Kandidatnummer: 132

MRI – Popular Science Essay

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Innholdsfortegnelse

Introduction

Some time ago my grandfather complained about his upcoming MRI scan and that the machine they would put him in would be both loud and uncomfortable. He asked me to contact the clinic and ask around if the procedure could be performed without the need for such a contraption. Knowing my grandfather to be a stubborn man, I agreed to call and ask even though I assumed they would have no resolution for his problem. As expected they communicated that the MRI scan would have to be done inside the machine, and that there was nothing they could do for his claustrophobia other than allowing him to listen to music.

To this my grandfather exclaimed his disbelief, since there was no way they would put important individuals or state leaders inside the scanner. Surely rich and powerful people enjoyed privileges that meant they didn't have to spend upwards of 40 minutes inside a large blaring machine. Although his logic was quite simple and direct, it did ignite thought in me. I decided to delve into the issue and find what research had been done on ways to deal with claustrophobia in MRI scans, and through that hopefully be able to put into words an explanation that would satisfy him.

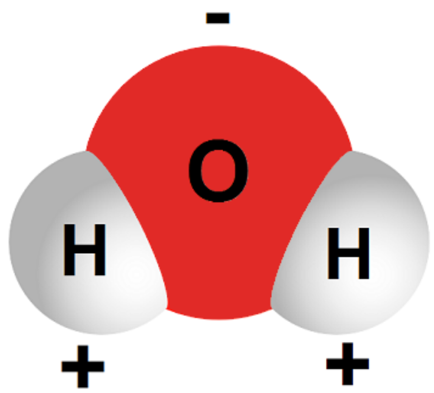
Naturally, it is essential to clarify and explain what MRI scans are and how they work. So that you can fully comprehend the issue and how it relates to claustrophobia. Many of us will undoubtedly have scans at one point or another in our lives. At the very least, we would certainly know someone who has had a scan, be it a relative or a friend. However, we seldom take the time to think about how this instrument operates, and why we have to stay completely still inside a giant suffocating tube. Are the doctors and scientists just playing some elaborate prank or is there actually some justification behind our inconvenience?

How a typical MRI-machine looks from the outside. (iStock, u.d.)

MRI stands for magnetic resonance imaging and is used to diagnose a plethora of different medical issues. Specifically, the imaging process creates images of the soft tissue within the body and is often utilized to diagnose issues related to the back and brain. By many it is regarded as one of the most crucial tools within medical imaging. But what do we know about the history of this tool?

A history lesson

The history of MRI scans can be divided into three parts. The first of which is linked to Wolfgang Pauli's observation in 1924 that atomic nuclei had magnetically related spins. It was this observation that laid "the physical basis of magnetic resonance upon which everything else in this field was established." (Filler, 2009). Now this might sound complicated, and it is, but essentially, what needs to be considered is the fact that the water molecule H_2O is electrically charged. It has a negative side in direction of the oxygen atom, and two positively charged hydrogen protons. Such an electrical charge results in an electrical current, which in turn creates a small magnetic field. Meaning that every proton has a tiny magnetic field. Furthermore, the protons are constantly spinning, and this phenomenon causes all the water molecules and their small magnetic fields to spin around inside our bodies at all times. We of course notice little of this, since the protons spin in different directions, and essentially keeps our bodies in a neutral state. One might say that they are cancelling each other out. (Grätz, 2020)



H_2O molecule. The hydrogen protons are also known as atomic nuclei and have magnetically related spins. (Socratic, 2017)

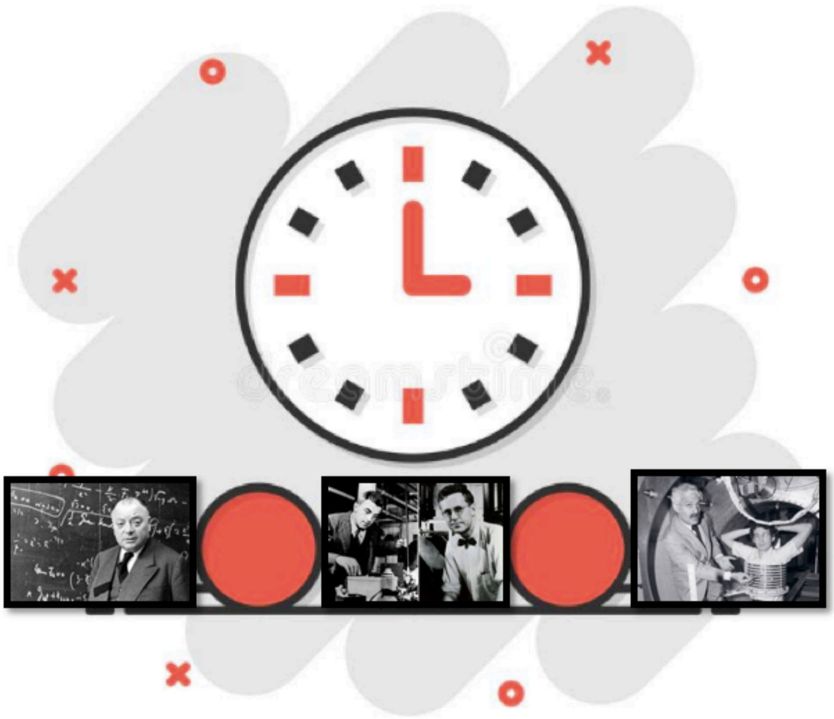
Many physicists set out to prove and further develop Wolfgang Pauli's discovery. The most notable of them was Isidor Rabi, who in 1938 conducted an experiment that involved sending a gas of atomic nuclei past a magnet. The gas beam would be deflected by the magnet, and hit a detector set up by Rabi. Then the American physicist added another electromagnet who he could rapidly fluctuate the field strength of. By tweaking the frequency and the field strength he finally discovered a combination that would cause the gas beam to bend to a new deflection point. Thus, the results proved the existence of magnetic spins, and further showcased the possibility of manipulating the magnetic resonance. It is precisely this term; resonance that is at the heart of MRI. (Filler, 2009)

The definition of resonance is "the enhancement of an atomic, nuclear, or particle reaction or a scattering event by excitation of internal motion in the system" (Merriam-Webster, u.d.). In other words, by utilizing a certain frequency it is possible to load the protons with energy, causing them to move. After some time, the protons will reset to their starting position, and this process will release energy at the original frequency.

