Meeting the needs of people with Neuro-Developmental Disorder through a phygital approach

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ABSTRACT

The paper introduces Reflex, a mirrored camera mobile training application for persons with Neuro-Developmental Disorder (NDD). The game, offered through a cross-platform application for smartphones and tablets, bridges the digital and the physical worlds by tracking, via a bottom-looking mirror positioned on the device camera, physical items placed on the table. This interaction paradigm defined as phygital, its co-designed features and the first pilot study reveal an unexplored potential for learning.

CCS CONCEPTS

• **Social and professional topics** → **People with disabilities**; • **General and reference** → Empirical studies; • **Software and its engineering** → Interactive games.

KEYWORDS

Neuro-Developmental Disorder; Phygital; Tangible; Digital; Physical; Autism; Down Syndrome; ADHD; Disability, Accessibility

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1 INTRODUCTION

A Tangible User Interface (TUI) is a physical environment that a user can physically interact with to manipulate digital information. While TUI has opened up a new range of possibilities for interacting with digital information, significant challenges remain when implementing it and evaluating the efficacy of such an interface for people with Neuro-Developmental Disorder (NDD). This work sheds a light on the potential of phygital (physical + digital) approaches to answer to the following research questions:

- What are the must-have features of a phygital application that fit at most the needs of persons with NDD?
- Which functioning level among the entire NDD spectrum can benefit the most from this phygital approach for different activities?

To answer these questions, we collaborated with therapists to define some guidelines when developing phygital applications for NDD people and we used a common framework to evaluate users-functioning level and clearly define the proper target group.

The paper is organized as follows: section 2 focuses on the theory behind interactive technology and on current solutions adopting tangible user interfaces for people with NDD. The third section described designing and developing of our solution, called Reflex. The fourth section explains the exploratory study we administered to answer our research questions. Section 5 provides results and discusses about the outcome and the limitations of the exploratory study. Finally, we conclude the paper with potential speculations and future works.

2 BACKGROUND

2.1 Theory

Neuro-Developmental Disorder (NDD) is an umbrella term for a group of disorders arising during the developmental period that is characterized by severe and often co-occurring deficits in the cognitive, social, communicative, motor, behavioral and emotional spheres [3], and includes, among other disorders, Intellectual Disability (ID), Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorder (ASD) and Down Syndrome. The disorder profoundly affects the capability of adaptive behavior and basic skills needed in everyday life [27].

From this perspective, the use of digital interactive technology is regarded as a promising approach that does not replace current therapies but can be incorporated into them and support care-givers in their daily routine [11, 13, 14]. To this end, the potential of technologies that require bodily interaction is grounded on theoretical approaches that recognize the relationship between physical activity and cognitive processes [4, 16], and are supported by a growing body of evidence from psychology and neuro-biology [39]. According to Antle [1] and Falcao [9] the possibilities provided by

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tangible interfaces, such as physical manipulation, physical-digital mappings, exploration, collaboration and accessibility represent promising novel opportunities for learning. Eisenberg et al. [8] also support the fact that tangible technologies provide richer sensory experiences through the interweaving of computation and physical materials, extending the intellectual and emotional potential of people's artifacts and integrating compelling and expressive aspects of traditional educational technologies with creative and valuable educational properties of physical objects.

2.2 State of the art

People with Intellectual Disabilities (ID) have benefited from tangible games to increase independent exploratory learning; inclusion; assistive and collaborative learning; and e-accessibility [40]. In particular, Marshall [26] discusses the advantages of using tangible user interfaces and argues its benefits in learning, effectively summarizing tangible interfaces as follows: "as interaction with tangible interfaces is assumed to be more natural or familiar than with other types of interface, they might be more accessible to young persons, people with learning disabilities or novices, lowering the threshold of participation". Zajc et al. also focus on the usefulness of computer TUI-supported games (Raindrop Catcher) in inclusive classrooms for students with severe to mild learning difficulties and physical impairments. The exploitation of TUI-based games allowed all students to be equally engaged in the game-based learning process [40], thus supporting collaborative learning and overcoming those limitations noticed in computer-based activities only [35]. In addition, Falcao [10] points out the effectiveness of tangible interaction for exploratory learning purposes letting people with ID play with different tangible artifacts (LightTable, Drum Machine, Softeo cubes and augmented objects) and he argues the most efficient gaming paradigm as the one with a clear mapping between specific physical objects and their meanings. Cerezo et al. [6] present NIKVision, a combination of a tabletop computer and tangible interaction for children with special needs that aims at promoting collaborative learning by co-designing with pre-schoolers. Schneider et al. [32] discuss the role of tangibility in problem-solving task for pedagogical collaborative learning by comparing tangible interfaces with multi-touch ones and providing evidence in favor of tangible interfaces. Finally, Tangible Play in 2014 created Osmo [29], a phygital system consisting of an IPad stand, a camera attachment, and some specially designed games. Currently, we have not found any study on this latter application. Given the above premises, research in the tangibles field is still in its infancy, urging for a better understanding of the advantages and drawbacks of bringing tangibles into the learning process [2], particularly in the case of people with Neuro-Developmental Disorders [41]. Initial empirical studies with the NDD population have indicated positive effects on engagement, collaboration and initiative, although the field still needs more systematic research. This work aims at shedding a light upon the exploration of Reflex as a way to convey learning "phygitally" by defining a set of design guidelines for phygital applications.

