Magnetic Interactions as a Somatosensory Interface

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ABSTRACT

Thales is a *composed instrument* consisting of two hand-held magnetic controllers whose interactions with each other and with other magnets produce the somatosensory manifestation of a tangible interface, that the musician generates and shapes in the act of performing. In this paper we provide a background for the development of Thales by describing the application of permanent magnets in HCI and musical interfaces. We also introduce the instrument's sound generation based on a neural synthesis model and contextualise the system in relation with the concept of *magnetic scores*. We report on our preliminary user study and discuss the somatosensory response that characterise Thales, observing the interaction between the opposing magnetic field of the controllers as a tangible magnetic interface. Finally, we investigate its nature from the perspective of performative posthumanist ontologies.

Author Keywords

Magnets, magnetic interfaces, haptics, somatosensation, neural synthesis

CCS Concepts

•Hardware → Haptic devices; •Applied computing → Sound and music computing;

1. INTRODUCTION

The artistic poetics that characterised the second half of the 20th century have endowed the interpreter with a higher degree of autonomy, compared to the tradition, in relating with the musical material. This is evident in the practices of authors such as Stockhausen, Berio and Pousseur, as discussed in detail in Eco's *Opera Aperta* [10].

With composers approaching music notation as a way to prescribe the performer's gestures rather than as pitch organised in time [15], the mapping of such relations became a crucial element in designing musical interactions [29].

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Out of the acquired freedom in defining sensible musical parameters and their modalities of representation, new compositional approaches have emerged [4]. Among such, an increasing number redefine the composer's and performer's traditional roles and attributed agencies [24], investigate the relational aspects of the inscription [11], or explicitly suggest a dynamic and undefined idea of the score's situatedness in relation to the instrument [30].

In describing the progressive embedding of the score within the instrument, Tomás and Kaltenbrunner [29] propose the idea of *inherent scores*, and trace the origin of the concept back to Alvin Lucier, who, in describing the performative practices of the Sonic Art Union, stated that their musical scores were inherent in the electronic circuits developed by the members of the collective [14].

Similarly to inherent scores, the concept of *composed instruments* describes the score as incorporated within the instrument itself, in the form of modular mappings whose features define the interaction between a controller and an arbitrary synthesis engine [27]. In such cases, the score is encoded within the dispositif in the form of a defined set of constraints, and is freely explored by the performer through an embodied approach [7].

From this stance, in this paper we introduce *Thales*, a composed instrument in which, through somatosensory feedback, the performer experiences the interaction between opposing magnetic fields as a tangible yet invisible interface: as our preliminary user study shows, the dynamics between Thales' magnetic fields evoke in the user the impression of interacting with objects of different resistance, shape and materials.

In the next section, we frame the use of permanent magnets and neural synthesis in musical instruments, as they represent two of the main features of our system, and contextualise Thales' composed nature in relation with *magnetic scores*, a novel type of inherent scores that, similarly to how Thales generates the interface, encode the inscription in the form of magnetic fields.

2. BACKGROUND

2.1 Permanent Magnets

Permanent magnets constitute a key component of most audio electronics, and are extensively incorporated in the design of modern musical instruments and amplification technologies. However, if within HCI the haptic properties of permanent magnetic fields have been explored [31, 8], similar applications have not been proposed in the design of musical instrument as of yet.

A notable example of the use of permanent magnets as key components in the interaction design of an instrument-score is the *Chowndolo* by Giacomo Lepri[1]: a pendulum whose movement is dynamically controlled through a set of permanent magnets on its base. A different approach is instead explored by David Griffith in the *Pattern* Matrix,[2] a tangible AR live coding environment controlled through the orientation of permanent magnets on a tangible 5x5 matrix.

In the *Marble Machine,*[3] the merging of the score with the instrument becomes particularly apparent, as the instrument's sounds are generated through the interactions of ferromagnetic marbles with different surfaces, membranes or strings, and their timing is controlled by a tangible step sequencer made of small magnetic cylinders attracting and displacing the marbles.

In NIME's proceedings from 2001 to present, among a large number of papers describing different applications of electromagnetism in actuators [9, 3, 17, 13], magnetic tape [12] and gestural control [23], we identified three papers describing the application of small permanent magnetic tags for position sensing [21, 16, 22] and one for haptic response in VR settings [6]. In these cases the sound is mapped through the dynamic repositioning of the passive elements in relation to a fixed magnetic sensor, or depends on the relative position of the controllers without including magnetometer's readings.

