Netychords: An Accessible Digital Musical Instrument for Playing Chords using Gaze and Head Movements

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Abstract: Research on Accessible Digital Musical Instruments (ADMIs) dedicated to users with motor disabilities, facilitated by the introduction of new sensors on the mass market during the last decades, has carved out an important niche within the scenario of new interfaces for musical expression. Among these instruments, Netytar, developed in 2018, is a hands-free ADMI enabling the performance of monophonic melodies, controlled using the gaze (for the selection of the notes) and the breath (for the control of the dynamics), through an eye tracker and an ad-hoc breath sensor. In this article we propose Netychords, a Netytar extension developed to allow a quadriplegic musician to play chords. The instrument is controlled using gaze and head movement. A head tracking paradigm is used to control chord strumming, through a cheap ad-hoc built head tracker. Interaction methods and mappings are discussed, along with a series of experimental chord keys layouts, problems encountered and planned future developments.

1 INTRODUCTION

Other than being an engaging activity, playing a musical instrument can improve one's cognitive abilities (Jaschke et al., 2013), contribute to their health (Stensæth, 2013) and the social aspects of their life (Costa-Giomi, 2004). The right of participating to cultural and artistic activities in the society is recognized by the Declaration of the Human Rights (United Nations, 2015). Despite the developments in interfaces for musical expression and accessibility research, people with motor disabilities often have various difficulties in participating in musical activities, such as playing an instrument. A quadriplegic disability hinders the control of hands and feet, necessary to play most of the instruments and music interfaces designed for able-bodied users. According to a World Health Organization report, spinal cord injuries affect between 250,000 and 500,000 people worldwide on average every year (World Health Organization, 2013). Accessible Digital Musical Instruments (ADMIs) are able to extend or transcend the creative possibilities offered by traditional musical instruments, providing interaction based on unconventional physical interaction channels. In the literature, a few instruments are found dedicated to this niche of motor disability. A recent survey (Davanzo and Avanzini, 2020c) is dedicated to their design and analysis. Such instruments can exploit alternative interaction channels available from the neck upwards: eyes and eyebrows, mouth and related facial muscles, head movement and neck tension, brain activity detected via electroencephalogram. In this article we propose Netychords, an ADMI and MIDI controller which allows the performance of chords through two of the listed channels: gaze, which is used for chord selection, and head movement, used to perform strumming. The instrument is inspired by Netytar, an ADMI presented and discussed in (Davanzo et al., 2018) and (Davanzo and Avanzini, 2020d), designed to perform monophonic melodies, controlled through gaze (again for notes selection) and breath (which controls notes dynamics and note on/off events). Netychords could complement it in collective musical performance. As we will see in Sec. 2, a small amount of instruments dedicated to quadriplegic users found in literature allow to play chords, thus Netychords could fill that niche. We will discuss the related state of the art in Sec. 2, the current implementation of Netychords in Sec. 3, and its main design-related aspects in Sec. 4. Finally, we will discuss problems as well as future work, testing and evaluation in Sec. 5.

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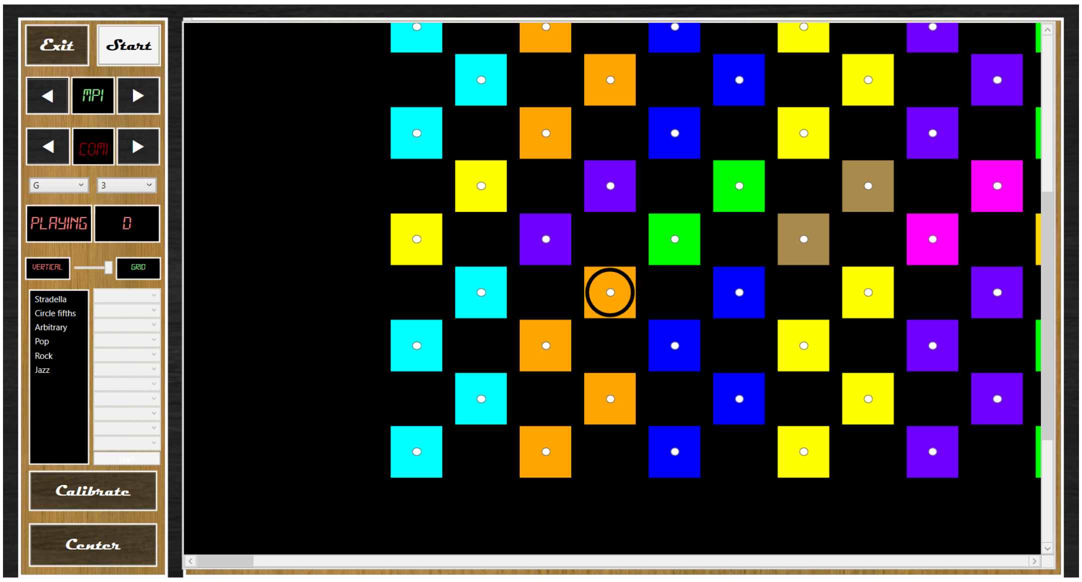

Figure 1: Netychords interface. On the left, options such as layout selection and customization, sensors calibration and customization are present. The layout of the virtual keyboard is drawn on the right.

