Pufff: a touch-sensitive interactive toy for purposeful hand use in children with Rett Syndrome

Eleuda Nunez
Institute of Systems and Information Engineering
University of Tsukuba
Tsukuba, Japan
eleuda@ai.iit.tsukuba.ac.jp

Giampiero Bartolomei
Institute of Cognitive Sciences and Technologies, National Research Council (ISTC-CNR)
Rome, Italy
giampiero.bartolomei@istc.cnr.it

Martina Semino
AIRETT Research and Innovation Centre
Verona, Italy
martina.semino@airett.it

Michela Perina
AIRETT Research and Innovation Centre
Verona, Italy
michela.perina@airett.it

Taku Hachisu
Institute of Systems and Information Engineering
University of Tsukuba
Tsukuba, Japan
hachisu@iit.tsukuba.ac.jp

Gianluca Baldassarre
Institute of Cognitive Sciences and Technologies, National Research Council
Rome, Italy
gianluca.baldassarre@istc.cnr.it

Valerio Sperati*
Institute of Cognitive Sciences and Technologies, National Research Council (ISTC-CNR)
Rome, Italy
valerio.sperati@istc.cnr.it

Beste Ozcan*
Institute of Cognitive Sciences and Technologies, National Research Council (ISTC-CNR)
Rome, Italy
beste.ozcan@istc.cnr.it

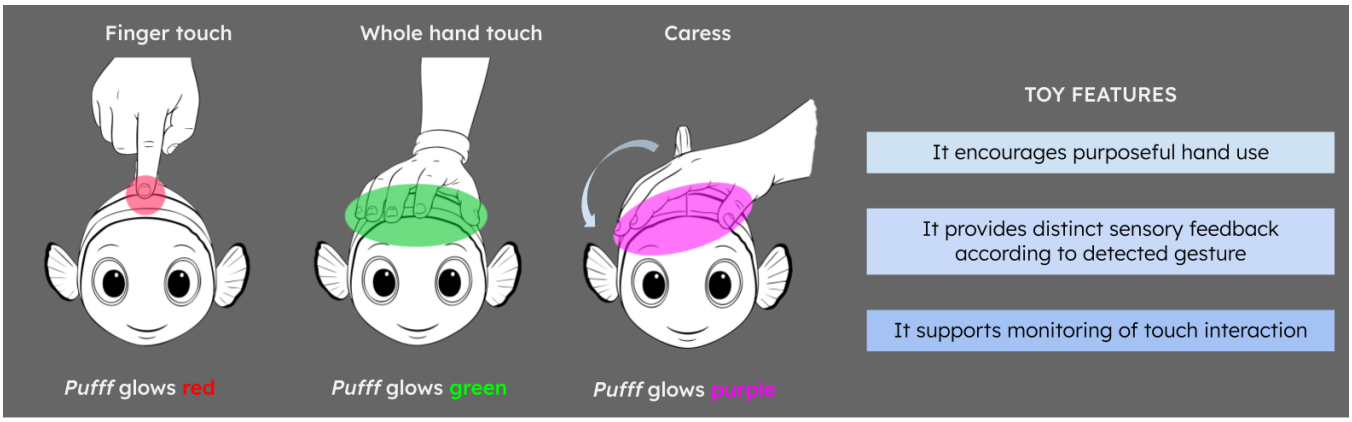


Figure 1: *Pufff* design concept. The toy is designed to distinguish between three target touch interactions, namely finger touch, whole-hand touch, and caress, and to provide distinct sensory feedback accordingly, with the aim of supporting playful hand use and basic monitoring of touch interaction in children with Rett Syndrome.

Abstract

Rett Syndrome is a rare neurodevelopmental disorder associated with severe intellectual and motor impairments. Among its core symptoms, children with Rett progressively lose purposeful hand use, limiting their ability to reach for, touch, and manipulate objects in the surrounding environment. Early intervention is therefore important to help maintain opportunities for functional hand use through repeated and motivating activities. To support this goal, we developed *Pufff*, a touch-sensitive interactive toy that provides visual feedback during touch-based interaction. Using signals acquired from a six-patch capacitive sensing array and a lightweight machine learning model, the system distinguishes three types of touch and triggers different responses accordingly. This interaction paradigm is intended to support future therapist-led activities

*Both authors contributed equally to this research.