3 REFLEX

This work builds upon prior work [12, 15], meant to describe the technical work performed, and extends it by performing an empirical study.

3.1 Inspiration

Since the launch of the Apple iPad, there has been a great deal of excitement in the NDD community about collaborative touch-based devices and their possible use in interventions for children with NDD. The specific features of tablets portability, mobility, accessibility, size, ease of recording, wireless Internet access and naturalness of touch interactions have facilitated the widespread implementation of technology in schools, therapeutic centers and houses. Children with NDD have benefited from tablets to compensate for limited verbal communication abilities, facilitate literacy development, increase overall academic performance, and decrease challenging behavior [17, 18]. Autism Speaks [34], a leading advocacy and science organization dedicated to autism, provides a list of approximately 648 applications for children suggesting significant interest in this area. Research has also suggested that tablets are currently being used effectively with NDD children in a variety of distinct manners and for a variety of distinct functions [23], categorized below:

- the tablet serving as a means/tool to deliver instructional video (video-based modeling) [5]
- the tablet functioning as a speech-generating augmentative and alternative communication (AAC) system [25]
- the tablet, in conjunction with various applications, serving as a means to facilitate learning of academic content through collaboration with educators or peers [7, 31]

Based on the last point, Osmo, created in 2014 by Tangible Play [28], commercializes a system consisting of an IPad stand (1), a camera attachment (2), and some specially designed games (3) as described in Figure 1. Osmo offers a great mix of the strengths described in the Background section: it provides multisensory stimulation, it requires bodily interaction, it can be used in group; and, thanks to it, it has been adopted in over 25,000 schools in 42 countries around the world. Teachers are raving about how their students love experimenting, exploring, creating and collaborating with Osmo.

Figure 1: Osmo components: IPad stand (1), a camera attachment (2), and some specially designed games (3)

3.2 Paradigm

We chose to adopt a hybrid approach defined as "phygital" as it digitally virtualizes a physical environment of Tangible Objects (TOs) manipulable by the user. This approach uses a platform which augments a hand-held computing device, such as a phone or tablet and utilizes novel computer vision algorithms to sense user interaction with the tangible objects. This technology yields numerous advantages including, but not limited to providing a low-cost alternative for developing a nearly limitless range of applications that blend both physical and digital mediums by reusing existing hardware (e.g., device camera); leveraging novel lightweight detection and recognition algorithms; having low implementation costs; being cross-compatible with existing computing device hardware; operating in real-time to provide for a rich, virtual experience; processing numerous interactions with one or more TOs simultaneously without overwhelming the computing device; recognizing TOs with substantially perfect recall and precision (e.g., 99% and 99.5%, respectively); being capable of adapting to lighting changes and wear and tear of TOs; providing a collaborative tangible experience between users; being natural and intuitive to use; requiring few or no constraints on the types of TOs that can be processed (no specialized markers or symbols are required to be included on the TOs in order for the platform to recognize them [20, 38]).

3.3 Requirements Elicitation

Inspired by the phygital approach enabled in Osmo, we decided to test it with therapists to clearly evaluate its potential. Given the nature of the study (which could have lead to the adoption throughout the entire therapeutic center) we decided to opt for a focus group to commit therapists directly and promote cooperation. Due to the long-term fruitful collaboration, all participants (3 occupational therapists, 3 psychologists, 2 designers, 2 software engineers) felt comfortable and confident in speaking openly and frankly. The focus group started with a description phase, in which Osmo [29] was shown using the Starter Kit activities. We asked NDD specialists to impersonate into their therapy with persons with NDD, to try the application freely without any forced interaction flow. Therapists tried Osmo activities for 15 minutes each and took notes when required. We then met them in the focus group and the moderator asked questions about their experience.

Some noted that Osmo's effects can be too rich of stimulus (sounds, colors, feedback, imagines), defined by therapists as "overwhelming" and unpredictable therefore, to better accommodate NDD users' needs, they should be limited to only relevant information. Goals are too broad and require players to keep memory of the goal for a prolonged amount of time. Quantitative performance results (e.g. points or extra time won) as happens in Osmo are not valued as much as cartoon videos, funny animations, cheerful music, and applause. Moreover, specialists found that with Osmo, their users might find difficult to position elements onto the "tracked" area with just a virtual constraint and that a very clearly defined playground was needed to facilitate understand-ability. On top of the players' experience, therapists also asked a way to add or configure their activities, precisely calibrated for each individual's peculiarities. In Osmo, there was no way to track personal improvements such as completion times, errors, successes, interaction patterns. Finally, the Osmo kit worked only with an last generation Apple Ipad and some noted they might not be able to afford the costs. We summarized and categorized therapists' comments and asked to review them and cite the source of their suggestions as explained in the Discussion section. Given the above outcomes from the requirements elicitation phase, a development of a new system was required to satisfy participants' needs. We called the system: Reflex.

