Early detection of developmental disorders and skill-improving by a mobile-application which facilitates physical activity and analyzes motion automatically
KH 129603
Final report

1. Background

Autism spectrum disorder (ASD) and attention deficit hyperactivity disorder (ADHD) are two developmental disorders with high prevalence [1] causing high level of suffering for the affected individual and the family [2, 3] and high costs for public insurance. The project's main aim was to improve the wellbeing and quality of life of these children and their parents through facilitating an earlier diagnosis and an effective, less time-consuming treatment which can be available for many children at home.

In contrast to the high prevalence and high level of compromised wellbeing, the etiology of the disorders is largely unknown [4]. There is no specific treatment and although earlier intervention leads to better prognosis [5], children often only get diagnosis when they are 5 years of age or older, especially in high-functioning cases. There is no biological or behavioral marker, or test, that can provide a clear diagnosis, thus the diagnostic process is complicated, time-consuming and does not reach satisfactory levels of objectivity and stability [6, 7].

The base of the project was that movement can be exploited as a diagnostic source of information. ASD and ADHD is often characterized by problems with motor coordination, gross and fine motor skills, and the motor development of these children is frequently delayed and follows an atypical pattern [8]. However, movement as a source of information in the diagnostic procedure is largely undervalued. A limited number of studies showed that children's motor patterns successfully predict later ASD or ADHD diagnosis [9]. However, in these studies, movement was measured by manual scoring made by the experimenters. It would be better to measure and analyze movements automatically, as this would enable researchers to collect large amounts of data and analyze them in an objective way.

Despite the huge need, automatic diagnosis by artificial intelligence (machine learning) is still in its infancy. In cases of ASD and ADHD, there are only a few methods/tools with limited success [10-12]. ASD was predicted by facial gestures [12], but this method can be used only under laboratory conditions. Diagnostic tools like those above are based on short-term measurements of behavior, and their predictive power is low. Additionally, these tools/tests are not suitable to improve the skills of children, although this aim is also important as motor problems can lead to later failure in social and occupational life [13] and improvement of motor skills has beneficial effects on other skills as well (e.g. executive function and socio-emotional skills [14]).

In this project, we developed and tested a system, that can automatically measure and analyze movements, and detect ASD and ADHD based on inertial data. This system, called SensKid, is made up of a smartwatch, a smartphone, machine learning algorithms and a game application (the latter is still under development).

2. Method

2.1. Data collecting system

The project started with the development of the data collecting system. For safe storage, we built a database on a server. A smartwatch-smartphone system was redesigned for the purpose of the current research. By means of a program we collected inertial data (acceleration and angular velocity) and synchronized them with the video. After finishing the test, the data and the video could be uploaded to the server.

In the second project year, we changed and improved the data collection system because of the pandemic situation to make it usable remotely at home. The main aim of this development phase was a more user-friendly interface which the parents could use without professional intervention. We modified the data transfer protocol and server connection to make the data collection available in poor network condition. We changed the video recording and synchronization protocol to make it work more reliably in the hands of the parents.

2.2. Data collection

We collected data from 6-8-year-old children: typically developing children (N =39) and children with ADHD and ASD (ASD N=20; ADHD N=12; comorbid ASD and ADHD diagnosis N=8; total sample N=40).

Data collection with the typically developing children took place in primary schools, in PE classes. Data collection with atypically developing children took place at Eötvös Loránd University, in a big seminar room. We used the Budapest Movement Test Battery (BMTB), which was developed by our research group. It contains complex movements (the movements and their definitions are presented in the Supplementary Materials, Table 1) which are executable by 6-8-year-old children. The selection criteria for the movements were that they should be motivating enough for the children to be integrated later into a game application, they should improve different motor skills after regular practice (fine and gross motor movements, arm-leg coordination, cross-side and same-side movements), and they could be either shown by a character on the mobile/tablet's screen or explained (asked) verbally. Therefore, two main types of movements were included: playful, entertaining movements (mostly mimicking movements of animals) which the child could be motivated to perform and everyday movements which (being part of a child's everyday routine) the parent would be motivated to ask from the child (e.g. taking off the shoes, washing hands).

