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An Affordance-Based Requirements Approach for Developing Therapeutic Artefacts - a Case Study of Speech and Language Toys

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Abstract. An effort to solve real-world problems through the creation of new or improved products, such as rehabilitation or therapeutic devices, requires a human-centred design approach. Lack of domain knowledge about the use context and accessibility to key experts or end users pose significant challenges to the designer during the task clarification stage in understanding the end-user requirements. This article presents a computer-based design support tool, ACQUAINT-SALTT, based on a prescriptive computer architecture that allows the generation of affordance-based requirements (ABRs) for an emerging family of products known as speech and language therapeutic toys (SALTTs). Considering affordances, the end-user requirements can be detailed as a relationship between the product and the user within a context while keeping the problem as abstract as possible without restricting creativity. A prototype therapeutic toy, *Olly Speaks*, was developed and evaluated through usability studies carried out with clinicians, caregivers, and pre-schoolers to assess its therapeutic impact both within and outside the clinic.

Keywords: affordances, requirements, therapeutic toys, speech and language therapy, user needs
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1 INTRODUCTION

1.1 Speech and Language Therapeutic Toys (SALTTs)

It is estimated that 7% of the entire population possesses a considerable deficit in language skills, which cannot be attributed to any causative health factor [18]. If left untreated, children may suffer repercussions in their educational, behavioral, emotional, and social development and can even persist into their adult lives. Speech-Language Pathologists (SLPs) work to prevent or alleviate developmental speech and language disorders in children as young as two to five years old, an age range in which intervention is most successful [27]. Play is crucial for language development, so toys are given great importance in therapy. SLPs working in early intervention deemed that speech-language therapy (SLT) services were much more needed in households where children lacked toys [24]. This explains why SLPs devote around 70% of their sessions with children in using adapted toys and other low-tech resources for their activities. Typical toys include educational flashcards, nesting cups, toy food and vehicles, and doll houses among others.

Since such toys are not explicitly designed for SLT, SLPs must use an extensive range of media to cater to the children's diverse needs, which becomes problematic when they need to carry out the therapy outside a clinical setting. On the other hand, caregivers lack the knowledge and the tools to carry over therapy at home. Toys specifically designed for SLT, which in this article are referred to as Speech and Language Therapeutic Toys (SALTTs), are commercially unavailable. One of the reasons for this is that designers' knowledge and experience in developing such niche products are limited, or they may find it difficult to transfer skills they use in other domains to this one [11].

1.2 Designer Challenges

In an effort to solve real-world problems through the creation of new or improved rehabilitation devices, a multidisciplinary team is required. However, the task of collating the requirements, as well as, designing and implementing the solution remains in the hands of the design engineers. The task clarification stage is characterized by complex information processing, decision making and uncertainties which often result in wrong assumptions, time delays or product failures [12]. The understanding of end-users needs is the basis of any design process and is fundamental for product success. For technical solutions to support the needs of niche areas, they must be considered with respect to the use context [28].

User-centered, participatory, and meta-design approaches call for a greater user involvement and collaborative design. However, in practice, designers have limited interactions with the end users. Findings discussed in [2] disclose how designers complain that the requirements are often vague or that the key experts are not readily available. Short time-to-market development cycles restrict designers on how deep they can investigate a problem, empathize with the end user, generate domain knowledge, and find a gap in the market. This leads to an incomplete understanding of the customers' needs and an incomplete list of the requirements. Although approaches such as those reported in [20] explain how to generate requirements in a systematic way, they are often not contextual enough to the end-users needs. As a result, without the relevant experience and domain knowledge, designers find the task clarification stage challenging.

1.3 Design Affordances

The theory of affordances looks at the relational opportunities that exist between living organisms and the environment they inhabit. As defined in [6] an affordance is the relational and beneficial action for a user offered by an artefact. Based on the pioneering work of Gibson and Norman, Maier and Fadel [20] introduced the notion of affordance-based design to cater for limitations introduced by design theories which do not support products that have non-functional requirements, that is, requirements that are not necessary for the artefact to be used but important for a high-quality experience for the end user. The affordances of any artefact depend on what the designers create and make possible. However, an artefact may provide affordances which the designers do not wish for, have not anticipated, or would like to avoid. Krippendorff [16] discusses affordances as a meaningful way to perceive the use of artefacts. Therefore, affordances need to be properly understood and worked out in a collaboration between designers, users, and the artefact.

