Algorithms and robotics allow to describe how we learn handwriting and how to better help children with difficulties

ECOLE DOCTORALE
COGNITION, LANGAGE, INTERACTION

UNIVERSITÉ PARIS 8 VINCENNES-SAINT-DENIS

Thomas Gargot,

Defense for a

European Thesis in Computer Science

CHArt Cognitions Humaine et Artificielle

La pitié Salpétrière

ISIR INSTITUT DES SYSTÈMES INTELLIGENTS ET DE ROBOTIQUE

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April, 20th 2021

Motor learning difficulties, especially in handwriting, are frequent and impairing.

How could electronic sensors and algorithms help to better describe and rehabilitate these difficulties?

Outline

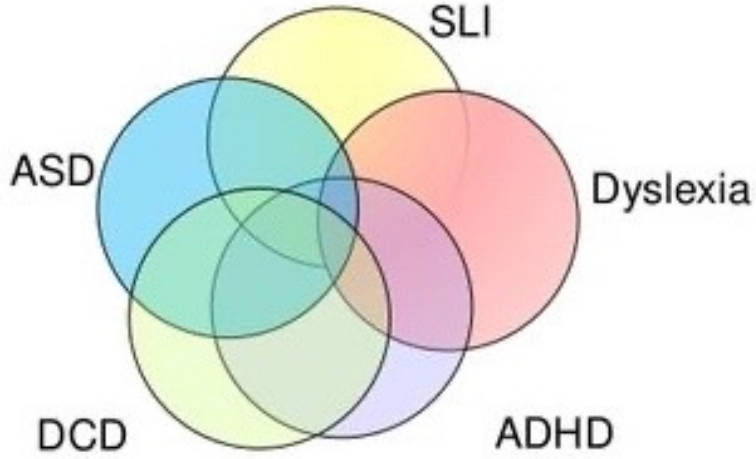
- Introduction
  - Neurodevelopmental disorders and motor difficulties
  - Innovative assessment of motor disorders
  - Writing assessment

- Experimental work
  - Dysgraphia classification with electronic tablets
  - A new classification of dysgraphia
  - Writing rehabilitation with robotics
  - Potential of a social robot

- Discussion and perspectives
  - Sensorimotor issues in autism spectrum disorders

Neurodevelopmental disorders and motor difficulties

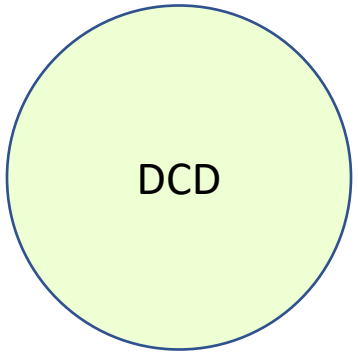
- Onset during childhood, often before school
- Clinical diagnosis, supported by standardized scales
- Wide range of difficulties
- Frequent comorbidities and large heterogeneity



DSM-5, 2013

Neurodevelopmental disorders and motor difficulties
Developmental coordination disorder (DCD), dyspraxia

- Motor learning difficulties: difficulties to do own's shoelace, do skipping rope, throw a ball
- Around 5 % of the population
- 2 boys for 1 girl



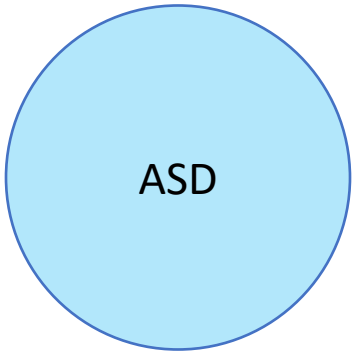
Daniel Radcliffe

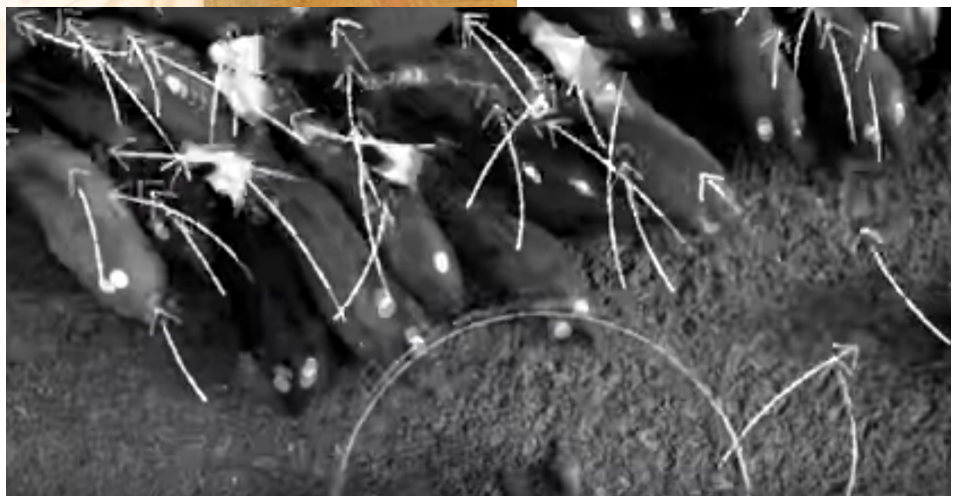
https://www.telegraph.co.uk/17 Aug 2008

DSM-5, 2013 ; Lingam et al., 2009

Neurodevelopmental disorders and motor difficulties
Autism Spectrum Disorder

- Difficulties social interaction and communication and
- Restricted and repetitive behavior
- 1.5 % of the population
- 4 boys for 1 girl
- ADI, ADOS

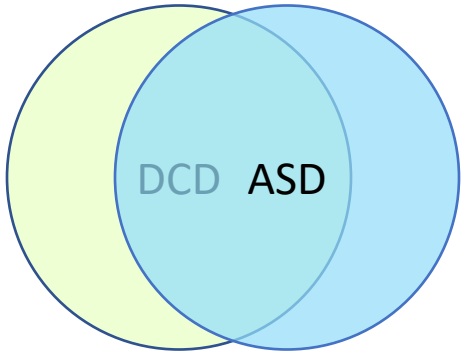




DSM-5, 2013
Lyall et al., 2017

Neurodevelopmental disorders and motor difficulties
Motor anomalies in ASD

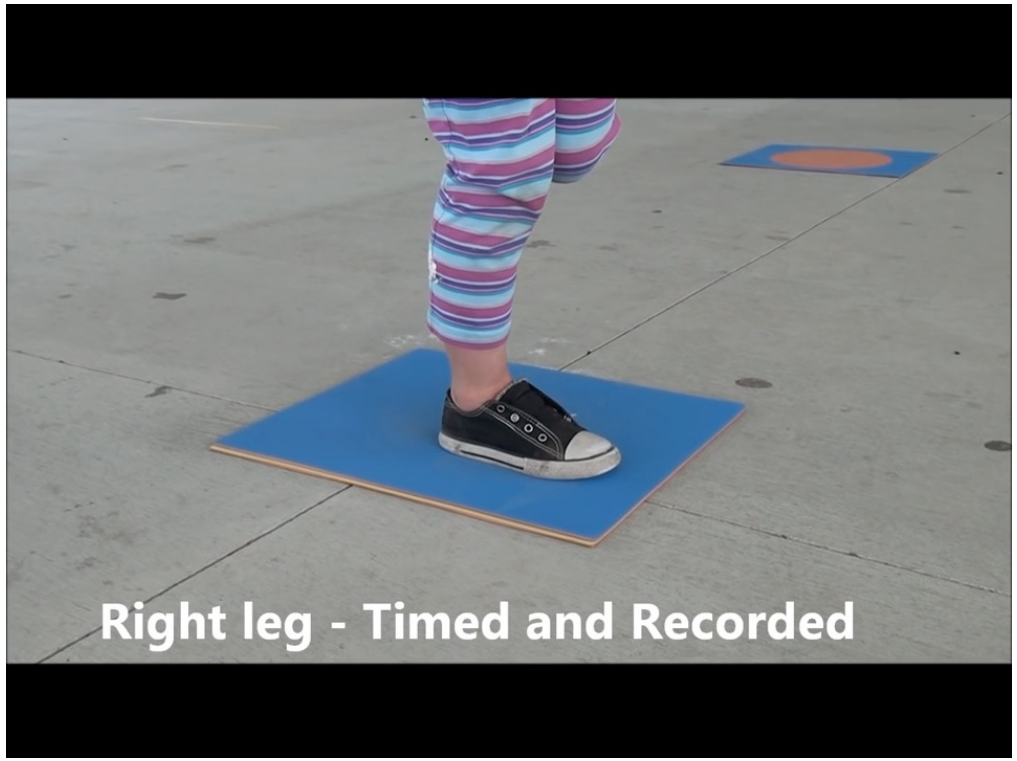
- Movement anomalies are frequent



- However, repetitive behaviours are the only motor symptomatology that is included in the diagnostic criteria.

(Kanner, 1943 ; Asperger, 1991 ; Fournier et al., 2010 , DSM-5, 2013)

Neurodevelopmental disorders and motor difficulties
A difficult assesment of movement difficulties

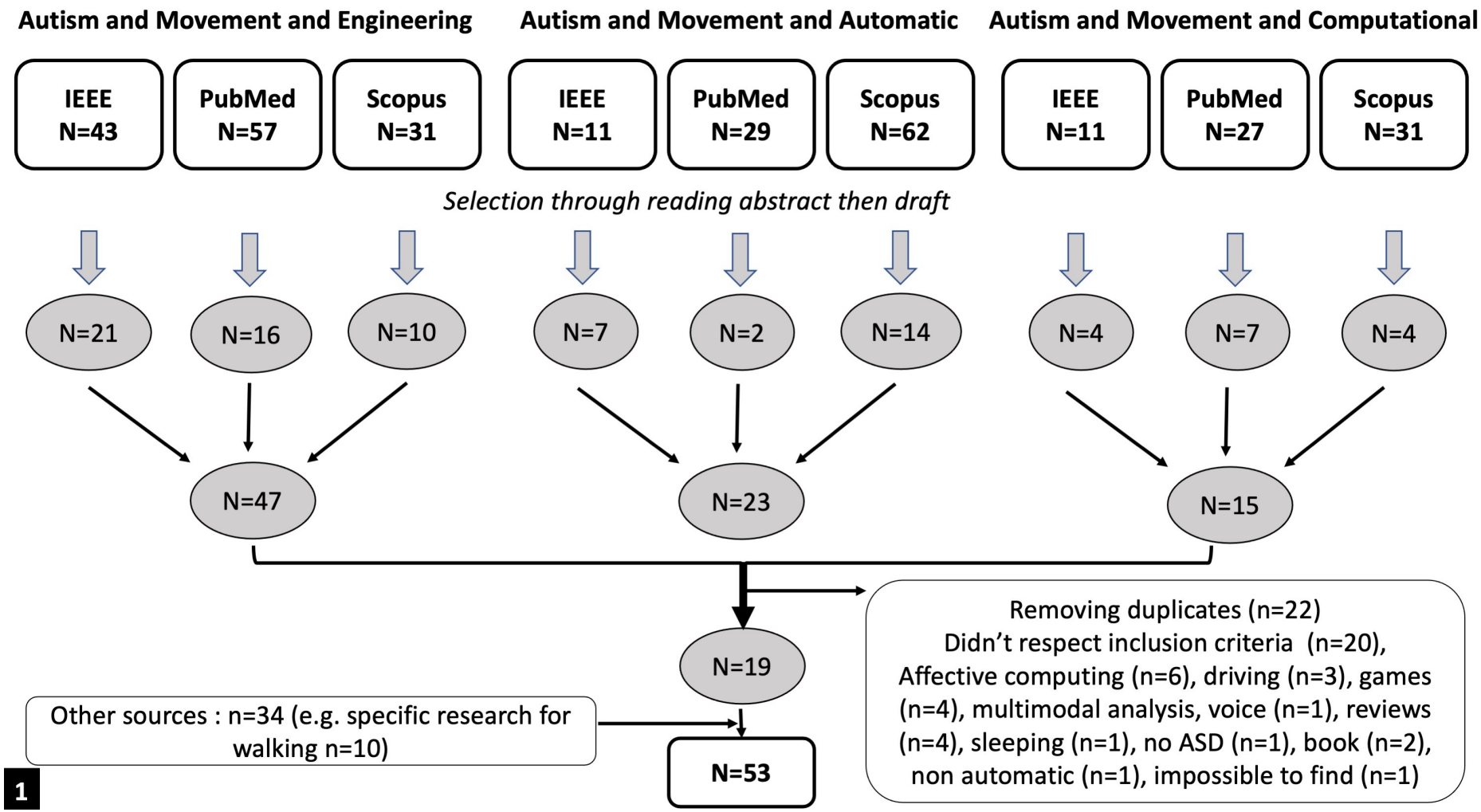


Movement Assessment Battery for Children (MABC-2)

Henderson et al., 2007

Can we use electronic sensors to measure and classify movement in ASD?

