (0.74)] on the question "would you use this tool in your assessment (U=1250, $p < 0,05$, effect size=0.23) (figure 6).

The relevance of assessing the PPML is also lower in the group that felt insufficiently trained in this process [Mean (SD)=4.17 (0.55)] compared to the group who felt sufficiently informed in PPML [Mean (SD)=4.48 (0.55)]; (U=1250, $p = 0,02$, effect size=0.23) (figure 6). On the other hand, these two groups were not different in terms of their date of graduation, their agreement on the definition of the PPML and in the interest of a new tool (figure 6).

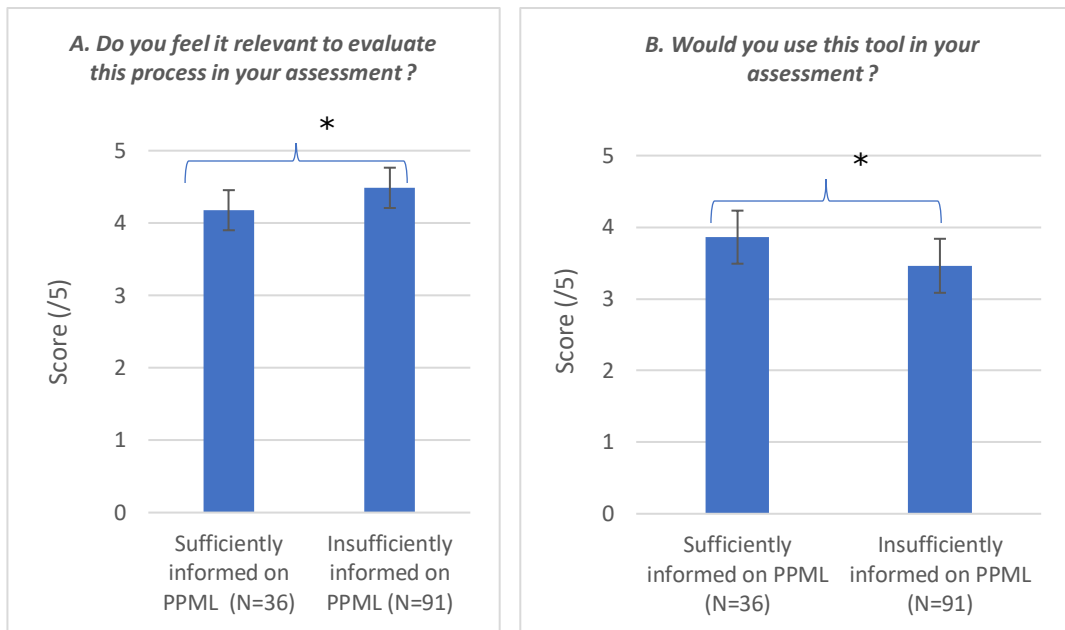


Figure 6 : Differences between participants who feel sufficiently informed on Procedural Perceptual-Motor Learning (PPML) (N=36) and participants who feel insufficiently informed on PPML (N=91). Vertical bars represent inter-individual variability (standard errors) ($p < 0,05$).

3.5. Evaluation of the tasks' parameters to assess PPML

Most participants (82%) answered that they have access to the necessary equipment to perform the tasks. Graphic and sound environments were appropriate for their intervention population, to 86% and 64% of participants respectively. Less than half of participants (49%) considered that the use of the mouse seemed appropriate for the population. For 85% of participants, instructions were understandable for the population. For 22% of participants, the duration of the task seemed to be appropriate to the population they see in practice. Only 28% considered that feedback was understandable for the population. The vast majority of participants (97%) considered that results given in standard deviation were easily understandable (figure 7).