Maier and Fadel [20] argue that affordances can be used to explain customer needs. For needs to be translated into affordances, one must consider the dispositions of affordances with respect to the goal that the user intends to achieve with the product. As shown in Figure 1, users perceive the artefact's affordances which in turn are influenced by the environment or context in which the user interacts with the artefact. This extends the sense, meaning and action model of Krippendorff [16] whilst adopting the intentional stance of Crilly [8]. A goal may only be realized if the user has the intention, the artefact enables it, and the context allows it. For example, a radio may afford users the ability to listen to music in a quiet room but not when there is a loud background noise.

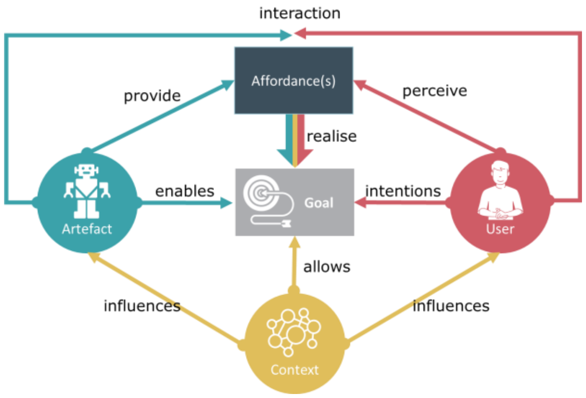

Figure 1: Disposition of affordances.

1.4 Paper Structure

Computer-based support systems can provide active support to cater for the challenges experienced during the design process. Duffy and O'Donnell's methodology [10] was used to understand the current reality of the designer and to develop a software tool that supports the generation of affordance-based requirements (ABRs) for SALTT artefacts. In Section 2, an overview of the existing work on requirements elicitation is provided. The proposed computer-based support tool is described in Section 3, whereas Section 4 discusses a prototype SALTT and the user tests that were carried out. Conclusions and future work recommendations are drawn in Section 5.

2 RELATED WORK

Work on requirements elicitation has long been carried out due to its importance in the subsequent design activities. Requirements elicitation is the process of capturing, extracting, and obtaining needs from relevant stakeholders. Within this context, a critical literature review was conducted to identify the gap in existing research supporting the requirements elicitation activity. Using the guidelines for a systematic review discussed in [15], relevant studies were established through a systematic scoping process. The question that this literature review focused on was: how are designers being supported in the task clarification stage to generate and understand the end-users requirements? As a research boundary, this literature review did not include requirements elicitation for software solutions. CADIMA [17], a systematic review tool that supports the exclusion of studies that do not match the inclusion criteria was used. Relevant literature was classified based on the support provided towards requirements elicitation as outlined in the following sub-section.

2.1 Requirements Elicitation Approaches

Methodology-based approaches use established design methodologies to structure and control requirements elicitation. In [4], a framework that uses four design methodologies - Inclusive, Emotional, Robust, and Participatory Design - is proposed to leverage human-centered and product-centric design principles for wearable healthcare products. In [22], the Quality Function Deployment is used iteratively to find the ideal suppliers for the users' needs. Moreover, generic checklists such as those reported in [23] do not provide insight into the design problem.

On the other hand, key characteristic approaches focus specifically on a field or problem by providing guidelines or critical aspects about the needed solution. In [11], five design lenses for therapeutic lenses are recommended. These feature distinctive clinicians' needs in toy-mediated therapy. Research in such novel fields provides designers with the groundwork to establish a design direction and ensure that subtle functional and non-functional requirements captured from rigorous field observations are reflected. However, such guidelines can be broad and interpreted differently.

