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Research Article

Exploring the potential link between prostate cancer and magnetic fields

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A R T I C L E I N F O

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A B S T R A C T

Prostate cancer is the most common solid cancer in men worldwide. Various lifestyle factors have been established as contributors to cancer risk, and prostate cancer is no exception. Elements such as advanced age, diet, obesity, smoking, alcohol consumption, circadian rhythm disruptions, Afro-Caribbean ethnicity, and sexual activity have all been linked to an increased risk of prostate cancer. Notably, famous male guitarists from bands spanning the last few decades are now entering the age demographic most closely associated with prostate cancer. It is not surprising that they may fall into the 'at-risk' category. Media speculation has hinted at a potentially higher incidence of prostate cancer among guitarists compared to their bandmates, although no tangible correlation has been established. This speculation piqued our curiosity and prompted an exploration into potential reasons why musicians, particularly guitarists, might be at an elevated risk of developing prostate cancer. We hypothesise the electromagnetic fields generated by the electric guitar may in part explain the possible increase in prostate cancer risk among electric guitarists. This study delves into these intriguing possibilities, shedding light on an area of research that remains speculative but warrants further investigation.

Introduction

During a recent public awareness campaign centred on prostate cancer (PC) risks among ethnic minority groups, we were intrigued by specific questions relating to media reports, highlighting cases of renowned guitarists who have been diagnosed with PC [1–3]. Such cases could be disregarded as nothing more than media sensationalism into the lives of celebrities, but PC is on the increase worldwide and is the most common cancer amongst men, with 357,000 annual deaths worldwide [4]. Several lifestyle factors have been closely linked with cancer, and PC is no exception. Age, diet, obesity, smoking, alcohol, circadian rhythm disruption, race, and sexual activity are all linked to increased cancer risk. Famous high-profile male guitarists from bands of the last few decades are obviously now entering the age range demographic predominantly associated with PC, therefore, it may not be surprising that they would now constitute an 'at-risk' group. However, via this media speculation, it has been implied that there may be an increased association of PC in guitarists specifically, as compared to their relatively closely matched band members. No true correlative link has ever been made and it remains speculative, nevertheless, it intrigued and challenged us to explore possible reasons as to why musicians, or specifically guitarists, might be at an increased risk of developing PC.

Although a stereotypical viewpoint, musicians in high-profile bands would, of course, be exposed to many of these risk factors which could account for the prostate cancer cases, but it is interesting to hypothesise why guitarists may be more at risk than their bandmates, who, due to their close working conditions may have been exposed to similar risk factors [5].

On face value, the only difference in electric guitar players and other band members would be the instrument itself. Playing the electric guitar involves holding the instrument close to the pelvic region for considerable lengths of time. An electric guitar does generate regional electromagnetic and magnetic fields, and their effects have been speculated as being potentially carcinogenic in other milieu, reviewed in [6].

When the strings of an electric guitar are plucked, the oscillations are sensed by electric "pickups' that signal to an amplifier [7]. These are magnets (or electromagnets) that induce a magnetic field in which the strings induce current changes in a coil, which are converted to musical

Abbreviations: PC, prostate cancer; ROS, reactive oxygen species; MF, magnetic field; EMF, electromagnetic field; BRCA1/2, breast cancer gene 1/2′; DHT, Dihydrotestosterone; FAD, flavin adenine dinucleotide; ELF, extremely low frequency; HPV, human papilloma virus; RF-EMF, radio frequency electromagnetic field; EV, extracellular vesicles.

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signals. Many professional guitars have several pickups, and therefore magnets, to allow more sensitivity and range of frequencies.

Hypothesis. *The potential correlation between PC risk and musicians, particularly guitarists, remains largely unexplored, with this demographic typically overlooked as an extraneous variable in research studies. Nonetheless, due to the elevated visibility of this cohort and a genuine public curiosity, there has been an interest in investigating potential causative factors. In this paper, we hypothesise that the increased risk of PC among electric guitarists is in part related to magnetic field (MF) and electromagnetic field (EMF) exposure potentiating the lifestyle factors typically associated with PC risk.*

Specifically, does the act of playing an electric guitar, professionally, pose an occupational hazard for PC?