We used different instructional methods for the playful and everyday movements. Playful movements (N=10) were shown by the experimenter, and children were asked to imitate them. In contrast, children were instructed verbally to perform everyday movements (N=24). If they were not able to carry out them then the experimenter demonstrated the actual movement. The children were asked to repeat each of them 5 times to obtain more data. Some of the movements require some equipment e.g. ball, book, building blocks, glass, spoon, snack, toothbrush, toothpaste.

Because of the covid-19 pandemic, data collection was suspended for 7 months (from March 2020 to July 2020, from March 2021 till the end of May), and even between the lockdown times few parents applied for the tests. We made huge efforts to advertise our project to the public (see Recruitment and Dissemination activities).

2.3. Video coding

In the machine learning process, the gathered data need to be labelled to establish the ground truth. To label movements videos were coded by the members of our team with a video-coding software, based on a criterion set up previously.

As the first machine learning (ML) model's validation accuracy was not appropriate (41%, see below), we applied a new coding method in which we segmented some of the movements into smaller units. We applied this new coding method on all the videos.

2.4. Detecting movement types by ML

Our first aim was to train the machine learning model to detect movement types in the typically developing sample.

We analyzed data of 34 typically developing children (19 girls; age range: 6.59 – 8.38; median age = 7.5 years).

We have preprocessed sequences of the collected inertial data. After labelling the sequences a software has cut the specific sequences and stored their data in the folder assigned to that label. Based on this process, we obtained inertial data according to the different movement types, which were the input of the AI training software we use.

The movement recognition was a binary classification task which was evaluated with a LightGBM boosted tree machine learning algorithm, with a 3-folds cross validation. We calculated accuracy and AUC (area under the curve) as indicators of performance. (The accuracy measures are provided only for comparison with similar data in the literature because we favor AUC as the main performance indicator.) We used sliding window technique during the signal processing, and we aimed to find the best window size for the analysis of each behavior unit to achieve the most effective settings.

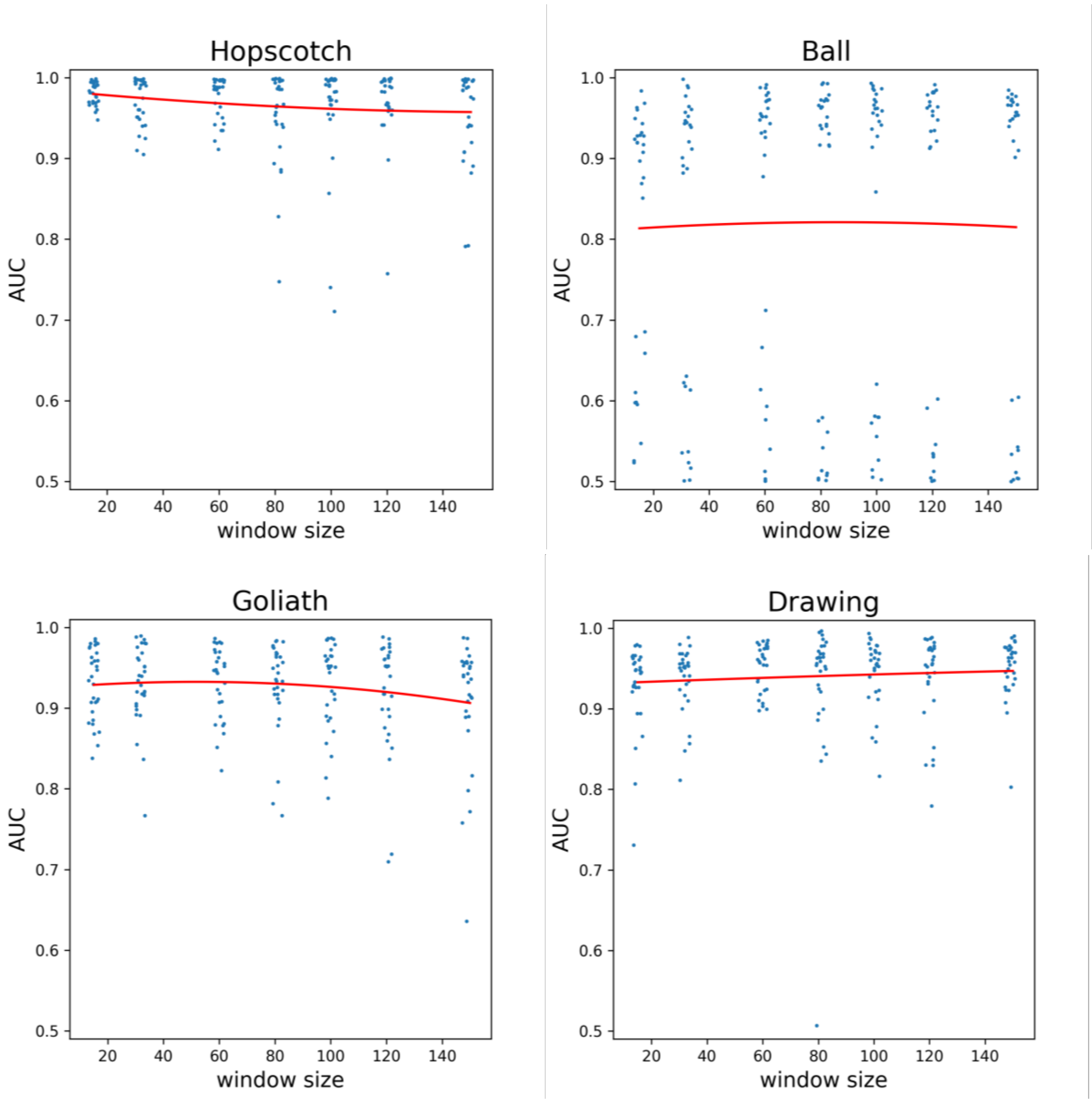
2.5. Differentiation between groups based on machine learning models