Despite the promising start, the development of modern MRI scans was greatly haltered, courtesy of the second world war. It would as a matter of fact take nearly 20 years from Pauli's original discovery before scientists could once again work on utilizing MR to create images. This set afoot the second part where a breakthrough came independently from physicists Purcell at Stanford and Bloch at Harvard. “Each published their finding that the magnetic resonance effect that Rabi had observed in gases could be detected in solid materials as well.” (Filler, 2009). Their success subsequently opened the door for the study of biological specimens. As mentioned when energy is contributed to the protons, they are manipulated to move in a certain direction. Upon turning off the energy pulse, they fall back to the way they were originally. The result would be an electromagnetic signal that could be recorded via an antenna. As for the time it takes for the proton to fall back into its place it is regarded as the “relaxation time”.

Our human anatomy constitutes that different parts contain different density and occurrence of water (protons), and for this reason the relaxation times will differ for each type of biological matter. It is precisely these differences in relaxation times that make it possible to deduce the composition of our tissue and create an image using powerful computers. The relaxation times themselves can be categorized in to T1 and T2.

The last chapter of our story began when Raymond Damadian noticed that the T2 relaxation time was longer in tissues with tumours compared to normal tissue. An exciting revelation since it implied that MRI scans could be useful to detect the presence of cancer in tissues. Following this Damadian filed the first patent for an MR machine in 1972, and in 1977 the first MR machine was officially invented. There were however several issues with the machine, such as it not being able to create an actual image, and not being fully operational. It did however set the grounds for Latebour and Peter Mansfield to create imaging using magnetic resonance. Which then made it possible for a team lead by John Mallard to create the first full body scanner. Similar to the ones that are used today. (Filler, 2009)

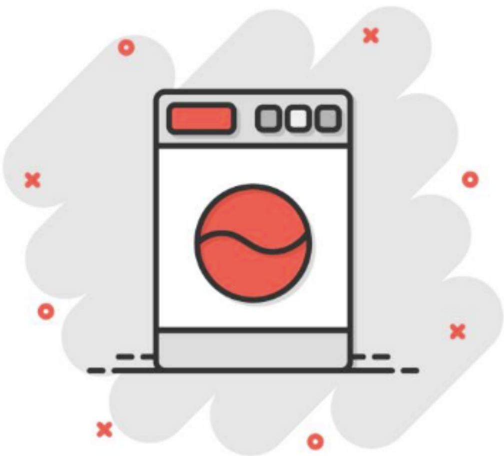


From left to right; Wolfgang Pauli, Purcell and Bloch, Raymond Damadian. (ETH Zurich, u.d.) (Computer History Museum, u.d.) (Alumni Park, u.d.)

An outline of the scanner can be presented as the following; the MR machine utilizes the fact that nuclei spins by creating a magnetic field around the patient, thereby aligning the protons inside the human body with that of the magnetic field in the machine. Afterwards electric impulses are sent out to make the protons move a certain way. When the protons align back the way they were originally they send out an electromagnetic signal. This signal can be received and processed using computers to create the image. More precisely the differences in relaxation times is what the computers look at to build the image.

“Perhaps when you find yourself lying inside the MRI machine, you should steer your focus away from the cold hard surface underneath you, and that bothersome itch in your left leg. Similarly, you should not let the cramped space, or tight air worry you. Rather take the time to appreciate how large magnets are seamlessly able to manipulate the microscopic molecules within your body. All at the expense of nothing but a slight uncomfortable noise.” I suppose I could say something along these lines to my grandfather, but I don’t think it would go over particularly well.

Well, at the very least we now have a bit more insight as to why the machines are so unbearably noisy. As mentioned one integral part of MRI consists of registering the electromagnetic signals that are sent out when the protons reset. Specifically, modern day MRI machines use gradient coils (circular copper with electricity flowing through) in order to create additional smaller magnetic fields in all directions of space. This way the machine can precisely locate the signal when it comes back. However, for this to work large amounts of electrical current needs to be generated. The current in question is then constantly turned on and off within the span of milliseconds, causing the coils to expand and contract rapidly. It is in fact the continuous expansion and contraction of cobber coils at a high rate, that produces the vibrating noise heard inside the machine. Interestingly, it is the sole reason behind the entirety of the commotion and vibration heard inside the machine. Furthermore, the hollow inside of the machine amplifies the sound, and only serves to make the clattering even louder. Imagine finding yourself inside a drum or a tumble dryer. (Dandino, 2016)



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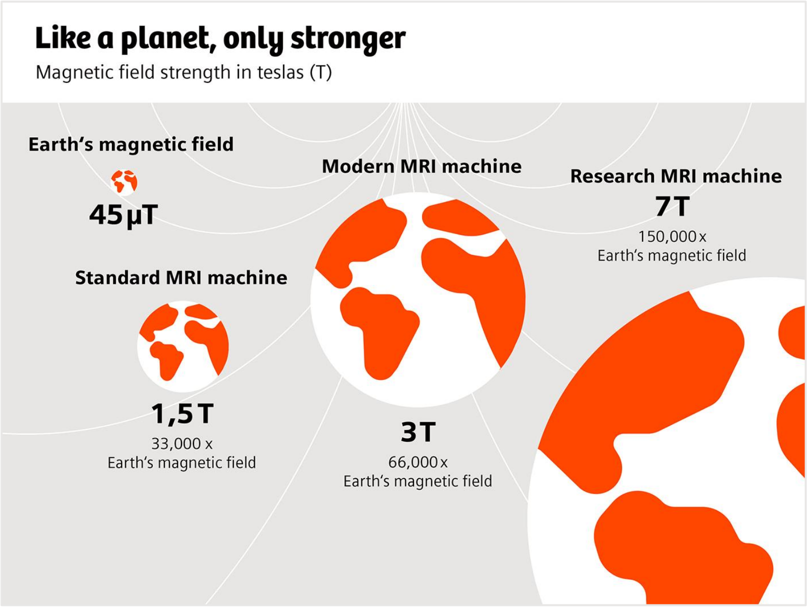
As for the narrowness of the machine, the main culprit is the need to create and sustain a large electromagnetic field over extended periods of time. Standard MRI machines have magnetic fields that are either 1.5 or 3 Tesla (The unit of measurement used to determine a magnetic fields strength, not the popular car). For reference the earth's magnetic field is that of 0.5 Tesla. Naturally the process of creating such an electromagnetic field is therefore very energy demanding, and not easily altered. For this reason, the magnet is never turned off, neither between scans or at any other time. Moreover, the energy needed to keep the machine powered is comparable to 11 formula one cars (The popular cars). Understandably the process of creating a bigger machine would only serve to demand even more energy and would necessitate huge changes in modern MRI machine structure. In other words, it is neither cost efficient, energy efficient or scientifically easy. (Grätz, 2020)



(Grätz, 2020)

Ethics

It is here that we stumble upon an ethical dilemma. Should engineers use considerable time and resources to facilitate extensive changes in MRI machine structure and design? Changes that would not serve any other purpose than to make us more comfortable. It would not increase the quality and precision of imaging, nor would it make the process of diagnosing more effective. Quite the contrary it could quite easily prove to create a more energy costly and slower machine. Reportedly some institutions like the Cincinnati Children's Hospital even have new MRI scanners that are capable of using low noise image sequencing. However due to the decrease in image quality caused by this technology, the machines have not been approved by radiologists for use in clinical studies (Dandino, 2016). So, what should be the answer?