Evaluation of the hypothesis

Prostate cancer has yet to be linked with a single causative risk apart from increased age, but several cumulative risks are well known and discussed below.

Diet

Western diets, often consisting of a high glycaemic load with a high consumption of macronutrients such as refined carbohydrates, added sugars, fats and processed meats can be a source of high endogenous ROS (Reactive Oxygen Species). ROS are highly damaging and are associated with inflammation and cancer development in many types, including PC [8–10]. This is exacerbated by the fact that Western diets are poor in antioxidant and anti-inflammatory compounds, derived from fruits, vegetables, and whole grains, that help protect against ROS-induced cancer development. Foods that contains high amount of fat have been reported to increase ROS-mediated inflammation and enhance oncogene expression [11].

Ethnicity

Afro-Caribbean men have a 1 in 4 chance of developing prostate cancer, which is the highest for any male group [12]. This is an active area of research and may include several overlapping factors including genetics – higher incidence of BRCA1 and BRCA2 gene mutations, hormone levels (higher levels of testosterone and DHT), and importantly socioeconomic factors such as access to healthcare [13].

Sexual activity

Certain sexually transmitted diseases may be associated with an increased risk of PC. HPV, gonorrhoea, chlamydia, and non-specific bacterial infections have been linked to prostate inflammation and prostatitis, which in turn is a strong potential risk factor for prostate cancer [14,15]. However, the relationship between prostatitis and prostate cancer is complex and not yet fully understood.

Circadian rhythm disruption & Melatonin effect

The circadian rhythm, plays a crucial role in regulating various physiological processes, including testosterone production and secretion.

Studies have reported that ROS levels exhibit oscillations that align with the circadian cycle, and disruptions in the balance of ROS can influence the functioning of the circadian clock [16]. For example, increased ROS levels can affect the expression of clock genes and disrupt the normal circadian rhythm. On the other hand, the circadian clock itself can regulate the expression and activity of repair and antioxidant enzymes that help counteract ROS accumulation, ROS-induced damage and maintain redox balance. Circadian rhythm disruption, e.g. shift work, jet lag, or irregular sleep patterns, can impact testosterone levels which could result in imbalances and related health issues [17]. Disruption of the circadian rhythm has been previously linked to an increased risk of PC in males [18,19], particularly among those involved in long-haul flights where factors like jet lag and circadian rhythm disturbances are significant.

Sleep deprivation & DNA damage repair

To date, numbers of reports have discussed anticancer activity of melatonin. In a study with rats, when a carcinogen is given at night during the highest levels of melatonin, DNA damage is significantly lower (20 %) than those receiving a carcinogen exposure during the day [9,20,21]. Individuals working night shifts face an elevated risk of hormone-dependent cancers. This risk has been linked to light exposure, which suppresses melatonin production, resulting in increased oestrogen levels and a heightened risk of breast cancer [22]. The complex oncostatic action of melatonin results from several complementary mechanisms. These include antioxidant activity; activation of the cytokine system; suppression of fatty acid uptake and metabolism; increased degradation of calmodulin, (which is a key player in cell proliferation); inducing apoptosis and possibly acting as a natural antiangiogenic molecule [23–30]. Accumulating evidence suggests that melatonin has both an anti-proliferative and pro-apoptotic functions in PC and an association between decreased pineal melatonin syntheses with increased PC development [28]. Additionally, melatonin has effects on apoptosis, androgen sensitivity, metastasis, and transition to androgen independence in prostate cancer cells. Deregulation of their circadian rhythm in men may put them at a higher risk of developing PC [31].

We wanted to explore the possibility of whether an electric guitar could exacerbate these common risk factors, to openly address the public concern regarding recent media coverage of male guitarists being diagnosed with PC, and what the potential molecular mechanisms could be from a scientific perspective. This hypothesis is discussed below.

Magnetic Fields

Previous studies have identified an association concerning childhood leukaemia and magnetic fields from power lines, resulting in them being classified as being potentially carcinogenic to humans. Although a low risk, this link was made several years ago and is now accepted as being an avoidable risk factor [32,33]. Interestingly, it was also reported that low MF increases HIF-1 alpha activation, an oncogenic event, which correlates with resistance to hypoxia in tumours, and suggest that low MF might facilitate and promote dormant state of the PC cells [34].