Innovative assessment of motor disorders
Method



Gargot et al., Cognitive computation, under review

Innovative assessment of motor disorders

Sensors

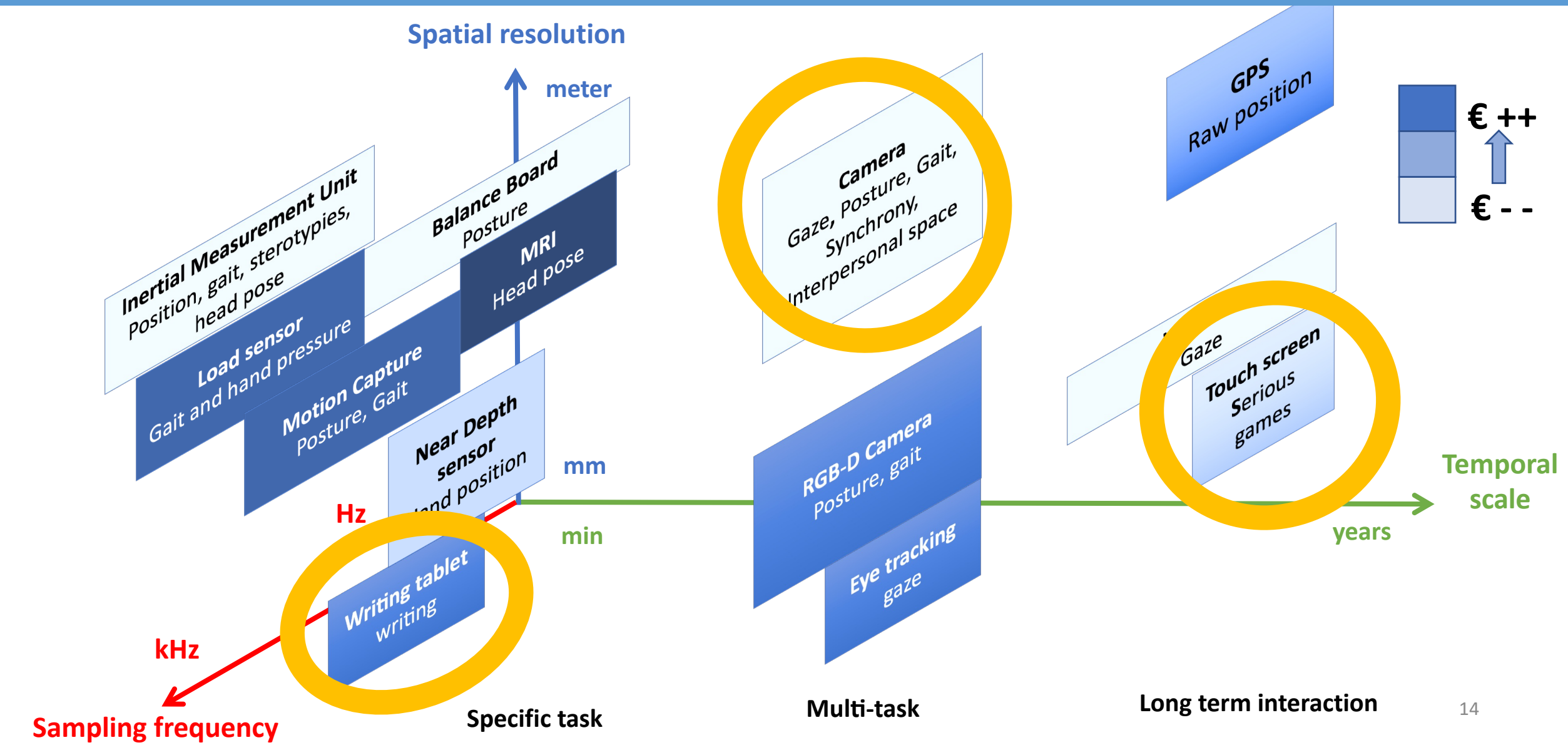
Clinical Stride: Walk assessment

Kinect RGB-D: Posture assesment

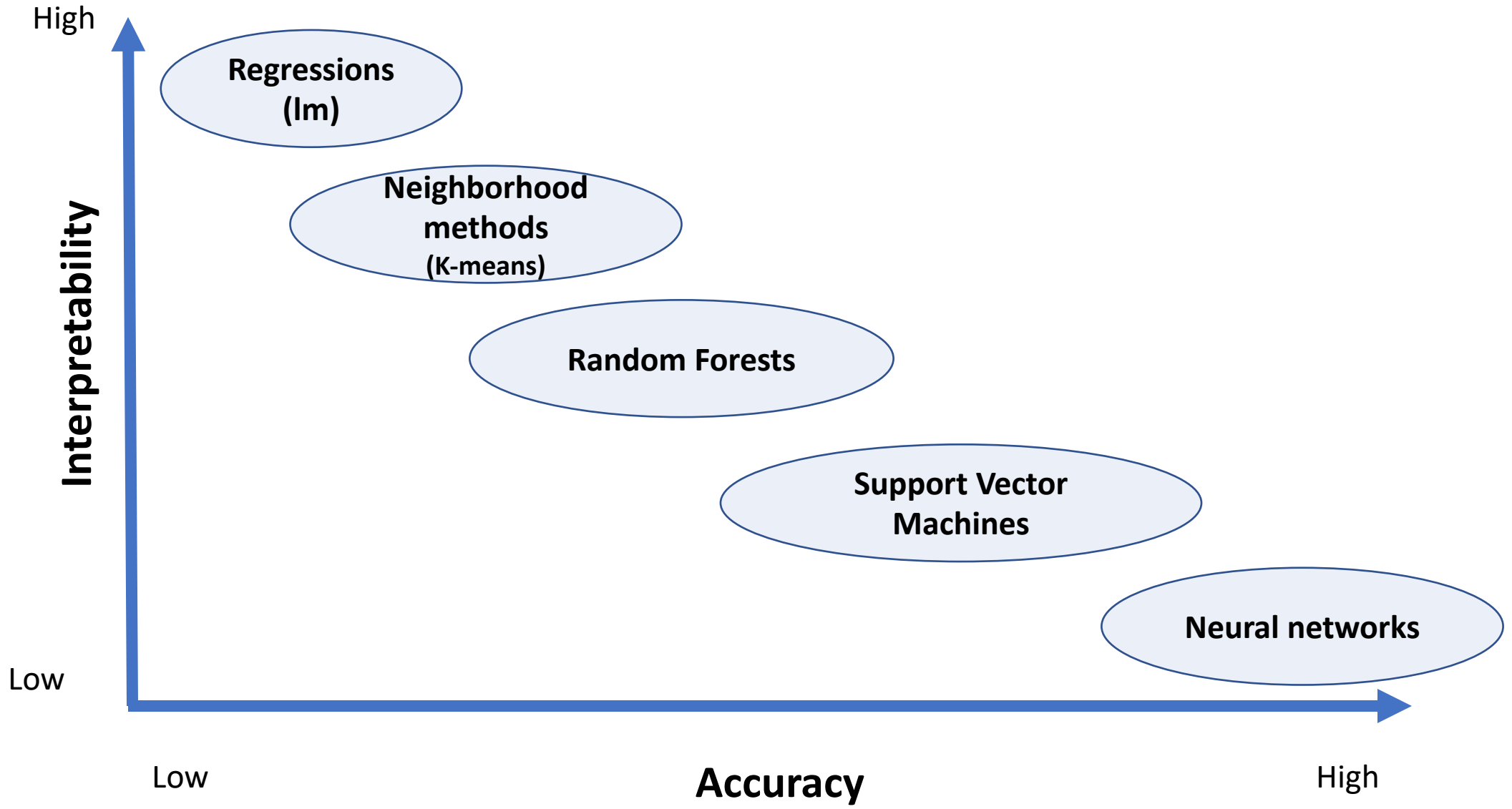
Wii board: Posture assessment

Innovative assessment of motor disorders

Sensors



Innovative assessment of motor disorders
Classification algorithms



Summary

- New metrics can evaluate the motor difficulties and progression of patients (digital phenotyping)

Writing assesment
Dysgraphia

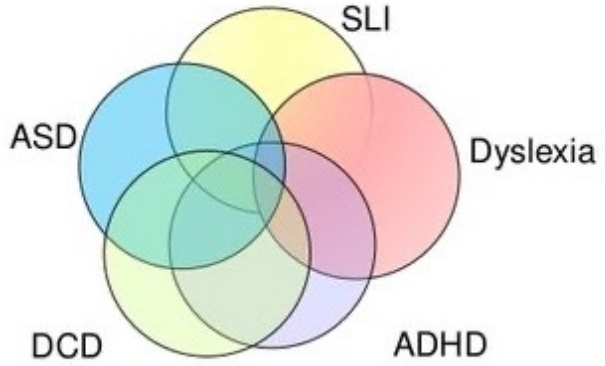
Table 1. Dysgraphia Subtypes

Dyslexic dysgraphia
Spontaneously written text is poorly legible, with textual complexity influencing legibility
Oral spelling severely abnormal
Copying of written text relatively preserved
Drawing relatively preserved
Finger-tapping speed normal
Dysgraphia due to motor clumsiness
Spontaneously written text is poorly legible
Oral spelling relatively preserved
Copying of written text poorly legible
Drawing usually compromised
Finger-tapping speed abnormal
Dysgraphia due to defect in understanding of space
Spontaneously written text is poorly legible
Oral spelling relatively preserved
Copying of written text poorly legible
Drawing severely abnormal
Finger-tapping speed normal