As a preliminary analysis, we tested in case of every movement, separately, whether groups differ in AUC values (ANOVAs). Based on these results, the next step will be the meta-learning phase, i.e. we train a model on the probability outputs of the best (most differentiating) classifiers (movements) in case of children of all groups, and we label these metadata with the group membership.

3. Results

3.1. Detecting movement types by ML

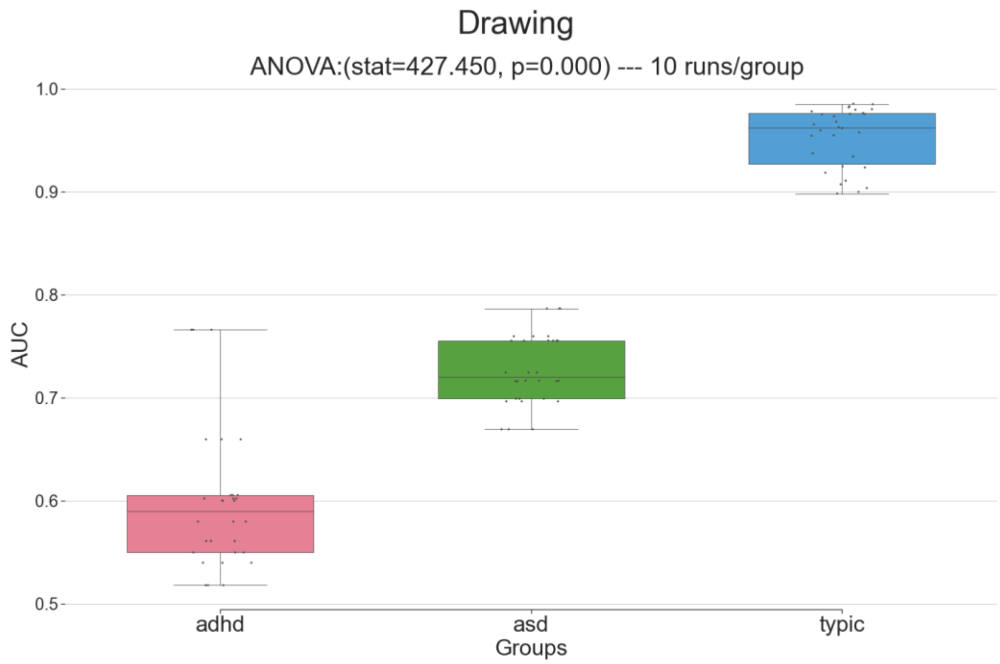
The mean classification accuracy was 0.95 ± 0.04 (M±SD) and the mean AUC (area under the curve) was 0.76 ± 0.15 (M±SD). The AUC varied from 0.5 (Shoe_off_same, Sock_off_other) to 0.98 (Hopscotch) (Table 1). The recognition was the highest (AUC > 0.9) in the case of Hopscotch, Ball, Goliath, Drawing, Crab, Swimming, Spider, Seal, Building blocks and Bear (some examples are presented in Figures 1-4.). Seventeen movements were successfully recognized with AUC values above 0.8. There was no significant effect of the window size.