However, deriving the causal link and a biological mechanism has been difficult, mainly due to animal and *in vitro* experiments providing only limited support for carcinogenic effects of extremely low frequency (ELF) magnetic fields. There is a lack of consensus on a mechanism of how magnetic fields can interact with biological material and biomolecules – outside the theory of thermal interaction. How do magnetic fields and electromagnetic radiation affect biochemistry within cells to illicit effects within an organism? On one hand, research has dismissed such biochemical interactions as being impossible, whilst on the other hand magnetoreception in fish, arthropods, birds, and mammals has long been accepted. However, it has been hypothesised that such magnetoreception may not be as simple as once believed.

The fundamental mechanism of magnetoreception was first reported to utilise a magnetite-based (iron particle) detector for highly sensitive detection of faint magnetic field gradients. However, additional recent research has demonstrated the existence of another system – a light-dependent magnetic compass functioning through a radical pair mechanism [35]. The radical pair mechanism (RPM) has been proposed as a possible explanation for the biological effects observed in weaker magnetic fields [36].

A radical is a molecule that has at least one unpaired valence electron, which makes them highly chemically reactive. Formed by breaking a chemical bond or electron transfer between two molecules, a radical pair has electron spin dynamics which are fundamentally quantum mechanical in nature, giving the radical a magnetic moment, which can be affected and influenced by magnetic fields. Radical pairs are, therefore, magnetically sensitive, highly reactive intermediate molecules and chemical reactions involving them may be influenced by magnetic fields. In low magnetic fields, radical pairs may give rise to reaction products with more free radicals and may decrease radical formation in high magnetic fields. Enhanced ROS production and oxidative stress caused by EMF and their effect has been studied in animal and cell models [37,38]. Animal studies have reported that oxidative stress caused by EMF associated with abnormal sperm maturation, and effects in new-borns. Other animal research has examined the impact of electromagnetic field (EMF)-related reactive oxygen species (ROS) on the neuronal system. These studies discovered that prolonged exposure to RF-EMF-induced oxidative stress could result in DNA damage within neurons [39–43].

It was reported that 10 months exposure of EMF led to DNA modifications in white blood cells of male Sprague-Dawley rats, which suggest that this effect produced by oxidative stress could be mutagenic [44]. *In vitro* studies demonstrated that many cellular mechanisms and stress responses as well as ROS formation and oxidative stress could be induced with EMF in a tissue/cell dependent manner. For instance, when triple negative breast cancer cell line MDA-MB-231 cells were exposed to RF-EMF for a short time, increased ROS formation and enhanced cell death was reported [45]. Koh *et al.*, exposed prostate cancer cell lines LNCaP, DU145 and PC-3 to MF, as a result, inhibition of cellular growth, apoptosis and ROS were increased [46]. Other studies demonstrated that decrease of cellular proliferation via apoptosis might not be always the case; however enhanced cellular senescence led by MF was reported [47,48]. Therefore, MF alone may not be the direct cause of cancer however it may contribute to ROS-production and generate oxidative stress that leads to increased expression of oncogenes [49,50]. More, in depth studies are needed to understand the cellular mechanisms of EMF, ROS, and prostate cancer. RPM has been extensively demonstrated *in vitro* cell-free chemical systems and has led to the relatively new field of spin chemistry and has become an increasingly studied phenomenon called 'quantum biology'. ELF magnetic fields, unlike ionising or UV radiation, do not have enough energy to break chemical bonds, or to create radical pairs. For magnetic fields to be able to affect chemical reactions requires the prior formation of a radical pair. Sensitivity to weak magnetic fields is one of the key properties of radical pair reactions, and importantly to magnetic interactions of magnitude smaller than thermal energy. The effects of magnetic fields and radical pairs in various aspects of biology have been extensively reviewed in Zadeh-Haghighi, & Simon [51]. Normal reactive radicals formed in cells such as superoxides, hydroxyls, and nitric oxide are not influenced in themselves by spin chemistry. Therefore, where are radical pairs generated within cells?