2 RELATED WORKS

The aforementioned work (Davanzo and Avanzini, 2020c) analyzes 15 musical instruments operable by people with quadriplegic disability. Only 6 of these seem to allow the performance of chords, with various degrees of versatility. (Frid, 2019) proposes an analysis of general accessible musical interfaces in the state of the art, dividing them into 10 categories. Of the 83 instruments analyzed, only 2 fall in the gaze-based category, suggesting how this interaction channel can still be exploited. One further survey (Larsen et al., 2016) lists 16 musical applications (performance instruments, sequencers, video games and more) which can be operated by people with different types of disabilities.

Head tracking and eye tracking are widely consolidated as interaction channels for accessible applications. Their use in selection tasks have been recently evaluated and compared through Fitts' Law tests (Davanzo and Avanzini, 2020b), showing that gaze pointing is particularly fast and fairly stable, especially if the eye tracker data stream is filtered, while head movement is slightly slower but has excellent stability. However, it has also been demonstrated that a maximum limit of physiologically possible saccadic eye movements per second can be obtained (Hornof, 2014), which potentially hinders the performance of fast sequences. This limit is potentially more important if gaze is used for notes selection while performing melodic lines, whereas for chord changes it could be sufficiently fast. While precise eye tracking requires a dedicated peripheral, head tracking has been exploited for accessibility purposes (e.g. to navigate tablets) also through integrated cameras (Roig-Maimó et al., 2016). However, for Netychords we preferred to use a wearable peripheral in order to improve tracking precision. Head tracking was also used to control and direct wheelchairs: a review on the topic is proposed by (Leaman and La, 2017). Head motion peculiarities from a physiological point of view have also been extensively studied (Sarig-Bahat, 2003).

As already stated, some ADMIs dedicated to quadriplegic people already allow to play chords. Tongue-Controlled Electro-Musical Instrument (Niikawa, 2004) consists of a PET board mounted on the palate. Using the tongue it is possible to press one of the buttons, arranged in a cross shape, to play the corresponding chord. Eye Play The Piano is a gaze-based interface which allows to control a real piano through actuators placed on the keyboard. Although the instrument is not described in any scientific publication, the material available on the official website (Fove Inc., nd) shows that it is possible to customize the interface to play chords. Jamboxx (Jamboxx, nd) is an ADMI bearing similarities to a digital harmonica: a cursor moved using the mouth along a continuous horizontal axis is mapped to pitch selection. Although no scientific publication on the istrument is available, as with the previous one, it seems that it is possible to play chords. The EyeHarp (Vamvakousis and

Ramirez, 2016) is controlled entirely by gaze. Keys are arranged in a pie shape. In the described prototype it is possible to build arpeggios through a sequencer layer, then use some of the circularly arranged keys to trigger chord changes. Those will be played continuously in the background following the defined arpeggio pattern at a fixed tempo. P300 Harmonies (Vamvakousis and Ramirez, 2014) is an electroencephalogram based interface that allows to generate and edit arpeggios live in a simplified way, by editing a 6-note loop.

Only two ADMIs found in the literature are controlled through head tracking. In Hi Note (Matossian and Gehlhaar, 2015), head movements are tracked to move a cursor over a virtual keyboard having a special layout. Breath is used to control notes dynamics. It is unclear if chords performance is possible. Clarion (Open Up Music, nd) is an ADMI whose layout can be customized according to the musical piece to be played, drawing colored keys of various sizes. It is controllable using touch screen, gaze point or head tracking, according on the setup. In both Clarion and Hi Note, head movement is used to control a cursor and is mapped to note selection.

Netychords is somehow related to a guitar: in both instruments, notes selection and strumming are controlled by two different channels (the two hands in the guitar, gaze and head movement in Netychords). Some guitar-inspired ADMIs, in the form of augmented instruments or novel interfaces, are already present in the literature, though not operable by a quadriplegic user. The Actuated Guitar (Larsen et al., 2013; Larsen et al., 2014), for example, consists of a guitar adapted for by people with hemiplegic paralysis. The able hand is placed on the neck, while a pedal controls an actuator capable of plucking the strings. Strummi (Harrison et al., 2019) is an instrument relatively similar to a digital guitar, which allows the performance of chords, designed for partial motor disabilities.