Several state-of-the-art support tools make use of ontologies. An ontology is the formal representation of the concepts and the categories related to a domain that can characterize and classify expert knowledge [30]. It can be seen as a taxonomy of classes with various hierarchies and related properties, providing a structure to formalize and construct reusable domain knowledge into models. In [13], five ontologies are used to implement a design support tool that considers stakeholders' requirements, end-users ergonomics, design and design process data, and relevant documentation. The benefit of ontologies is that they can capture different requirements, users, and domains in a descriptive way. However, due to their complexities, considerable time and effort need to be invested in creating an accurate representation of the artefact and its requirements.

Nowadays, research is focusing on the automatic extraction of information from written or transcribed texts. Progress in this domain has focused on improving the efficiency, quality and reliability of requirements extraction from large data sources by training computers to identify requirements based on the rules that govern the natural language. In [19], the users' needs are extracted from customer reviews, whereas in [14], a dynamic requirements elicitation framework was proposed such that data is continuously mined at a fixed time interval, whilst updating a dictionary containing domain knowledge. The limitation of such an approach is that the market needs to be well established for data to be easily accessible.

Modelling approaches are helpful in transforming abstract models of complex systems into more concrete models without losing information, where various graphical models are comprehensible to designers and computers. In [5], a framework based on SysML diagrams was used to support the requirements elicitation, analysis through systematic decomposition, and validation activities.

2.2 Findings from Existing Solutions

This analysis led to the conclusion that, currently, there is a gap in the literature to support the generation of requirements for SALTT artefacts. Generic design support tools or frameworks lack the knowledge required to handle the SALTT artefacts' distinctive requirements. Moreover, the reviewed literature does not discuss how the needs of multiple end-user groups of the same artefact differ. SALTT artefacts need to satisfy multiple interrelated use-phase requirements composed of goals, behaviors, context, and actions, which can be difficult to be expressed as technical specifications. Furthermore, general human-centered design methods such as co-design and participatory design are all relevant in the discovery of requirements but due to the challenges highlighted in [2], designers interaction with end users is limited in industry.

In order to interpret such customer needs, designers are required to take a human-centred design approach. Thus, semantics are essential during task clarification stage because the natural language is used to communicate the requirements and constraints to the designers. Since data-driven methods rely on a posteriori knowledge (such as dictionaries or ontologies) to infer results, data-mining techniques are less viable in emerging markets. Furthermore, the extraction of requirements tends to separate the needs from the context in which they are said and are prone to misinterpretation. On the other hand, use contexts are better explained in model-based approaches because requirements beyond the main functionality can be seen in scenarios. An affordance-based approach communicates needs beyond the function required from the artefact. The work presented in [6] shows that affordances are appropriate to help identify a more extensive set of requirements when considering the context and how the artefact will be used by various users rather than how the product can be useful to the user.

Descriptive approaches such as checklists and ontology-based methods focus on providing knowledge support to the actual needs of the users. Prescriptive research, such as methodologies and model-driven methods, defines new ways to execute or support the early design tasks. Cotran [7] stated that "requirements for engineering systems cannot be created by a single approach" due to the complexity of requirements and domain specificity. In [9] a prescriptive and descriptive approach was taken to provide holistic support. This suggests that designers must follow procedures and use appropriate knowledge to ensure that requirements are entirely drawn and understood.

3 AFFORDANCE-BASED REQUIREMENTS GENERATION ARCHITECTURE

As detailed in [2], design support tools that assist in the understanding of user needs and requirements generation phases are perceived as beneficial as long as they do not affect their creative design process. Based on their study with 14 international toy designers, which identified the designers' challenges during the design process, they proposed the prescriptive architecture shown in Figure 2 for the development of a computer-based tool. This architecture urges the designer to be close to all the users within the artefact's lifecycle and adopt design affordances at the task clarification design stage. Table 1 explains each layer of the architecture and in Section 3.1, the 9 steps in which the customer needs are elicited, refined, extended, and mapped into affordance-based requirements (ABRs) are detailed.