If one were to look at the issue from a consequentialist perspective, we might get some idea on how to tackle the problem. The consequentialist ideology states that we would have to weigh up the sum positive and negative outcome of the options. That, however is very complex and speculative. We cannot possibly figure out what scientific breakthroughs could potentially be made in the future if resources are kept away from the modernization of MRI machines. Similarly, although people have tried to perform cost analysis on the financial impact of claustrophobic events in MRI, filtering in all factors and calculating an exact number is near impossible. Thereby we lack an estimate of what the actual cost of claustrophobia in MRI is, nor do we know the probability of a scientific breakthrough taking place if resources and time is spent elsewhere. This theory might be well suited within the parameters of a philosophical dilemma, but in the real world looking that far ahead is extremely difficult.

On the other hand, by taking an internalistic-based approach it is possible to argue that the comfort of the individual should come before everything. That is after all a fundamental right which should be prioritized. Patients that are in distress, and suffering must be helped no matter what. By using this way of thinking the consequences and the situation are not relevant. Here it may also be beneficial to look towards studies that show how cost and benefits is balanced in order to create accessibility on the internet.

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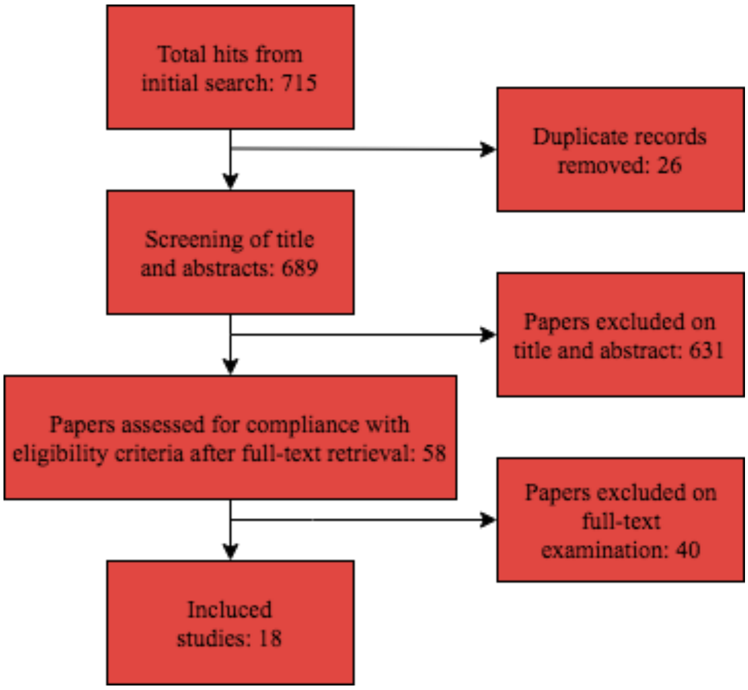
Clearly, there are multiple outlooks on the matter, and no definite answer. Only through discussion we might come closer to some verdict. That being said, the thought of spending my evening debating any issue in light of ethical theories with my grandfather is not a very tempting one. For reference he once spent half an hour arguing that commercial airplanes can stay completely still in the air for however long the pilot pleases.

Therefore, the reasonable next step would be to look at the frequency of claustrophobic events when it comes to MRI. Is my grandfather alone in his experience, or is this a common problem? Luckily various studies have been conducted over the years in regard to this.

Studies show that ….

For instance, in the research article "Claustrophobia in magnetic resonance imaging: A systematic review and meta-analysis" it is estimated that 1 out of 100 or 12 out of 1000 patients undergoing an MRI scan experienced claustrophobia to the point that the scan had to be aborted. The study in question was conducted using a literature search where all studies reporting on claustrophobic events since 1996 were included. The term claustrophobic event was in this case defined as an event where the scan was either prematurely terminated, a refusal took place, or the scan was otherwise not completed. As for the year, it was chosen based on the researcher's belief that this was a suitable cut-off point "between traditional MRI systems and the introduction of newer, more patient-friendly systems." (Munn, Moola, Lisy, Riitano, & Murphy, 2015)

For the search itself, the researchers decided that the articles chosen had to contain a sample size of over 200 subjects. This criterion was chosen to ensure adequate size. Popular databases such as Medline and Embase were employed, resulting in the finding of 715 articles. However, this tally was significantly shortened through the process of removing duplicates and screening of the title and abstracts. The reviewers were left with 58 articles, of which 18 met the criteria. (Munn, Moola, Lisy, Riitano, & Murphy, 2015)



Overview of the literature search. Figure 1 from "Claustrophobia in magnetic resonance imaging: A systematic review and meta-analysis" (Munn, Moola, Lisy, Riitano, & Murphy, 2015)

Having read these articles, the researchers found the percentage of aborted scans throughout the studies to range from 0.46% to as much as 5.29%. Upon meta-analysis of the studies they were able to calculate that 1-2% of MRI patients are unable to complete their scan due to a claustrophobic reaction (meta-analysis is a means of analysing the results of previous research). Based on these findings the article recommended medical professionals working with MRIs to be prepared to encounter claustrophobic patients. However, it is important to note that said study does not give an overview over the number of patients that experienced claustrophobia but were able to complete their scans. (Munn, Moola, Lisy, Riitano, & Murphy, 2015)

To shed some light on that aspect we can refer to a study conducted in 1997 where it was found that 134 of 939 (14,3%) patients required sedation to undergo their MRI scan. For this study the method was based on reviewing the medical records of a large hospital over a random 7-week period. After identifying every patient that had to use some sort of sedation to complete their MRI scan, the age, sex, type of MRI scan, type of sedation, and previously undergone scans were subsequently reviewed for each patient. This was done in order to see if there were any connection between these factors and the need for sedation. Lastly the statistical tool; “Fishers exact test” was applied to evaluate the results. (Murphy & Brunberg, 1997)