3 NETYCHORDS IMPLEMENTATION

Netychords interface is depicted in Fig. 1. The idea for its implementation stems from a general lack in the literature of polyphonic instruments (i.e., able to play chords) dedicated to users with severe motor disabilities. As an example, the aforementioned EyeHarp (Vamvakousis and Ramirez, 2016) allows for the performance of chords only in diatonic logic and using predefined rhythmic patterns. Netychords shares with Netytar the use of the gaze point to perform notes selection. However, while Netytar exploits breath to control note dynamics, Netychords exploits head movement to perform note strumming events, which actually trigger a group of notes at the same time. The instrument is operable through low cost sensors. It has been developed using a Tobii 4C eye tracker, which features 90 Hz image sampling rate through near infrared illuminators (NIR 850nm)[1]. We built an ad-hoc head tracker using an MPU-6050/GY-521 accelerometer/gyroscope and an Arduino Uno microcontroller, both mounted on an headphone set, interfaced via USB port and featuring a ∼100 Hz sampling rate. The device is depicted in Fig. 2. The Netychords code is available[2] under the Open-Source GNU GPL V3 license. A demo video of the instrument is linked in the GitHub *Readme*.

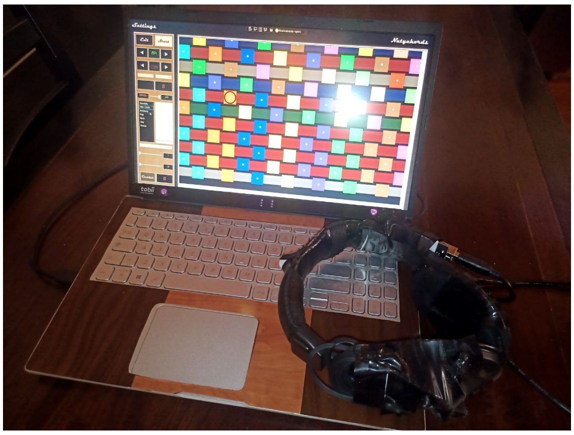

Figure 2: Netytar running on a laptop, equipped with Tobii 4C and the ad-hoc build head tracker.

3.1 Chord Selection

Gaze point is used to navigate a virtual keyboard, having differently colored keys to indicate different chords. Each color corresponds to a different root note, while different color shades indicate different chord types. Six different layouts have been implemented in the current iteration, allowing the user to choose the most suitable for their performance. Each key is assigned a square shaped gaze sensitive area (*occluder*). Given the noisiness of the eye tracker signal, there is a trade-off between selection accuracy and length of movement required. For this reason, most of the implemented layouts have two display modes having different distances between keys:

[1] Tobii 4C eye tracker: https://help.tobii.com/hc/en-us/articles/213414285-Specifications-for-the-Tobii-Eye-Tracker-4C

[2] Netychords on GitHub: https://github.com/LIMUNIMI/Netychords/

square grid (Fig. 2, 3, 4 and 5) or slanted (Fig. 1). The reader can use Table 1 as a reference for the chords named below. The implemented layouts are the following:

- **Stradella.** It is inspired by the Stradella bass system (Balestrieri, 1979), used in some italian accordions, which arranges the chords using the circle of fifths. While each column of keys corresponds to the same root note, each row corresponds to a different family of chords, as shown in Fig. 3. The original Stradella includes 4 chord families. In Netychords these have been extended to 11: major, minor, dominant 7th, diminished 7th, major 7th, minor 7th, dominant 9th, dominant 11th, suspended 2nd, suspended 4th and half-diminished 7th.
- **Simplified Stradella.** Since the original Stradella bass system is designed for a fingered keyboard, the distance between the keys could be disadvantageous for gaze based interaction. In this simplified version, all the chords from Tab. 1 have been grouped into 5 families (major, minor, dominant, diminished and half-diminished). While maintaining the circle of fifths rule for horizontal movements (each key is incremented by seven semitones from the previous one), the first chord of each row is different according to the chord family. Taking as fundamental the first major chord (for example, a C chord), the minor chords row starts from the VI degree of the major scale (relative minor, therefore in the example an A chord), the dominant sevenths start from the V degree (in our example, a G chord), the diminished rows follows the same arrangement as the major one while the half-diminished rows starts from the VII degree (in the example, a B chord). Fig. 4 shows how, with this arrangement, chords belonging to an harmonized diatonic scale are kept close together, resulting in less eye movement required to play musical pieces in a single key. Diatonic scale harmonization is resumed in Tab. 2. By removing rows from this layout, three simplified genre-specific presets have been obtained, potentially useful for playing pop, rock and jazz music. In the *jazz* preset, for example, the major and minor chords are replaced with major 6th and minor 6th chords, following the indications of Pino Jodice, jazz pianist (Jodice, 2017), thus keeping close the grades listed in Tab. 2 (right half). The *rock* preset instead contains only major, minor (thus keeping close the degrees described in the left half of Tab. 2), dominant 7th, suspended 2nd and suspended 4th chords. The user is also able to create a new custom layout selecting which chord rows to include, and in which order.