In Thales we followed a different approach, as each controller, whilst incorporating position sensing, couples a magnetometer and a permanent magnet as a default configuration. The changes in the readings of the sensors depend on the temporary encounters of the magnetic fields in the controllers with those of other magnets displaced in the performative space and with each other. As a result, the interactions between the magnets are experienced by the performer as somatosensory responses, and produce the tangible manifestation of the magnetic interface.

2.2 Neural Synthesis

The recent introduction of deep learning techniques has added new and exciting state-of-the-art technologies for the generation of raw audio waveforms, such as WaveNet [20]and SampleRNN [18]. However, despite their unprecedented audio quality, the high amount of data they require and the slow responsiveness has initially limited their application in real-time interactive scenarios.

Recent models such as NSynth and GANSynth have improved such limitations, thus facilitating the application of neural synthesis techniques in musical interfaces such as NSynth Super.[4] To our knowledge, the first NIME leveraging these features is AI-Terity, a non-rigid musical interface for real-time audio synthesis [28].

More recently, the introduction of RAVE [5], a Realtime Audio Variational Autoencoder (VAE) that performs fast and high-quality audio synthesis, has drastically facilitated the application of neural synthesis in interactive contexts. RAVE can be used in real-time environments and standard CPUs, and is capable of modelling 48kHz audio signals through a training procedure that consists in a representation learning phase performed on a regular Variational Autoencoder (VAE), followed by an adversarial generation phase for perfecting the sound quality. Notably, once the model is trained, the latent dimensions can be navigated in visual programming environments such as Pure Data or Max/MSP through dedicated objects, as in the case of our system.

We chose RAVE for the sound engine of Thales as it provides a flexible yet advanced platform for the application of Neural Synthesis. The data forwarded by the controllers mostly relates with spatial dimensions such as absolute orientation and position of the magnetic field. Similarly, the latent spaces in autoencoders may be interpreted as coordinates in a multi-dimensional space. Because of this, coupling the controllers with RAVE felt as a very natural choice. As we will see, the recording and selection of the audio samples for the dataset, as well as the core interaction design situates Thales in close continuity with *magnetic scores.*

2.3 Magnetic Scores

During childhood, it is a common experience to play with magnets, to be intrigued by the invisible forces that cause them to attract or repel with each other, and to spend time observing their behaviour against different materials. This playfulness that magnets evoke is visible in the amount of games and gadgets that make use of them in various ways, from levitating machines, moulds, to spheres of all dimensions, science kits and magnetic brick sets.

Magnetic scores aim to bring all this into the musical practice through the embodied experience of the magnets' interactions. We already defined magnetic scores as the combination of a composed surface with embedded magnets, and two magnetic controllers that decode the information and provide somatosensory feedback to the performer [19]. As the musician navigates the score, the magnets in the controllers and those in the surface attract and repel each other, suggesting the performer's gestures [5].

Because in magnetic scores both the surface and the controllers have magnets embedded within, the score can not be considered as inscribed on the surface alone, nor is it the unilateral result of the performer's action: it rather discursively emerges as a series of encounters between the composer's ideas as inscribed through the displacement of the magnets, and the performer's exploration of the surface with the magnetic controllers

Because we developed our systems out of the same intuition, we imagine Thales' magnetic interface and magnetic scores as alternative manifestations of the same core interaction design, as the extremes of a compositional continuum ranging from the granular encoding of detailed magnetic inscriptions to their quasi absence, with the controllers interacting with one or few magnets, or even simply with each other.

3. THALES

Our instrument is named after Thales of Miletus, the philosopher that, according to Aristotle [1], first studied magnets and described them as "having a soul".

The performativity of the inscription that characterises magnetic scores, emerging as a consequence of the performer's actions on the magnetic surface, is leveraged in Thales with the aim of creating a tangible interface that the user generates in the act of performing, and exists because of the momentary interaction between the magnets.