Table 1. Analysis of sedation requirements of 939 patients undergoing MRI				
Group	Sedated	Non-sedated	Total	Sedated %
Total	134	805	939	14.3%
M	48	387	435	11.0%
F	86	418	504	17.1%
Brain	89	461	550	16.2%
M	29	209	238	12.2%
F	60	252	312	19.2%**
Spine	29	161	190	16.3%
M	11	59	70	15.7%
F	18	102	120	15.0%
Extremity	3	119	122	2.5%
M	1	76	77	1.3%
F	2	43	45	4.4%
Abdominal	13	64	77	16.9%
M	7	43	50	14.0%
F	6	21	27	22.2%

Table showing the results of the study. Table 1 from “Adult claustrophobia, anxiety and sedation in MRI” (Murphy & Brunberg, 1997)

Note; I´m assuming my grandfather would be unfamiliar with statistical tests such as Fisher´s exact test or the Chi-square test. In this context it would therefore be sufficient to tell him that the tests return a value P and based on this number scientists can determine if there is a significant difference between two groups. Now whether or not my grandfather will attribute any credibility to the work that has been put into this field over the years, or appreciate the meticulous development of this framework for the benefit of scientific research remains to be seen.

Interestingly the statistical analysis (Fisher´s exact test) indicated that sedation was more likely to be used by women rather than men, in brain MRIs and often when the patient had undergone scans before. The patients that did not require sedation were used as a control group in this regard, or in other words they served as a comparison. Lastly the study also concluded that there is a need to identify the population that has the greatest need for sedation, as this will aid in the development of stress reducing methods. The reviewers further reflect that these methods will have a positive effect on patient comfort, as well as reducing the number of terminated scans, and causing less motion artifact. (Murphy & Brunberg, 1997)

Let's clarify what this term means as we will encounter it later; Motion artifacts are occurrences where the image capturing process is affected by the motion of the patient, resulting in a negative effect on the image quality. For our case this is highly relevant as anxiety-driven and claustrophobic reactions often can cause the patient to move involuntarily.

A concept which researchers from the departments of radiology and psychiatry at the university of Vienna explored in greater detail. Their study incorporated 297 first time MRI patients who were surveyed before and after the procedure. Here it was reported that patients that were worried beforehand had a higher risk of MA impairing than patients that reported no worry before the procedure. (Dantendorfer, et al., 1997)

The research took place during a 3-week period at an undisclosed MRI facility. As for the method 3 different questionnaires were deployed. The first of which was the commonly used Spielberg State-Trait Anxiety Inventory (STAI). A collection of forms that is used to evaluate state anxiety (how one feels at a particular moment) and trait anxiety (how one usually feels). For this experiment the patients were only required to answer the state anxiety component. It consists of 20 questions related to anxiety which subjects are asked to answer according to a 4-point scale ranging from "Not at all" to "Very much so".

1	2	3	4
Not at all	**A little**	**Somewhat**	**Very Much So**

1. I feel calm 1 2 3 4

Example of a typical question in the state form. From https://www.advancedassessments.co.uk/resources/Mental-Health-Test.pdf

The two other questionnaires were specifically designed for the project, and further aided in the assessment of the anxiety levels before and after the scan. Unlike the previous study the researchers did not use Fisher´s exact test and instead opted for the Chi-square test and T-test for analysis. Moreover, the tool used for performing these tests, was the popular statistical analysis system SAS. (Dantendorfer, et al., 1997)

sas

(Wikimedia Commons, 2009)

Interestingly the founder of the Chi-square test; Karl Pearson was an important figure in early positivism and the philosophy of science. His book "The Grammar of Science" was even recommended by Einstein himself as an important introduction into the philosophies of science. Pearson was furthermore a proponent of social Darwinism. An ideology that is built on the belief that the rich, and successful people of the world are in their positions based on the concept of survival of the fittest. Therefore, he was opposed to social programs, government handouts or interventions of any kind, as he believed helping people in bad positions would be a waste of resources. His world view is easier understood by this quote from his book "Darwinism, Medical Progress and Eugenics";

“The right to live does not connote the right of each man to reproduce his kind ... As we lessen the stringency of natural selection, and more and more of the weaklings and the unfit survive, we must increase the standard, mental and physical, of parentage.” (Pearson, 1912)

In our case patients who are suffering from claustrophobia are less likely to complete their MRI scans, and thereby less likely to discover any impending medical problems. Pearson would likely argue that the best course of action is to do nothing and let these people die so that society may evolve. It might be smart to not bring up this particular point of view to my grandfather.

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Anyway, after the calculations were concluded the article presented that 6,4% of the patients showed MA that impaired the quality of the image to the point where the diagnostic quality was compromised. Looking at the pre-scan questionnaire these patients were more prone to have stated worry before the procedure than patients that had stated that they were not worried. Undoubtedly the considerable percentage of MA and the correlation to pre-scan anxiety highlights the time and cost consuming issue of claustrophobia within MRI. A notion that is echoed at the end of the article, whereby the authors have commented that; “Given the cost and increasing number of MRI examinations performed worldwide, the prevention of anxiety-related adverse reactions is not only important from a patients' standpoint but also to prevent the waste of nonrecoverable staff and equipment time." (Dantendorfer, et al., 1997)

Continuing on that thought it is therefore quite relevant to look at the financial consequences of claustrophobic events within MRI. The review article named "Prevalence and Financial Impact of Claustrophobia, Anxiety, Patient Motion, and Other Patient Events in Magnetic Resonance Imaging" attempts to break down this very issue. Specifically, "the financial implications of these events are discussed from a microeconomic perspective, primarily from the point of view of a radiology practice or hospital" (Nguyen, et al., 2020).

The researchers cite several studies containing varying estimates. For example, one study mentioned assessed the financial impact in the US alone from claustrophobic events to range between $425 million and $1.4 billion. Similarly, a European study from 2011 "estimated a loss of 1 billion euros a year from MR procedures that are either prematurely terminated or cannot be performed due to claustrophobia" (Nguyen, et al., 2020). Another study used a different approach and calculated that the loss of revenue from patient motion and inefficient scanner use could be as high as $592/scanner/hour. (Nguyen, et al., 2020)

Having discussed the aforementioned studies the authors concluded that "Although value-based incentives and other changes in reimbursement may alter future emphasis on patient volume, efforts to mitigate effects of claustrophobia or undesired motion in MRI are nonetheless likely to benefit patients and the healthcare system through decreased patient distress and greater diagnostic value of acquired images" (Nguyen, et al., 2020). The operational efficiency of the health care practise was also stated to benefit from such efforts.