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aimed at encouraging purposeful hand use through play, while also enabling basic monitoring of touch interaction patterns. This paper presents an early implementation of the toy and demonstrates the technical feasibility of the approach.

CCS Concepts

• **Human-centered computing → Human computer interaction (HCI)**; **Empirical studies in HCI**.

Keywords

Rett Syndrome, neurodevelopmental disorders, interactive toy, touch gesture recognition, machine learning.

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1 Introduction

Rett Syndrome (RTT) is a rare neurodevelopmental disorder associated with severe intellectual, motor, and communication impairments [12]. After an initial period of apparently typical development, children with RTT often undergo regression, which may include the loss of purposeful hand use, i.e., the ability to intentionally reach for, touch, and manipulate objects [9]. Because hand use plays a central role in interaction with the physical and social environment, its loss has a major impact on everyday activity and participation. RTT affects almost exclusively females and has an estimated incidence of approximately one in 10,000 live births worldwide [6].

A practical challenge in RTT intervention is how to support repeated and motivating opportunities for functional hand interaction despite limited motor control. Early behavioural intervention can help maintain motor, social, and cognitive abilities over time [8, 11], yet available tools are still largely compensatory rather than designed to actively encourage hand use itself [10]. Although some exploratory work has investigated digital technologies for RTT [1, 3, 7, 14, 16, 19], few systems specifically explore touch-based interaction as a therapist-led target. This makes simple and engaging interactive tools a relevant direction to explore.

In this context, we propose *Pufff* (Fig. 1), a low-cost touch-sensitive toy designed to support playful touch-based interaction in RTT-oriented intervention. The concept is to encourage simple forms of purposeful contact through responsive sensory feedback while also enabling basic monitoring of how the toy is touched. The current prototype focuses on three interaction types selected as relevant for therapist-led play, namely finger touch, whole-hand touch, and caress.

The contribution of this WiP is not a clinical evaluation of therapeutic effectiveness, but an early technical feasibility study of this interaction concept. In particular, we ask whether a compact capacitive sensing layout embedded in a soft toy can reliably distinguish between the three target touch interactions in real time. Through this, the paper contributes (1) the design rationale and implementation of *Pufff* as an RTT-oriented interactive toy concept, and (2) an initial evaluation of the sensing and gesture recognition pipeline as a step toward future studies with children with RTT.

The rest of the paper is organised as follows: Sec. 2 describes the toy design and implementation, including the system for gesture recognition; Sec. 3 presents the performance of the system; finally, Sec. 4 outlines the next steps planned to finalise the prototype and evaluate it with participants with RTT.

2 Material and Methods

2.1 *Pufff* rationale, design considerations and implementation

In the context of RTT, prior work on intervention and assistive technologies suggests that interactive systems should ideally tolerate motor variability, provide clear action–effect mapping, offer motivating sensory feedback, and support therapist- or caregiver-mediated interaction. The concept underlying *Pufff*, the fish-like plush toy developed in this work (Fig. 1), was shaped through discussions with therapists experienced in RTT treatment[1]. These exchanges helped define the main design priorities for the prototype, namely low-effort interaction, clear action–effect feedback, and suitability for therapist-led activities. Alternative interaction schemes involving more complex sequences, stronger force requirements, or precise timing were not pursued at this stage, as the goal of the prototype was to explore simple and easily elicitable forms of contact that could be integrated into therapeutic play.

After an initial briefing, the team agreed on three target touch behaviors: finger touch, whole-hand touch, and caress. These behaviors were selected as a pragmatic set of simple interactions that could be demonstrated and elicited during therapist-led play, while spanning different forms of intentional contact with the toy. In particular, finger touch represents localized contact, whole-hand touch represents broader surface contact, and caress represents dynamic exploratory contact across the sensing area. Although these behaviors do not exhaust the range of purposeful hand use, they provide a practical starting point for capturing different forms of intentional contact with the toy, ranging from localized touch to broader and more exploratory hand interaction [4, 18]. These considerations informed both the physical and technical design of the prototype. Since children with RTT are often characterized by weak, imprecise, or inconsistent arm and hand movements, we chose to embed capacitive sensors on the surface of *Pufff* to detect even light contact without requiring forceful input. Compared with force- or pressure-based sensing, capacitive sensing is more suitable in this context because it can respond to gentler and less stable contact, and can also function as a proximity-based input. This makes the interaction more tolerant to limited motor control.