3.4 Description

Reflex is a cross-platform application that tracks and recognizes items placed on a bordered (solid black) mat (Play Zone as in Figure 2.5) via a bottom-looking mirror position on the device camera. The software app (Figure 2.1) adopts the Osmo's phygital approach [29] by benefiting from a device stand (Figure 2.2) and a camera attachment (Figure 2.3). The camera attachment adapts a camera integrated in a device and includes a housing including a slot on a first side, the slot configured to receive and retain an edge of a body of the computing device, the housing configured to cover at least a portion of the field of view of the camera of the device, and a reflective element recessed at an angle into the first side of the housing to redirect the camera field of view toward an activity surface located proximate the device [33]. The app processes the reflected video stream; identifies contours of each object placed on the Play Zone and infers an object shape by mapping the coordinates of vertices, orientation, position, colors. The virtual information on the screen is then generated based on the recognized objects.

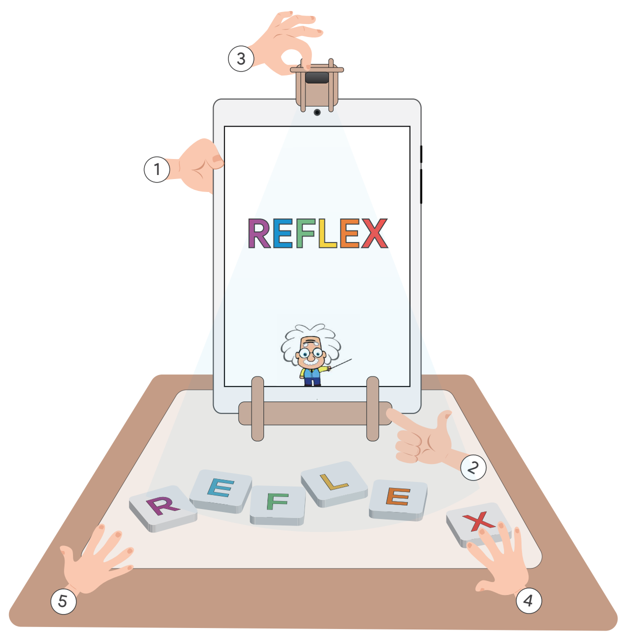
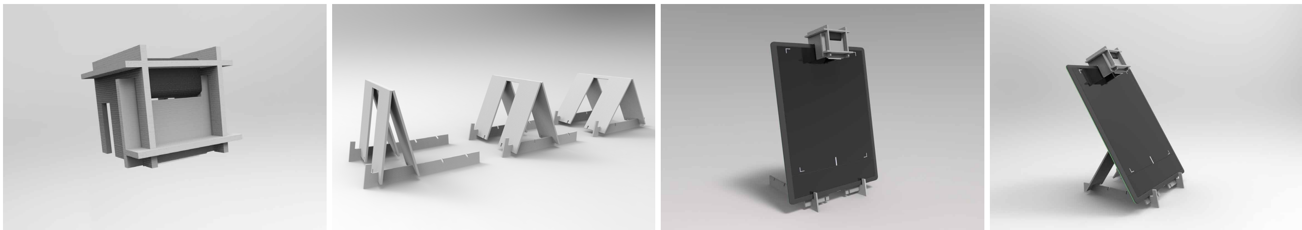


Figure 2: Reflex components: generic tablet (1), tablet stand (2), adjustable camera attachment (3), cards (4) and specifically designed software, playground mat with solid black borders (5)

3.5 Activities

Although Reflex does not seem to add anything new to Osmo - it requires a stand to hold the tablet, a camera mirror to reflect the image from the desk to the camera, and some activities to work



(a) (b) (c) (d)

Figure 3: Reflex DIY Kit: Reflex adjustable camera attachment (a) and stand (b), two examples of generic tablets fitting in Reflex solution (c,d)

phygitally - it capitalizes on the above requirements and offers a fully integrated set of features.