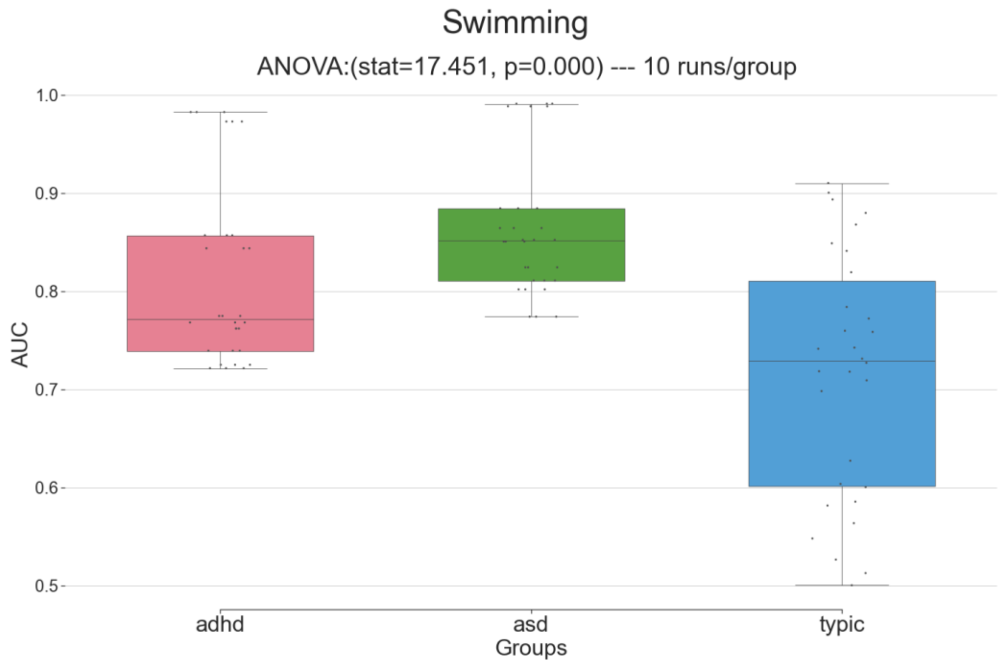


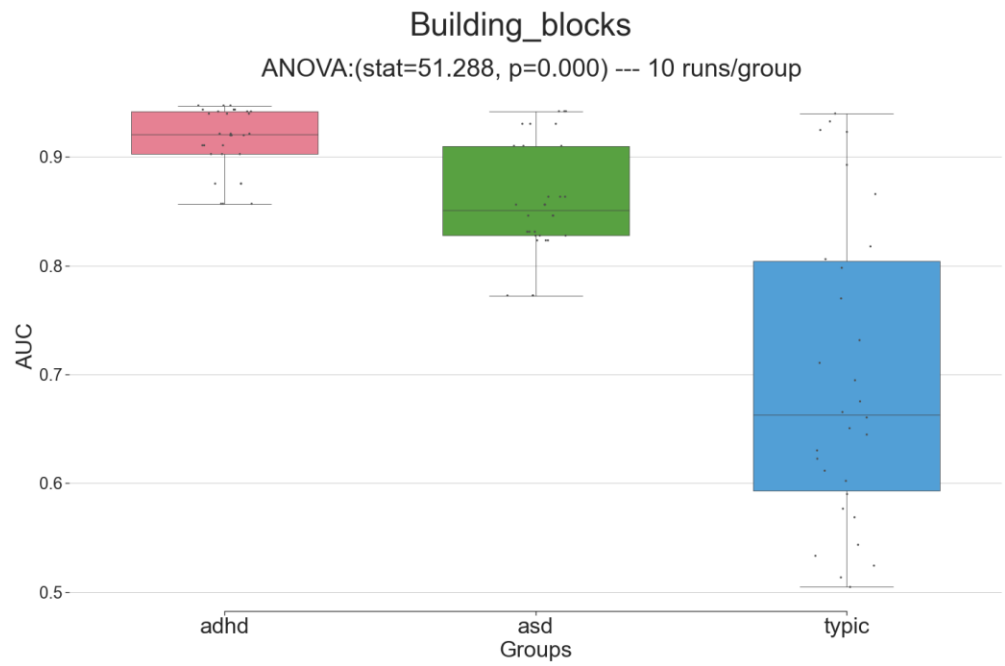
Figures 1-4: AUC values for different window sizes, presented for four movements with the highest AUC values.