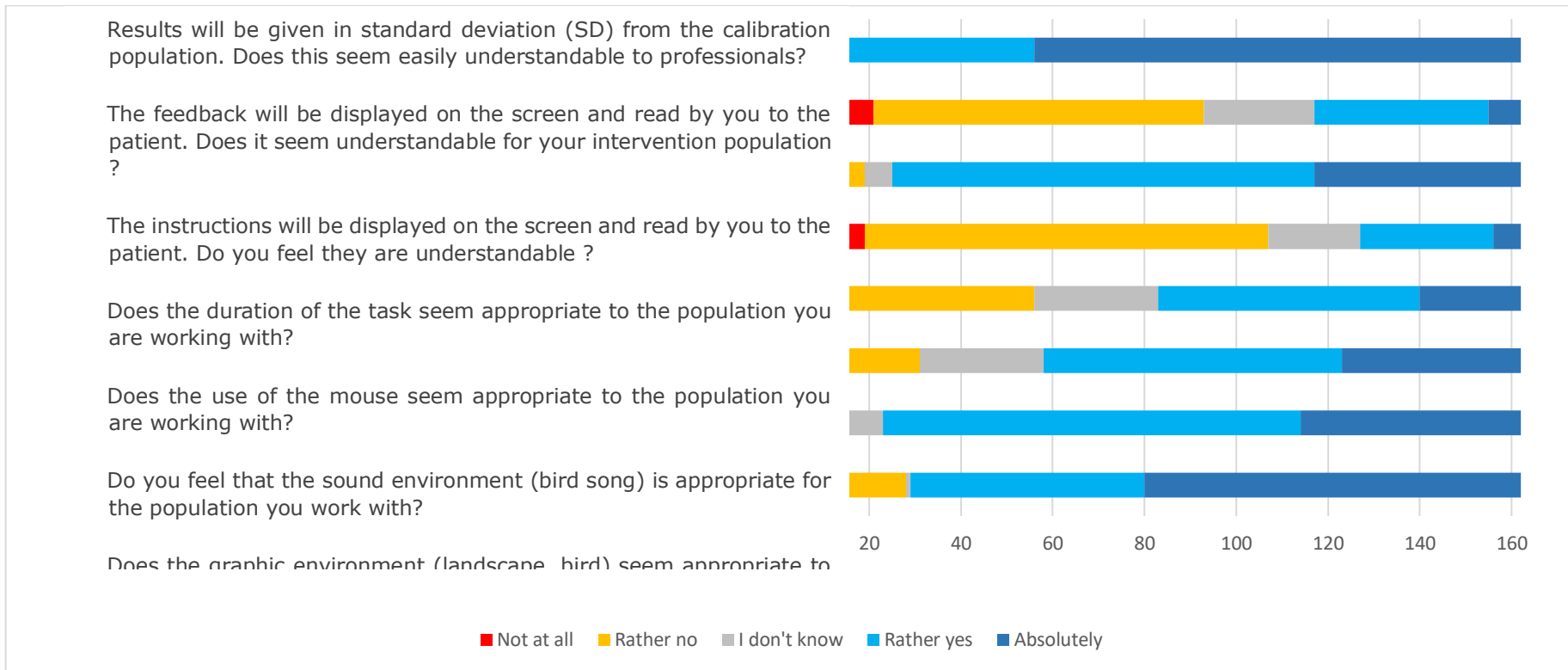


Figure 7: Evaluation of tasks parameters by participants working with children with neurodevelopmental disorders (N=162).

3.6 Analyses of open-ended questions

For the open-ended question "Why don't you think this tool is relevant?", 52 responses were recorded, and for free comment at the end of the survey, 45 responses were recorded. The most used words were "long" (31 occurrences), "screen/computer" (12 occurrences), "ecological" (12 occurrences), "mouse" (12 occurrences), and "attention(al)" (8 occurrences).

4. Discussion

The goal of rehabilitative interventions for children and youth with neurodevelopmental disorders is to improve learning of psychomotor skills in order to improve daily-life activities and social participation. However, to our knowledge, there is no clinical tool to assess perceptual-motor learning (PPML) before intervention. This survey is the first, to our knowledge, that asks the opinion of professionals working with children with neurodevelopmental disorders about: (1) the relevance assessing PPML; (2) the relevance of the tool we have created (the EVAL_APP tool) to assess PPML; and (3) the parameters of these tasks in order to adapt the tool in order to be applicable in clinical practice with children with neurodevelopmental disorders.

Results of the survey reveal that a satisfying sample of French professionals responded to our survey during a short period (6 months). It is difficult to make direct comparisons between our response rate and those reported in the literature, as the number of children with NDD, the number of practitioners and recruitment methods vary considerably from one country to another. However, we note that response number is comparable as those of Hayes's study (241 responses included), Hunt's study (175 responses included) or Karkling's study (169

responses included) (Hayes et al., 1999; Hunt et al., 2023; Karkling et al., 2017).”The majority of respondents were specialized in neurodevelopmental disorders and the number of psychomotor therapists who completed our survey was larger than the number of occupational therapists. Majority of non-respondents stopped at the subsection 3, when the first video was playing. Unfortunately, our software does not provide insight into the specific moment within the video when they exited the questionnaire. This raises the question of whether watching videos prompted participants to switch tasks or if the videos were too time-consuming for them. Globally, respondents expressed an interest in PPML, in the EVAL_APP tool to assess PPML and in guidelines to adapt the parameters of the tool to children with neurodevelopmental disorders.