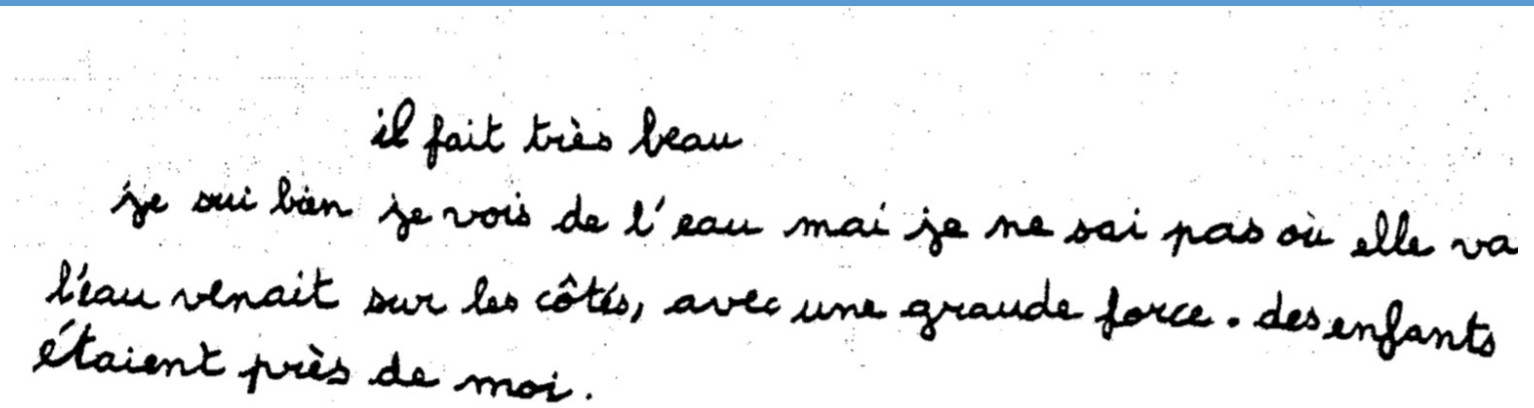
- 5 % of children in school have writing difficulties

Deuel, 1994

- Found in
  - Developmental Coordination Disorder
  - Autism Spectrum Disorder
  - Attention Deficit / Hyperactivity Disorder
  - Dyslexia



Writing assesment
Concise Evaluation Scale for Children's Handwriting (BHK)


il fait très beau
je suis bien je vois de l'eau mai je ne sai pas où elle va
l'eau venait sur les côtés, avec une grande force. des enfants
étaient près de moi.

BHK scores	BHK quality score based on the sum of 13 quality item scores (raw and normalized with age)	Writing is too large
		Widening of left-hand margin
		Bad letter or word alignment
		Insufficient word spacing
		Chaotic writing
		Absence of joins
		Collision of letters
		Inconsistent letter size (of x-height letters)
		Incorrect relative height of the various kinds of letters
		Letter distortion
		Ambiguous letter forms
		Correction of letter forms
		Unsteady writing trace
	BHK speed (raw and normalized with age)	The numbers of characters written in 5 min

Depends a lot from culture and alphabet

Charles et al., 2003

- Overlearning,
- Time consuming
- Highly trained professional

Electronic tablet
(Paper on Wacom)

BHK
Paper

Rule-based algorithm
Clinical items mimicking

- Overlearning,
- Time consuming
- Highly trained professional

No access to hidden features

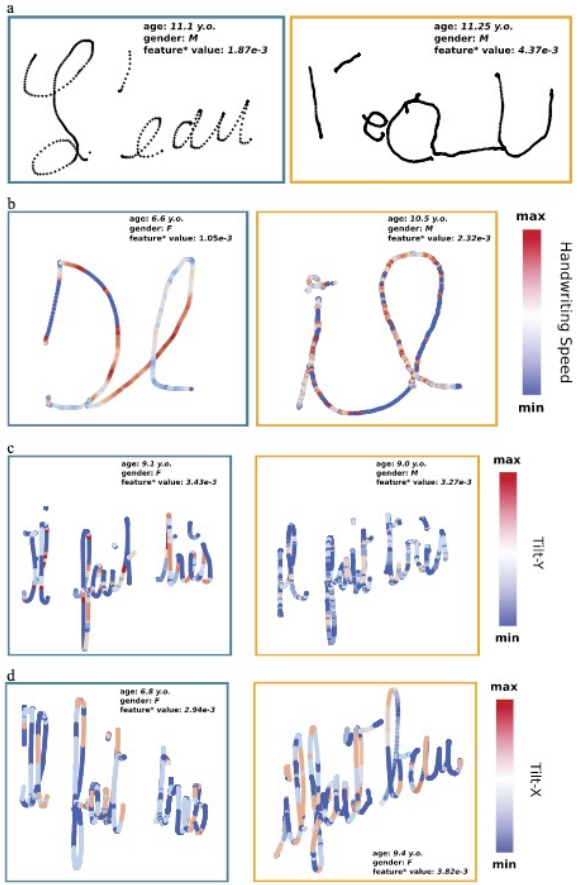
Can we use
(1) electronic tablets,
(2) interpretable and accurate algorithms
to improve characterization of handwriting ?

Dysgraphia classification with electronic tablets

Raw data

- Position x, y, z
- Tilt x,y
- Pressure

Resolution
- 200 Hz
- 0.25 mm



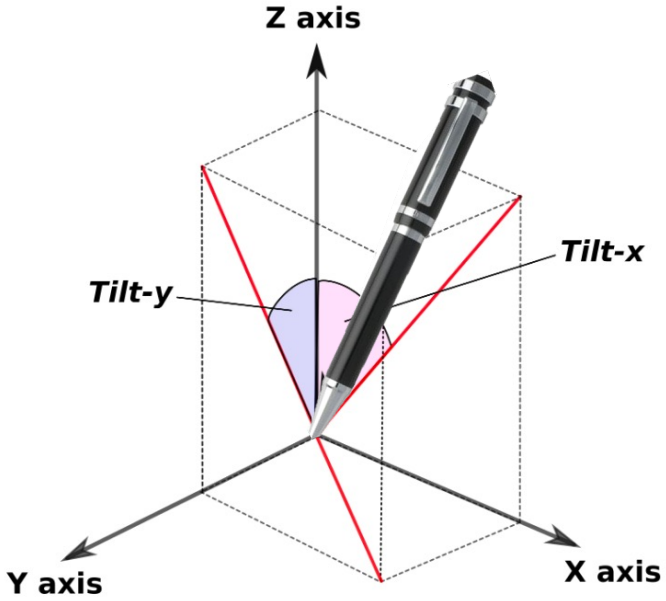
npj | Digital Medicine

www.nature.com/npjdigitalmed

ARTICLE OPEN

Automated human-level diagnosis of dysgraphia using a consumer tablet

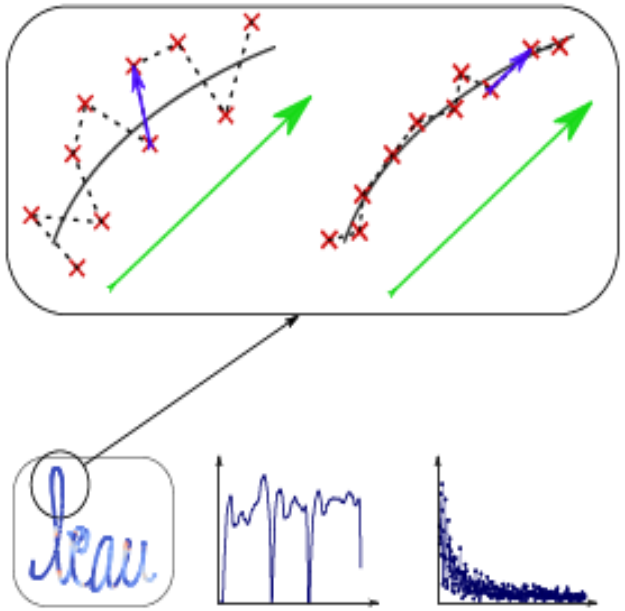
Thibault Asselborn[1], Thomas Gargot[2,3,4], Łukasz Kidziński[5], Wafa Johal[1,6], David Cohen[2], Caroline Jolly[7,8] and Pierre Dillenbourg[1]



Asselborn, Gargot et al., 2018

Dysgraphia classification with electronic tablets
Signal processing

- Derivatives (speed and acceleration)
- Frequency analysis (Fourier transform)
- In air-time ratio
- Geometry : size of handwriting, space between words, density
- Distribution (mean and standard deviations)

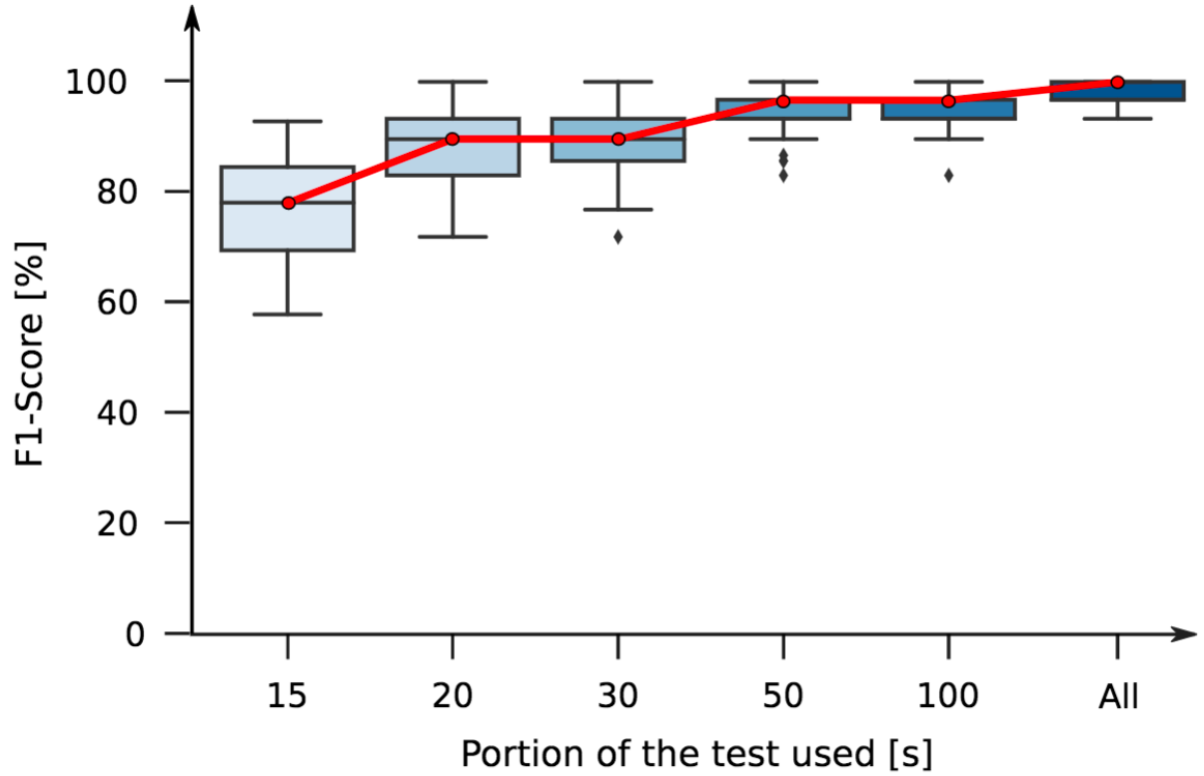


Automatic features (x 53)

- Static (geometric)
- Dynamic (kinematic)
- Pressure
- Tilt

Dysgraphia classification with electronic tablets
Automated diagnosis

Samples:
- ✓ **TD: 242 children**
- ✓ **DYS: 56 children**



Random forest

- 96.6 % sensibility
- 99.2% specificity

Electronic tablet
(Paper on Wacom)

Neural Network //

No interpretability of automatically extracted features

Signal processing

Automatic binary diagnosis

Feature engineering

Random Forest

(Asselborn, Gargot et al., 2018)