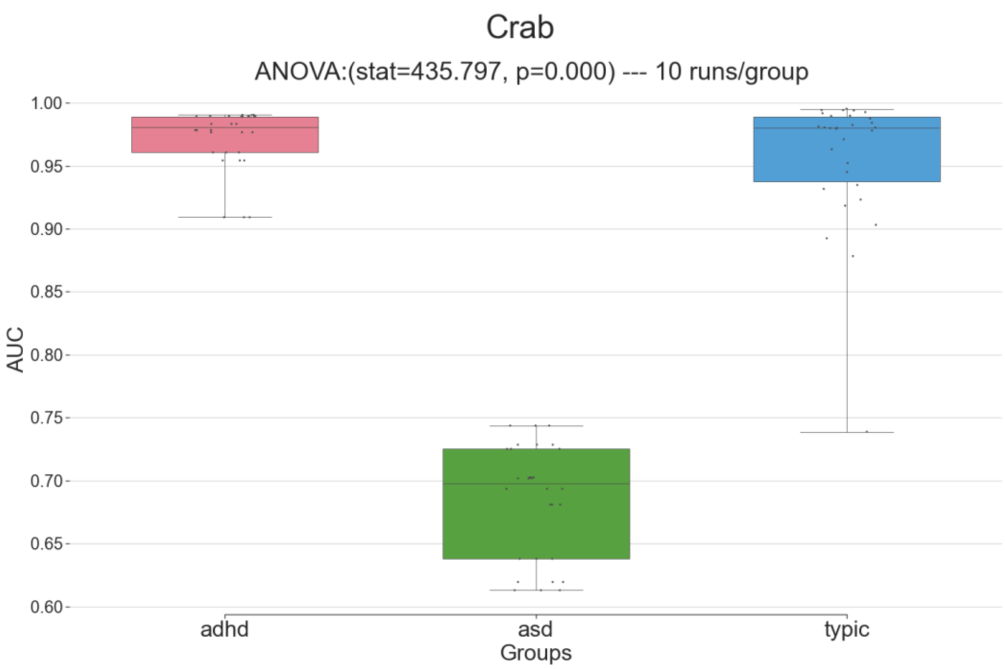
3.2. Differentiation between groups based on machine learning models

In the case of fourteen movements, the group differences were highly significant ($p<0.001$; some examples are presented in Figure 5-8).


Drawing
ANOVA:(stat=427.450, p=0.000) --- 10 runs/group
1.0
0.9
0.8
0.7
0.6
0.5
AUC
adhd
asd
typic
Groups


Swimming
ANOVA:(stat=17.451, p=0.000) --- 10 runs/group
1.0
0.9
0.8
0.7
0.6
0.5
AUC
adhd
asd
typic
Groups





Figures 5-8. AUC values (box plot) for different groups (ADHD, ASD, typically developing) in case of four movements.

4. Discussion

We found that the Light Gradient Boosted Machine (LGBM) is a very promising solution for human movement recognition. The overall accuracy was 0.95, which is at the top segment of the earlier published similar movement recognition data. Our results provide a firm basis for a more precise and effective recognition system that can make behavioral analysis of human behavior faster and more objective.

Moreover, based on this result the development of a game application became possible as the ML model integrated into the Senskid system can give feedback to the user about the accuracy of movement execution. At least the 17 movement types can be used in the application as these were identified with a very high accuracy.