4.1 The place of motor learning in pediatric rehabilitation with neurodevelopmental disorders

Firstly, it is important to report that a very large percent of professionals agree with the definition of PPML we provided in the survey (91.9%). Our study does not directly measure the application of the principles of PPML in rehabilitation but reveals that 85.9% of the professionals who responded to our survey agree on the value of evaluating this process in their clinical assessment of children with neurodevelopmental disorders. Even though these rates are not directly comparable, these results suggest that using the principles of motor learning have gained popularity in pediatric rehabilitation, which is in line with research conducted in Canada and Australia (Brown et al., 2005; Feder et al., 2000). In a survey from Canadian and Australian research teams, only 30.5% and 33.0% pediatric occupational therapists used motor learning theory in their intervention

with children with neurological conditions (Brown et al., 2005). In Australia, only 20.4% of occupational therapists used motor learning theory for children with neurodevelopmental disorders (Brown et al., 2005). Of 50 Canadian pediatric occupational therapists, 68% used motor learning as intervention approaches with children with handwriting and fine motor difficulties (Feder et al., 2000). However, 46.1% of professionals who responded to our survey stated that they have not received sufficient training on PPML. This lack of knowledge about PPML is confirmed with the open-ended questions highlighting a confusion between performance and motor learning. The 11.7% of participants who said they were familiar with tests measuring PPML cited the MABC-2 (Henderson et al., 2007), TGMD 2 (Ulrich, 2000), NEPSY subtest (Korkman et al., 2012), Charlop-Atwell, (Albaret et al., 1994) and Purdue Pegboard (Tiffin et al., 1948). These tests assess motor performance, but not PPML. Although performance and motor learning are closely linked, their distinction is essential in the management of motor disorders. Tools proposed by the professionals who responded to our survey are measuring motor performance (MABC-2, TGMD-2, etc.). It is interesting to note that some participants specify assessing PPML when observing the development of a skill over several trials in the above tests (N=4). However, only few trials are administrated in these tests. Moreover, only the mean of performance over trials is considered to assess performance. Finally, sequence learning is not distinguished from visuomotor adaptation.

Secondly, when asked about their intention to use our tool in their clinical assessment, 55% responded positively and 11% negatively. This result seems to be related to the feeling of being trained on the PPML process. In fact, there is a link between the information received about PPML and the use of a new tool in

their practice. More precisely, participants who reported that they were trained to PPML responded favorably to the relevance of measuring PPML and the future use of the EVAL_APP tool. Participants who felt more trained in this process were in more agreement with our PPML definition. These results are in accordance with a previous survey in which pediatric physical therapists were asked about their knowledge and use of theories of motor control, development and learning (Hayes et al., 1999). Therapists who believed they had the most knowledge about these theories were those who modified aspects of their practice based on this knowledge (Hayes et al., 1999). Moreover, there is a correlation between the year of graduation and teaching on PPML during initial education. The more recent the professionals' graduation, the more teaching they received on PPML during their initial training. It appears that education on PPML is improving. However, this observation is somewhat surprising. While some professionals who responded to the survey were trained before 1990, the majority were trained after the 2000s' and may have been aware of the work of Schmidt (1993) and Doyon et al. (1998). There are many practical guides in the literature about implementation of PPML strategies in rehabilitation (Kafri & Atun-Einy, 2019; Larin, 1998; Levac et al., 2009; Mathiowetz & Haugen, 1994; Zwicker & Harris, 2009). Despite this, there is still a gap between scientific knowledge and clinical practice. It is imperative that the initial education of psychomotor and occupational therapists include elements on PPML and their implementation in clinical practice.

4.2 Place of a digital tool in pediatric rehabilitation

A limitation of our study is that we did not consider the use of a digital tool as obstacle to use of our tasks. A large majority of professionals (82%) have an easy access to a computer with a wired mouse. However, comments of nine

psychomotor and occupational therapists revealed they did not intend to use this tool because it is digital (screen), which represents half of the respondents who indicated that they would not use the EVAL_APP tool.