Table 1: Intervals describing each type of chord present in Netychords. Colors reflects the chord families subdivision implemented in the Simplified Stradella layout: major (red); minor (blue); dominant (green); diminished (orange); half-diminished (gray).

Suffix	Chord name	Intervals (degrees)	Sample C-chord
-	Major	1, 3, 5	C-E-G
min	Minor	1, ♭3, 5	C-E♭-G
maj6	Major 6th	1, 3, 5, 6	C-E-G-A
min6	Minor 6th	1, ♭3, 5, 6	C-E♭-G-A
maj7	Major 7th	1, 3, 5, 7	C-E-G-B
min7	Minor 7th	1, ♭3, 5, ♭7	C-E♭-G-B♭
7	Dominant 7th	1, 3, 5, ♭7	C-E-G-B♭
o7	Diminished 7th	1, ♭3, ♭5, 𝄫7	C-E♭-G♭-A
ø7	Half-dimin. 7th	1, ♭3, ♭5,♭7	C–E♭–G♭–B♭
sus2	Suspended 2nd	1, 2, 5	C-D-G
sus4	Suspended 4th	1, 4, 5	C-F-G
9	Dominant 9th	1, 3, 5, ♭7, 9	C-E-G-B♭-D
11	Dominant 11th	1, 3, 5, ♭7, 9, 11	C–E–G–B♭–D–F

Table 2: Harmonized diatonic major scale pattern used in Netychords. On the left, harmonization with 3 notes per chord; on the right, harmonization with 4 or more notes per chord. Degrees are provided using jazz notation.

3 notes / chord		4+ notes / chord	
Degree	**Example**	**Degree**	**Example**
I	C	I	Cmaj7
ii	Dmin	ii	Dmin7
iii	Emin	iii	Emin7
IV	F	IV	Fmaj7
V	G	V7	G7
vi	Amin	vi	Gmin7
vii	Bmin	$vii^{ø7}$	$B^{ø7}$

- **Flowerpot.** This layout has a completely different structure from the previous ones. The keyboard is divided into groups of 5 keys arranged in a cross, called *flowers*. A *major flower* is red; the middle key is mapped to a natural major chord, while the other keys are mapped to dominant 7th, major 7th, major 6th and suspended 4th chords. A *minor flower* is blue; the central key is mapped to a natural minor chord, while the other keys are mapped to minor 7th, minor 6th, diminished 7th and half-diminished chords. Flowers are grouped in proximity to each other, obtaining a square grid tessellation without empty spaces. After selecting the tonal center, the central flower will correspond to the I degree of the harmonized diatonic major scale, while the adjacent flowers, arranged in a circle, will cover the other degrees (again according to the scheme shown in Fig. 5). This layout could therefore be practical for playing songs without key changes.

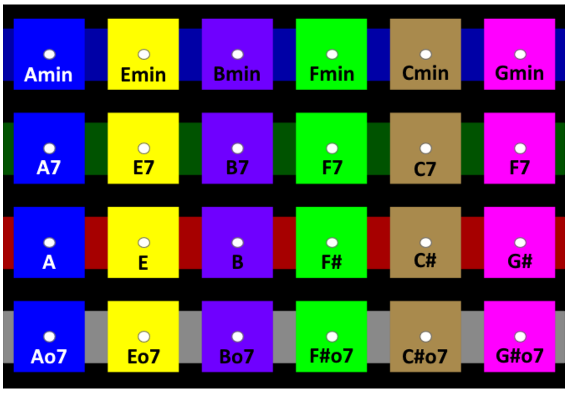

Figure 3: A four rows/six chords detail of the Stradella layout implementation. Chord labels are not visible while playing.