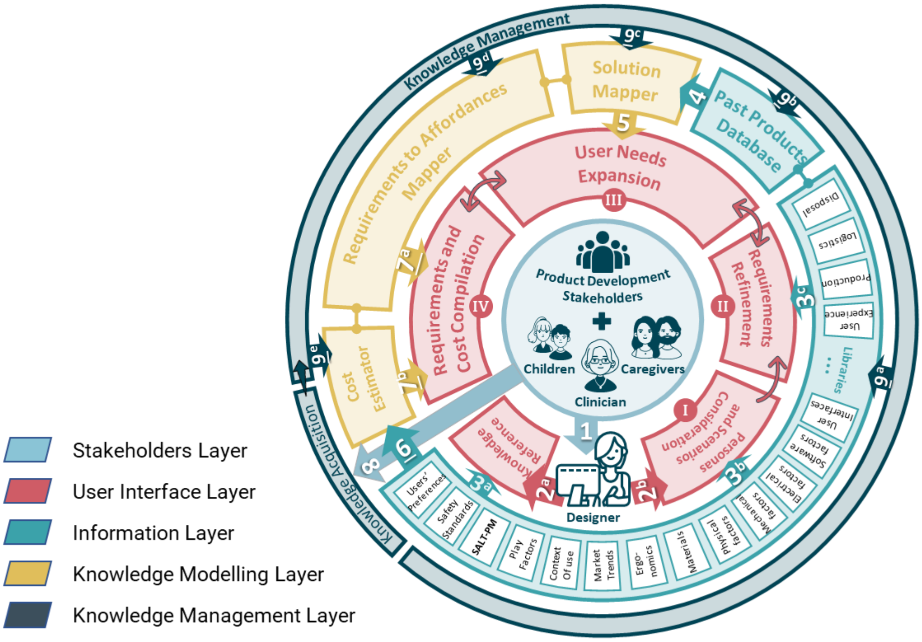

Figure 2: A prescriptive framework architecture for requirements elicitation.

Layer	Description
Stakeholders Layer	Identifies every user the artefact will encounter during its lifecycle.
User Interface Layer	Allows the designer to input, elicit, refine and expand users' needs.
Information Layer	Contains information libraries about the product development which the designer / tool can access to support the requirements generation process.
Knowledge Modelling Layer	Infers the selected user needs to expand them, translates user needs into affordance-based requirements, and estimates product cost.
Knowledge Management Layer	Maintains the Knowledge Modelling Layer and Information Layer up-to-date, as necessary.

Table 1: The layers of the framework architecture.

3.1 The Process of Generating Affordance-Based Requirements

The following sub-sections explain the steps of the framework shown in Figure 2 through the designer's interaction with a computer-support tool for the generation of requirements.

Identifying the initial user needs

Step 1	The stakeholders' needs, including those of the end-users, are (directly or indirectly) passed to the designer in the form of a design brief or established as the designer observes the respective users.

Accessing information within the computer-based support tool

Steps 2^a and 3^a	At any stage of the design process, the designer can use the tool to access the domain and process knowledge located within the different information libraries of the tool.

Eliciting user needs based on personas and scenarios

Step 2^b	The designer can use the tool to input/generate (stage I), refine (stage II), expand (stage III) users' needs and translate them into affordance-based requirements (stage IV).
Step 3^b	In Step 2^b - stage I, the designer refers to personas and scenarios to elicit the essential user needs. The tool loads a precompiled list of user needs based on the selected persona(s) and/or scenario(s) located in the Information Layer. Personas or scenarios must be constructed from the correct and well-researched representations of the user and situations. The attributes related to a particular persona can be linked to the domain problem requirements to generate basic end-users needs quickly.

Refining user needs

Step 3^c	In Step 2^b - stage II, the designer refers to knowledge libraries to refine the user needs. The tool loads checklists from the libraries, within the Information Layer, for each user of the product during its lifecycle. This stage aims to make the designer understand the domain problem by going through every customer need. For the application being considered in this study, that is, SALTT artefacts, SALTT use-phase requirements were made available as checklists. As discussed in Section 3.3.1, these were captured by the Speech and Language Therapy Potential Model (SALT-PM).