Screens are now part of our environment and the effectiveness of their use in rehabilitation is a subject of much interest, particularly in neurodevelopmental disorders. Nowadays, digital tools are used for DCD because they offer immediate feedback in very realistic game environments, they have motivational qualities and they are adaptable to individualized child's needs (Lino et al., 2021; Lorusso et al., 2021). In contrast to these works, many studies have shown the negative impact of screen exposure on language development (Madigan et al., 2020), social interaction (Zimmerman & Christakis, 2005) and psychomotor development (Suggate & Martzog, 2021). Children's exposure time to screens is now a real social issue, and there are any recommendations on this topic (Hill et al., 2016; Haut Conseil de la Santé Publique, 2021). The open-ended results of our survey clearly indicate that the place of screens in rehabilitation settings is a concern of 440 professionals, with some who refuse to use screens during rehabilitation. In any case, using a digital tool for assessment does not mandatory imply using a digital tool for rehabilitation.

4.3. Guidelines from the psychomotor and occupational therapists to adapt our tool to children with neurodevelopmental disorders

Most participants (89.5%) responded that a new PPML measurement tool would use our open-access tool in their clinical assessment and after viewing the video, 54.3% responded that they would use our open-access tool in their clinical

assessment. To better understand their opinion, we asked participants about parameters that need to be changed to be more suitable for children with neurodevelopmental disorders. One of the first barriers to use our tool appears to be the length of the tasks (approximately 10 min per task). We agree that clinical assessment should be relatively short. However, learning needs repetition and so, it is relatively long. It is necessary to account the trade-off between repetition and learning. The second barrier mentioned by professionals is the ecological value of the tasks. This issue for the ecological validity of measurement tools is legitimate in rehabilitation and is at the heart of our work. It is a matter of understanding what can be inferred from a test about the person's actual abilities in daily life (Crépeau, 1997; Pinto et al., 2023). In this regard, we have recently conducted a study in which we test the links between learning during experimental tasks and during several ecological situations (Martin et al., in prep).

We can also consider concerns about the materials. Firstly, our survey does not show that the use of the mouse is inappropriate, but in view of the comments of some participants, it seems that the use of the mouse is very variable from one child to another. In order to avoid a bias in measurement, it seems relevant to us to adapt the task to children by proposing to use a touch screen. The touch screen has already been used in a number of studies with children with neurodevelopmental disorders to perform a SRTT (Desmottes et al., 2016a, 2016b, 2017; Gabriel et al., 2011, 2013, 2015; Gordon, 1988; Lejeune et al., 2013). Some authors hypothesized that using a keyboard or a response box was too complex for children with neurodevelopmental disorders and that performance on the SRTT task could be affected by deficits in manual dexterity, difficulties to match the location of the target on the screen to the corresponding key and previous working

memory when participants used keyboard or response box (Blais et al., 2021; Lejeune et al., 2013; Tallet et al., 2015). Secondly, our tool provides feedback regularly, at the end of each block. The average time is given in milliseconds and the accuracy in percentage for each block. In our investigation, we refer to the concept of augmented feedback as defined by Schmidt & Lee (2014). Two types of feedback are distinguished by these authors: "knowledge of performance" and "knowledge of results". Knowledge of performance provides specific information about how a movement is performed or specific correction of the movement. Knowledge of results concerns the success of the action. Our tool provides the knowledge of results. Its main function is to create motivation and encourage the learner, but not to provide elements to correct the movement. We used average feedback.

Feedback is not given trial-by-trial, but the learners wait for a series of trials (a block) before receiving information about their average accuracy and average time they performed. Compared to every-trial feedback, the average feedback is known to enhance retention (Yao et al., 1994). To the question: "The feedback will be displayed on the screen and read by you to the patient. Does it seem understandable for your intervention population?", some participants responded that the form of numbers could be difficult to understand for children, especially if they have neurodevelopmental disorders. The use of smiley faces or pictorial feedback could be more appropriate, especially because their function is to maintain motivation.

Strengths of the EVAL_APP include the graphic and sound environment and the easily understandable instructions for children with neurodevelopmental

disorders. Results given in standard deviation seem also to be easily understandable to professionals.

For some statements, participants did not provide an answer of agreement or disagreement, with high percentages of "I don't know" answers. By choosing to communicate our survey via social networks of clinical professionals, we did not select experts in assessment, as in the Delphi survey but it could be made in a future participative research (see Kleyner et al., 2015 for example). This may possibly explain the heterogeneity of opinions about our tool. We are aware that there is a bias in the recruitment of our sample, since the survey was distributed only via social networks and participants had to volunteer to spend 10 minutes completing it.