To enable recognition of the selected touch behaviors, we implemented a compact sensing area composed of six conductive patches (approximately 6 × 2 cm each), arranged in two parallel rows and sewn onto the spine of *Pufff* (Fig. 2). This patch layout was designed to capture simple spatial differences in touch distribution while remaining compact, interpretable, and low-cost. To

[1]Personnel from *Airett Research and Innovation Centre.*

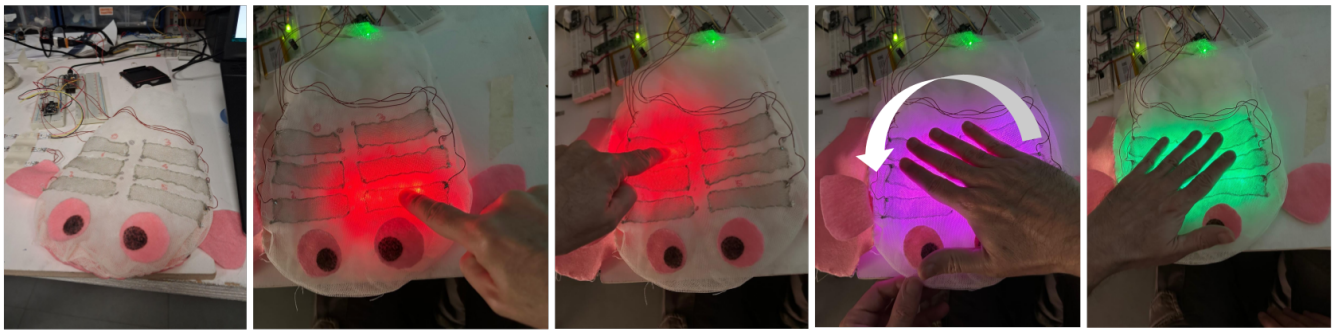


Figure 2: *Pufff* early prototype; on the left, the six conductive fabric patches connected to the MPR121 capacitive sensing board; in the centre and on the right, examples of the visual feedback produced according to the detected gesture.

reinforce the action–effect relationship and maintain engagement, the toy provides immediate visual feedback through embedded RGB LEDs beneath the sensing surface. *Pufff* was also designed as a soft stuffed toy to make interaction more approachable and pleasant [15, 17, 21]. From a technical point of view, the internal electronics were implemented using an *ESP32* board connected to an *MPR121* capacitive sensing module and an addressable RGB LED strip for visual feedback. The *MPR121* was connected to the six conductive fabric patches[2]. To generate the visual output, segments of three LEDs were placed beneath each patch. The transparency of the conductive fabric and the cotton padding allows the light to diffuse, creating a soft, pleasant visual effect (Fig. 2).

2.2 Gesture Recognition System

To assess whether the proposed sensing layout could support meaningful differentiation of touch interactions, we conducted a controlled feasibility evaluation of the recognition pipeline. The goal was not to assess therapeutic effectiveness, but to determine whether the prototype could reliably distinguish the three target interaction types using a lightweight embedded implementation. A Machine Learning (ML) approach was adopted to improve robustness beyond simple thresholding [5, 13].

2.2.1 Data Acquisition Protocol. In this feasibility test, interaction data (i.e., activations of the six conductive patches) were collected from six adult participants with Typical Development (TD) recruited from the same laboratory that developed the toy. Although *Pufff* is conceived for children with Rett Syndrome, this initial evaluation focuses on establishing the technical feasibility of the sensing and classification pipeline, forming the basis for subsequent studies with the target population. Each participant completed one recording session, resulting in six sessions in total. Participants performed three target gestures: *finger touch*, *whole-hand touch*, and *caress*. To reduce variability, the gestures were verbally described before recording: *finger touch* was defined as touching one sensing patch with one fingertip, *whole-hand touch* as placing the hand statically over the sensing area, and *caress* as a continuous sliding motion across the surface.