Expanding user needs

Steps 4 & 5	In Step 2^b - stage III, the designer compares the user needs with similar existing products, if any, to expand the offerings of the required product. The tool uses the user needs specified by the designer in stage II to find similar existing solutions residing in the Past Product Database, and outputs the existing solutions together with their marketed offerings to the designer to highlight further or unforeseen user needs. In case no existing solutions are found, a market gap will be communicated to the user.

Mapping user needs into affordance-based requirements and cost compilation

Steps 6 & 7	In Step 2^b - stage IV, the designer converts the user needs into affordance-based requirements and gets an estimation of the product's cost. The tool maps the inputted user needs into affordance-based requirements by accessing the information residing in the Information Layer and knowledge within the Knowledge Modelling Layer (KML). The formalism explained in Section 3.2 is used to maps user needs into ABRs. If the KML contains suitable cost models, each user need can be assigned a relevant cost factor.

3.2 Formalizing ABR Statements

In contrast to functions which express the user needs from the designer's perspective, affordances allow designers to understand the same needs from a user's perspective, thus revealing unpredicted usages while keeping requirements solution independent.

Cormier et al.'s [6] affordance statement formalization was adapted to translate the customer needs. However, based on the disposition of affordances (Section 1.3) and the work reported in [21], this was modified to refer also to the use context. All ABRs should be proposed in terms of their context. The same can be said for atypical user characteristics because designers may take user capabilities for granted and fail to facilitate the affordance. However, the context becomes relevant when the disposition of an affordance is affected by the context. Note that during the task clarification stage, requirements are solution independent, which implies that ABRs are considered at the artefact level, that is, the artefact represented as a black box rather than as a collection of sub-components.

According to [29], requirements should be expressed as positive statements. Consequently, ABRs are expressed according to the relational benefit they will provide to the users or other artefacts within the environment, even though an affordance can have a positive or a negative consequence [21]. The following statement describes the formalism used:

The principle artefact affords a [user(s)] [with user characteristic (optional)] the [affordance] [+ adjunct (optional)] of [target object or environmental entity] [+ additional information (optional)].

The adjunct or affordance modifier consists of conditional, locative, temporal, frequency, adverbial or a measure belonging to the requirements. Examples of ABRs for SALTTs are listed in Table 2.

Principle Artefact	***User (s)***	***User characteristic***	***Affordance***	***Affordance modifier***	***Target object/entity***	***Other information***
The product affords	children	with mild hearing impairment	accessibility		to the product	
The product affords	children	aged less than 36 months	the ability to play	safely	with the product	at home.
The product affords	clinicians, caregivers, and children		improved hearing capabilities		of the product	in noisy environments.

Table 2: Examples of ABRs for SALTTs.

3.3 ACQUAINT-SALTT - A Prototype Implementation of the Architecture

The architecture explained in Section 3.1 was implemented as a standalone computer-based implementation using Duffy and O'Donnell's computer-based tool development framework [10]. The application was called ACQUAINT-SALTT, which stands for **A**ffordan**c**e-based Re**qu**irements Gener**ati**o**n** **T**ool for **S**peech **a**nd **L**anguage **T**herapeutic **T**oys.

3.3.1 The Speech and Language Therapy Potential Model (SALT-PM)

In order to support the requirements elicitation of SALTT artefacts, an ontology about the end-users needs was developed as one of the information libraries within the Information Layer. A total of 123 user needs were collected from SLPs, parents and children via a thematic analysis on data collected from focus groups, workshops, and semi-structured interviews, together with other findings from the literature. These were grouped into twelve elements of the Speech and Language Therapy Potential Model (SALT-PM) shown in Figure 3.