5. Conclusion

Overall, our results show that French therapists are not systematically trained in PPML as a key process for rehabilitation. However, our results indicate that knowledge about PPML is associated with the idea that measuring PPML is relevant for clinical practice, and the intention to use the EVAL_APP tool to monitor intervention. In line with current scientific research and recommendations, it seems crucial to integrate systematically, in the initial education of clinical professionals, updated theoretical information about PPML and its crucial role in rehabilitation. Half of the professionals are interested in using the EVAL_APP tool to assess PPML and provided suggestions to adapt our tool to clinical practice as effectively as possible. Even if some parameters of our tool are well designed (graphic and sound environment, instructions, results in standard deviations), others could be improved in order to be adapted to children with

neurodevelopmental disorders (duration of the test, use of the mouse, type of feedback). It is important to take into account these expectations and suggestions to improve the tool and optimize its usage in clinical practice. Finally, our study highlights the importance of involving therapists to strengthen the link between research and clinical practice. The acceptability of a new tool and its integration into clinical practice must consider the opinion, the experience and the expertise of clinical professionals as future users of the tool.

Conflict of interest statement

Authors declare no conflict of interest. There is no financial gain for authors.

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Supplementary data:

Questions of the survey in French and in English

References

- Albaret, J. M., & Noack, N. (1994). Manuel de l'échelle de coordinations motrices de Charlop-Atwell. Paris: Éditions du centre de psychologie appliquée.
- Hill, D. L., Ameenuddin, N., Chassiakos, Y. R., Cross, C., Hutchinson, J., Levine, A., Boyd, R., Mendelson, R. A., Moreno, M., & Swanson, W. S. (2016). Media and young minds. *Pediatrics*, *138*(5). <https://doi.org/10.1542/peds.2016-2591>

Bayley, N. (2006). Bayley Scales of Infant and Toddler Development– Third Edition. San Antonio, TX: Harcourt Assessment. *Journal of Psychoeducational Assessment, 25*(2), 180-190.

Blais, M., Jucla, M., Maziero, S., Albaret, J.-M., Chaix, Y., & Tallet, J. (2021). Specific cues can improve procedural learning and retention in Developmental Coordination Disorder and/or Developmental Dyslexia. *Frontiers in Human Neuroscience, 15*, 744562. <https://doi.org/10.3389/fnhum.2021.744562>

Bland, J. M., & Altman, D. G. (1995). Multiple significance tests : The Bonferroni method. *BMJ : British Medical Journal, 310*(6973), 170.

Bo, J., Langan, J., & Seidler, R. D. (2008). Cognitive Neuroscience of skill Acquisition. Dans Elsevier eBooks (p. 101-112). [https://doi.org/10.1016/s0166-4115\(08\)10009-7](https://doi.org/10.1016/s0166-4115(08)10009-7)

Brown, G., Rodger, S., Brown, A., & Roevers, C. (2005). A comparison of Canadian and Australian paediatric occupational therapists. *Occupational Therapy International, 12*(3), 137-161. <https://doi.org/10.1002/oti.2>

Clark, G. M., & Lum, J. A. G. (2017). Procedural learning in Parkinson's disease, specific language impairment, dyslexia, schizophrenia, developmental coordination disorder, and autism spectrum disorders : A second-order meta-analysis. *Brain and Cognition, 117*, 41-48. <https://doi.org/10.1016/j.bandc.2017.07.004>

Clark, G. M., Lum, J. A. G., & Ullman, M. T. (2014). A meta-analysis and meta-regression of serial reaction time task performance in Parkinson's disease. *Neuropsychology, 28*(6), 945-958. <https://doi.org/10.1037/neu0000121>

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (0 éd.). Routledge. <https://doi.org/10.4324/9780203771587>

de Graaf, J. B., Péliçon, D., Prablanc, C., & Goffart, L. (1995). Modifications in end positions of arm movements following short term saccadic adaptation:

NeuroReport, 6(13), 1733-1736. <https://doi.org/10.1097/00001756-199509000-00007>

Crépeau, F. (1995). De la validité écologique en neuropsychologie. Dans CMJ. Braun (dir.), *Évaluation neuropsychologique* (p. 49-97). Edition Décarie.