Additionally, the results of our preliminary analysis to differentiate between groups (typically developing/ ASD/ ADHD) is promising: at least fourteen actions can be used to differentiate between groups by ML technology. The next step will be the meta-learning phase, i.e. we train a model on the probability outputs of these 14 classifiers in case of children of all groups, and we label these metadata with the group membership. We carry out this analysis on the current laboratory data, but afterwards we can integrate the model into the game application and collect and analyze data in home settings.

5. Additional development: movement-facilitating game application

We aimed to design a game application that motivates children to execute physical activities and improve their motor skills. This game application will be used also to collect and (with the integration of the ML model) analyze movement data and detect developmental disorders. The development of the application has not been fully finished, but many features have been developed and implemented.

In case of the playful movements, the users (children) will watch animations in which a child-friendly character (animal or enchanted character, e.g. dwarf) demonstrates the action. The IT expert in our group has designed and made the animations.

In case of the everyday actions, the users will listen to verbal instructions. These have already been recorded as audio files.

If the user cannot perform the action, he/she can watch a video with a real human demonstrator. We have recorded these demo videos in which a young woman executes the playful and everyday movements.

If the user executes the action, the application will evaluate its accuracy (based on the ML model) and give feedback to the user. Feedback will be presented via a cute, living-like emotional vocalization. As part of another project, we recorded 50 sounds (reminiscent of a living creature, but not of a specific animal species or human) produced by a young female actress. The sounds were rated by 87 participants according to what kind of emotions they felt the sounds expressed. For the present project we selected 3-3 sounds for the two emotions (happy and sad).

Besides, we built a new server-side application which can communicate with the client side and synchronize with the database stored on the central server. This improvement enables uploading new client data and new measurement data of the children on the internet. In this way, parents could connect to the program online and could share measurement data with the researchers.

6. Recruitment and dissemination activities

Recruitment is the most difficult task in such studies on a clinical population, and it became even more difficult when the pandemic burst. We made huge efforts to advertise our project

to the public. To recruit participants and share information about the project we created a webpage (https://www.alfageneracio.hu/kutatasok/asd-adhd/) and a Facebook page (https://www.facebook.com/alfageneraciolabor), where we frequently post contents to reach the target population (parents with ASD or ADHD children).
We disseminated our project also by writing an article into a popular online journal (https://divany.hu/szuloseg/2019/10/26/exergame-kutatas/?fbclid=IwAR007PSfEEFI8xCErBGUSMRT8iKffWv4nZcoKDQK1nW8OM7FKgmqjoOrM6U).
We hold a workshop on a Hungarian online program (Researchers' Night), on which almost 300 people participated:
https://www.youtube.com/watch?v=SsMtb1pMdvc&t=277s.
We also held a lecture on the same program in which we disseminated our project, this was watched by almost 600 people:
https://www.youtube.com/watch?v=8khLuJguKo0&t=235s
We compiled a video montage from our tests, which we aim to post on our Facebook page to recruit more participants (consents were obtained from parents whose children show up on the videos):
https://www.youtube.com/watch?v=Y8AGEXMVjTg&feature=youtu.be
We disseminated our project in an article at an online popular psychological magazine (Mindennapi Pszichológia Magazin):
https://mipszi.hu/cikk/200919-hagyjam-vagy-ne-hagyjam-kutyuzes-hatasa-gyerekekre
Our project helped in educating the new generation of researchers as well. Two BSc students (Zoé Farkas, Ábel Rozmán) have successfully written and defended their theses based on the results of the project.

7. Scientific publication

We presented our project two times (in 11.11.2020 and 07.07.2021) at the professional days of the ELTE Thematic Excellence Programme supported by the National Research, Development and Innovation Office (TKP2020-IKA-05):
https://www.youtube.com/watch?v=WBY-E1KAtTs&list=PLgRcdsdBKBDIsjNnMQnJPgkNJAzzPrLlO&index=13
We gave a presentation about our results at a prestigious international conference (Budapest CEU Conference on Cognitive Development 2021): http://bcccd.org/program-overview.htm (Session 5)

We submitted our manuscript on the results of the movement detection study to Biologia Futura:

Csizmadia, G., Liszkai-Peres, K., Ferdinandy, B., Miklósi, Á., Konok, V. (submitted) Human Activity Recognition of children with wearable devices using LightGBM machine learning. *Biologia Futura*.