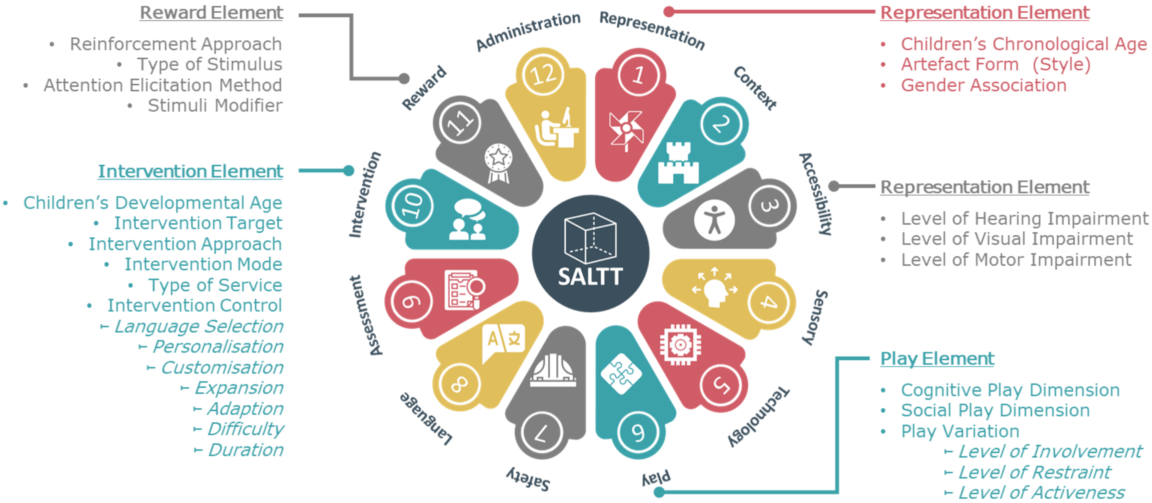

Figure 3: A partial representation of the Speech and Language Therapy Potential Model.

A SALTT product is suitable for therapy when the designed features meet the needs of the clinicians, caregivers, and children. Thus, the SALT-PM suggests that the potential of the SALTT artefact is determined by the number of end-users requirements (sub-elements) realized during the design process. A mainstream toy may be adapted to be used during speech therapy. However, its potential would be lower than a SALTT designed explicitly for SLT. Furthermore, the potential of a SALTT artefact towards different users may vary. For instance, the potential of a SALTT artefact for a child with acute Developmental Language Disorder (DLD) may be higher than that of a child with mild DLD.

3.3.2 Existing products database

Apart from the SALT-PM, a database of play media, such as educational resources, toys that promote speech, and tablet applications, was placed in the Information Layer so that the Knowledge Modelling Layer could infer additional user needs, as explained in Section 3.1. Their marketing description was extracted from a single e-commerce website, where the advertised usage modes made it possible to translate the text into ABR formal statements, as discussed in Section 3.2.

3.3.3 Supporting designers understand the requirements for SALTT

In ACQUAINT-SALTT, the designer is guided to generate SALTT requirements by exploring the user's needs. As seen in area A of Figure 4, the 12 elements of the SALT-PM are represented as tab views within the computer tool, allowing the designer to consider each element freely and in their preferred order. Area B shows the sub-elements of the active element, whereas area C displays relevant products that match the criteria in area B. When choosing a relevant past product, a list of ABRs generated from the marketing description is presented in Area D. The tool allows the designer to view the ABRs generated in real time. In the end, the final list of requirements can be printed or shared digitally. The evaluation of this tool is documented in [1].