Desmottes, L., Meulemans, T., & Maillart, C. (2016a). Later learning stages in procedural memory are impaired in children with Specific Language Impairment. *Research in Developmental Disabilities*, 48, 53-68. <https://doi.org/10.1016/j.ridd.2015.10.010>

Desmottes, L., Meulemans, T., & Maillart, C. (2016b). Implicit spoken words and motor sequences learning are impaired in children with Specific Language Impairment. *Journal of the International Neuropsychological Society: JINS*, 22(5), 520-529. <https://doi.org/10.1017/S135561771600028X>

Desmottes, L., Meulemans, T., Patinec, M.-A., & Maillart, C. (2017). Distributed training enhances implicit sequence acquisition in children with Specific Language Impairment. *Journal of Speech, Language, and Hearing Research*, 60(9), 2636-2647. https://doi.org/10.1044/2017_JSLHR-L-16-0146

Doyon, J., & Benali, H. (2005). Reorganization and plasticity in the adult brain during learning of motor skills. *Current Opinion in Neurobiology*, 15(2), 161-167. <https://doi.org/10.1016/j.conb.2005.03.004>

Doyon, J., Laforce, R., Bouchard, G., Gaudreau, D., Roy, J., Poirier, M., BÉdard, P. J., BÉdard, F., & Bouchard, J.-P. (1998). Role of the striatum, cerebellum and frontal lobes in the automatization of a repeated visuomotor sequence of movements. *Neuropsychologia*, 36(7), 625-641. [https://doi.org/10.1016/S0028-3932\(97\)00168-1](https://doi.org/10.1016/S0028-3932(97)00168-1)

- Eustache, F., & Desgranges, B. (2008). MNESIS: Towards the integration of current multisystem models of memory. *Neuropsychology Review*, 18(1), 53-69. <https://doi.org/10.1007/s11065-008-9052-3>
- Eysenbach, G., & Wyatt, J. (2002). Using the Internet for surveys and health research. *Journal of Medical Internet Research*, 4(2), E13. <https://doi.org/10.2196/jmir.4.2.e13>
- Feder, K., Majnemer, A., & Synnes, A. (2000). Handwriting: current trends in occupational therapy practice. *Canadian Journal of Occupational Therapy*, 67(3), 197-204. <https://doi.org/10.1177/000841740006700313>
- Fisher, B. E., Morton, S. M., & Lang, C. E. (2014). From motor learning to physical therapy and back again: the state of the art and science of motor learning rehabilitation research. *Journal of Neurologic Physical Therapy*, 38(3), 149-150. <https://doi.org/10.1097/NPT.0000000000000043>
- Gabriel, A., Maillart, C., Guillaume, M., Stefaniak, N., & Meulemans, T. (2011). Exploration of serial structure procedural learning in children with language impairment. *Journal of the International Neuropsychological Society: JINS*, 17(2), 336-343. <https://doi.org/10.1017/S1355617710001724>
- Gabriel, A., Maillart, C., Stefaniak, N., Lejeune, C., Desmottes, L., & Meulemans, T. (2013). Procedural learning in specific language impairment: Effects of sequence complexity. *Journal of the International Neuropsychological Society: JINS*, 19(3), 264-271. <https://doi.org/10.1017/S1355617712001270>
- Gabriel, A., Meulemans, T., Parisse, C., & Maillart, C. (2015). Procedural learning across modalities in French-speaking children with specific language impairment. *Applied Psycholinguistics*, 36(3), 747-769. <https://doi.org/10.1017/S0142716413000490>

Gordon, B. (1988). Preserved learning of novel information in amnesia : Evidence for multiple memory systems. *Brain and Cognition*, 7(3), 257-282. [https://doi.org/10.1016/0278-2626\(88\)90002-4](https://doi.org/10.1016/0278-2626(88)90002-4)

Griffiths, A., Toovey, R., Morgan, P. E., & Spittle, A. J. (2018). Psychometric properties of gross motor assessment tools for children : A systematic review. *BMJ Open*, 8(10), e021734. <https://doi.org/10.1136/bmjopen-2018-021734>

Haut Conseil de la Santé Publique. (2021). Effets de l'exposition des enfants et des jeunes aux écrans.