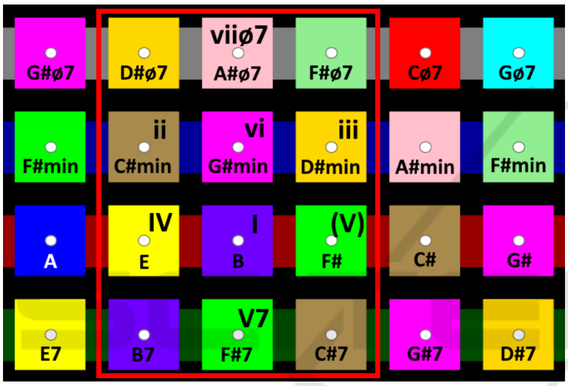

Figure 4: A four rows/six chords detail of the Simplified Stradella layout implementation. Keys belonging to the diatonic harmonization of the B major scale (labels indicate the various degrees) are enclosed in the red square. All the labels are not visible while playing.

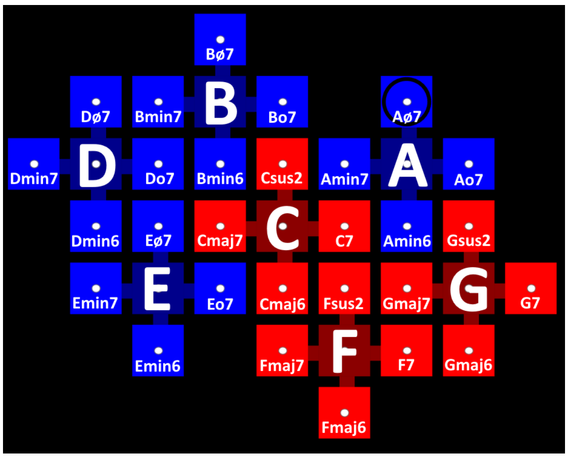

Figure 5: Current implementation of the Flowerpot layout with C as root note. Labels are not visible while playing.

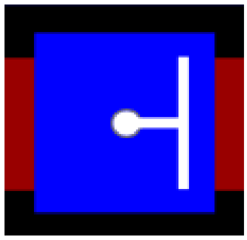

Figure 6: Head position feedback handle (in white).

For most of the layouts, keys cannot all be shown within the application window, due to the size of the screen and because too small keys would be difficult to select using gaze pointing. Netychords therefore implements the same autoscrolling system as Netytar (Davanzo et al., 2018), which smoothly moves the fixated key to the center, taking advantage of the "smooth pursuit" capabilities of the eyes (Majaranta and Bulling, 2014). Octave choice is based on "reed" selectors (recalling again the Stradella accordion), to reduce the number of keys drawn on the screen.

3.2 Strumming

Chords strumming (traslated into MIDI note on/off events and velocities) is controlled through head tracking. Here we discuss the strumming modality implemented for Netychords, which to our knowledge has not been previously proposed in the literature of digital musical instruments.

Head rotations on the horizontal axis (yaw) are tracked. A strum occurs when a change in rotation direction is detected. A MIDI velocity value (which in turn determines the resulting sound intensity) is generated as a proportional value to the angle described by the head with respect to a center position (calibrated before playing), where the proportionality factor is adjustable through a slider. In order to actually trigger a new strum (i.e., to generate a MIDI note on event), it is necessary to pass through a central zone called *deadzone*, defined around 0°. The deadzone has an adjustable size, within which changes in direction are not detected.

Visual feedback of head rotation is given directly on the key that is being fixated, through a white handle whose width corresponds to the head rotation angle with respect to the center, which is indicated by a white dot, as depicted in Fig. 6.

A known problem to face when designing gaze-based interfaces is that of *Midas Touch* (Majaranta and Bulling, 2014), namely the involuntary activation of interface elements (e.g. keys) when these are crossed by gaze trace. In previous works, different gaze controlled instruments addressed the problem in

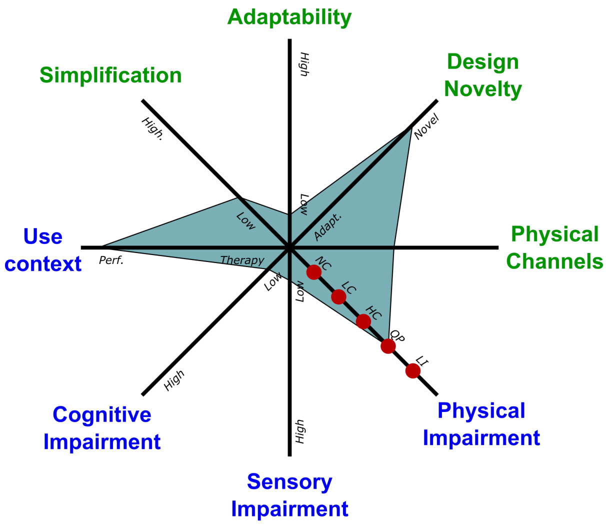

Figure 7: The main design aspects of Netychords, visualized on a dimension space for the evaluation of ADMIs (Davanzo and Avanzini, 2020a).