In order to produce this impression, both the magnets mounted in the controllers and those displaced in the performative space have to be oriented facing each other with identical polarities. Thanks to this simple stratagem, the reciprocal repulsion of the magnetic fields suggests the pres-

[1]Chowndolo
[2]The Pattern Matrix
[3]The Marble Machine
[4]NSynth
[5]Thales Video Link

Figure 1: Magnetic Score

ence of an invisible object, whose perceived resistance, material and shape depend on the reciprocal interaction of the magnets under the performer's gestures, and whose existence is enclosed within the performative act.

This feature, along with the absence of a composer that predetermines the presence or the position of other magnets, is what defines the peculiarities of Thales in relation with magnetic scores: using the controllers' magnetic fields against each other becomes a natural performative approach, and even though it is possible to interact with external magnets, these may be freely positioned in space by the performer. Through this simplified use of the notation, the inscription coincides with the interface, and the system acquires the qualities of a composed instrument, allowing flexibility and freedom of movement through the simple and affordable design of the magnetic discs.

Figure 2: Magnetic Discs

3.1 Magnetic Discs

The magnetic discs are two 3D printed, PLA cylindrical controllers. In a diameter of 10 cm and thickness of 2 cm they mount a three-dimensional gyroscope and accelerometer, a three-dimensional magnetic sensor, one ESP32 microcontroller and a 1000 mAh battery. At the centre of the discs, a cavity hosts cylindrical magnets of a 3 cm diameter. The magnets are loose within the discs, and are held in place by the performer's palm. When the magnet on the disc is approached to an external magnet with identical polarity, it pushes on the performer's hand thus providing a proportional haptic response. At the same time, the resistance of the palm transfers the force of the magnet to the whole arm, thus influencing the performer's proprioceptive perception.

Through a dedicated wifi protocol[6], a wireless network is instantiated between the microcontrollers mounted on the discs and a third one connected to the laptop and acting as a server. In an open space, the client devices can reach the server within a distance of 320 metres. This solution provides great freedom of movement to the performers and lower overall latency compared with the OSC protocol, as it eliminates the need for a dedicated router. In addition, the protocol does not require the user to specify the receiver's IP and Port, it allows to add any number of client devices and even to instantiate parallel communication between them, thus opening to the design of entangled behaviours.

Each magnetic disc wirelessly forwards to a laptop two data points: one relative to the xyz orientation of the device and one to the xyz strength of the magnetic field it is exposed to, but because the sensors transmit position-related data and no switches are embedded in the discs, the activation of specific behaviours at will is not easily achieved by the performer. We consider this as a feature of the system that makes it suitable for the navigation of latent dimensions in autoencoders.

Nonetheless, in order to offer to the performer the possibility of triggering specific parameters, we leveraged the design features of the embedded magnetic sensor whose axes individually saturate when the magnetic field is too close. Indeed, the magnet's cavity is placed on the disc's lid two millimetres above the back of the sensor. Because of this, when the magnet is entirely inside the disc the z axis saturates, returning the maximum value regardless of the presence of an external magnetic field. When the performer encounters a magnet with identical polarity and releases the palm's pressure on the disc, the disc's magnet moves away from the sensor, and the z axis starts reporting correct values.

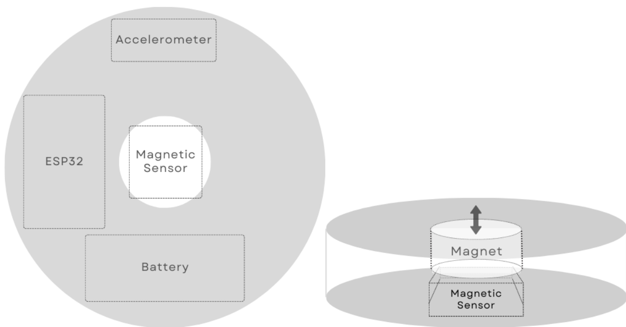

Figure 3: Magnetic Disc's Design

3.2 Sound Processing and Interaction Design

Our first piece with magnetic scores used magnets both for the generation of the inscription and for the sound: we embedded magnets of different shapes and sizes underneath a wooden board, free to move inside small containers. Upon the interaction with the discs, the magnets would bounce on the board and scratch its surface. The sound was cap-

[6]EspNow

tured by two piezoelectric sensors in stereo configuration and processed with the sensor's data.