The catalytic cycles of some flavin-dependent enzymes are either known or potentially involve the production of radical pairs [52]. Flavoenzymes or flavoproteins participate in a huge variety of chemical reactions within the body. In avian magnetoreception, the cryptochrome protein has been postulated as being involved. Light, of a specific wavelength, in the blue region of the spectrum, can activate cryptochrome molecules in the retina, to generate radical pairs between the flavin adenine dinucleotide (FAD) cofactor and tryptophan residues in the protein. A magnetic field can then affect the photosensitivity of those neurons, via the radical pairs, affecting downstream biochemical reactions – allowing neurological sensing of a magnetic field. Although no such magnetoreception has ever been proven in humans, cryptochrome proteins are an intrinsic mechanism of the central biological clock. The cryptochrome genes CRY1 & 2 in humans form part of the central oscillator (or clock) mechanism that runs on a 24 h cycle, together with the PER1-3 genes, and components of the CLOCK and ARNTL genes. This is the basis of the circadian clock (or circadian rhythm), which controls melatonin production in the pineal gland of the brain. Therefore, radical pairs are readily formed in normal biological systems, and their reactions and products may be influenced by EMF (Fig. 1).

Additionally, magnetic fields may potentially affect the behaviour of quantum systems within biological molecules. For instance, magnetic fields can influence the spin states of electrons and the interactions between electron spins in molecules. These effects might have implications for processes and enzymatic reactions, where electron transfer plays a crucial role e.g., in mitochondrial ATP production, and consequently ROS production. Although in its infancy, the field of quantum biology is growing and gaining momentum. Quantum effects have been recognised as having contribution to photosynthesis, navigation, enzyme catalysis, olfaction, and importantly DNA mutation [53,54].

Electromagnetic radiation

Although the mechanism of the electric guitar does not, in itself, depend on electromagnetic radiation, the use of wireless connectivity from the amplifier to the speakers has become more commonplace to allow for greater movement on stage. This increases the electromagnetic influence near the pelvic area when using an electric guitar. High energy or high frequency forms of electromagnetic radiation have been known for many years as having the potential to increase risk of cancers and other diseases due to their ability to ionise and damage molecules such as DNA. However, evidence of the effects of lower energy and longer wavelength forms of electromagnetic radiation remains debated and inconclusive. Electromagnetic fields (EMFs) caused by electrical products and exposure to extremely low-frequency electromagnetic fields (ELFs) at all stages of production up to the consumption of electrical energy led to severe health effects [55]. The amount of exposure to EMF depends on the location, size, and distance of the user from the source [56]. The World Health Organization (WHO) announced that the exposure rate of most studied subjects to ELF magnetic field was less than 0.1 μT and a small percentage was higher than 0.3 μT [57].

Our use of devices which emit radio-frequency electromagnetic fields

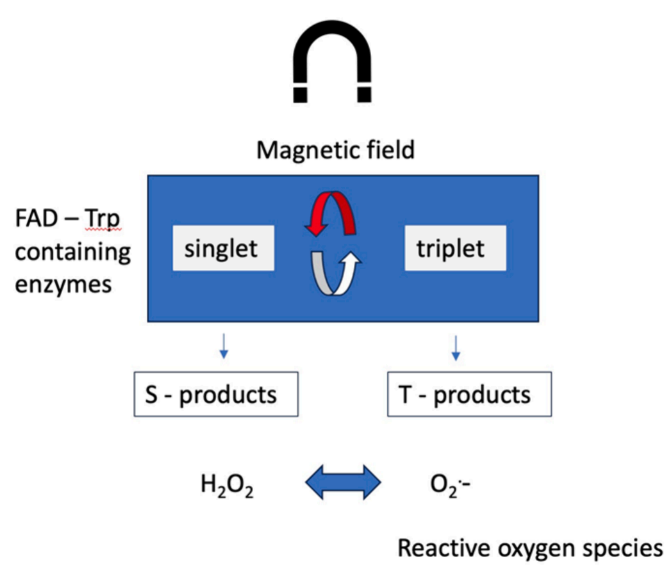

Fig. 1. A flavin (FAD) and tryptophan-based enzyme catalytic site utilising either singlet or triplet radical pairs. The initial spin configuration of the donor and acceptor molecules, singlet, or triplet, will determine the state of the radical pair and they may fluctuate between these different states. The interconversion is tuned by the magnetic fields experienced by the electrons. In chemical reactions involving radical pairs, reaction products may be influenced by magnetic fields, increasing, or reducing free-radical reaction products, which may lead to reactive oxygen species (ROS) generation.