Differently from Osmo, which proposes predefined games with predefined game rules, graphics, logic and mechanics, with Reflex, caregivers can create their own activities by setting:

- "output": the instructions shown on screen such as images, texts, videos, sounds;
- "input": the elements that have to be recognized such as letters, numbers, shapes, pictures or real elements;
- other parameters such as reward type, sound effects, hints.

and save their activities for one or more users. As an example therapists developed the following activities:

- "Images": a video with a main character requiring help in finding something. The user is then asked to find from a predefined set of printed images and show the required image to the system.
- "Tangram": an animal figure composed by 7 essential geometric shapes is shown. The user has to match the given animal image by putting every items in its exact position and rotation.
- "Numbers": some repeated elements are shown on screen and the user needs to count them and put the relative number in the play zone.
- "Letters": the initial letter of a word is required from the virtual avatar to finish composing the word. The image of the word and all the other letters are shown and spelled.
- "Words": as in "the hangman" game, the user has to put in the play area the corresponding letters that fill the exact blank spaces and represent the image shown. The user neither receive any feedback nor lose guesses for a wrong letter positioned into the play zone.

For this study all activities were previously defined with therapists and implemented by researchers, meanwhile researches lay the groundwork for creating a tool that could allowed, through a simplified interface, caregivers to create and configuring new games for subjects. Reflex also offers a starter toolkit that includes different sets of letters, numbers and images and the playground mat (printable on A4 paper); the technical vector-based and 3D drawings of the camera mirror and the tablet stand (printable on light cardboard with a regular printer or a 3D printer or with a laser cutter); and instructions to assemble them. Both the camera mirror and the stand can be adapted to many devices thanks to their modular parts as shown in Figure 3.

4 EXPLORATORY STUDY

A 3-months exploratory study was conducted in order to discover the most appropriate user profile, in terms of functioning level, and its most suitable activities. As a first operational step, a multidisciplinary working group was set up, composed by: one daycare center facility manager working as external consultant and project's adviser, five occupational therapists (hereinafter therapists or caregivers), and three members of the technical team who developed Reflex. In the purely design phase, they all proposed Reflex's activities. Subsequently they worked closely in order to i) define the study procedure and goals; ii) guarantee the reduction of methodological bias; iii) favor a reliable and meaningful data acquisition and analysis.

This section is organized as follows. The context explains the ambience and the situation in which the research was performed. The second section tells details about the participants of the study such as their associated study ID, age, gender and functioning level. Next we provide the reader with a description of the study setting.

4.1 Context

This study has been developed in close collaboration with a Day-Care Treatment Center for subject with a broad range of disabilities, both physical and mental, or various Congenial Pathological Conditions and NDD diagnosis. The Day-Care Treatment Center provides numerous facilities to the person with disability and welcomes subjects between the age of 10 and 64. The internal organization provides different services, from purely assistance interventions to job-training classroom, in which subjects are welcomed based on personal characteristics, cognitive functions, age, needs and personal programs drawn-up upon admission. Alongside strictly educational and operative laboratories, the center offers individual therapy sessions, psychological support, self-improvement and autonomy sessions, school support, mindfulness, arts and crafts. The Day-Care Treatment Center receives subjects after the compulsory schooling period, and acts as a bridge between institutions, the job market and health facilities. Particular attention is paid to strengthening and maintaining the cognitive-relational skills matured by the subject during the training years. Hence all therapists in the center are highly qualified.

4.2 Participants

Data collected from the exploratory study included performances from 27 subjects with NDD between the age of 19 and 44 (M = 26, SD = 6.69, Females = 44.4%, Males = 55.6%) years old. Subjects were taken from three classes: the first class included a group of 13 subjects (M=23 years old, SD=3), the second class included a group of 10 subjects (M = 22 years old, SD = 3) and the third class included a group of 4 subjects (M = 19 years old, SD = 1.7). Participants were selected according to the following rules. Table 1 lists the participants' information.

Written authorization to perform the study following the above protocol was obtained by the Ethical Committee of the Center (Fraternita' ed Amicizia in Milan) where the study took place. Parental/legal informed consent for participation and photo/video recording was signed for all participants. The form contained the rights and characteristics of the study adopted that suited the specificity of each person's disability.

Table 1: Participants of the exploratory study

Subjects	*Age*	*Gender*	*Functioning Level*
P1	21	M	Moderate
P2	30	M	Severe
P3	25	F	Moderate
P4	32	F	Severe
P5	29	M	Severe
P6	24	M	Mild
P7	25	F	Mild
P8	25	M	Moderate
P9	27	M	Severe
P10	20	F	Moderate
P11	37	F	Severe
P12	24	F	Moderate
P13	28	M	Mild
P14	21	M	Moderate
P15	41	F	Moderate
P16	27	M	Mild*
P17	27	M	Moderate
P18	20	F	Severe
P19	34	F	Severe
P20	44	F	Moderate
P21	22	M	Mild
P22	19	F	Severe
P23	19	M	Severe
P24	19	F	Moderate
P25	21	M	Moderate
P26	21	M	Mild
P27	22	M	Mild

Identification of an homogeneous sample: at the beginning of the study, assuming functioning have strongly heterogeneous expressions in NDD people, we aimed at extracting an homogeneous sample in order to have statistical significance during the data evaluation. Each participant was assessed with the International Classification of Functioning (ICF) [1] - Minimal Generic Set [24], [37] in order to set a generic baseline and to ensure group's homogeneity. As we were using the short version of the test, we assessed participants according to two dimensions: i) Bodily Functions and ii) Activity and Participation, both directly necessary to be able to test Reflex application. All participants presented mean score from 2.9 to 4 (SD = 1.3) in the Bodily Functions Category and from 2.7 to 4 (SD = 0.79) in the Activity and Participation Category. So we set a range of raw ICF level between 2.5 and 4. All subjects below or above this level were excluded from the study.