In Thales, as a natural continuation of this process, we recorded and selected one hour of interactions between the magnets and the board, and built our dataset for the training of the RAVE model. By using these sounds, we aimed to formalise the composed nature of the instrument in continuity with our previous work.

In Thales, each of the values forwarded by the magnetic discs controls one latent dimension of the RAVE model. The changes in the readings of the magnetic sensor activate the generation of a dynamically filtered white noise, that is forwarded to the RAVE model. The model attempts to reconstruct the noise with the dataset of magnetic interactions it has been trained upon, thus generating the system's sound.

By moving the controllers around a magnetic interface, by changing its shape through the disc's orientation and by changing the pressure on the magnetic field or partially releasing the disc's magnet with the palm, the performer navigates a tangible manifestation of the neural synthesis model.

Thales' magnetic interface may be generated in two ways: by facing the discs with each other, or by interacting with the magnets previously displaced in the performative space. These approaches produce very different experiences: in the former case, the magnets' dimensions are predefined and the controllers interaction becomes subtly perceivable at around 10 centimeters to then increase exponentially. In the latter case, much of the interaction depends on the dimension, orientation and shape of the external magnets, and on the resistance of the surface that hosts them. In our user study, we explored both these ways of performing with Thales, in order to understand, among other things, which one the participants enjoyed the most.

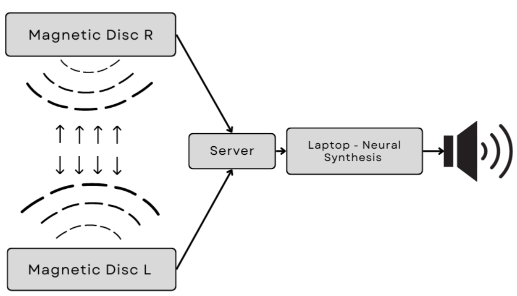

Figure 4: Referenced as S1 in the Evaluation.

4. PRELIMINARY EVALUATION

A preliminary user study took place during our weekly OpenLab event, in which we regularly invite the community to present and discuss projects involving music and technology. We invited seven participants, here identified as U1 to U7, to individually try out Thales and to describe the experience of interacting with magnetic fields through the controllers. We consider this first study as an initial inquiry on our instrument, focused on the perception of the interaction between Thales' opposing magnetic fields as a tangible

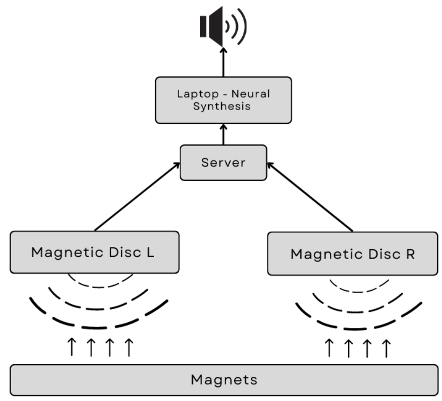

Figure 5: Referenced as S2 in the Evaluation.

interface.

Being regular and active participants to our OpenLab events, all of the subjects had previous relations with us. U1, U4 and U6 defined themselves as sound designers; U2, U3, U5 and U7 as musicians.

The tests were performed individually in a dedicated room, and lasted about 15 minutes per person. Two scenarios were proposed: S1, with the magnetic interface as experienced through the reciprocal interaction of the discs, and S2, with the magnetic interface as experienced through the interaction with magnets placed on a table.

In order to explore the possible developments of the system, we also presented to the users one additional scenario (S3): the magnetic interface as experienced through the interaction with an electromagnet operated thorough a 10 Hz square wave on a 20 Watts, class D amplifier. This third situation will be discussed as future work.

We report some of the users' comments that may provide valuable insights for the discussion.

Scenario 1:

U1: You can really control where you want to be... if I mapped it on certain things I feel I can be really precise, but also, since I cannot be that precise, I feel it would be more organic.

U2: There's a soft bag in-between that jumps. A little trampoline or something.

U3: It is very fun!

U5: It feels like a hidden globe, a hidden tennis ball.

U6: It is possible to play near, but also to find other paths, like as if you're playing a cymbal (performs gesture).

U7: It feels slippery when you move in opposite directions.

Scenario 2:

U1: It feels different, I can angle and control better in the other one. Plainly spoken, I like this (S1), I don't like this (S2).