different ways. In Netychords the Midas Touch is to an extent solved by design, as notes are triggered by strumming and head movements, rather than fixations. Therefore, notes are let ring until a new strum action is detected regardless of gaze moving to other keys. In addition, neutral areas between occluders are also placed. To trigger chord stops (pauses), eye blinking is exploited. By closing both eyes for a sufficiently long period (corresponding to 4-5 samples of the eye tracker data stream, adjustable) the sound is stopped.

4 DISCUSSION

We will discuss in this section some notable properties of the instrument design, as well as the rationale behind the outlined design choices. (Davanzo and Avanzini, 2020a) proposed an 8-axis “dimension space”, inspired by (Birnbaum et al., 2005) for the evaluation of the general characteristics of ADMIs. This dimension space can be useful for summarizing and visualizing Netychords features.

The *Simplification* axis indicates which degree of simplification was introduced to enable less trained musicians (or to make up for some deficits) through the introduction of specific aids. In Netychords, no layout allows the selection of the single notes in a chord, differently from most polyphonic acoustic instruments. This however translates into a potential gain in ease of use and could be considered an aid. Apart from this, no other aids have been introduced. Playing aids like strumming temporal quantization could be introduced for facilitating the learning process.

Hence, the *Use context* is more oriented towards performance. According to McPherson et al. (McPherson et al., 2019), there is a clear distinction between performance interfaces, dedicated to skilled users, and musical interfaces dedicated to music therapy, usually simplified to be usable without prior music training. Netychords is thought to belong to the performance category, as it does not offer particular performance aids. It is a complex instrument requiring training to be mastered.

The *Design Novelty* axis indicates whether an ADMI resembles the design of a traditional musical instrument or departs from such traditional designs. Although Netychords differs from any acoustic instrument, some similarities can be found with accordions, with particular regard to the octave management system, the reed system and the Stradella Layout.

The usability and the expressivity of an instrument are largely affected by the amount of *Physical Channels* that the user can employ in the interaction. Netychords uses two channels, namely head movement and gaze pointing. This choice is the result of a trade-off between expressivity (as an example, no continuous control on the emitted chord is possible after it has been triggered) and usability (with particular regard to the Midas Touch problem discussed earlier). Although the two interaction channels are largely independent from each other, the eye tracker can only tolerate a certain degree of head rotation. We found that a head rotation angle of about 30 degrees is sufficient to strum at different intensities without compromising gaze detection.

The dimension space clusters categories of impairments into three main axes: physical, cognitive, sensory (or perceptual), and classifies target user groups along these three categories, also considering that physical, sensory, and cognitive impairments are often intertwined due to the multidimensional character of disability. Although Netychords is potentially usable by a quadriplegic user, the head movement required makes it incompatible with the maximum degree of the discrete *Physical Impairment* scale (*LI*, or Lock-In syndrome, characterized by the possibility of move your eyes only). Instead it falls into the *QP* (Quadriplegic Paralysis) level.

Future iterations of the instrument may however include the choice for new input methods. Blink based strumming could be tested for users with difficulties in rotating the head. This could influence and improve the actually low *Adaptability* of the instrument, namely the possibility to adapt to the individual user needs. *Sensory* and *Cognitive Impairments* are instead not addressed by Netychords.

5 CONCLUSIONS

We have presented the first iteration in the design and implementation of a polyphonic ADMI, Netychords. Future work will be mainly addressed at evaluation with target users, in order to guide subsequent iteration of the instrument design.

One primary element of evaluation concerns an in-depth study of new key layouts and a comparative study of existing ones. Representing a large amount of chord families on the screen requires a great number of keys. We plan to experiment with separating, among different interaction channels, root note selection and chord type selection. Different head rotation axes (or different angles) could for example correspond to different chords (e.g. major, minor).

The proposed strumming modality also needs thorough evaluation, and may be further extended to allow for more expressive interaction. In the current prototype, chords notes are played all in the same time while strumming. A method for sequential note strumming (arpeggio) could be implemented, in a similar fashion as guitar strings, by subdividing the head rotation interval. Strumming can be good for simulating plucked instruments or piano. Continuous intensity detection could be implemented, suitable for playing strings, for example evaluating head rotation velocity for each sample.