We aggregated diagnoses and cognitive functioning level of the subjects in three clusters: Severe, Moderate and Mild as shown in Table 2.

Table 2: Clustering of participants

Functioning Level	*Number*	*Relative %*
Moderate	11	40.8
Severe	9	33.3
Mild	7	25.9

4.3 Setting

Differently from Day-Care Center's regular group classrooms, which present several stimuli (e.g., noisy environment, colorful furniture), we set-up, with the collaboration of day-care center facility manager and therapists, a separate classroom to perform sessions during the pilot study. The study room was familiar to the subjects, but not associated to any specific everyday activity nor structured in a special way for the study purpose. The user sat on a chair in front of a table. Reflex's components were positioned on the top of the table as in Figure 4.

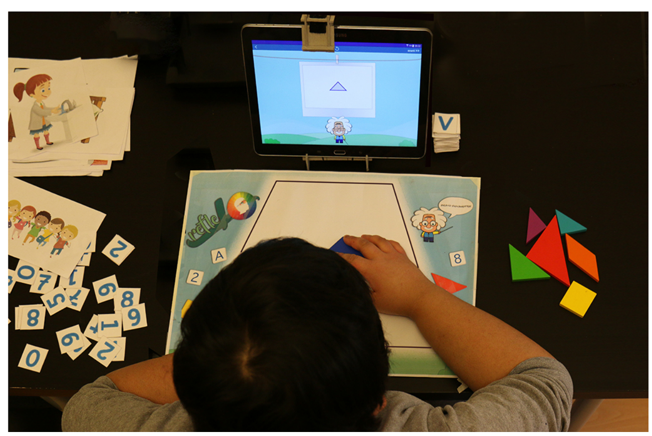


Figure 4: Reflex setting

[1] The ICF belongs to the World Health Organization (WHO) family of international classification. The main aims of the ICF are the following: to provide a scientific basis for the understanding and study of health seen as the interaction between an individual and his/her environment; to provide a common language for the description of health and health-related conditions in order to improve the communication between health care professional researchers, policy makers, and the population, including persons with disabilities; to allow the comparison of data collected in different countries, disciplines, services, and times; to provide a systematic method to code information in health information systems. The importance of this assessment relies on the definition of an homogeneous group of subjects and a baseline score to be used as a comparison-value for data analysis (thus monitoring the patient's genetic progress).

4.4 Procedure

Subjects were invited to enter the room, take a seat or move into the space according to they will. Each participant was required to perform four sessions of five activities (images, numbers, letters, words, tangram) of five tasks each lasting at maximum 2.5 minutes to avoid frustration and set a threshold for task accomplishment. The threshold has been established as the average value, in minutes, of group's first session time performances, following removal of the highest and the lower value. Each session was structured as follows:

- Activities were sorted by therapists' supposed difficulty level, from the easiest to the hardest: images, tangram, numbers, letters and words;
- Each activity was composed by five tasks ordered by their complexity (e.g. for tangram activity, the tasks differ for the number of shapes to be reproduced).

For the first session, a external caregiver self-introduced herself (familiarization) with the reassuring presence of therapist, demonstrated the use Reflex and all the physical components and guided each subject through all the activities offered by the application. This familiarization phase was specifically designed to allow subjects to become familiar with the technology (introduced to all subjects as new game to play with Einstein) and to asses the threshold 2.5 minutes cut-off described above.

At the beginning of every session, Reflex was placed on the table in front of the subject and participants were instructed to use only the space defined by the board and to interact with items within the working space. Therapists were solicited to encourage an autonomous use of Reflex and its items, providing only verbal instructions to the subject if she was no longer able to perform in an appropriate manner. Therapist were yielded to ask subjects to provide abstract example of the images they selected to promote abstract reasoning.

As soon as the subject showed a decrease in attention level or of miss-performance for the specific task, therapists skipped the activity in order not to create too much frustration. After three failures of the same task, we assumed participants reached their top level of performance for that activity and therapists invited the subject to move to the next activity.

During the administration of the study, the application recorded all the information in order to allow therapists to verify subjects' performance as described below.