Whole-hand touch and *caress* were each performed 20 times, with both gestures involving contact over approximately the full sensing surface. For *finger touch*, they were asked to touch each patch individually four times, for a total of 64 gesture segments (trials) per participant. Data were collected at a sampling rate of 20 Hz[3]. Participants were instructed via a display and asked to perform the target gestures in a randomised sequence. Each trial followed a fixed temporal structure consisting of: (1) a preparation phase, during which the toy was not touched (2.0 s, *steady*); (2) a gesture execution phase (3.0 s for *finger touch* and *whole-hand touch*, and 4.0 s for *caress*); and (3) a release phase (3.0 s, *steady*). Labels were assigned automatically from the scripted trial sequence during acquisition. In particular, each sample was labelled according to the currently instructed trial phase, resulting in one non-contact label (`steady`) and three contact categories: `touch_finger_patchX`, `touch_hand_full`, and `caress_full`, where `patchX` indicates the active patch index for finger-touch trials. No visual feedback was provided by *Pufff* during the data collection phase.

2.2.2 Signal Processing and Feature Representation. The continuous signals were first segmented into contiguous runs with a consistent ground-truth label, and segments shorter than 0.8 s were discarded to remove transient contacts. Each segment was then divided into overlapping analysis windows of 1.0 s (20 samples) with 50% overlap. Each window was summarised into a single 18-dimensional feature vector for classification. The feature vector was designed for embedded deployment and captured both activation magnitude and spatial distribution across the six sensing patches. It included the mean absolute activation and signal energy of each patch (12 features total), four aggregate features describing overall and lateral activation magnitude (total activation, left-column activation, right-column activation, and their difference), and two features summarising the center of activity and its temporal variation over the window. All features were z-score normalized using statistics computed on the training data within each cross-validation fold.

2.2.3 Hierarchical Classification and Localization. Gesture recognition was formulated as a hierarchical problem to match real-time deployment. A first-stage classifier discriminated between *steady*

[2]Knitted Superlight Conductive Fabric by INNTEX.

[3]*Pufff* loop was updated every 50 ms

and *contact* windows, and a second-stage classifier predicted contact type (*finger touch*, *whole-hand touch*, or *caress*) using only contact windows. Both stages used linear logistic regression with L2 regularization, chosen because it is computationally lightweight, interpretable, and suitable for embedded real-time inference. Finger localization was computed deterministically rather than learned. For windows classified as *finger touch*, the active patch was estimated as the index of the maximum absolute mean activation across patches. This reduced computational cost while preserving interpretability and aligned with the localized nature of finger interaction.

2.2.4 Evaluation Protocol. We evaluated generalisation using leave-one-session-out (LOSO) cross-validation, where each participant session was held out once for testing while the remaining five sessions were used for training. Performance was assessed mainly through type accuracy on contact-only windows and aggregated confusion matrices. A simple rule-based baseline was also implemented for comparison. This baseline classified interaction type using threshold rules based on overall signal magnitude and spatial spread across the sensing patches, without using learned temporal or multivariate decision boundaries.

2.2.5 Embedded Integration. The trained models were exported and deployed on the ESP32 board embedded in *Pufff*. The system implemented the full real-time inference pipeline, including rolling signal buffering, feature extraction, gesture classification, and deterministic patch localization. During early deployment, the output was sometimes unstable around gesture transitions, producing flickering feedback and occasional spurious activations. To improve interaction quality, we applied a short rolling majority vote together with simple onset and release heuristics. These modifications improved the stability of the toy's visual feedback and supported more interpretable real-time interaction. A short demo of the early prototype is available at the following link: https://im-twin.eu/video/#pufff

3 Results

Figure 3 (A) shows the mean spatial response patterns across the six sensing patches for the target interactions, including finger touch on each patch, whole-hand touch, and caress. For visualization, each map was independently normalized to the [0,1] range. Finger touch produced localized activation concentrated on a single patch, whereas whole-hand touch and caress generated broader responses across the sensing surface. This suggests that even a small number of conductive patches can encode useful information for distinguishing touch behaviors. The confusion matrix in Fig. 3 (B) shows that the learned classifier achieved generally high recognition performance, with the main ambiguity occurring between whole-hand touch and caress. In contrast, finger touch was detected more reliably and supported accurate patch localization. This suggests that interaction types with similar contact extent remain more difficult to separate than localized finger touch, and that richer temporal information may be useful for improving discrimination between static and dynamic touch in future iterations. For comparison, a simple threshold-based baseline, implemented using hand-defined rules on overall activation magnitude and spatial spread, achieved