Evaluating a musical instrument from an objective point of view is a complex task. (O'Modhrain, 2011) proposes a framework for the evaluation of Digital Musical Instruments from the perspective of the various stakeholders (performer/composer, designer, manufacturer and audience), consisting in a set of parameters to be evaluated. (Vamvakousis and Ramirez, 2016) for example implemented this framework for the evaluation of The EyeHarp from the point of view of the audience through questionnaires submitted to the attendees of a concert. As O'Modhrain highlights, being able to trace a link between the performer's motion and the perceived sound is a very important element for the audience to appreciate a live performance, and this is a concern for gaze based interfaces since movements are very subtle. Head rotation in Netychords could be a way to convey the expressive intention.

Interaction in both Netytar (Davanzo et al., 2018) and EyeHarp (Vamvakousis and Ramirez, 2016) has been evaluated quantitatively, also from a precision and accuracy point of view, through the recording of simple musical exercises in order to measure timing errors and number of wrong notes. We feel however that a comparative evaluation between Netychords and another instrument could be difficult to make since all the instruments listed in Sec. 2 offer a different degree of control of the chords performance.

The COVID-19 pandemic has so far prevented testing Netychords with target users. We thus conclude by discussing a test procedure for Netychords we intend to carry out in the future. This is similar to the one used for Netytar's evaluation (leaving aside the comparison phase). A sample of at least 25-30 individuals, possibly with musical experience, will be recruited. A *training phase* of at least 20 minutes will provide a minimum of familiarity with the instrument and the proposed interaction methods; a *practical test* will involve the performance of musical exercises (or songs), and the performance will be recorded as a MIDI track and analyzed later. We intend to detect elements such as error rates, strumming and chord change speed, as well as the flexibility of the various layouts in allowing chord changes between distant keys; a *qualitative test* will include a questionnaire with general questions on the usability of the system. Elements such as perceived fatigue, degree of naturalness and simplicity of interaction and interface clarity will be detected. Case studies should be also carried out with musicians having physical (quadriplegic) disabilities.

Another session could be devoted solely to testing the proposed head-based interaction method. While the movement precision and stability have already been discussed in other experiments (Davanzo and Avanzini, 2020b), it would be useful to detect through recorded exercises the head's rhythmic capabilities, namely the relationship between precision and speed/frequency of head strums.

REFERENCES

Balestrieri, D. (1979). Accordions Worldwide. *Accord Magazine, USA*.

Birnbaum, D., Fiebrink, R., Malloch, J., and Wanderley, M. M. (2005). Towards a Dimension Space for Musical Devices. In *Proc. Int. Conf. on New Interfaces for Musical Expression (NIME'05)*, pages 192–195, Vancouver, BC, Canada.

Costa-Giomi, E. (2004). Effects of Three Years of Piano Instruction on Children's Academic Achievement, School Performance and Self-Esteem. *Psychology of Music*, 32(2):139–152.

Davanzo, N. and Avanzini, F. (2020a). A Dimension Space for the Evaluation of Accessible Digital Musical Instruments. In *Proc. 20th Int. Conf. on New Interfaces for Musical Expression (NIME '20)*, NIME '20.

Davanzo, N. and Avanzini, F. (2020b). Experimental Evaluation of Three Interaction Channels for Accessible Digital Musical Instruments. In *Proc. '20 Int. Conf. on Computers Helping People With Special Needs*, pages 437–445, Online Conf. Springer, Cham.

Davanzo, N. and Avanzini, F. (2020c). Hands-Free Accessible Digital Musical Instruments: Conceptual Framework, Challenges, and Perspectives. *IEEE Access*, 8:163975–163995.

Davanzo, N. and Avanzini, F. (2020d). A Method for Learning Netytar: An Accessible Digital Musical Instrument:. In *Proceedings of the 12th International Conference on Computer Supported Education*, pages 620–628, Prague, Czech Republic. SCITEPRESS - Science and Technology Publications.

Davanzo, N., Dondi, P., Mosconi, M., and Porta, M. (2018). Playing music with the eyes through an isomorphic interface. In *Proc. of the Workshop on Communication by Gaze Interaction*, pages 1–5, Warsaw, Poland. ACM Press.

Fove Inc. (n.d.). Eye Play the Piano. http://eyeplaythepiano.com/en/.

Frid, E. (2019). Accessible Digital Musical Instruments—A Review of Musical Interfaces in Inclusive Music Practice. *Multimodal Technologies and Interaction*, 3(3):57.

Harrison, J., Chamberlain, A., and McPherson, A. P. (2019). Accessible Instruments in the Wild: Engaging with a Community of Learning-Disabled Musicians. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, CHI EA '19, pages 1–6, New York, NY, USA. Association for Computing Machinery.