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Based on the studies we have been through there is evidently a direct correlation between claustrophobia and MRI scans. Many of the studies highlight the importance of preventing anxiety related issues and specifically comment that there are many benefits in doing so. Clearly, my grandfather was not alone in his experience, which further increases the likelihood that some potential solutions have been tried out. So, what do rich people do as he would put it, what are they offered and how are they able to endure these procedures? What do they have access to that we do not?

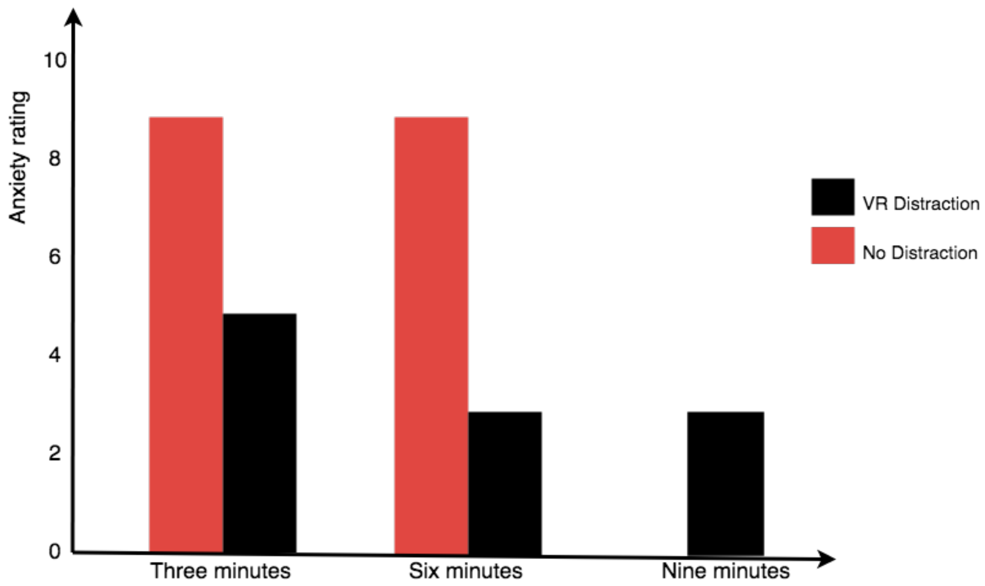
Solutions

Virtual reality

One interesting experiment that has been conducted took place in 2007, whereby two patients underwent mock MRI scans. A mock MRI scan is performed inside an exact replica of a normal MRI machine. However, this machine contains no magnet, and therefore no real scan is performed. For the duration of the time that the patient is inside the scanner, a built-in speaker produces the same set of sounds that one would typically hear during an MRI scan. Essentially giving the subject the effect of undergoing a normal MRI scan.

The case report presented in detail how two patients who both fit the criteria for having claustrophobia underwent two consecutive mock MRI scans. In the first event both patients had to abort their scans and were not able to stay throughout the procedure which was set to 10 minutes. Both subjects aborted the scan at approximately 6 minutes. Then by random selection one of the patients was chosen to receive virtual reality distraction, whereas the other was given music. Specifically, the virtual reality experience put the patient within a snow themed world where he could spend his time looking around and shoot snowballs at penguins, and snowmen. (Garcia-Palacios, Hoffman, Richards, Seibel, & Sharar, 2007)

Every 3 minute the patients were asked to rate their anxiety on a scale from 0 to 10. In her second go the patient taking use of VR distraction was able to complete the full scan. Not much change was seen in the patient receiving music though, as she asked to have her scan aborted at 3 minutes. The fact that the patient with VR access was able to complete her scan, while the patient given music showed little difference led the authors to conclude that; "Virtual reality distraction successfully reduced claustrophobic fear during a mock MRI examination, providing converging evidence for a growing literature showing the effectiveness of VR distraction as a new technique for reducing anxiety and discomfort. Music alone did not reduce a claustrophobic response." (Garcia-Palacios, Hoffman, Richards, Seibel, & Sharar, 2007)

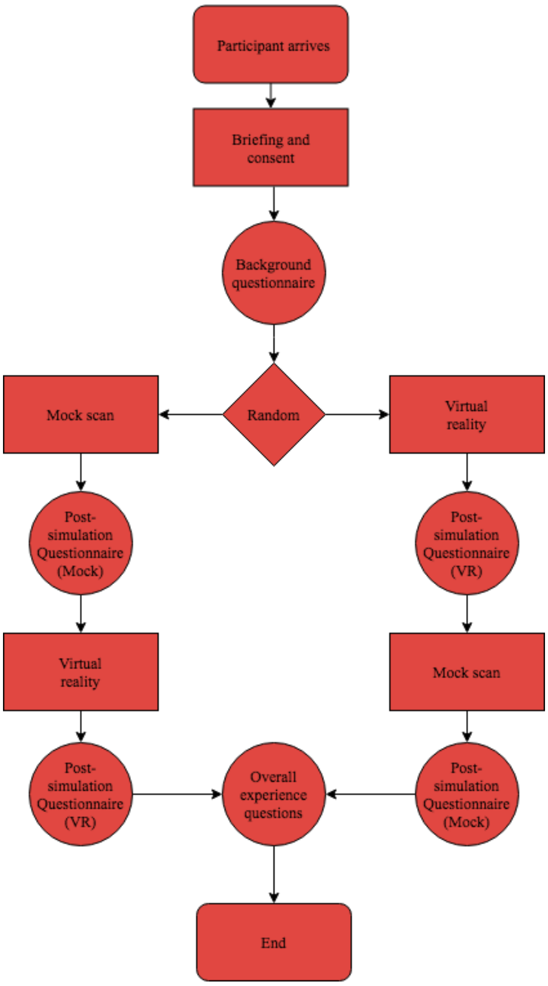


Anxiety rating for the two patients at 3-minute intervals. The patient with no distraction present was unable to last the full 10 minutes. Figure 1 from "Use of Virtual Reality Distraction to Reduce Claustrophobia

Symptoms during a Mock Magnetic Resonance Imaging Brain Scan: A Case Report" (Garcia-Palacios, Hoffman, Richards, Seibel, & Sharar, 2007)