4.5 Data gathering and elaboration

Manual Data Gathering. To clearly annotate users' performances and improvements along sessions, we defined the Profile Level Session (PLS). The PLS is a matrix which merges the chosen activities (images; tangram; numbers; letters; words) and the tasks level of difficulties (from 1 to 5) as depicted in Table 3. PLS is filled out for every session and every subject. The first session PLS is defined as "baseline PLS". At the end of the study, the PLS for each user is compared with the baseline PLS sessions to track the user performance. We called this comparison as *Delta Score.*

Table 3: Example of baseline PLS for subject P4. The subject achieves a score of 2 for the Images and Tangram activities, a score 3 in Numbers and Letters and a score of 1 in Words

	Images	*Numbers*	*Letters*	*Words*	*Tangram*
Level 1	X	X	X	X	X
Level 2	X	X	X		X
Level 3			X		
Level 4					
Level 5					

Automatic Data Gathering. Reflex records each task and stores it on the cloud. Each task entity on the cloud is composed by:

- id: uniquely identifies the session
- activity_id: the id of the activity type
- task_id: uniquely identifies the task
- server_id: the id of the therapist
- client_id: the id of the user who is playing the activity
- start_configuration: starting configuration of the task
- live_configuration: live configuration of the task
- notes: annotator's notes (when available)
- result: true or false, specifies if the task was successfully completed (true) or not (false)
- dateStart: the start time of the task in milliseconds
- dateEnd: the end time of the task in milliseconds

All sessions were also video-recorded starting the recording phase by indicating the user id and task id and pointing the camera towards the desk.

Data Elaboration. Both automatic and manual gathered data were checked for ambiguity (e.g. a task that was manually annotated as uncompleted but automatically reported as completed), solved (by looking at the video recordings) and merged. No data were lost during the previous and the current procedure. In Tab.4, we collect the performance data of a Severe Subject P5.

Table 4: Example of performance data for subject P5 during the four sessions: PLS, mean session data and mean *DeltaScore*

	PLS	*Mean Performance*	*DeltaScore*
Images	4	4.25	0.25
Letters	3	3.75	0.75
Numbers	0	0.25	0.25
Tangram	1	2.75	1.75
Words	0	0.5	0.5

5 RESULTS AND DISCUSSION

The aim of this study was to investigate the must-have features of phygital application and also the optimal target group for this specific application. The following sections will focus on answering to our research questions:

(1) What are the must-have features of a phygital application that fit at most the needs of persons with NDD?
(2) Which functioning level among the entire NDD spectrum can benefit the most from this phygital approach for different activities?

5.1 Contribution 1: Design Guidelines

To answer to the first research question, we specifically asked therapists to express their opinions on the usability of a phygital application (Osmo in our case) and their personal will to use it in everyday centre-routine. We asked them to focus on the design and the improvement that might be added to it according to their expertise. All therapists were willing to contribute and pointed out some design guidelines when developing phygital applications in the form of specific Osmo's constraints hence Reflex requirements:

- *Minimalism*: "effects are too overwhelming". They should be limited to only relevant information. Clear graphics, audio and stimuli are needed to support NDD persons' filtering process [22].
- *Predictability*: "there are many unpredictable effects during the activity". Although this situation can provide novelty and thus engagement, persons with NDD are often confused by unpredictability, social nuance, and rapid changes [19]. Predictable rules may be also well matched to the systematic processing styles of NDD individuals [24].
- *Clarity*: "Goals are too broad". Within a play session, NDD users should have a unique, explicit, well focused game goal to reach. The goal should be associated to one single task and a clear set of movements the person can afford to promote the cognitive process related of organizing movements to achieve a given objective [36].
- *Reward*: After having completed the single activity, offering a rewarding stimulus which is "valued" or "liked" by the person increases motivation, enhances player's engagement and implicitly improves her skills [36]. "Quantitative performance results (e.g. points or extra time won) are not valued as much as cartoon videos, funny animations, cheerful music, and applauses". In case of scarce game performance, these elements should not be necessarily removed at all, but can be reduced and completed with something that fosters NDD users to do better, e.g., visual instructions, in order to help managing frustration issues [36].
- *Configurability*: "Activities are offered by the creators, they are not customized at all". The software should be designed to provide as much additional one-to-one individualized support as required. It must enable caregivers to adapt a gaming experience to the individual skills and preferences of each person, customizing multimedia contents, rewards, play time, body movements [36].
- *Levelability*: "I want to able to setup levels for each person". The same game is typically played many times in the same configuration. Eventually, the NDD user will need to move from a level in which she has proved to be successful to the next one, which unlocks new challenges and opportunities. It must be very easy for the caregiver and the user to repeat a game, as well as to move to the next level. Research suggests the time of restarting a session or switching from one level to the next one must be minimized, to reduce the risk of losing concentration during the transition [36].
- *Assessability*: "There is no way I can track personal improvements". The data collected by computers can also be useful for assessing progress in learning [30].
- *Constrainability*: "NDD Users might find difficult to position elements onto the "trackable" area with just a virtual constraint" because the playground (i.e. the place where elements are tracked by the camera) is open and players are only informed by the tablet screen whenever they are out of the viewable area. Individuals with NDD often require their playground to be clearly defined by using tapes or marks with solid borders.
- *Avatar*: "Einstein is very friendly". The presence of a familiar and reassuring avatar, who encourages subjects and provide information, appears to be an excellent trigger of attention and a modulator for the sense of frustration that person with NDD very often experience when asked to perform a task. Appealing look, short and clear sentences are needed to support NDD persons in processing the instructions.