BHK Paper

Rule-based algorithm
Clinical items mimicking

- Overlearning,
- Time consuming
- Highly trained professional

No access to hidden features

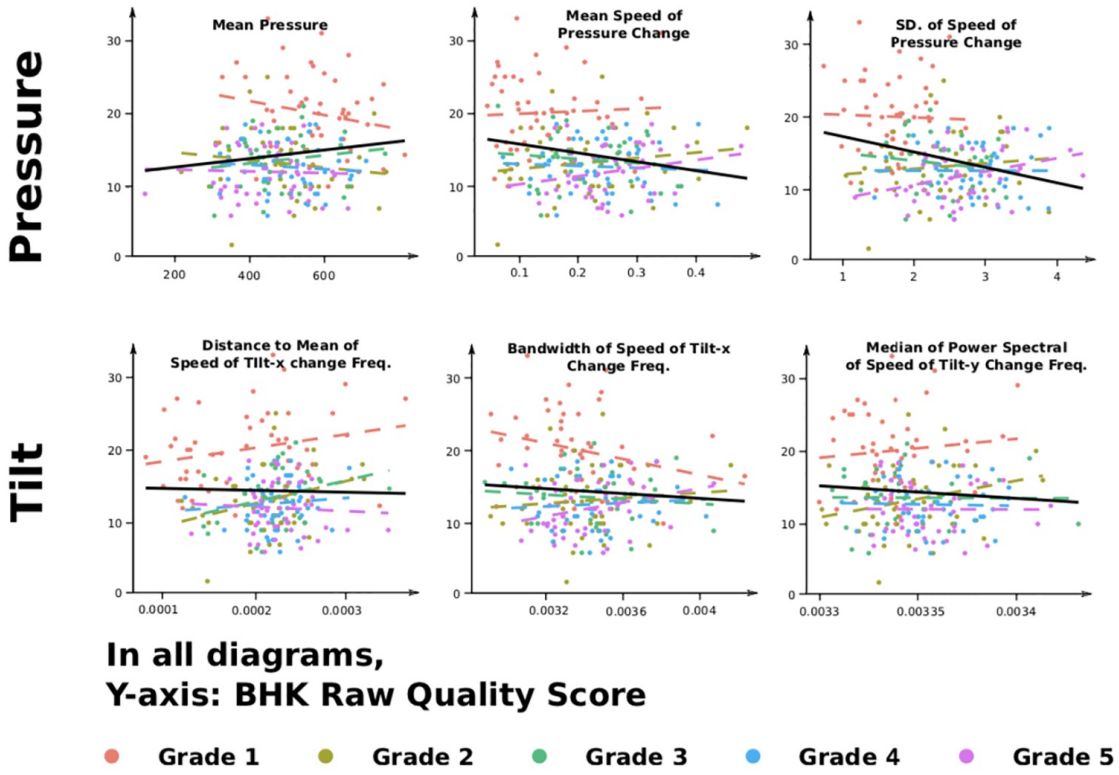
What is the role of the most important features in the development?

Are there subtypes of dysgraphia?

A new classification of dysgraphia

Developmental approach

Linear models



PLOS ONE

RESEARCH ARTICLE

Acquisition of handwriting in children with and without dysgraphia: A computational approach

Thomas Gargot[1,2,3]*, Thibault Asselborn[4], Hugues Pellerin[1], Ingrid Zammouri[1], Salvatore M. Anzalone[3], Laurence Casteran[5], Wafa Johal[6], Pierre Dillenbourg[4], David Cohen[1,2], Caroline Jolly[7,8]

Samples:

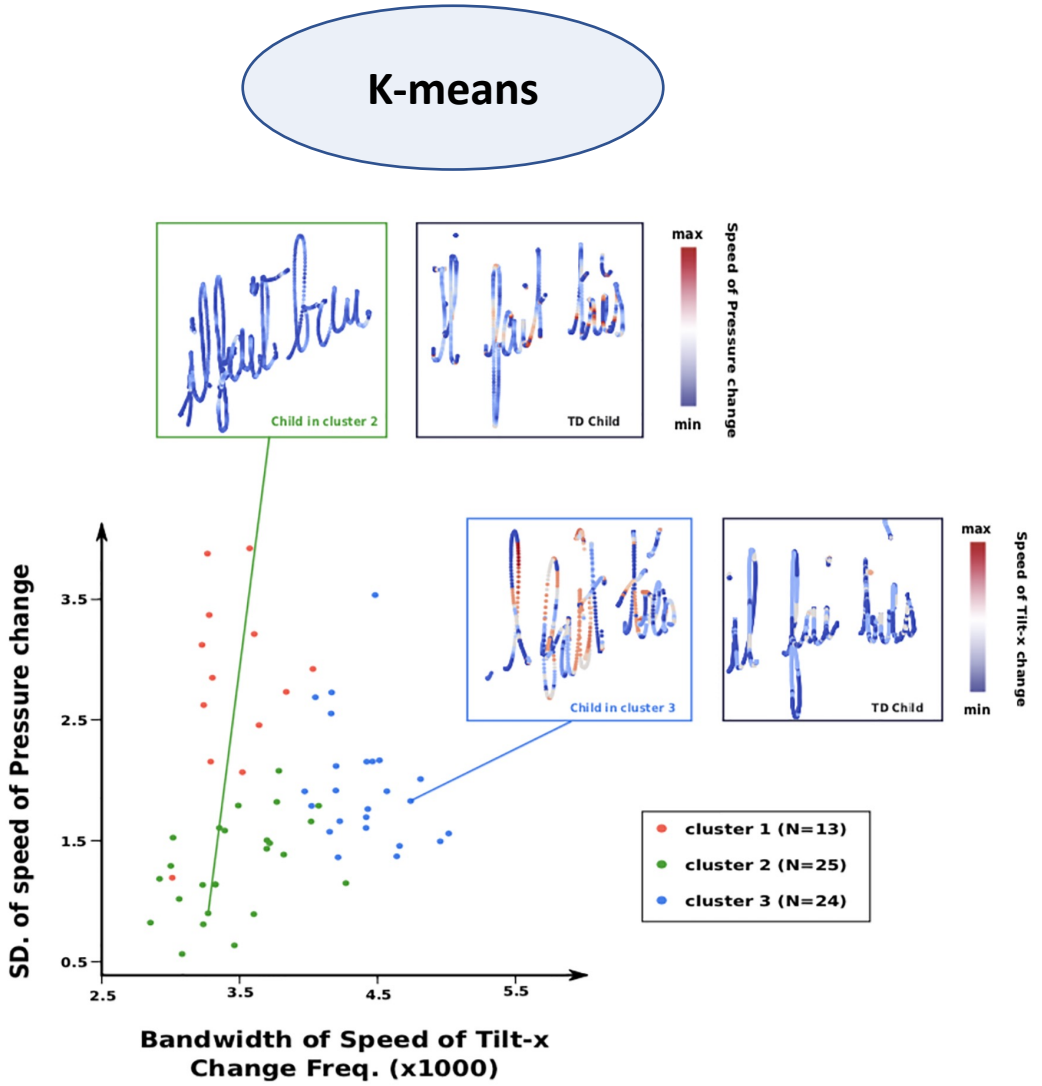
- ✓ **TD: 218 children**
  - ✓ **42 ± 6 children from 1st to 6th grade**
- ✓ **DYS: 62 children**

Gargot et al., 2020

A new classification of dysgraphia
A more personalized approach

Samples:
✓ **DYS: 62 children**

1. **Mild dysgraphia**: in schools
2. **Severe Dysgraphia:** Kinematic and Pressure
3. **Severe Dysgraphia:** pen Tilt



Summary

- New metrics can evaluate the motor difficulties and progression of patients (digital phenotyping)
- Writing analysis thanks to electronic tablets allow to extract features that could be promising to tailor the diagnosis and guide the remediation

Electronic tablet
(Paper on Wacom)

Neural Network //

No interpretability of automatically extracted features

Signal processing

Automatic binary diagnosis

Automatic continuous diagnosis

Sub group identification
Subject centered analysis

Feature engineering

Random Forest

(Asselborn, Gargot et al., 2018)

Linear models

K-means clusters

(Gargot et al., 2020)

BHK Paper

Rule-based algorithm
Clinical items mimicking

No access to hidden features

- Overlearning,
- Time consuming
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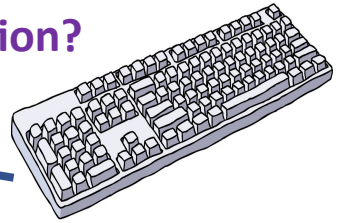
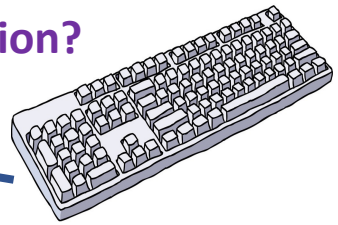
Remediation and/or compensation?



Spontaneous evolution

Longitudinal data

Remediation and/or compensation?



Spontaneous evolution

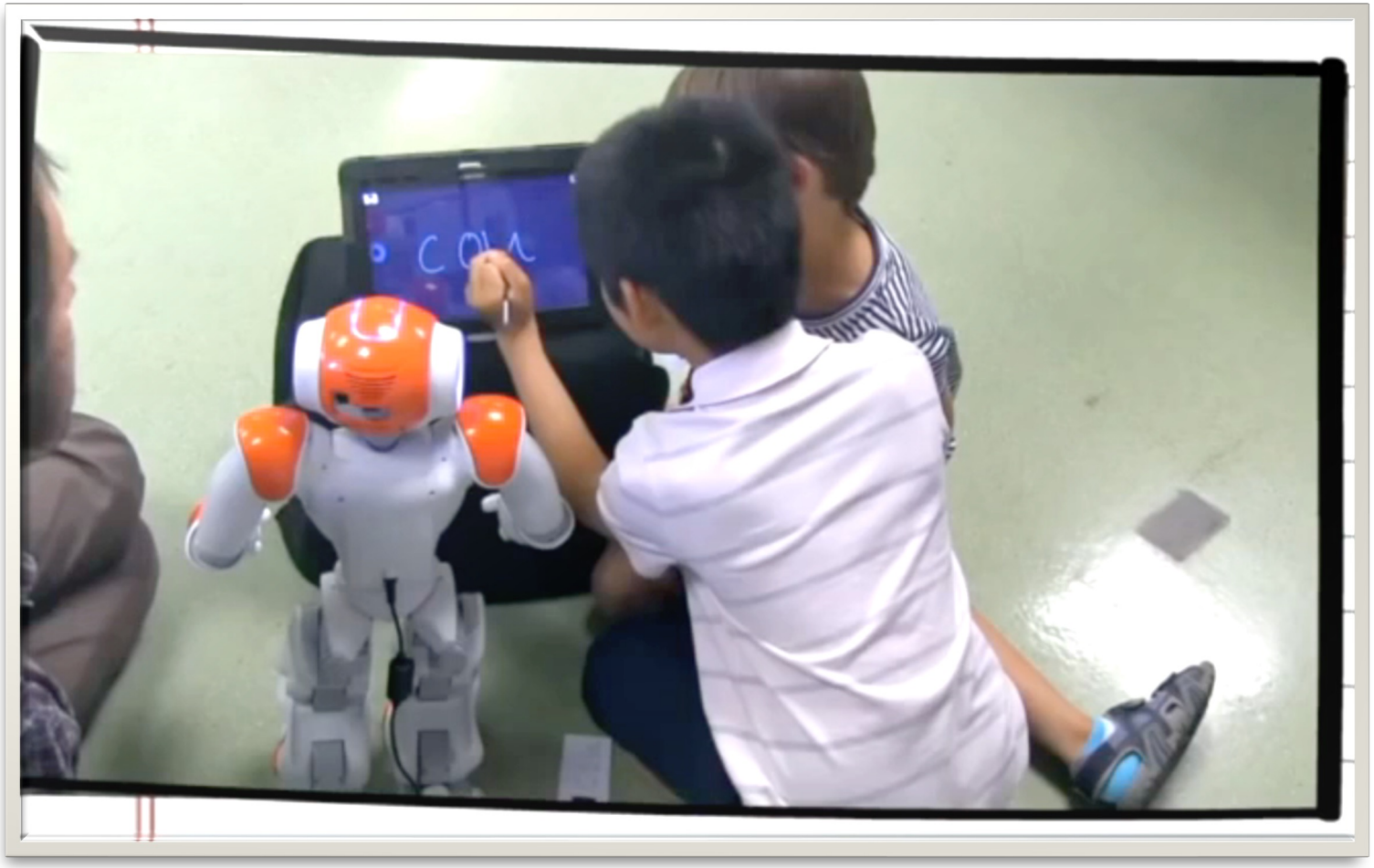
Longitudinal data

Remediation outcome

Dynamico

Progressivity and/or Intensity?