U2: It reminds me of something I have experienced and I can't remember what.

U3: Here it has more water (S2), and here less (S1).

U4: This feeling is more soft. This power leads me and it is ok for me, it's nice.

U5: I feel a little bit less control. Close to the centre it wants to roll me off. It's like polishing or wiping something off.

U7: It feels like a round, slippery bubble.

For all of the users, S1 and S2 were very different experiences. S1 seemed to be a more organic approach for most participants, offering more control over the instrument. One notable exception was U4, that felt more at ease in S2, as she perceived the interface in S1 was hampering the discs to touch each other.

A first, crucial aspect emerging from the user's study, and one that confirms the initial intuition of observing Thales from the perspective of the magnetic phenomenon, is that the magnetic fields, dynamically moulded by the users, were perceived as properties of an invisible object, and described as in S1 as a "soft, bouncing ball", a "slippery surface", a "soft bag that jumps while in S2 as a "solid sphere", a "ball filled with water" or a "tennis ball".

5. DISCUSSION

5.1 Performing Invisible Interfaces

In Thales, the interface is both invisible and ephemeral, as it emerges from the interaction between the magnetic fields as informed by the performer's gestures. At the same time, it changes in shape and response based on the reciprocal position, pressure and resistance of the magnets.

Our preliminary study indicates that the experience of interacting with the magnetic interface is very subjective, and that the lack of a visual anchor offers an ideal ground to the participants' imagination, that in describing the quality of the gestures recurred to a number of creative metaphors.

The movements performed by the participants closely mimicked the description of the imagined object, but, notably, at the same time they produced its impression. This suggests that invisible interfaces, that can be operated and sensed through haptic response and focus on sensuous embodiment, have the potential of evoking subjective and intimate ways of performing.

The interaction was generally perceived as fun and enjoyable. Participants were surprised by the response of the discs, as they could not possibly observe the presence of the magnetic interface beforehand, and felt engaged in playfully exploring it. In three cases (U4 and U5), the magnets evoked childhood experiences of playing with magnets, or suggested memories that could not be articulated in words (U3). In different occasions users explicitly said the experience was fun, and many of the metaphors they adopted (ball, trampoline, jump, bubble) related with playfulness. Overall, this refers to an evocative potential and sense of enjoyment characterising Thales.

5.2 Somatosensory design

The key component of Thales, and one of the novelties arising from this work, is the somatosensory design that generates the performer's perception of the interface. Even though haptics are often observed from the perspective of tactility, in the somatosensory experience both the tactile and the proprioceptive dimensions interact at perceptual and physiological levels. In this work, we refer to somatosensation as the combination of the user's spatial self-perception in relation to the forces of the discs and the small-scale, haptic response that the magnets exercise on the performer's palms through their reciprocal interactions. These two perceptual layers integrate with each other, as research suggests that the mental representations of tactile sensations interact with the three-dimensional geometric representation of the body scheme [25].

The two different dimensions were clearly distinguished by the participants. The haptic response of the disc's magnet on the palm was initially perceived as destabilising, as causing a lack of control, as a sensation of "clunkiness" or "tingling" on the palm. In all cases, once explained, it was described as an addition worth exploring. This was clearly explicated by U5, stating that this is "(...) a new dimension in the sensation, it makes me more interested in trying something new".

Another aspect emerging from the study relates with the perception of effort: a critical dimension in facilitating the audience's understanding of cause and effect, and, as S1 pointed out, one that computer music has often a disadvantage in representing [26]. In our study, the participants' effort while interacting with the system was particularly apparent, both in the posture as well as in the tension of the face and arms' muscles, thus potentially enhancing the communication with the audience in live performances. As two of the participants noted (U1 and U3), this aspect may be further enhanced by using stronger magnets in order to generate a larger magnetic interface.

The resistance generated by magnetic fields increases with the inverse cube of the distance, thus changing from very low to extremely strong in a few centimetres. In Thales, this produces the impression of pushing a soft ball against a wall: the participants have described the magnetic interface as a "ball filled with water", as a "bag", or as a "globe". As the pressure is released, it becomes possible to navigate the spatial and temporal dimensions more thoroughly, as U5 noted. The control over the system is therefore inversely proportional to the distance from the center of the magnetic interface.