5.2 Contribution 2: Functioning Level

As expected, although all participants were able to use Reflex, not all the proposed activities and tasks were suitable for some functioning levels. From *Delta Score* values, we were able to detect the most appropriated functioning level of NDD subjects for each activity type. From an inverted analysis, the most encouraging data we have extrapolated is that none of the subjects involved in the study reported a lower score in the last session than in the first one. Regardless of the type of activity and the cognitive level of subjects, it is possible to highlight improvements or stability in the scores obtained. This data is critical because it allows us to hypothesize that the interaction paradigm used, so-called phygital, seems to be usable and to enable disabled subjects a free and constructive approach.

Fig. 7 describes data collected from all participants in all four sessions. Particularly, illustrate the Delta Mean Value for the subjects group for each activity. These data allowed us to better understanding if subjects improved their performance score between the first and the last session. The wilder is the delta score the biggest is the difference of score obtained by a subject comparing the first and the last session. It appears to be clear that, among all the activities, that tangram, delta score 1.70, is the one that has shown a clear progression. All subjects, independently from their level of functioning, increased their scores from the first session (PLS) to the last one. Meaning that the majority of subjects shift from a low score (2-3) the first time they tried tangram activity, and rapidly improved, during sessions to reach a higher score (4-5). All the other activities have a delta score that settles below 0.7, with almost homogeneous scores for Images and Letters, respectively 0.59 and 0.60; a score slightly lower for Numbers, 0.51 and one marginally more for words, 0.68t. This means that subjects did not substantially modify the score acquired in the first session compared to the last one.

Some more exciting consideration can be made if we separate data according to subjects functional level (Mild, Moderate, Severe). Fig.8 illustrate Delta scores for all activities for functional level. The most significant difference in performance is the one regarding Numbers(0,19) and Words (0,25), where subjects with Severe Cognitive Impairment performed very low since the first session and not improved during the study. If we compare scores of this group with scores of both Moderate (0.61) and Mild (0.75), we can easily

Figure 6: Reflex Study

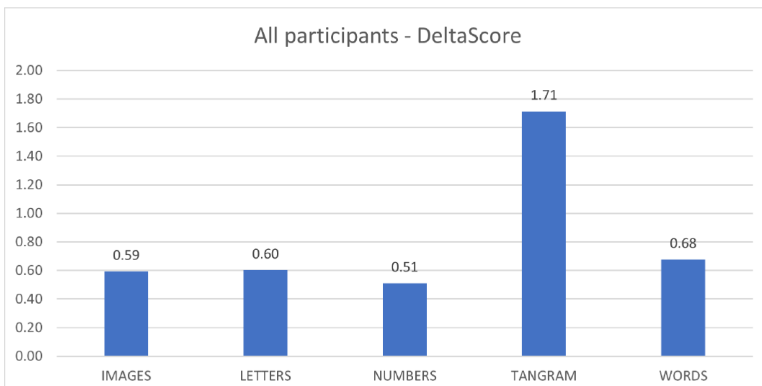


Figure 7: Average Delta Score of all participants

spot the difference. Subjects with Mild and Moderate increased their score with the progress of all session, independently from the initial score. Subjects with Severe Impairment did not improve at all. More homogeneous performances can be observed, among the groups, for the other activities. Where the delta score differ from each other but not in such a significant way

All subjects with Severe Functioning Level found difficulties in "Numbers" and "Words" activities, with a mean *Delta Score* of 0.2. In fact both their starting and final values were very low (0-1).

"Letters" and "Images" activities mean *Delta Score* was low (0.6) for all participants since their baseline PLS scores were very high (4-5). This outcome demonstrates that these activities were too easy since the beginning and all NDD users might find easier to start with them. The only exception is "Tangram" activity. Evidences from the study highlight that subjects score the baseline PLS very low (1-2) while in the final session they improved it significantly (4-5). So the mean *Delta Score* is broader (1.7) compared to the other activities, proving that there was an improvement in the performances of all subjects. Overall all users demonstrated an high level of engagement throughout the entire study. As a general guideline we deducted that activity that requires an active manipulation of a physical object activated by a digital stimulation with a real time-feedback as support, "Images", "Letters" and "Tangram" activities, are the ones suitable for all NDD subject.