The premise of using VR is backed up by another study named; "Can virtual reality simulation prepare patients for an MRI experience*?*". Here the researchers indented to see if there would be any difference between a virtual reality MRI scan and a mock MRI scan. Method wise, a total of 20 test subjects underwent both a VR scan and a mock MRI scan. The VR scan was performed by having the patient lie on a hospital gurney, whilst wearing a VR helmet. As in the previous study, the mock MRI was carried out using a replica of a full-scale MRI machine without a magnetic field. Both simulations had pre-recorded sound equivalent to what one would hear during a regular MRI experience playing in the background. (Nakarada-Kordic, et al., 2019)

The participants were assessed multiple times throughout their simulations, and in addition had to answer a total of 3 questionnaires each. The questionnaires revolved around the level of anxiety, comfort and relaxation felt, and also contained direct questions asking patients to compare the two different simulations. At the end they were given the opportunity to provide general comments about their experience. At this time, they were also asked which type of simulation they found to be more realistic/helpful, and whether they would be willing to undergo said simulations at home for preparation. (Nakarada-Kordic, et al., 2019)



Overview of the process. Figure 1 from "Can virtual reality simulation prepare patients for an MRI experience?" (Nakarada-Kordic, et al., 2019)

Afterward the Friedman two-way analysis of variance was utilized to compare the scores. The analysis revealed no significant difference in subjective experience of anxiety between the two types of simulations. Thus, the results suggest that using virtual reality-MRI scans as a means to prepare an anxious patient is a viable, effective and relatively cheap method. The conclusion of the article reflects this sentiment; "VR could be a feasible and accessible alternative to mock scanning. It has the potential to improve patient experiences of potentially stressful MRI examinations." (Nakarada-Kordic, et al., 2019)

Considering these two experiments, it is at the very least safe to assume that VR can play some role in reducing stress and anxiety for claustrophobic patients. Either through preparation, or as a means of distraction during the procedure. An intriguing thought since the technology is rapidly evolving, and VR is becoming increasingly popular in households. Still, I do think some time will pass before my 80-year-old grandfather is overly excited by the idea of putting a virtual reality helmet over his head and positioning himself on the kitchen table for an hour.

Chemicals

As we are forced to turn to other viable solutions we might find them in the form of chemicals. Specifically, a drug named Midazolam. This is a drug often used in medical clinics to prevent anxiety and panic in patients. A particular benefit with this medicine compared to other types of sedation is that it has a relatively slow duration and is out of the system quickly.

German researchers attempted to examine the advantages of said drug when they conducted an experiment between June and October 1999. The study included 54 patients between the ages of 18 to 65. These participants were specifically chosen based on the fact that they had not experienced an MRI scan before. (Hollenhorst, et al., 2001)

For the procedure itself participants were first asked to answer the Spielberg State-Trait Anxiety Inventory (STAI). You might remember that from one of the first studies introduced. In addition to the STAI, participants also answered a custom form about anxiety. During the experiment half of the contestants were given intranasal (through the nose) midazolam. The other half were given what's known as a placebo in the form of NaCl (table salt). A placebo is an inactive substance that has no effect on the tested individual but is used only to make certain that the results of the trial are legitimate. What the researchers intended to achieve by doing this is creating additional support for their testing by comparing the results with that of a control group. While the experiment was under progress the authors evaluated the level of sedation the patient was under. Both sets of participants underwent an MRI scan, and upon completion a radiologist was asked to rate the quality of the imaging. (Hollenhorst, et al., 2001)

The results were positive and showed that for the midazolam group 27 out of 27 patients were able to complete their MRI scan. On the other hand, 4 out of the 27 patients that had received a placebo had to abort their procedure mid scan. Furthermore, the patients that had received midazolam reported significantly lower anxiety scores, compared to the other group. Lastly the results showed that the quality of the MR image was better in the midazolam group, ranging from good to excellent. In the other group it ranged from poor (not usable) to good. (Hollenhorst, et al., 2001)

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The experimentation concerning chemical solutions did not stop there. In 1994, 57 patients that were scheduled to undergo MRI scans at Memorial Sloan-Kettering Cancer Center agreed to partake in a study exploring the usability of fragrance. In this particular study the intention was to find out if fragrance could be used in a clinical setting to relax patients that are suffering from claustrophobic feelings because of the MRI machine. (Redd, Manne, Peters, Jacobsen, & Schmidt, 1994)

Before the procedure subjects had to fill out two forms related to anxiety. One being the state anxiety part of STAI, and the other being a custom questionnaire. Among other things, patients were asked to report how pleasant, relaxing and intense they felt the fragrance. Both forms were answered before and after the scan. Similarly pulse and blood pressure was also measured before and after the scan. (Redd, Manne, Peters, Jacobsen, & Schmidt, 1994)

The patients were divided into 37 patients who only received humified air, and 20 patients who received the fragrance. Thus, a control group was once again utilized to uphold the potential findings. The fragrance in question smelt like vanilla and was administered through a nasal cannula. Here the system was such that the fragrance was pumped out for 30 seconds, before unscented air was sent through for a duration of 60 seconds.

Using a collection of methods called analysis of variance the authors were able to compare and analyse the values that had been collected before and after the scan. The most important finding would be that the fragrance receiving patients expressed a 47% reduction of anxiety on average. Whereas the patients who only received air reported a 5% reduction in anxiety. The difference was deemed to be statistically significant. Worth noting here is that the patients that experienced reduction of anxiety found the fragrance to be moderately to extremely pleasant according to their answers. (Redd, Manne, Peters, Jacobsen, & Schmidt, 1994)

The report discusses; "In this first clinical trial of the use of fragrance to control anxiety during MR imaging, patients who received the vanilla like scent heliotropin and who rated the fragrance as pleasant reported a significant decrease in average anxiety during imaging, while patients who received only humidified air did not. These results raise a number of interesting questions regarding possible underlying mechanisms, the importance of patients' liking of the scent, and the clinical utility of fragrance administration as a behavioural intervention in medical settings." (Redd, Manne, Peters, Jacobsen, & Schmidt, 1994)

The researchers further reflect that there might be two main reasons for the decrease in anxiety within the patients that received the fragrance. The first reason might be that the fragrance worked as a distraction, and took the patients focus away from the MRI scan. This happens when patients that like the scent have positive associations to it, and those associations are unable co-exist with the feeling of anxiety. Second reason would be that the fragrance itself directly caused a physiologic response in the patients. Meaning that the components of the substance affected their bodies. (Redd, Manne, Peters, Jacobsen, & Schmidt, 1994)

(iStock, u.d.)