<https://www.hcsp.fr/Explore.cgi/AvisRapportsDomaine?clefr=759>

Hayes, H. A., Hunsaker, N., & Dibble, L. E. (2015). Implicit Motor Sequence Learning in Individuals with Parkinson Disease : A Meta-Analysis. *Journal of Parkinson's Disease*, 5(3), 549-560. <https://doi.org/10.3233/JPD-140441>

Hayes, M. S., McEwen, I. R., Lovett, D., Sheldon, M. M., & Smith, D. W. (1999). Next step: survey of pediatric physical therapists?? Educational needs and perceptions of motor control, motor development and motor learning as they relate to services for children with Developmental Disabilities. *Pediatric Physical Therapy*, 11(4), 164-182. <https://doi.org/10.1097/00001577-199901140-00002>

Hunt, J., Zwicker, J., Godecke, E., & Raynor, A. (2023). Assessing children to identify developmental coordination disorder : A survey of occupational therapists in Australia. *Australian Occupational Therapy Journal*, 70(4), 420-433. <https://doi.org/10.1111/1440-1630.12864>

Karkling, M., Paul, A., & Zwicker, J. G. (2017). Occupational therapists' awareness of guidelines for assessment and diagnosis of developmental coordination disorder : Mesure selon laquelle les ergothérapeutes connaissent les lignes directrices relatives à l'évaluation et au diagnostic du trouble du développement

de la coordination. *Canadian Journal of Occupational Therapy*, 84(3), 148-157.
<https://doi.org/10.1177/0008417417700915>

Kafri, M., & Atun-Einy, O. (2019). From motor learning theory to practice: a scoping review of conceptual frameworks for applying knowledge in motor learning to physical therapist practice. *Physical therapy*, 99.
<https://doi.org/10.1093/ptj/pzz118>

Klein, E. S., Licari, M., Barbic, S., & Zwicker, J. G. (2023). Success or Failure? Are We Meeting the Needs of Children With Developmental Coordination Disorder? *Canadian Journal of Occupational Therapy*, 00084174231197618.
<https://doi.org/10.1177/00084174231197618>

Kleynen, M., Braun, S. M., Rasquin, S. M. C., Bleijlevens, M. H. C., Lexis, M. A. S., Halfens, J., Wilson, M. R., Masters, R. S. W., & Beurskens, A. J. (2015). Multidisciplinary views on applying explicit and implicit motor learning in practice: An International Survey. *PLOS ONE*, 10(8), e0135522.
<https://doi.org/10.1371/journal.pone.0135522>

Knopman, & Nissen. (1987). Implicit learning in patients with probable Alzheimer's disease. *Neurology*, 37(5), 784-784. <https://doi.org/10.1212/WNL.37.5.784>

Korkman, M., Kirk, U., & Kemp, S. (2012). NEPSY-II: Manuel d'administration. Paris: Éditions du centre de psychologie appliquée.

Henderson, S. E., Sugden, D., & Barnett, A. L. (2007). Movement Assessment Battery for Children-2. American Psychological Association.
<https://doi.org/10.1037/t55281-000>

Larin, H. M. (1998). Motor learning: A practical framework for paediatric physiotherapy. *Physiotherapy Theory and Practice*, 14(1), 33-47.
<https://doi.org/10.3109/09593989809070042>

Lejeune, C., Catale, C., Willems, S., & Meulemans, T. (2013). Intact procedural motor sequence learning in developmental coordination disorder. *Research in Developmental Disabilities*, 34(6), 1974-1981.

<https://doi.org/10.1016/j.ridd.2013.03.017>

Levac, D., Wishart, L., Missiuna, C., & Wright, V. (2009). The application of motor learning strategies within functionally based interventions for children with neuromotor conditions. *Pediatric Physical Therapy*, 21(4), 345-355.

<https://doi.org/10.1097/PEP.0b013e3181beb09d>

Lino, F., Arcangeli, V., & Chieffo, D. P. R. (2021). The virtual challenge: virtual reality tools for intervention in children with Developmental Coordination Disorder.

Children, 8(4), 270. <https://doi.org/10.3390/children8040270>

Lorusso, M. L., Borasio, F., Da Rold, M., & Martinuzzi, A. (2021). Towards consensus on good practices for the use of new technologies for intervention and support in Developmental Dyslexia: a delphi study conducted among italian specialized professionals. *Children*, 8(12), 1126.

<https://doi.org/10.3390/children8121126>

Madigan, S., McArthur, B. A., Anhorn, C., Eirich, R., & Christakis, D. A. (2020). Associations between screen use and child language skills: a systematic review and meta-analysis. *JAMA Pediatrics*, 174(7), 665.

<https://doi.org/10.1001/jamapediatrics.2020.0327>

Martin, E., Seiwert, S., Clausses, Y., & Tallet, J. (submitted). A systematic review about procedural perceptual-motor learning in neurodevelopmental disorders: which place for motor disorders?

Martin, E., Seiwert, S., Fautrelle, L., Amarantini, D., & Tallet, J. (In prep) Is there a link between experimental and ecological assessments of PPML ?

