Abstract (~200 words)

Introduction (~1300 words)

The evolution and nature of prominent, well funded scientific research is intimately linked with the demands of society and the interest of the government which continuously increase in complexity ([1],[2]). The ever increasing challenges have prompted the amalgamation of separate scientific domains, unifying the skills from each discipline to form an indispensable toolbox in tackling the modern multifaceted obstacles. In particular, the growth of physics over the last century is firmly tied to the growth of its interdisciplinary component (<show figure>). In 1910 only $8\%$ of the scientific literature were physics publications whilst this number has now increased to $\sim22\%$, with $12\%$ of these being in interdisciplinary fields ([3],[4]). The practicality of Physics in modern interdisciplinary research stems from its key paradigms ([5],[7]) which include the abstraction of complex multivariate problems to their core fundamental variables and their connections, a deep understanding of ubiquitous phenomena like waves, energy and entropy and the phenomenal computational prowess of the modern physicist. The latter allows for the simulation of physics and conduction of experiments, provides fast numerical analysis tools and facilitates quality research output without the need for heavy granular theoretical knowledge on a topic ([6]). The research presented in this paper epitomises the influence and importance of key physics skills in developing an innovative product in an interdisciplinary setting to answer societal demands.

Poor eye health is a prominent issue in our technology-driven society, especially amongst individuals who spend a large portion of their day in front of a computer screen ([8]). The problem is formally coined digital eye strain (DES) or computer vision syndrome (CVS) ([9]) and can have detrimental short term consequences such as headaches, dry and itchy eyes, blurred vision and increased tiredness ([8],[9]) as well as long term eye damage , particularly among the younger population, like a reduction in the calibre of retinal arterioles which can lead to symptoms of cardiovascular disease including obesity and metabolic syndrome ([9],[10]). DES is not only adverse to the health of the individual but can also severely impact their productivity at work ([11]). It is therefore natural that a large portion of research is devoted to developing strategies to minimise DES ([8],[9]) and these are of heightened relevance given the staggering and continual increase of computer users in modern society. By 2019 99% of adults aged 16-44 were internet users in the UK ([12]) and over 80% of adults in the USA used digital devices for over 2 hours daily, of which 59% reported DES symptoms ([13]). Amelioration techniques for DES include lubricating eye drops, the use of computer glasses, correcting pre-existing refractive eye errors through surgery or otherwise and regular eye care including taking breaks and training the eyes ([8],[9],[14]).

We exploited the latter non-invasive DES management strategy to create a visual training product which allows users to perform targeted eye motions in a fun and engaging manner. The final product is the renowned Tetris game, playable with the eyes. With the suggested way of playing detailed in Section … we believe that the controlled eye movements that the game demands coupled with the enjoyment of playing Tetris will aid in regular ocular training which can help mitigate the temporary effects of DES.

In order to link the eye movement of the user directly to an electronic system we form a brain-computer interface (BCI) by exploiting the neurophysics of brain waves. Brain data can be non-invasively collected by measuring electric potential variations between a pair of electrodes attached to the head of the user. The collected oscillatory electric signal is termed electroencephalogram (EEG) ([15]) and mainly stems from the cerebral cortex in the cerebrum of the brain due to its near-surface positioning (show pic.) ([16]). This region is responsible for movement initiation, interpretation of the senses, emotions and fine movement detections. In particular, the cerebral cortex will record a spike in activity when eye movements are performed. Electrical signals are induced when brain cells (neurons) become activated. During periods of activity, a dipole is induced between the body (soma) and the ends (apical dendrites) of a special type of neuron called pyramidal cell (show pic). By aligning these induced dipoles and linking the neurons through electrically conducting structures (synapses), a local current of ions (mainly Na+, K+, Ca++, Cl-) can flow ([15],[16],[17]). This current can penetrate the skull and skin to induce a voltage difference between the electrodes attached to the scalp, thereby detecting the spiked cerebral cortex activity. A competitive property of EEG signals compared to other methods like MRI and PET scans is the small sub-second speed between the brain’s response to a stimulus and the EEG signal being detected ([16]). After penetration of the skull, the EEG is faint (in the order of mV) and needs to be amplified before being fed into the recording system. The process of EEG signal collection through electrodes, signal amplification and injection into the computer system is done using the Spiker Box provided by the Backyards Brain (BYB) team ([18]). More details about data collection can be found in Section … . With electrode set up 1 (show pic.) the Spiker Box can detect left, right and blink signals and with set up 2 (show pic.) it can detect up, down and blink signals.

Once the data collection process is achieved we need to accurately differentiate between the different possible eye movement signals which are represented on the computer screen as large amplitude deviations from the equilibrium position. We call the code that achieves the differentiation the classifier. To implement the classifier we turn to supervised machine learning (ML), an indispensable skill from our Statistic Major colleagues. ML, and more broadly the field of artificial intelligence, has spectacularly blossomed since the 1950s ([19],[20]) extending interdisciplinarily to fields like predicting the stock market ([21],[22]), forecasting sporting results ([23]), medical diagnosis of cancer ([24]), developing refined drugs in pharmacology ([25]) and in agriculture to boost production ([26]). The rapid multidisciplinary spread and high-impact of ML stems from its simple implementation and universal adaptation to different settings. The fundamental paradigm is to allow the machine to learn trends in a dataset with minimal human intervention. Supervised ML is a subset of ML where the models are trained with known results (labels) based on properties of the input data (attributes) ([27]). The trained model is a division of attribute space with each region predicting a different label. Learning of the model occurs by tuning the weight of different features so as to drive the topology of attribute space into a state of minimum error with respect to prediction on the features of the known input labels (show pic.). The algorithm used to train the models is of utmost importance and an active research frontier in ML. Two universal, robust learning algorithms that we will take advantage of in this paper are Support Vector Machine (SVM) ([28]) and k-Nearest Neighbors ([29]). Once the model is trained, it can be fed attributes of potentially unknown data and a label prediction is obtained based on the position of the attributes in the trained feature space.

By unifying the physics of EEG signal data collection, amplification and filtering and the statistics of supervised Machine Learning we develop an accurate brain-computer interface (BCI) able to accurately predict left, right, up, down and blink eye movements. We effectively blend the physics and statistics disciplinary skills with computer science knowledge to use the label outputs of the BCI to play a Tetris game developed in Python, demonstrating the power of interdisciplinary collaboration in efficiently developing a product aimed to address societal challenges.

In Section … we thoroughly detail the methodology of data collection, filtering, training and testing of the ML models, label prediction, implementing the game and efficiently unifying all components. In Section … we present the results regarding data collection and processing, model evaluation and overall cohesiveness and discuss them in Section … . Finally we conclude in Section … where we also propose avenues for future endeavors.

Methodology (~1300 words)

Presentation of results (~500 words)

Individual discussion (1000 words)

Conclusion (~700 words)

Potential future endevour: EEG has good temporal resolution but bad spatial ones ([15],[16],[17]). => use MRI or other instead

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