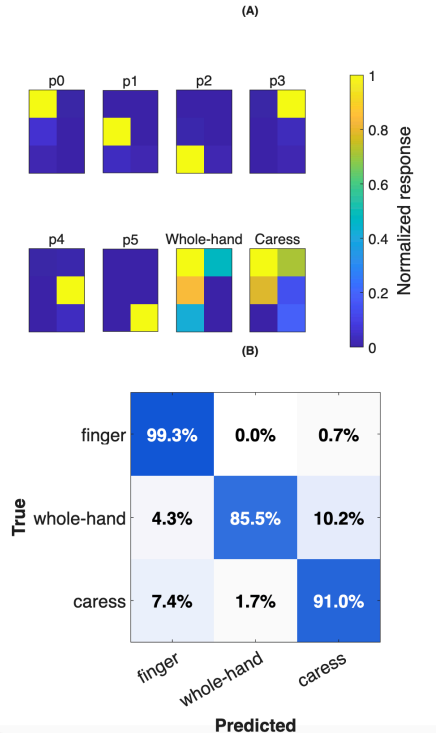


Figure 3: Gesture recognition results with *Pufff*. (a) Mean spatial response patterns across the six sensing patches for the target gestures, including finger touch on each patch, whole-hand touch, and caress. For visualization, each map was independently normalized to the [0,1] range. (b) Row-normalized confusion matrix under leave-one-session-out cross-validation.

46.7% accuracy, whereas the learned model reached approximately 92% accuracy under cross-session evaluation. This indicates that global activation alone was insufficient to separate gestures reliably, supporting the use of lightweight data-driven inference.

4 Discussion and Future Work

In this WiP we presented *Pufff*, an early prototype of an interactive toy designed to encourage purposeful hand use in children with RTT. The concept was developed in consultation with therapists experienced in RTT intervention and shaped around three design priorities: low-effort touch interaction, clear action–effect feedback, and suitability for therapist-led activities [2]. These considerations informed the choice of a soft toy form, a capacitive sensing surface, and a small set of simple target gestures.

The current prototype addresses the challenge outlined in the introduction by supporting purposeful hand use through touch-based interaction, while also providing motivating sensory feedback and enabling basic monitoring of interaction. Our results highlight two design considerations: first, the spatial distribution of activation across the sensing surface is informative even with a small number of patches; second, simple threshold-based approaches were insufficient to reliably separate gestures with similar spatial extent

(e.g., whole-hand touch vs. caress). In the current prototype, this ambiguity was addressed through a lightweight data-driven model as a practical solution for robust real-time interaction.

Future work will focus on finalising the prototype by embedding the remaining electronics, adding additional feedback modalities, and integrating a fabric cover that hides the sensing components while visually marking the touch areas.

We also plan to collect a new dataset, potentially including TD children, to better capture real-user variability, with the aim of conducting a pilot study with children with RTT. This test will assess the toy's potential for encouraging the target behaviours (e.g., by comparing conditions where sensory feedback is provided or not), and will provide valuable insights about the real motor interactions of RTT population.

By simultaneously addressing motor and cognitive impairments through simple, responsive, and low-demand interactions, *Pufff* may contribute to a more accessible and engaging approach to RTT rehabilitation. This is particularly relevant in RTT, where limited voluntary motor control and reduced sustained attention often interfere with interaction with traditional therapeutic tools.

The final device aims to be a non-invasive, accessible, cost-effective[4], and user-friendly tool for RTT-oriented intervention. Following an initial pilot study, *Pufff* may also have potential for home-based use by parents, consistent with recommendations highlighting the benefits of complementary family-mediated interventions in NDDs [20].

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Selection and Participation of Children

This feasibility study did not involve any child participants.

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[4]The electronics embedded in the device are relatively simple, and the total cost of implementing the toy is estimated to be below EUR 100.