8. References

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Table 1 The Budapest Movement Test Battery (BMTB)

Movement name	Description	Sequence	Movement type
hopscotch	alternating hopping on single leg and double leg on a hopscotch ground	one jump (from bouncing off till arriving)	playful
ball	throwing and catching a ball	from preparing to throw (hand rising) till catching the ball	everyday
goliath	walking on the toes, hands stretched upwards	from the first step till the last step; if child stops coding is paused	playful
drawing	drawing with a pencil on a paper	as the pencil touches the paper till lifting up the pencil	playful
crab	crawling backward (hands stretched, legs bent, chest upwards)	from the first step till the last step; if child stops coding is paused	playful
swimming	lying on stomach, hands moving around like swimming	from the first hand movement till end of the last	playful
spider	crawling forward (hands stretched, legs bent, chest upwards)	from the first step till the last step; if child stops coding is paused	playful
seal	legs and hips on the ground, hands stretched, moving only by using hands	from the first step till the last step; if child stops coding is paused	playful
building blocks	building a tower from 5 building blocks (coding only when the action is done with the hand smartwatch on it, and only if building a horizontal tower)	from reaching towards a cube till putting it onto another cube	everyday
bear	crawling forward (hands stretched, legs bent, chest downwards)	from the first step till the last step; if child stops coding is paused	playful
light off	turning off the light, then releasing hands	from lifting hand till the hand is next to the body in the start position	everyday

dwarf	walking in squat position	from the first step till the last step; if child stops coding is paused	playful
rabbit	legs between hands, first moving forward hands, then jumping with legs	begins with hand stretching, ends with completing the jump	playful
book	turning pages in a book	from grasping a page till releasing it	everyday
nose	touch nose	from reaching towards nose till releasing it	everyday
light on	turning on the light, then releasing hands	from lifting hand till the hand is next to the body in the start position	everyday
door handle	grabbing door handle, pushing down, releasing hands	from lifting hand till releasing the door handle	everyday
peck	peck the skin on the back of the hand	from reaching towards the hand till releasing it	everyday
frog	jumping with open legs, hands in the air beside the body	from moving upward till arriving to the lowest point	playful
glass grabbing	grabbing a glass	from reaching glass till grabbing	everyday
pudding eat	eating a pudding	one mouthful, from putting spoon into the mouth till moving it away from mouth	everyday
clapping	clapping hands	from approximating hands till start position	everyday
drinking	drinking from a glass	from touching mouth with the glass till releasing it	everyday
glass lifting	lifting a glass	from grabbing till lifting the upmost point	everyday
sock on (same side)	put on socks	from grasping a sock till the sock is on the foot	everyday
sock on (other side)	put on socks	from grasping a sock till the sock is on the foot	everyday
toothbrush (other)	put toothpaste on to the toothbrush	from grabbing toothbrush and toothpaste till finishing putting toothpaste on the toothbrush	everyday

hand wash	washing hands	from rubbing hands till hands are under water	everyday
snack eat	eating a snack	one bite, from putting snack into the mouth till moving away from mouth	everyday
knee (same)	touch knee	from reaching towards knee till releasing it	everyday
knee (other)	touch knee	from reaching towards knee till releasing it	everyday
shoe on (same side)	put on shoes	from grasping a shoe till the shoe is on the foot	everyday
pray	hands together in pray style	from approximating hands till releasing them	everyday
toothbrush (same)	put toothpaste on to the toothbrush (same: pushing toothpaste with the hand smartwatch on it)	from grabbing toothbrush and toothpaste till finishing putting toothpaste on the toothbrush	everyday
glass to mouth	lifting glass to the mouth	from lifting glass to the mouth till it touches the mouth	everyday
shoe off (other side)	take off shoes, opposite side of the body relative to the hand with the smartwatch	from grasping a shoe till the shoe is off the foot	everyday
shoe on (other side)	put on shoes	from grasping a shoe till the shoe is on the foot	everyday
sock off (same side)	take off socks	from grasping a sock till the sock is off the foot	everyday
sock off (other side)	take off socks	from grasping a sock till the sock is off the foot	everyday
shoe off (same side)	take off shoes, same side of the body relative to the hand with the smartwatch	from grasping a shoe till the shoe is off the foot	everyday