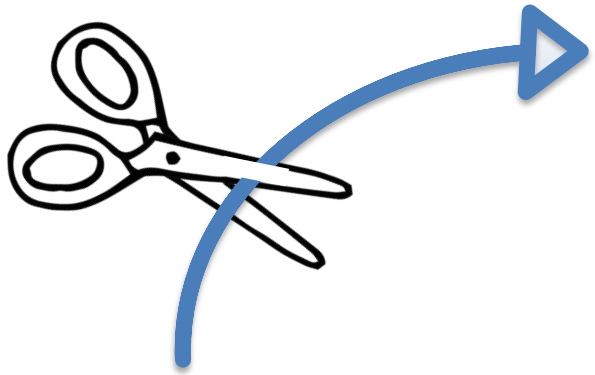
Adaptative exercises?



How these writing domains could be improved with robotics?

Jacq et al., 2016

Tablets to guide the rehabilitation of dysgraphia



Bad writing

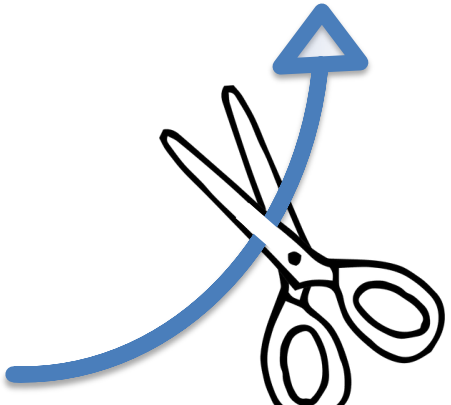
Think: “I should be better than that”, “I am not as good as my friends”, “They think I do it on purpose”

⬆️ anxiety
⬇️ self esteem

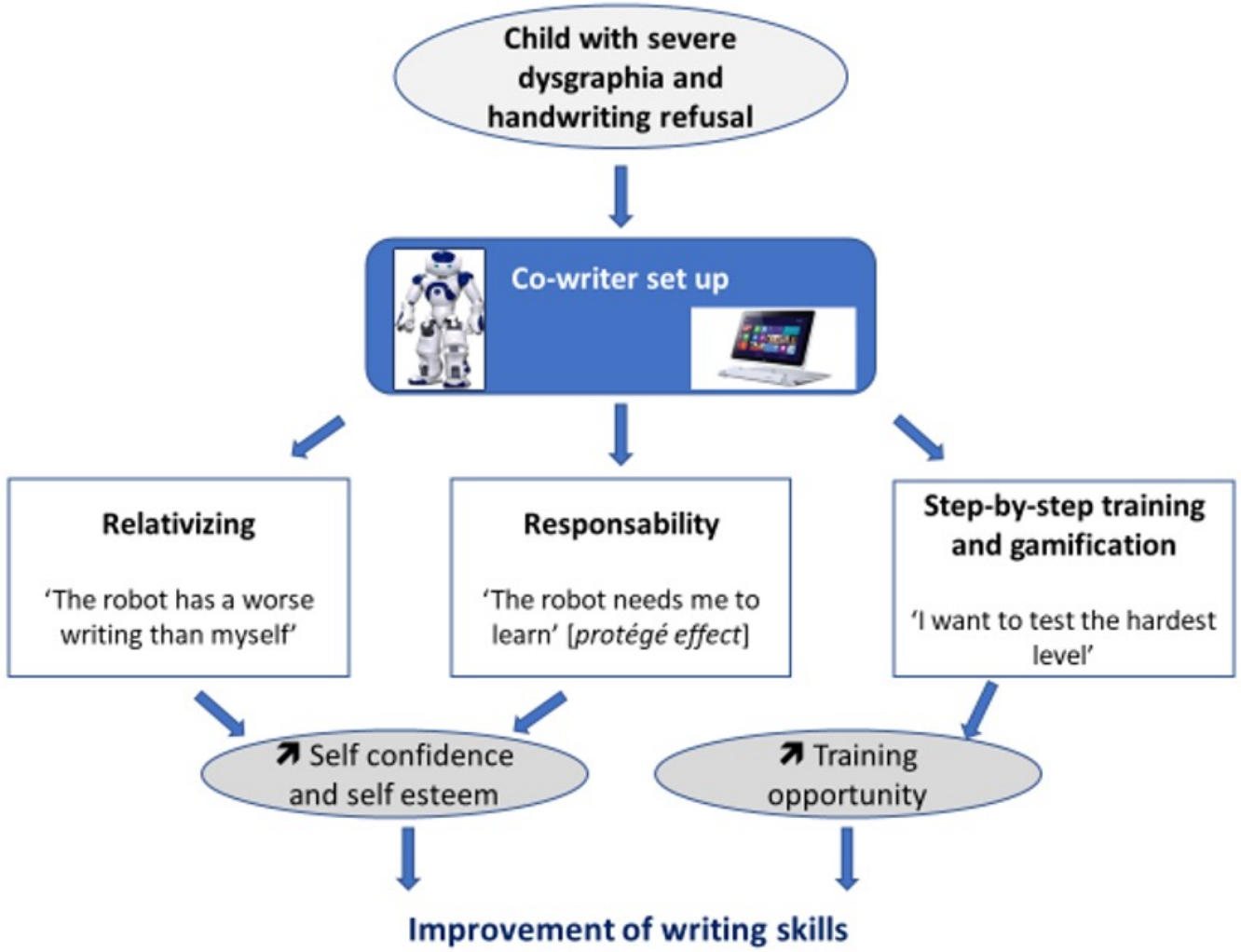
⬇️ learning opportunities

Negative reinforcement

Avoidance of writing



Tablets to guide the rehabilitation of dysgraphia



frontiers in Psychiatry

ORIGINAL RESEARCH
published: 23 February 2021
doi: 10.3389/fpsyt.2021.596055

"It Is Not the Robot Who Learns, It Is Me." Treating Severe Dysgraphia Using Child–Robot Interaction

Thomas Gargot[1,2,3†], Thibault Asselborn[4†], Ingrid Zammouri[1], Julie Brunelle[1], Wafa Johal[5], Pierre Dillenbourg[4], Dominique Archambault[2], Mohamed Chetouani[3], David Cohen[1,3†] and Salvatore M. Anzalone[2†]*

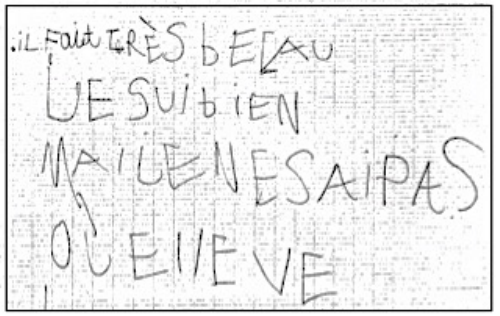
Samples:
- ✓ **N = 1**
- ✓ **20 weekly sessions**
- ✓ **Total : 500 min**

Gargot et al., 2021

Tablets to guide the rehabilitation of dysgraphia

February 2018 8 y.o.

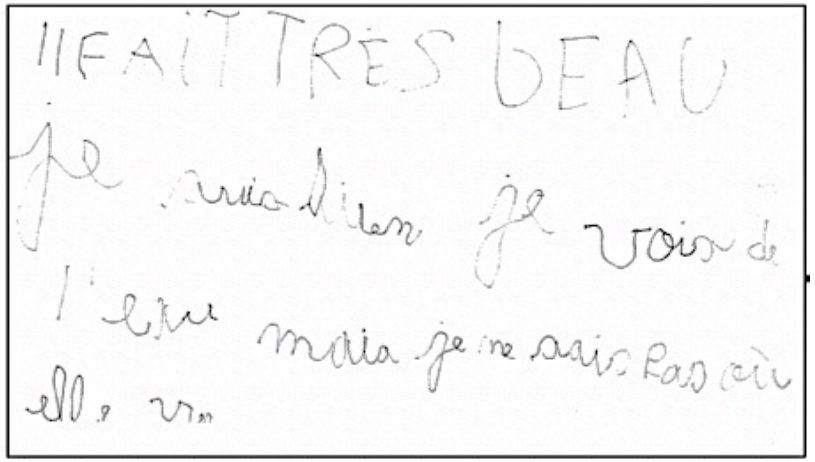
Non scorable



07/11/2018

Classical pencil and paper reeducation

November 2018 Non scorable 9 y.o.



♂, 10 y.o.,

Difficult labour, Premature, ADI < cut-off, ADHD, dyslexia, dysgraphia

repeat 1st grade

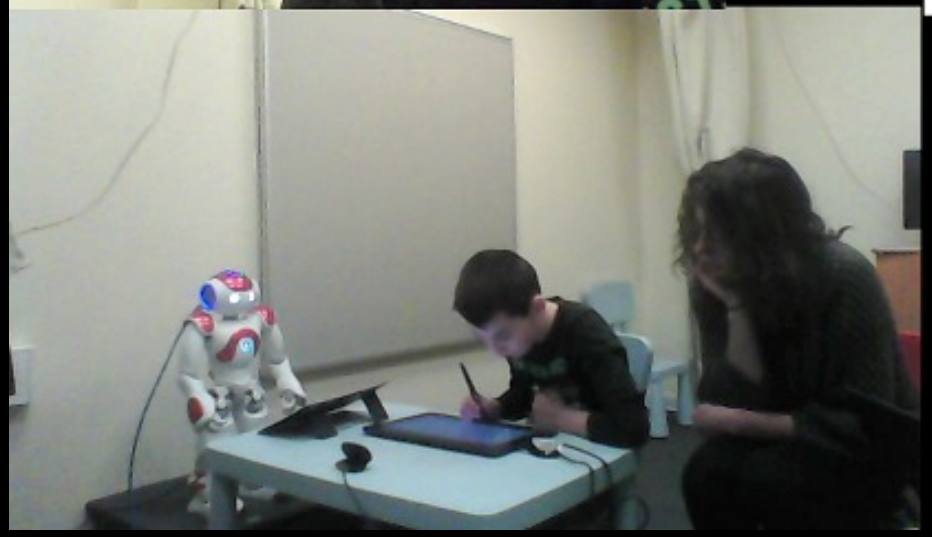
Ttt : methylphenidate, Speech therapist psychomotrician

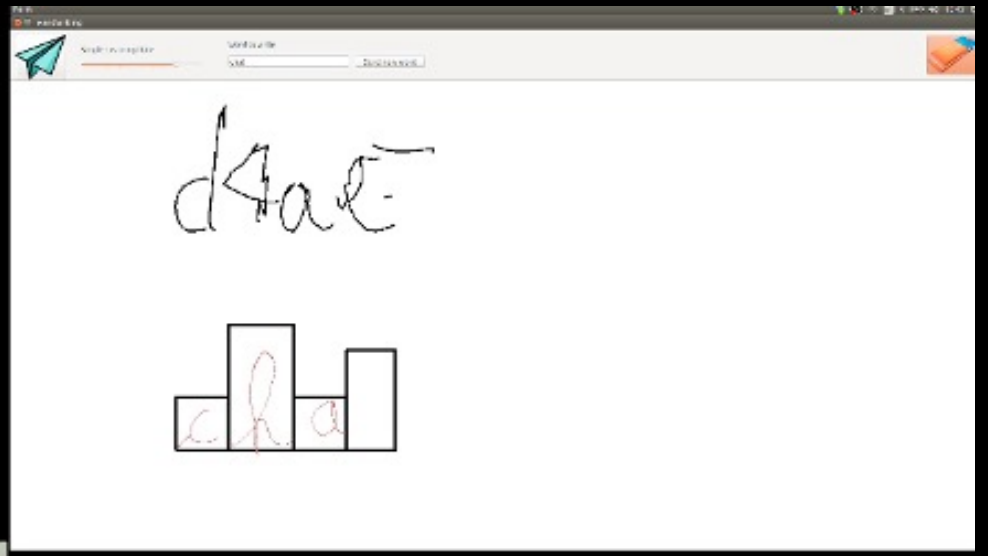
Why ?