(RF-EMF) have been increasing exponentially. Devices such as mobile phones, Wi-Fi, Bluetooth peripherals & wearables, security monitors, RADAR, medical diagnostics, small digital devices, and laptops have become ever more present in our lives, to the point where it has become virtually impossible to avoid EMF exposure. For example, mobile phone ownership has increased dramatically, where 96 %+ of all UK adults will own and use a smartphone (Statista.com, 2008). Data from a recent prospective study from the UK biobank highlighted a significant positive dose–response relationship between the extent of length of mobile phone use and PC incidence in men [58]. This again implies a proximity effect where phones may be carried in trouser pockets. The authors suggested that long-term exposure to RF-EMF could increase the incidence risk of cancer more so than short term high dose exposure. Exposure to RF-EMF may occur from sources close to the body, resulting in localised (near-field) exposure or may be whole-body far-field exposure from larger transmitters and base stations. RF EM radiation is classed as non-ionizing radiation as it comprises photons that do not have sufficient energy to break chemical bonds or ionize biological molecules. The possible biological effects of exposure to RF-EMF have not yet been proven and there is insufficient data on the biological hazards to provide a clear answer to possible health risks. Effects of RF-EMF on biological systems have largely been dismissed due to the main effect being mild thermal heating due to the movement of water molecules in tissues. Water molecules have a dipole moment, which may move and align them in a strong EMF. Since random movement of water molecules are rapidly dispersed and released as kinetic (heat) energy in the body, then thermal heating has been dismissed as being harmful. For example, the use of mobile phones (0.25 W operational power) emits energy that would cause a rise in brain temperature of only approximately 0.1 °C [59]. Although this may be minimal in terms of a biological system, a highly localised heating, which is then rapidly dissipated, may have stronger biological effects e.g., conformational changes in temperature-sensitive proteins. Other theories on how low-intensity RF-EMF exposures might affect physiological functions involve the alteration of ligand binding to hydrophobic sites in receptor proteins [60]. Ligand binding to receptor ligand-binding domains often includes hydrophobic interactions and associations that require the transient exclusion of water molecules, for example hydrophobic hormones such as steroids. RF-EMF exposure may transiently affect water molecule movement, but evidence to support this above thermal noise remains inconclusive [61]. Additionally, lipid–protein complexes appear to be more sensitive to perturbations from RF radiation at membrane phase-transition temperatures [62,63].

Melatonin can function as a potential shield against EMF and as such, it has been identified to have a protective role against cancer progression in an array of solid tumour types including breast, prostate and gastric [24,64,65]. Melatonin production (high at night) is modified by light exposure, as detected by blue light photoreceptors in the retina (containing cryptochromes). The retinal cells connect directly into the suprachiasmatic nucleus in the brain, which then connects to the pineal gland. Several reports demonstrated that the chronic exposure of rats to electric fields severely attenuated the night time rise melatonin production in the pineal gland, and that static magnetic fields have been repeatedly reported to perturb the circadian melatonin rhythm. The activity of the cryptochrome-containing cells of the retina have been implicated in this response, as the mechanisms of blue-light detection, radical pair formation, magnetic influence on cryptochrome function and downstream effects, converge.

Extracellular Vesicles and Magnetic Field

Extracellular vesicles (EVs) are small membrane-bound vesicles released by living cells into the extracellular space and function as critical mediators for intercellular communications. EVs contain a wide range of bioactive molecules, including proteins, lipids, and nucleic acids, that can be transferred between cells [66]. We and the others reported that EVs carry different nucleic acids, including microRNAs that can significantly regulate cell growth and metabolism by post-transcriptional inhibition of gene expression in target cells, strongly influencing the tumour microenvironment [67–69]. EV microRNA content can be both representative of the cellular microRNA pool and can show a degree of selective packaging, any cellular responses or stress challenges in the parental cells are mirrored in the EV content [67].