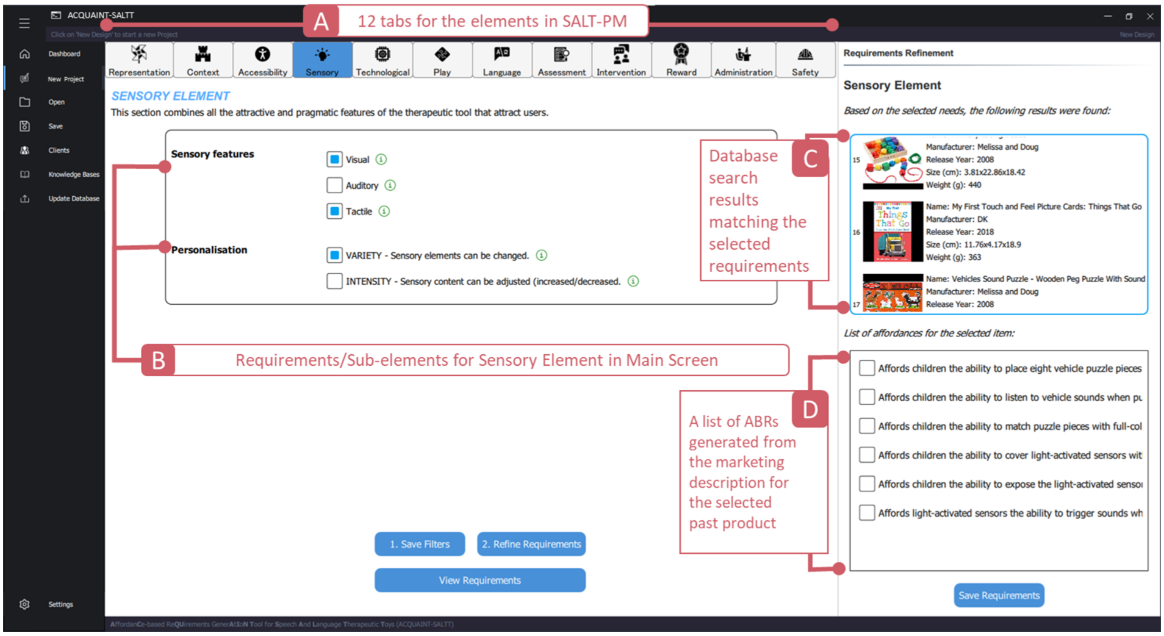

Figure 4: Requirements elicitation for SALTT artefacts using ACQUAINT-SALTT computer tool.

4 *OLLY SPEAKS* – A PROTOTYPE SALTT ARTEFACT

A prototype SALTT artefact called *Olly Speaks* was designed and developed after analyzing the generated high-level ABRs from ACQUAINT-SALTT. In turn, these ABRs were analyzed and transformed into lower-level, operational affordances in order to design the intended usage of *Olly Speaks* with the prospective end-users. An actual photo of *Olly Speaks* is shown in Figure 5, together with an overview of its specifications. Children's product preferences that emerged from [3] were used to enhance the overall design. The design team also consulted with qualified SLPs, especially when developing rewards mechanisms and the assessment and intervention games. Designers should keep in mind that SLPs require flexibility and control over intervention activities to cater for a broad spectrum of children's needs.

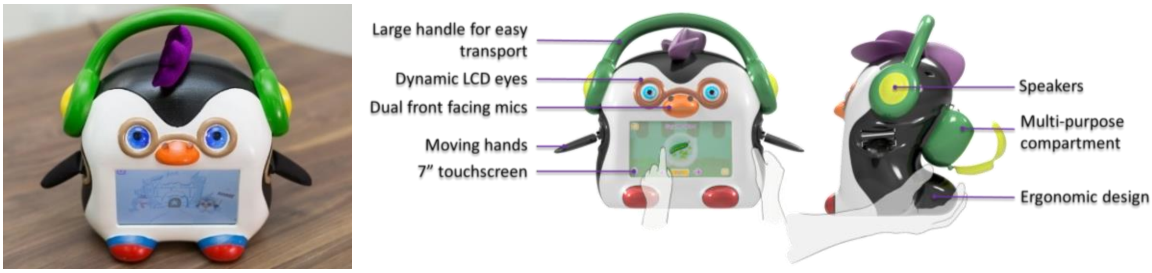

Figure 5: *Olly Speaks* and its design features.

4.1 *Features of Olly Speaks*

In terms of specifications, *Olly Speaks* measures 360x235x270mm and weighs 1.4 kg. It features a 7" TFT LCD touch screen, two 1.8" colour TFT screens as eyes, two motor actuators for the movement of the wings, a main computer board, two 2W speakers residing in the headphones, a soundcard, a solenoid-based locking mechanism in the backpack, a dual microphone located in the beak area, a Wi-Fi module, and a rechargeable battery. The backpack of *Olly Speaks* was intentionally designed to create anticipation in children so that the SLP can store rewards. The current version of *Olly Speaks* was built from Poly Lactic Acid (PLA) using Fused Deposition Modelling (FDM) 3D printers.