- Potential interesting effect size, 2nd line treatment
- User-centered design

Tablets to guide the rehabilitation of dysgraphia

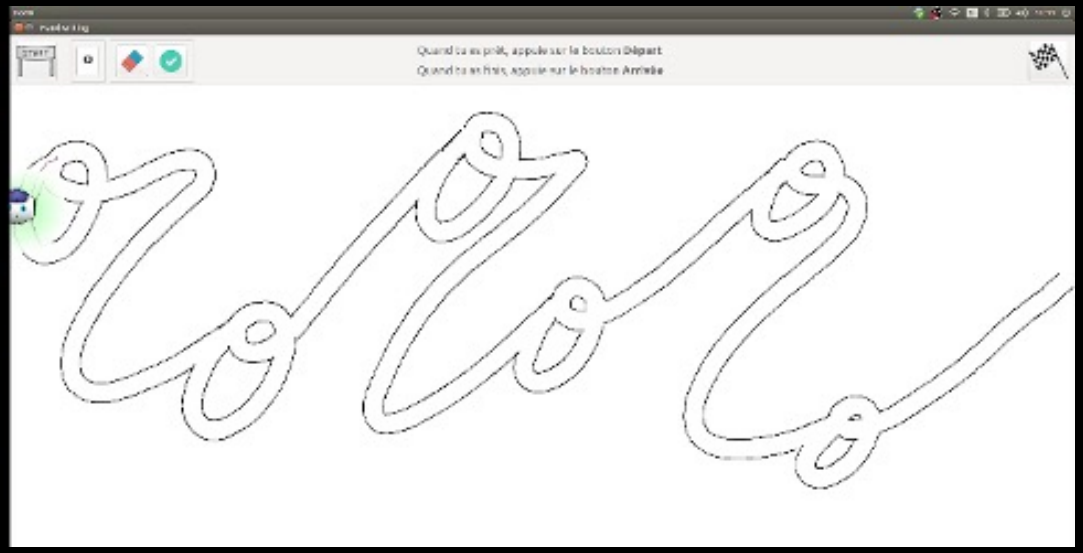
Learning by teaching (protégé effect)





Tablets to guide the rehabilitation of dysgraphia

Speed and letter shape



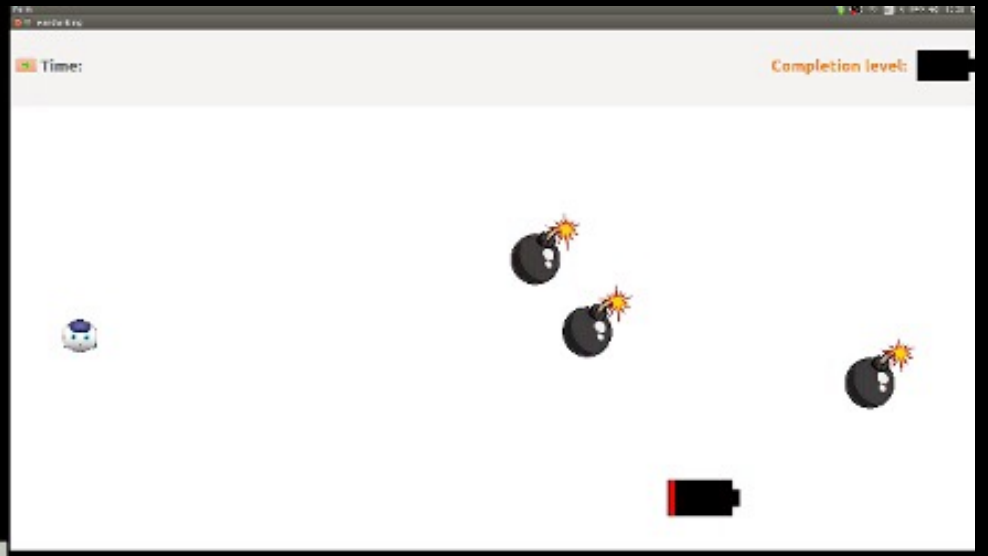
Impulsivity?

Tablets to guide the rehabilitation of dysgraphia

Pressure

Tablets to guide the rehabilitation of dysgraphia

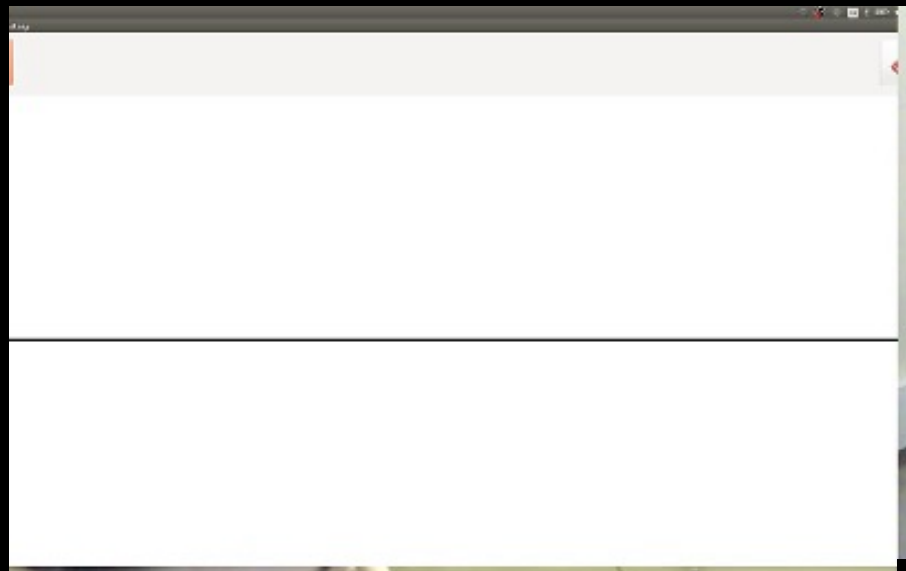
Tilt



Stability?

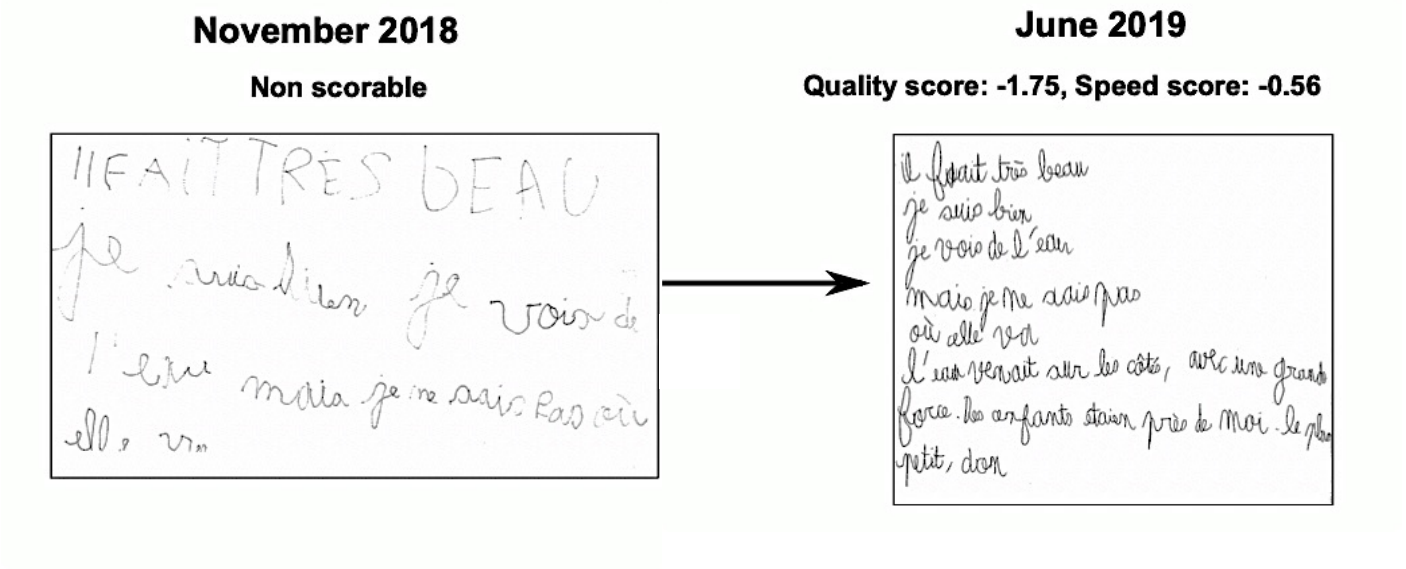
Tablets to guide the rehabilitation of dysgraphia