Hornof, A. J. (2014). The Prospects For Eye-Controlled Musical Performance. In *Proc. 14th Int. Conf. on New Interfaces for Musical Expression (NIME'14)*, NIME 2014, Goldsmiths, University of London, UK.

Jamboxx (n.d.). Jamboxx. https://www.jamboxx.com/.

Jaschke, A. C., Eggermont, L. H., Honing, H., and Scherder, E. J. (2013). Music education and its effect on intellectual abilities in children: A systematic review. *Reviews in the Neurosciences*, 24(6):665–675.

Jodice, P. (2017). *Composizione, Arrangiamento e Orchestrazione Jazz. Dalla Formazione Combo Alla Big Band — Volume I*, volume 1 of *Manuali e Saggi Di Musica*. Morlacchi Editore.

Larsen, J. V., Overholt, D., and Moeslund, T. B. (2013). The Actuated Guitar: A platform enabling alternative interaction methods. In *Proceedings of the Sound and Music Computing Conference 2013 (SMC 2013)*, pages 235–238. Logos Verlag Berlin.

Larsen, J. V., Overholt, D., and Moeslund, T. B. (2014). The Actuated Guitar: Implementation and User Test on Children with Hemiplegia. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 60–65. Goldsmiths, University of London.

Larsen, J. V., Overholt, D., and Moeslund, T. B. (2016). The Prospects of Musical Instruments For People with Physical Disabilities. In *Proc. 16th Int. Conf. on New Interfaces for Musical Expression*, NIME '16, pages 327–331, Griffith University, Brisbane, Australia. NIME.

Leaman, J. and La, H. M. (2017). A Comprehensive Review of Smart Wheelchairs: Past, Present, and Future. *IEEE Transactions on Human-Machine Systems*, 47(4):486–499.

Majaranta, P. and Bulling, A. (2014). Eye Tracking and Eye-Based Human–Computer Interaction. In Fairclough, S. H. and Gilleade, K., editors, *Advances in Physiological Computing*, Human–Computer Interaction Series, pages 39–65. Springer, London.

Matossian, V. and Gehlhaar, R. (2015). Human Instruments: Accessible Musical Instruments for People with Varied Physical Ability. *Annual Review of Cybertherapy and Telemedicine*, 219:202–207.

McPherson, A., Morreale, F., and Harrison, J. (2019). Musical Instruments for Novices: Comparing NIME, HCI and Crowdfunding Approaches. In Holland, S., Mudd, T., Wilkie-McKenna, K., McPherson, A., and Wanderley, M. M., editors, *New Directions in Music and Human-Computer Interaction*, pages 179–212. Springer International Publishing, Cham.

Niikawa, T. (2004). Tongue-Controlled Electro-Musical Instrument. In *Proc. 18th Int. Congr. on Acoustics*, volume 3, pages 1905–1908, International Conference Hall, Kyoto, Japan. Acoustical Society.

O'Modhrain, S. (2011). A Framework for the Evaluation of Digital Musical Instruments. *Computer Music Journal*, 35(1):28–42.

Open Up Music (n.d.). Clarion. https://www.openupmusic.org/clarion.

Roig-Maimó, M. F., Manresa-Yee, C., Varona, J., and MacKenzie, I. S. (2016). Evaluation of a Mobile Head-Tracker Interface for Accessibility. In Miesenberger, K., Bühler, C., and Penaz, P., editors, *Computers Helping People with Special Needs*, Lecture Notes in Computer Science, pages 449–456, Cham. Springer International Publishing.

Sarig-Bahat, H. (2003). Evidence for exercise therapy in mechanical neck disorders. *Manual Therapy*, 8(1):10–20.

Stensæth, K. (2013). "Musical co-creation"? Exploring health-promoting potentials on the use of musical and interactive tangibles for families with children with disabilities. *International Journal of Qualitative Studies on Health and Well-being*, 8(1).

United Nations (2015). Universal Declaration of Human Rights. https://www.un.org/en/universal-declaration-human-rights/index.html.

Vamvakousis, Z. and Ramirez, R. (2014). P300 Harmonies: A Brain-Computer Musical Interface. In *Proc. 2014 Int. Computer Music Conf./Sound and Music Computing Conf.*, pages 725–729, Athens, Greece. Michigan Publishing.

Vamvakousis, Z. and Ramirez, R. (2016). The EyeHarp: A Gaze-Controlled Digital Musical Instrument. *Frontiers in Psychology*, 7.

World Health Organization (2013). Spinal cord injury report. Technical report, World Health Organization.