Behavioural solutions

In 2006 British professors aiming to reduce the need for sedation in claustrophobic patients performed an experiment using something called neurolinguistic programming. The location of the experiment was a teaching hospital in Sheffield, England. Participants were 50 adults who were chosen based on the fact that they had had unsuccessful MR examinations in the past, and within this group the median age was 58.

Once again, the patient's level of anxiety was assessed using the Spielberg State-Trait Anxiety Inventory (STAI). First at the day of the Neurolinguistic programming and then again right before the MRI was performed. The neurolinguistic programming technique used was explained in detail by the authors;

«In brief, the patient was asked to describe the feelings they experience when they think about an MR scan. They were asked to associate (anchor) those feelings with something that they could see in the room. The patient was then asked to think about pleasant memories on other occasions when they were relaxed, happy or confident. As the patient thought about the good experiences, the NLP practitioner touched them on the hand or shoulder, thus anchoring the experience. By using the same touch and simultaneously looking at the object that they had chosen and holding both anchors until the previously phobic anchor has been "collapsed", the previously anxious thoughts associated with MRI can become much more comfortable and positive. » (Bigley, et al., 2010)

The article also stated that the time needed with each patient varies based on their need, but in most cases, it was approximately 1 hour.

The result of the experiment was that 38 of 50 people (76%) were able to complete the MR examination successfully. In terms of the anxiety score provided by the STAI, there was a significant reduction in anxiety for both people that failed the MR and those who succeeded in completing it. The Mann-Whitney test was put to use in order to compare the anxiety scores between the groups, and it estimated that those who failed their MR scans had significantly higher anxiety scores prior to the NLP than those who were able to complete the procedure. Thereby the authors concluded that "neurolinguistic programming reduced anxiety and subsequently allowed MRI to be performed without resorting to general anaesthesia in a high proportion of claustrophobic adults. If these results are reproducible, there will be major advantages in terms of patient safety and costs." (Bigley, et al., 2010)

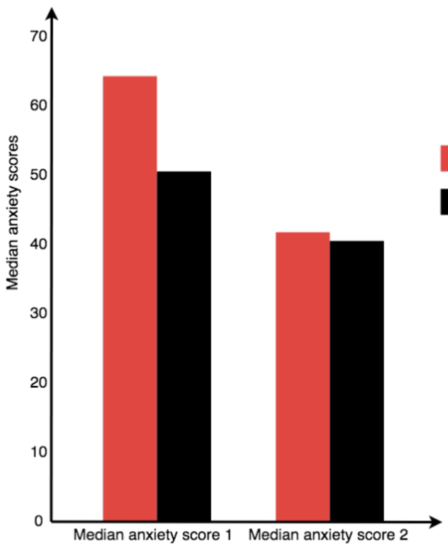


Chart showing the median anxiety scores before the NLP on the left, and after NLP on the right. Figure 1 from "Neurolinguistic programming used to reduce the need for anaesthesia in claustrophobic patients undergoing MRI»" (Bigley, et al., 2010)

If the concept of neurolinguistic programming was not too much for you, a more recent study looked into the use of hypnosis to calm anxious patients. The study was published in 2009, after two hospitals partnered up and sought to explore the effects of this type of training, through a joint venture.

The coaching was facilitated through three trainers that provided 17 hours of training to the hospital staff. “The format included lectures, large group discussions, small group practice, a computer-based module for self-practice, and a microteaching exercise to foster reflection and feedback” (Lang, Ward, & Laser, 2010) The arrangement was set up in a way that half of the staff were able to partake at one time. Thereby not causing any irregularity in the workflow of the hospitals. Furthermore, the training was performed in the hospital, so the participating staff could practise in a fitting setting.

The training itself could be divided into two parts, whereby the first part consisted of building rapport skills. Rapport skills include elements such as building confidence, communicating effectively and validating the patient. The latter part was hypnosis, and through this staff were given training in the fundamental elements of hypnosis, and practise through various exercises. After team training was completed the researchers used the Chi-square test to compare the rate of claustrophobia-caused noncompletions the quarter following the training with that of the quarter before the training. Additionally, comparing was done at a 1-year follow up. (Lang, Ward, & Laser, 2010)

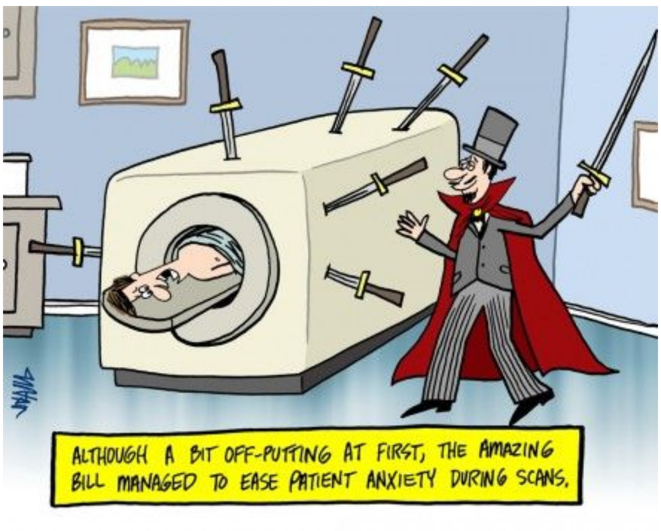
Results showed that there was a significant decrease in non-completions. Specifically, the rate of patients that were too anxious to complete their scan went from 1.2% (80 of 6,654) to 0.74% (52 of 7,008). However only half of the staff were trained, and before the other half were able to undergo it, the two hospitals had to close down the practise because of financial issues. (Lang, Ward, & Laser, 2010)

Tying it together it is clear that there are experiments out there that have produced positive results and have credible research behind them. However, some of these studies were conducted as far back as the 90´s, and despite the positive indications they have not been further developed. Reflecting this none of the mentioned interventions are offered as solutions to regular patients today. To understand why this is, it is important to highlight how these types of studies are dependent on having been through a substantial testing process and approval from external committees. In other words, these sorts of experiments cannot be tried out every other week, with different stipulations and test subjects. That would be too cost and time consuming.

Even in the case of a study receiving the approval of various committees and fulfilling the demand of patient confidentiality it still has to convince clinics and hospitals to adopt the intervention. In able to do so interested parties have to provide solid grounds in the form of detailed testing protocols and extensive cost models. It is understandable why hospitals would be sceptical to the implementation of any major changes to their MRI arrangement. Especially when this might affect them financially, and since it is an issue related to patient's health. One might also wonder how ethical it is to keep putting anxious patients through an experience they find horrific all in the name of research. Research that so far does not seem to lead anywhere.