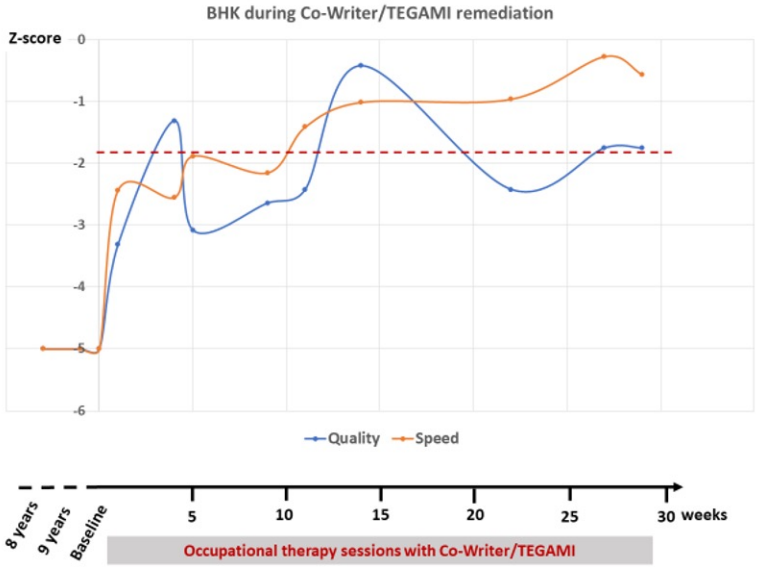
Pen lifts



Tablets to guide the rehabilitation of dysgraphia

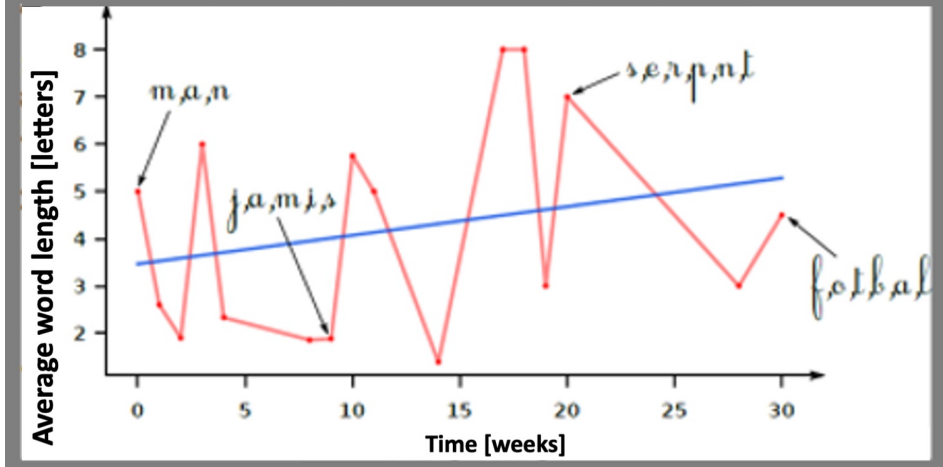
Clinical features



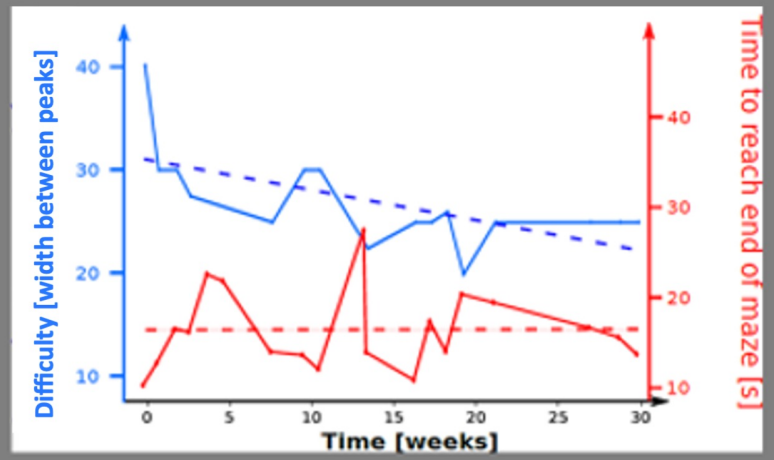


Tablets to guide the rehabilitation of dysgraphia
Automatic features

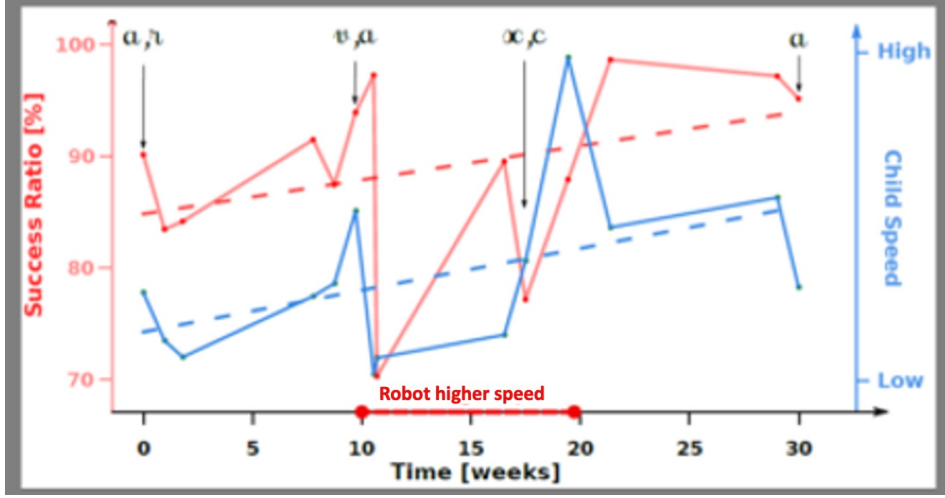
4A: *CoWriter*



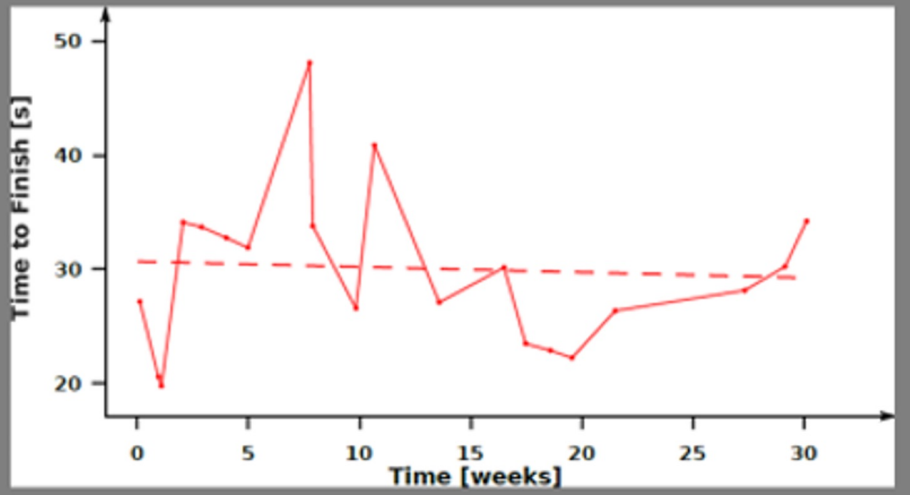
4C: *Pressure*



4B: *Tracking*



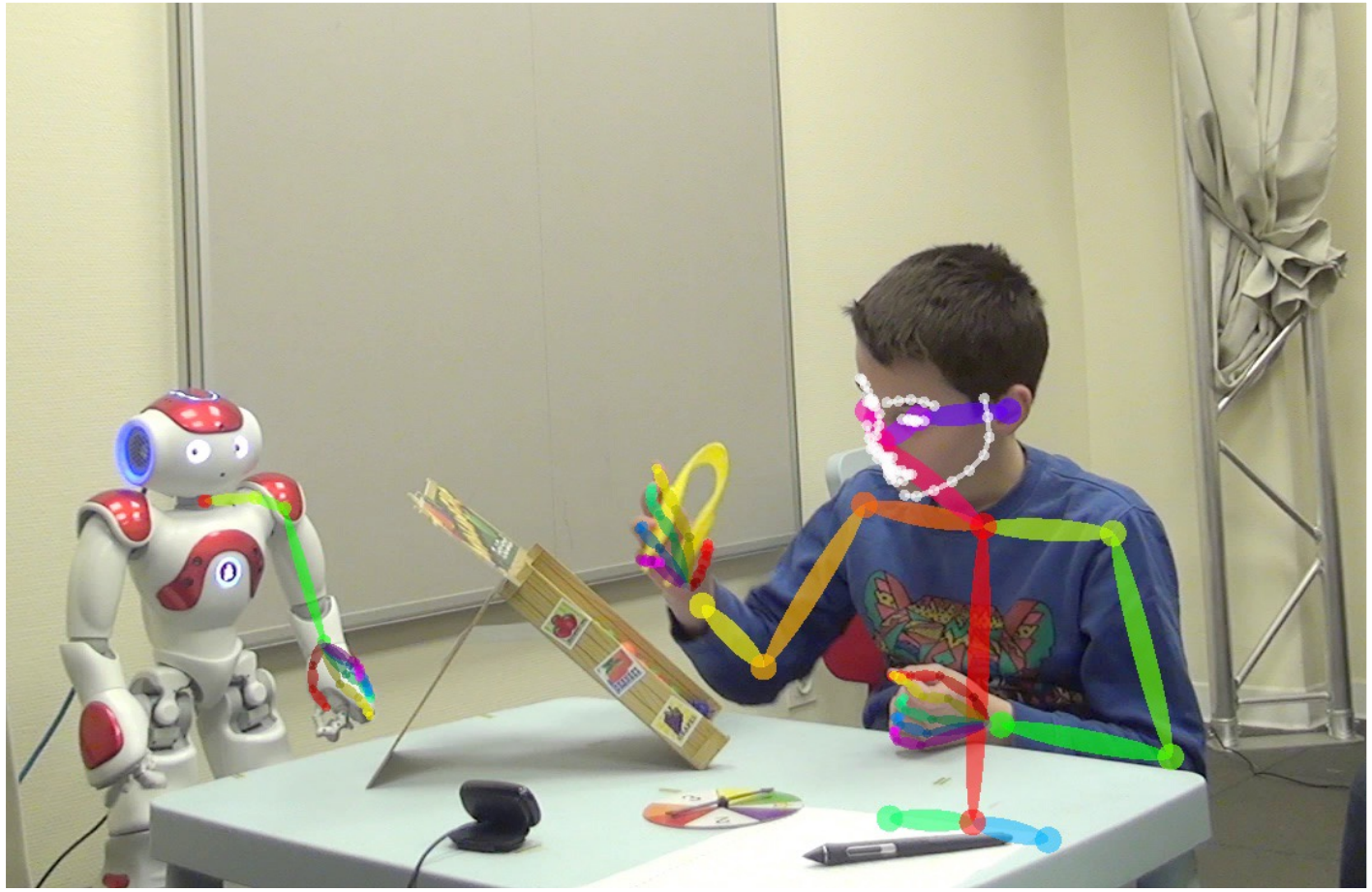
4D: *Tilt*



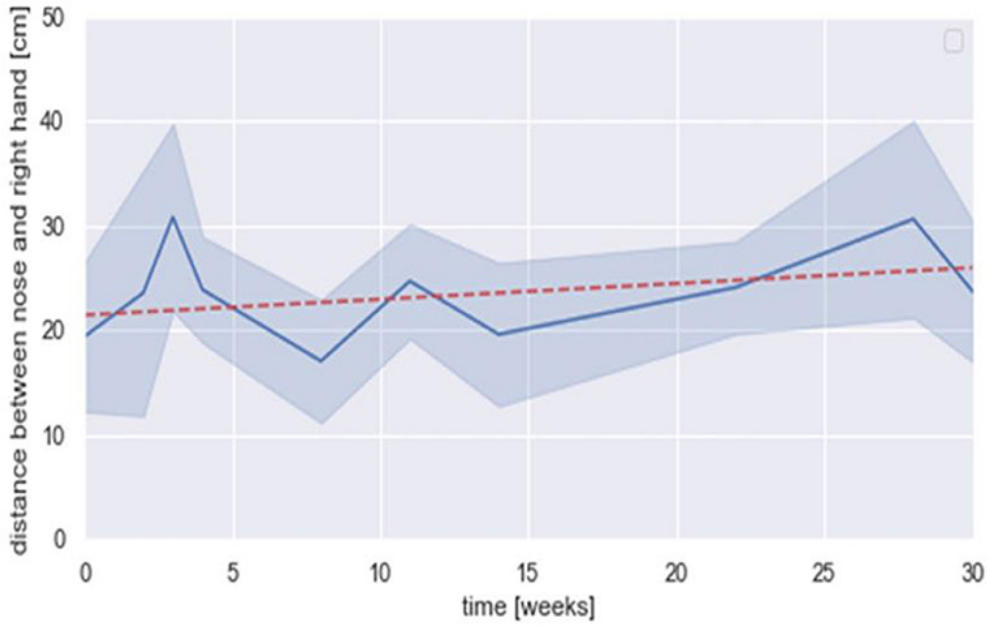
Tablets to guide the rehabilitation of dysgraphia

Posture: Openpose

HD Camera and Deep learning



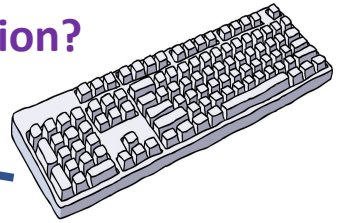
Neural Networks



Summary

- New metrics can evaluate the motor difficulties and progression of patients (digital phenotyping)
- Writing analysis thanks to electronic tablets allow to extract features that could be promising to tailor the diagnosis and guide the remediation
- These features could be improved thanks to a robotic system using a peer-robot (protégé effect)

Remediation and/or compensation?