- Martin, E., Scotté-Barranoff, C. & Tallet, J (2023). What neurological diseases tell us about procedural perceptual-motor learning? A systematic review of the literature. *Neurological Science*, 44(8), 2645-2665. <https://doi.org/10.1007/s10072-023-06724-w>
- Mathiowetz, V., & Haugen, J. B. (1994). Motor behavior research : Implications for therapeutic approaches to central nervous system dysfunction. *The American Journal of Occupational Therapy: Official Publication of the American Occupational Therapy Association*, 48(8), 733-745. <https://doi.org/10.5014/ajot.48.8.733>
- Nicolson, R. I., & Fawcett, A. J. (2007). Procedural learning difficulties : Reuniting the developmental disorders? *Trends in Neurosciences*, 30(4), 135-141. <https://doi.org/10.1016/j.tins.2007.02.003>
- Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology*, 19(1), 1-32. [https://doi.org/10.1016/0010-0285\(87\)90002-8](https://doi.org/10.1016/0010-0285(87)90002-8)
- Pinto, J. O., Dores, A. R., Peixoto, B., & Barbosa, F. (2023). Ecological validity in neurocognitive assessment : Systematized review, content analysis, and proposal of an instrument. *Applied Neuropsychology: Adult*, 1-18. <https://doi.org/10.1080/23279095.2023.2170800>
- Polatajko, H. J., Mandich, A., Miller, L. T., & Macnab, J. (2001). Cognitive Orientation to Daily Occupational Performance (CO-OP). *Physical & Occupational Therapy in Pediatrics*, 20(2-3), 83-106. https://doi.org/10.1080/j006v20n02_06
- Robertson, E. M. (2007). The Serial Reaction Time Task : Implicit Motor Skill Learning? *Journal of Neuroscience*, 27(38), 10073-10075. <https://doi.org/10.1523/JNEUROSCI.2747-07.2007>
- Schmidt, R. A. (1993). *Apprentissage moteur et performance*. Paris : Vigot.

Schmidt, R. A., & Lee, T. D. (2014). *Motor learning and performance: From principles to application* (Fifth edition). Human Kinetics.

Schmidt, R. A., Lee, T. D., Winstein, C., Wulf, G., & Zelaznik, H. N. (2018). *Motor control and learning: a behavioral emphasis*. Human Kinetics.

Squire, L. R., & Zola, S. M. (1996). Structure and function of declarative and nondeclarative memory systems. *Proceedings of the National Academy of Sciences*, 93(24), 13515-13522. <https://doi.org/10.1073/pnas.93.24.13515>

Suggate, S. P., & Martzog, P. (2021). Children's sensorimotor development in relation to screen-media usage: A two-year longitudinal study. *Journal of Applied Developmental Psychology*, 74, 101279. <https://doi.org/10.1016/j.appdev.2021.101279>

Tallet, J., Albaret, J.-M., & Rivièrè, J. (2015). The role of motor memory in action selection and procedural learning: Insights from children with typical and atypical development. *Socioaffective Neuroscience & Psychology*, 5(1), 28004. <https://doi.org/10.3402/snp.v5.28004>

Tiffin, J., & Asher, E. J. (1948). The Purdue Pegboard: norms and studies of reliability and validity. *Journal of Applied Psychology*, 32(3), 234-247. <https://doi.org/10.1037/h0061266>

Ulrich, D. (2000). *Test of gross motor development-2*. Second Edition. Austin, TX: Pro-ed.

West, G., Vadillo, M. A., Shanks, D. R., & Hulme, C. (2018). The procedural learning deficit hypothesis of language learning disorders: We see some problems. *Developmental Science*, 21(2). <https://doi.org/10.1111/desc.12552>

Yao, W.-X., Fischman, M. G., & Wang, Y. T. (1994). Motor skill acquisition and retention as a function of average feedback, summary feedback, and performance

variability. *Journal of Motor Behavior*, 26(3), 273-282.

<https://doi.org/10.1080/00222895.1994.9941683>

Zimmerman, F. J., & Christakis, D. A. (2005). Children's television viewing and cognitive outcomes : a longitudinal analysis of national data. *Archives of Pediatrics & Adolescent Medicine*, 159(7), 619. <https://doi.org/10.1001/archpedi.159.7.619>

Zwicker, J. G., & Harris, S. R. (2009). A reflection on motor learning theory in pediatric occupational therapy practice. *Canadian Journal of Occupational Therapy*, 76(1), 29-37. <https://doi.org/10.1177/000841740907600108>