Among those, "Tangram" is the most promising activity to enable problem-solving in NDD subjects. On the contrary, when a task requires some abstract conceptualization, e.g. "Numbers" and "Words", the phygital approach seems to be as ineffective as traditional method and suitable only for subjects with Moderate or Mild Cognitive Impairment.

To summarize, we shed a light on phygital-based activities in terms of functioning level among the broad NDD population. Evidences from the study suggests that subjects with "Moderate" or "Mild" Cognitive Functioning Level might benefit the most from the phygital approach, therefore those with a latent and residual ability to conceptualize imputes and stimulus.

Nevertheless, even if Reflex approach is equally ineffective for abstract and complex operations (e.g. mathematical calculations,

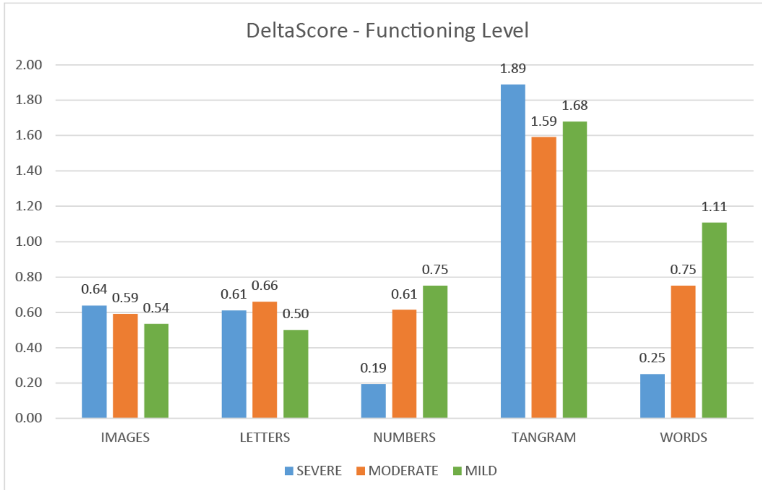


Figure 8: Delta Score of participants divided for functioning level

full sentence creation etc), all participants involved in the study showed very low levels of frustration, even for those tasks they never managed to complete, and verbally express their willingness to continue to use Reflex. This aspect is very promising under a user well-being point of view.

5.3 Limitations

Although the research has reached its aims, there were some unavoidable limitations. First, the data are self-reported introducing several potential sources of bias such as selective memory; telescoping; attribution; exaggeration. The study procedure and data analysis were mostly organized before performing the study and commented before the results publication. Still we had to face, as common in any study, different unexpected circumstances that may have induced therapists and researchers to hypothesize some facts after the study (known as harking [21]). Second, as technology limitation, we found out during the study that Reflex introduced some small delays that could have distorted the experience of our participants. On the other hand, the multimodality and multisensoriality of Reflex interaction modes, eventually influenced participants' focus of attention and related performances. Third, we were not able to detach the Reflex added features over the Osmo solution in quantitative terms. We limited to elicit co-redesign requirements using Osmo and subsequently interviewed external examiners and took down their notes as future suggestions for phygital applications designers. In addition, Reflex features have been defined in collaboration with therapists to "give voice" to those participants who were not verbal. We are conscious that co-designing with participants could have led to improved outcomes.

6 CONCLUSION AND FUTURE WORKS

This work presented the definition, development and evaluation of Reflex, a novel phygital system for persons with NDD. Reflex has been carefully designed with specialists in the NDD field, taking inspiration from commercial systems [29], who provided us with a list of guidelines to be considered while designing and developing digital technologies for NDD people.

Results from this study show the potential of phygital approaches in enhancing motivation, lowering frustration and eventually improving performances when using an appreciated interaction mode and an adapted task. From the focus-group conducted with therapists, a clear need for innovative but accessible new tools emerged, to address NDD persons' needs in terms of learning skills. To this extent, given the exploratory nature of the study, we were not able to clearly detach Reflex activities and participants' personal abilities and to find a correlation between participants' performances and learning (which posits the basis of developing autonomy in their life). Combining low-cost multimodal applications and strong customization features, Reflex offered a unique way of learning beyond the screen that have only been initially explored but have already shown its potential. In addition, the combination of an inexpensive cross-device kit, and an "app" that anyone can download, gives to Reflex an enormous promise for large scale adoption, within therapeutic centers and beyond (e.g. families and schools). Additional benefits arise from Reflex customization features, which empower caregivers and give them a control at a degree which is not allowed by any other existing commercial tool. Our next steps are in various directions. We are planning wider and longer controlled empirical studies to provide more rigorous evidence of the therapeutic benefits of phygital approaches in terms of problem-solving skills and eventually learning. We are adding content management features to the customization tool and expanding the platform with new experiences (e.g. real elements). Finally, we are working on the integration of machine learning approaches that exploit the progressively increasing amount of data automatically gathered by RM both for diagnostic purposes and to support self-adaptation of the interactive space.

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