Spontaneous evolution

Longitudinal data

HCI / HRI feedback loop

iReCheck

Remediation outcome

Dynamico

Impact of social behaviours ?

Progressivity and/or Intensity?

Adaptative exercises?

What would be the role of a social robot ?

How to implement a wizard of Oz system ?

Potential of a social robot

Methods

Robot behaviours based on:

- Functional analysis (vicious circles)
- Behaviour of the child during activity
- Operationalize relevant teacher behaviour from a cognitive science approach ?
- Test on 4 children during 3 weeks in CHUV Hospital in Lausanne with a wizard of Oz interface

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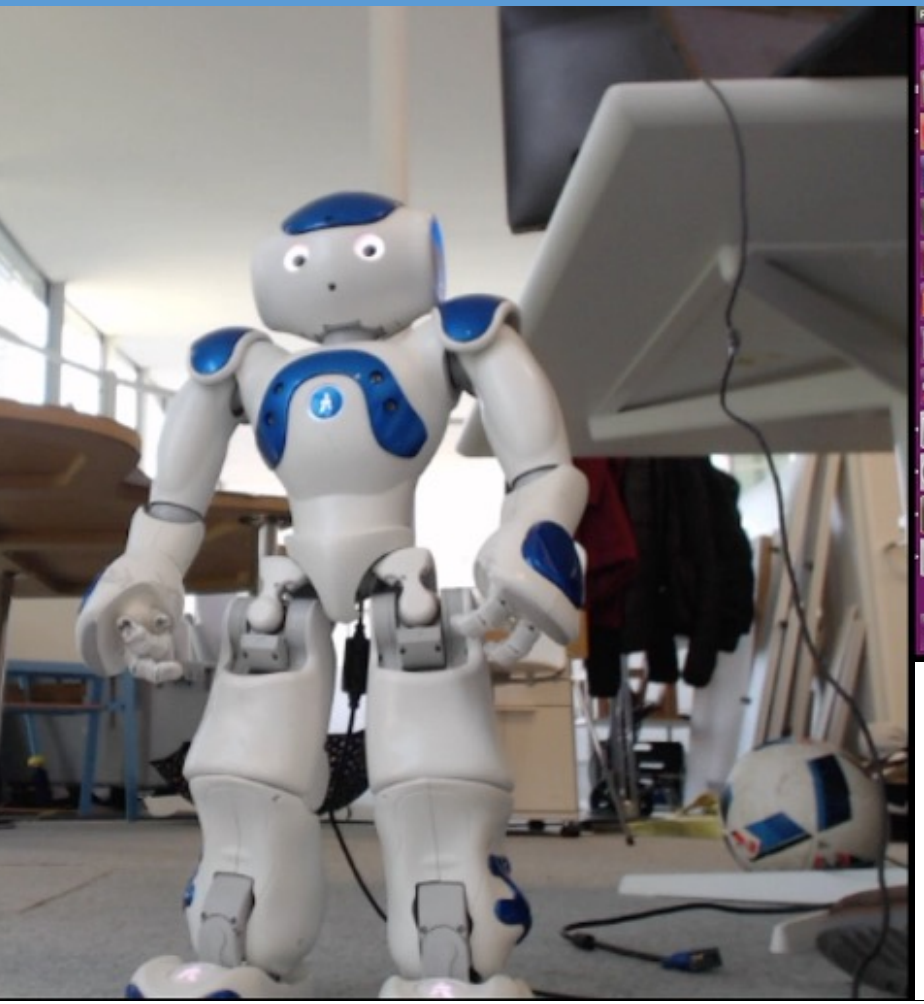
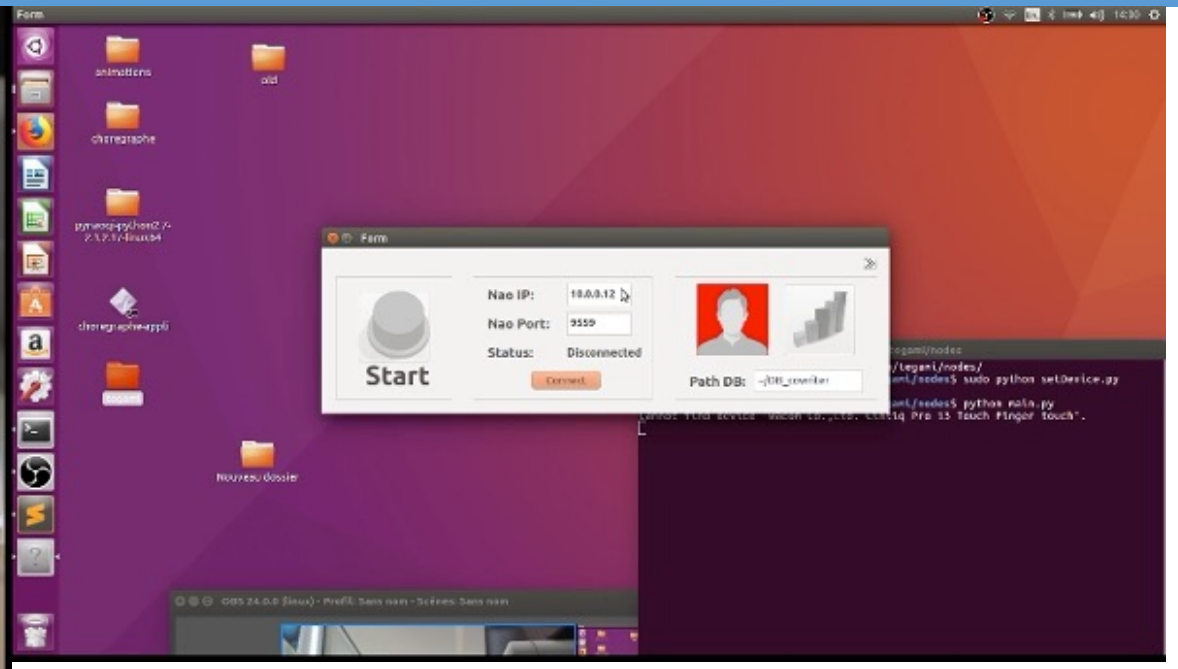
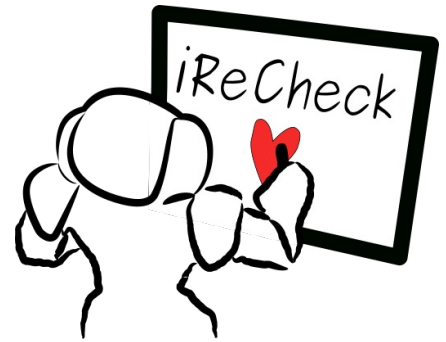
Potential of a social robot

Conceptual framework (22 behaviours)

WoZ with Python and QML







- Framing (n=8)
- Feedback (n=6)
- Metacognition and self-regulation (n=5)
- Motivation (n=3)

Mostly theoretical suggestions than **need to best tested** and evaluated in the field during long term interventions in hospital and schools

Potential of a social robot
Conceptual framework (22 behaviours)

Framing	Feedback
• Mystification • Framing the limits • Low performing robot with a humble attitude • Dealing with agressivity and frustration with humour • Congruent audio-motor behaviours	• Positive feedback • Negative feedback/ Error acceptance • Multisensory feedback
Metacognition and self regulation	**Motivation**
	• Intrinsic motivation • Extrinsic motivation

Summary

- New metrics can evaluate the motor difficulties and progression of patients (digital phenotyping)
- Writing analysis thanks to electronic tablets allow to extract features that could be promising to tailor the diagnosis and guide the remediation
- These features could be improved thanks to a robotic system using a peer-robot (protégé effect)
- The place of the robot would be complementary with the place of the therapist/teacher. Such system can’t be developed without an early input from the therapist and the teacher.

Limitations

- The classification of writing was not performed on the same tablet, even if correspondence is easy.
- The assessment of the evolution of the same features was not possible in the clinical-case (same device but different softwares).

Perspectives

- A comparative study is necessary to assess the efficacy.
- A stand-alone tablet (iPad®) would be more usable and scalable (Dynamico project). The surface is different but paper-feeling stickers are usable.

- What is the additive value of the social robot and the impact of its different behaviours in several long HRI?

Could these technologies help to understand, diagnose and treat the ASD?

Difficulty to socialise, to communicate his/her own's need

Behavioural disorders (e.g. tantrum)

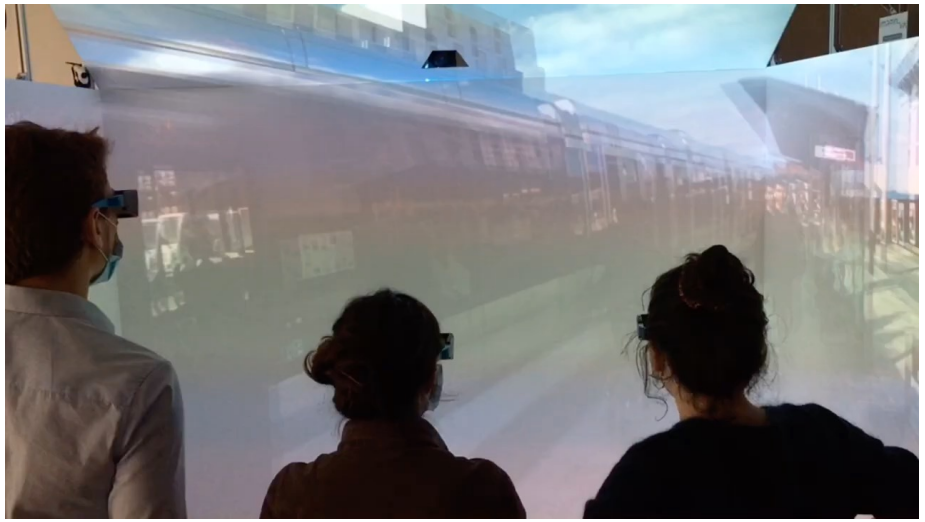
Difficulties in simulation of other mediated by imitation (e.g. face reading, Theory of Mind) (Neal, 2011)

Anxiety and avoidance

Sensorial difficulties (Kojovic, 2019)

Impaired learning due to neurobiological difficulties at a cellular level

Motor difficulties (Dziuk, 2007)



Conclusion

- Electronic sensors and algorithms can be useful to measure and understand the movement difficulties of children with NDD.
- We showed how we could use electronic tablets to characterize handwriting difficulties. This approach give opportunities in rehabilitation in the motivational aspect and dynamic, tilt, pressure and lifts training.
- Acceptability, interpretability and clinical standards needs to be take into account from the begining with end users.
- Long term HRI are possible and relevant. The role of the robot is better defined but should be properly evaluated.

Thank you

- Other collaborators:
  - Ingrid Zammouri, Psychomotrician
  - Véronique Simmonet, Specialized teacher
  - Soizic Gauthier, Post-Doc, PhD in Psychopathology
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