Finally, the directivity of the gestures emerged as a crucial aspect of Thales. The possibility of operating on the magnetic field from different directions and with linear or meandering paths is what allows the performative, dynamic redefinition of the interface: the sensations generated by direct movements were described as "bouncing" and "pushing" when fast, and as "soft" when slow. Indirect movements were instead described as "walking on a slippery surface", as "playing cymbals", as a "trampoline", or as "scratching" and "polishing something off".

5.3 Magnetic Interfaces

As we have seen, the interface of Thales is generated in the very act of performing and out of a the interaction between the magnetic fields. Attempting to frame the play of the agencies of the discs with each other and through the performer's gestures is of particular interest in our lab's research, as agency is a foundational aspect in interpreting human interaction with intelligent technologies. In the attempt of reflecting upon the nature of the magnetic interface, in this section we recur to performative and posthumanist ontologies.

In Thales, the dual nature of the magnetic fields both as a tangible entity and as an ephemeral phenomenon insists on the relational nature of matter: quoting Barad, "reality is not built by things-in-themselves or things-behind-phenomena, but of things-phenomena" [2]. This relationalist take rejects the separation between the subject and the object of knowledge: they rather discursively emerge in their reciprocal performativity.

Similarly, the magnetic interface does not come into being unless the performer approaches the discs close to each other or to a magnet, until he perceives a somatosensory response and thus performs the distinction of an "inside" and "outside" space. This in turn defines his agency within the performative space, the quality of the movement and the affordances of the system.

In this sense, the coming-into-being of the magnetic interface might be seen as a momentary stabilisation of a phenomenon, an *agential cut* that temporarily produces the boundaries through which it is perceived. The magnetic interface, in this discursive generation of things-phenomena, appears therefore as a temporary, negotiated making of a duality, of a distinction between a "this" and a "that".

6. FUTURE WORK

By leveraging the portability and long communication range of the magnetic discs we envisage embedding magnetic scores within three dimensional surfaces as well as architectural spaces such as entire rooms and buildings. In such situations, we wish to dig into the diffused character acquired by the interface, and into the different subjectivities emerging out of the interaction with differently informed spaces.

Currently, we are experimenting with the interaction of the magnetic discs with electromagnets, both individually and in matrices, in order to introduce new agents in the form of generative algorithms. Through this process, we hope to further explore the affordances and tangible qualities of magnetic interfaces, and aim to develop a system for sound design and for the haptic representation, sonification and analysis of data.

In our user study we also presented to the participants a third scenario (S3), in which the magnetic disc was held over an active electromagnet. Similarly to S1 and S2, the metaphors used to describe the interaction were quite creative, but of quite a different nature. The somatosensory sensation was described as "a car's engine", as "scratchy", as "feeling a bass string". We agree with U1 stating that this approach might prove useful in sound design, as it allows to feel the sound as it is being shaped, and as a matter of fact we are already exploring this route.

We consider the present user tests as a preliminary study, whose scope is limited by the number of participants as well as by the time they could spend with Thales. In future research we aim to involve a larger number of users, and beyond the community around our lab, and to explore the practices that musicians might develop around Thales through time.

7. CONCLUSIONS

In this paper we have introduced Thales, a composed instrument that leverages the features of magnetic scores, and by using magnetic controllers facing each other with opposing fields produces the manifestation of a tangible magnetic interface.

We also described the implementation of our controllers (the magnetic discs), the abstraction of the sounds that characterise our first piece with magnetic scores into Thales' neural synthesis model, and a preliminary user study in which the participants experienced the magnetic interface produced by Thales and described the qualities of the interaction.

In our reflection, we drew from performative and posthumanist ontologies, and suggested that the comings-into-being of the magnetic interface may be seen as momentary stabilisations of a phenomenon, agential cuts that temporarily produce the boundaries that define both the performer's agency and the magnetic interface.

Finally, we identified a series of possible developments of the system: currently, we are exploring the application of matrices of electromagnets for the haptic representation of sound and data.

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9. ETHICAL STANDARDS

This research has been funded by a European Research Council (ERC) grant. All the participants to the study have been informed on the nature of the research before the interviews, and have consented on the use and analysis of the anonymised data within the purposes of the study.

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