Profiling microRNA content within EVs is crucial for understanding cellular states, origins, and functional roles. Integrating EV microRNA analysis into high-throughput genomics studies enhances our understanding of cellular physiology and pathology, providing insights into disease mechanisms and potential therapeutic targets. Recent studies have investigated the impact of MF on EV release dynamics, suggesting potential alterations in EV composition and secretion patterns, as well as miR content. It was shown that MF could directly stimulate and promote the secretion of membrane-derived micro vesicles in the equine adipose-derived mesenchymal stem cells [70]. While further research is needed to fully understand the mechanisms underlying the influence of magnetic fields on EV release, our preliminary evidence suggests that they could indeed have an impact on this important cellular process, and we hypothesise that MF affects EV content as well as the release.

Limitations and concerns

The effects of magnetism and the quantum world upon biochemistry and biological reactions are a relatively emerging concept that cannot be ignored. Certain biological reactions and enzymatic activities within the body, which lead to hormonal imbalances and ROS production, could indeed be potentially influenced, and exacerbated by magnetic and electromagnetic fields. Holding a device, which generates moderately strong magnetic fields close to the pelvis for prolonged periods of time may form a ‘perfect storm’ scenario, where small biological effects working on top of the many risk factors may tip the balance towards carcinogenesis. Afro-Caribbean musicians might need to be more careful – due to their already higher risk. So, in answer to our opening question – do electric guitars cause prostate cancer, the answer is likely to be no. But, in answer to the question – could electric guitars cause, or contribute to, prostate cancer – it is unlikely but not impossible.

Future perspective and hypothesis testing

Animal studies would be an invaluable tool for testing this hypothesis. Several mouse prostate cancer or pre-cancer models are available for use. Models such as those that induce pre-cancerous lesions or prostate intraepithelial neoplasia (PIN) would indeed be useful e.g. the PB-Her2 [71], PTen knockout mouse [72], ARR_2PB-ERG [73], either as homozygous or heterozygous models could induce pre-cancerous prostate lesions upon which the effects of diet, daylength, ROS etc could be manipulated alongside MF / EMF to look for exacerbation of prostate hyperplasia to neoplasia.

Conclusion

There is strong evidence to show that risk factors such as advanced age, poor diet, Afro caribbean ethnicity is just a risk factor for PC not all cancers (Fig. 2). These risk factors in themselves can be linked to several cancer types, but with special regards to hormone-linked cancers such as prostate and breast. As the field of quantum biology expands, and we obtain a deeper understanding of how the quantum world influences biology, then such potentially small effects may well have influence on disease risk.

Declarations

Consent statement/Ethical approval: Not required.

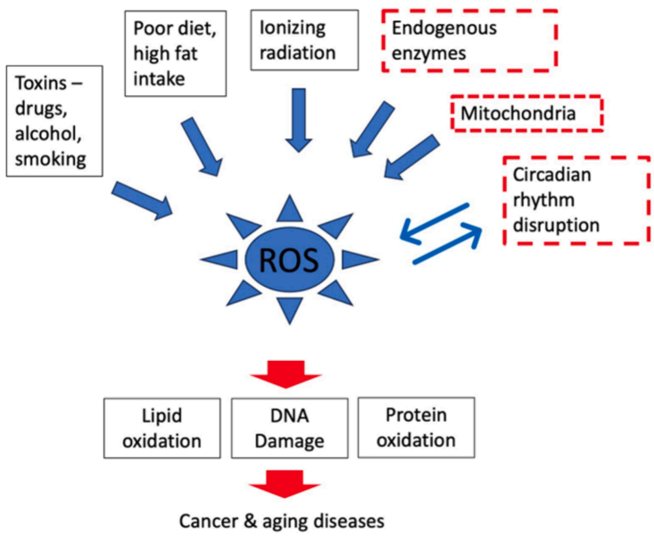

Fig. 2. Sources of exogenous and endogenous reactive oxygen species within cells. These go on to damage cellular machinery, which has been strongly linked to aging-related diseases such as cancer. Red-dashed boxes indicate sources of endogenous reactive oxygen whose pathways may be influenced by magnetic fields.

Availability of data and materials

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CRediT authorship contribution statement

D. Alwyn Dart: Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Conceptualization. **Sarah Koushyar:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis. **Pinar Uysal-Onganer:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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