Other forms of medical imaging

To this point we have been through solutions that aim to either distract or prepare the patient for his/her claustrophobic experience. In all likelihood my grandfather's next question would be; why can´t we just circumvent the use of the machine? There would be no need to acquire fancy fragrance or enlist the local hypnotist. The issue could be resolved if we were able to avoid the machine all together.



(CartoonStock, 2017)

To get some clarification on this I went to see professor Nils Sponheim at Oslo Met. Having taught in different subjects including medical imaging, he would have the necessary expertise needed to answer. I asked him if there was any technology or method out there that could provide the service of MRI, but without the constraints of the machine. His answer was a definitive; no. There were no other alternatives to MRI that could create high quality imaging of soft tissue, the back and the brain.

He mentioned that there were other medical imaging processes, but none of them could compare to MRI. Explaining what these are, and exactly why that is, might be beneficial in order to refresh our memory about what we have come to learn about MRI.

CT

Let's look at CT also known as computed tomography first. It is very common, in fact more common than MRI because of its cheap and reliable nature. At the same time CT is performed with similar factors in place. The procedure involves a machine and a flatbed for the patient to lie on during the scanning. However, the tunnel is significantly smaller, and the instrument produces pretty much no noise. In terms of the imaging process CT utilizes X-ray by sending out radiation. Then, by looking at the ability of said radiation to break through different parts of tissue, the computer can create an image of the person. For example, dense parts of your body such as bone will block the radiation and appear white on film.

The problem however is that it is not as accurate, nor as effective as the MRI machine. As mentioned MRI uses the water molecules inside us to build an image. Examining the difference between levels of water in our body has proven to be the most precise and effective way of creating an overview of soft tissue. Perhaps not surprising, since nearly 70% of our body is water. No matter how many CT scans you perform and however long you spend in there it is not possible to recreate the same level of efficiency. (Envision Radiology, u.d.)

That does not mean that CT scans are not applied though. Often, they are used in collaboration with MRI scans. The ease and speed of which a CT scan is performed makes it very useful for inspecting minor issues. In cases where the doctor suspects that there are bigger issues at play the MR machine is introduced. Perhaps my grandfather will be happy to hear that they are bringing out the big guns for him.

(iStock, u.d.)

X-RAY

X-rays are based on the same principles as a CT scan, but the main difference is that x-rays are used to create 2-dimensional pictures. Since x-rays do not incorporate image capturing from different angles, they cannot provide the 3-dimensional image an MRI machine can. Instead the 2-dimensional image they create is most useful in scenario´s where you are looking for broken bones or other fractures. Essentially, you could say that the aforementioned CT scans are a more powerful and sophisticated version of an x-ray. X-rays do hold certain advantages over their competitors though. The lack of a large machine makes it very appealing and practical for patients and doctors alike. It is also relatively fast both in terms of procedure time and the readying of results. (North Central Surgical Center Hospital, 2015)

(iStock, u.d.)

Ultrasound

Then there is ultrasound. “An ultrasound scanner uses high frequency sound waves to create an image of the inside of the body. […] During the scan, a small sensor, (transducer), is moved over the skin. This sensor projects and detects its own sound waves, which bounce off different parts of the body. A computer then organises the reflected waves into a dynamic picture, which the radiologist performing the scan uses to help make a diagnosis.” (Windflower Diagnostic Imaging, u.d.)

On the surface this tool sounds very promising. It has the ability to assess most joints and soft tissue. At the same time, there is no introduction of a claustrophobia inducing structure. It is also cheaper, faster and more accessible. To top it off the added benefit of dynamic picturing means that the doctor can see the image in real-time.

The drawback however is that ultrasound similar to CT is not particularly effective in issues related to the back and spine. Here the complicated structures inside joints are difficult for the tool to analyse. The effectiveness of ultrasound also suffers when the area that is examined is too deep and far from the surface of the skin. Dr. Forney from Cleveland Clinic explains; “Since ultrasound is like a flashlight, whereas MRI is like a flood light, there are times when ultrasound may not be able to make the diagnosis or may show findings that are indeterminate and need further testing.” (Cleveland Clinic, 2019)

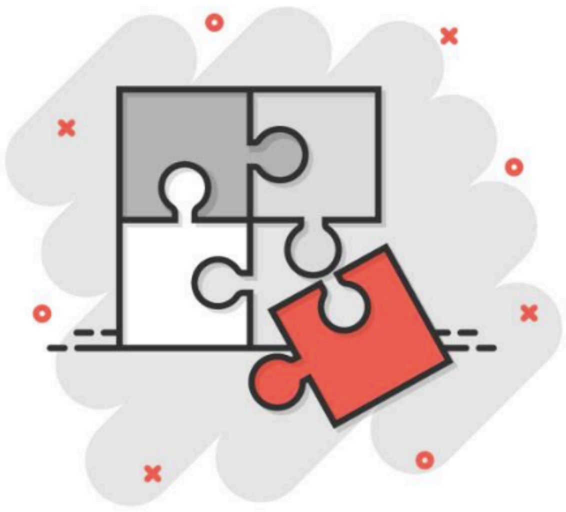
(iStock, u.d.)

Conclusion

To summarize there is no simple way to explain the difficulties and challenges that arise when tackling the issue of claustrophobia in MRI. First, we must recognize the related physical principles that greatly limit how we can attack the problem. Then it must be understood from a philosophical and ethical point of view. Some like the late Karl Pearson would insist that nothing should be done. Others would argue that the resources are better put to use elsewhere.

The only thing that there is little doubt about is that this is a complicated puzzle. A puzzle that researchers from several different backgrounds and fields have tries to solve. Numerous studies have been conducted over the years, all highlighting and raising awareness to the matter. Then interventions ranging from VR-distraction to neurolingustic programming has been introduced in order to resolve the issue. Despite positive results, the progress has been moving slow. This may be attributed to the intricate and troublesome process of getting approval for studies.

In the end there is yet reasons to be optimistic that the knot can be unravelled in the near future. The rapid evolution of technology is after all uncovering possibilities previously never imagined. Perhaps soon the prospects within science and engineering will finally be able to decipher the code. There is also a possibility that someone from a completely different field may turn up with the missing piece of the puzzle. Until then I have the similarly difficult challenge of keeping my grandfather calm.



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