Olly Speaks runs on an Android operating system, and a dedicated application was developed by a gaming company. The app consists of several sub-applications, which include two lexical (receptive and expressive) assessments, four speech games (Phonemes, Articulation, Syllables and Clapping) and four intervention games that support the development of language skills (Categorization, Picture Association, Odd One Out and Treasure Hunt). The assessments and the intervention games can be carried out in either Maltese or English, given that varying degrees of bilingualism in both languages is the norm.

A positive reinforcement approach was adopted in the intervention games, where a 'sparkle sound' and stars would appear around the correct input. On an incorrect response, the picture would shake. Once a whole intervention activity is completed, a pre-recorded compliment is played, *Olly Speaks*' wings flap and the eyes change visuals, to motivate children. Moreover, the backpack can be opened to give children physical rewards.

4.2 Evaluation Study

The potential of using *Olly Speaks* as a clinical tool for SLT in Malta was investigated through a three-component evaluation. In the first study, 153 three to five-year-old bilingual and typically developing Maltese children took part in a usability study. This study provided a performance baseline for bilingual Maltese children in terms of effectiveness and efficiency. With respect to satisfaction, the children's user experience that results from the use or anticipated use of *Olly Speaks* was measured both on the assessment and intervention features, and the overall design of *Olly Speaks* by using the non-verbal Smileyometer technique [26]. Results showed that children preferred the intervention activities over the assessment activities as they were more challenging. Regarding the overall design of *Olly Speaks*, all children except for one were satisfied with *Olly Speaks*. Fifty-three children liked the backpack feature most because the SLP was hiding rewards inside it. This was followed by the headphones (n = 24), screen/games (n = 23), squishy hair (n = 18), flapping wings (n = 16), animated eyes (n = 14), and beak (n = 6). Moreover, the children's happiness level was measured during four study instances: before using *Olly Speaks*, after the first assessment, after the intervention games, and after the second assessment. It was found that children's morale improved at each stage, especially after the first assessment.

In the second study, three bilingual Maltese children, aged between 5 and 6 years with a DLD, participated in a six-week intervention programme where intervention was facilitated using conventional methods and *Olly Speaks*. This study showed that *Olly Speaks* was an effective, efficient, and motivating tool for the SLT, as children were more engaged, cooperated and performed in a better way. This was also reflected in superior sitting tolerance when therapy was carried out with *Olly Speaks* in contrast to conventional therapy. However, further studies are required to evaluate whether SALTT products provide a more reinforcing modality for therapy.

In the third study, the potential of *Olly Speaks* as an effective and efficient therapeutic toy was evaluated with seven SLPs and three parents of children with DLD from a clinical perspective. SLPs acclaimed the benefits of the separate *SLP/Parent app*, the ability to maintain children engaged and motivated towards the therapy, and support carryover of therapy outside the clinic.

5 CONCLUSIONS AND FUTURE WORK

The contribution of this article lies in the novel framework architecture organised around the requirements elicitation process for computer tools that aim to incorporate affordance-based requirements and explore possible additional requirements from other products. ABRs provide detailed and organised requirements compared to informal user needs, while also communicating how the end-user is going to interact with it given its capabilities. Depending on the level of support provided, tools such as ACQUAINT-SALTT can unite multidisciplinary information to address knowledge gaps that the designers have in unfamiliar domains and allow the creation of socio-technical artefacts. Such tools allow designers to understand the different aspects that need to be considered about the principle artefact, the context in which it will be used, the features required by the different end users, and how each user relates towards the product. Moreover, the development and user testing of *Olly Speaks* enabled the verification of the SALT-PM. As future work, efforts in improving the functionality of ACQUAINT-SALTT will be made while also investigate the possible integration of other play-mediated therapy domains and the integration with existing CAD applications. Research on *Olly Speaks* with new case studies will continue to assess its applicability to end-users with different needs.

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