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Direct Brain to Brain (B2B) Communication without Interface Applications-Fact or Fiction?

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ABSTRACT

Direct brain communication has attracted a growing interest amongst the community of neurological research and practice. Experts in the field have advanced both knowledge and understanding of the human brain's sensory processes and its functional interconnections. They capitalised on the outcomes of experimental research in the area of brain-computer-interface (BCI) and developed potential solutions to achieve effective direct brain-to-brain (B2B) communication. The increased knowledge, understanding and development of CBI has led to the development and application of providing individuals who cannot move part or the whole body, with higher levels of autonomy through thought-controlled devices, to improve their social lives.

An improved comprehension how generated brain data could be analysed and evaluated (brain informatics) pioneered new approaches to advance direct B2B communication. The brain's plasticity will play an important role to achieve this goal. The creation of an artificial cortex has the potential to enhance brainpower, which could lead to elevated performance levels in brain communication capabilities. Research-based confirmation that the brain accepts both biological and virtual origins has been a major breakthrough in the development of producing workable solutions in B2B communication.

The outcome of this research suggests that ethical concerns and privacy issues need to be addressed in more depth. More focus needs to be on moral conduct, informed consent and the assessment of legal issues commensurate with further investigative and development work in the area of brain communication.

Keywords

Brain Plasticity, Brain-Computer-Interface, Brain-Machine-Interface, Brain-to-Brain Communications (B2B), Cerebral Cortex, Mind and Brain, Neocortex.

Introduction

Recent research suggests that so-called brain-to-brain (B2B) communication has received more attention, including direct and interface applications and approaches [1-3]. Human beings are striving continuously to improve their brains' electric circuits. Understanding how the human brain works is increasing all the time, including knowledge about the brain's ability to reshape itself according (brain plasticity) to the environment and new challenges it faces in the real world. It is already possible for the human brain to communicate with various machines such as a robotic arm with the help of a brain-machine-interface (BMI), via thought-control.

In their article 'Exploring a speechless world', Farisco and Evers [4] suggest that more needs to be done to explore the area of human beings' communicative abilities and practices that could ultimately provide an answer to typical questions (Section 1.2.2) such as: Is it possible to establish a relationship that can work between the cerebral cortex (highest mental capabilities) and the complex meaning of words (semantic complexity)? Would it be possible for two or more people to communicate directly by being able to read or explain what they think or feel, through direct B2B communication, without the need for any technological interface? There appears to be a current and immediate interest to put B2B communication into practice (direct or indirect). Missing is a condensed summary of expert knowledge and insight, in a single location, that has been examined to establish how direct B2B communication may be possible and how this could be accomplished.

Communication between human brains has been limited and often confined to human computer interface approaches in the past. This research investigated how direct B2B communication could be conducted without the need for an interface. A comprehensive literature review of what is known about B2B communications, direct and indirect, was completed to gain a better understanding of how this could be accomplished.

The research objectives of this research were to:

- Recapitulate the salient facts of direct B2B communication
- Confirm that B2B communications are feasible without the use of interfaces
- Determine relevant ethical and privacy implications
- Encourage fresh thinking and idea-generating within the community of practice to progress direct B2B communication
- Present a list of practical recommendations that will encourage further research

Next, a literature review is presented together with the Main Research Questions. This is followed by Methodology, Results, Discussion and Conclusions/Recommendations.

Suitable and fit for intended purpose recommendations will be presented in the final section of this paper, together with an associated ethical issues caveat on potential side-effects, including privacy and informed consent.

Literature Review

Past Thinking (Pre-2015)

Crick [5] asserts that scientists used machines and brains in different ways during the early years of the so-called computer age. One opinion was to make computers as smart as possible. This area became later known as artificial intelligence (AI, John Carthy, computer scientist, 1956). It appears that those who focused on exploring the rules governing the brain interconnections made the most significant contributions. A kind of 'neuronal algebra' [6-8]. Although merely electronic versions of hierarchical views of sensory processing were produced, a major breakthrough happened towards the end of the 1950s when Boden established that computer programmes could actually model quite sophisticated sensory processes and the programme's functions could change over time. The current clarification of objects was the direct result of this development work. A major breakthrough. It appears that later models explained even better how the human brain works, including revelations of real mechanisms. Despite enormous advances in computer facial recognition and developments in areas such as artificial scene analysis, the area known as machine vision needs to catch up more in relation to what goes on in people's heads.

Although many computational scientists and neurologists put in great efforts to learn more about what is going on when human beings see, people's understanding of this process still leaves much more to learn before levels of understanding can be improved significantly. The current limitation is a lack of theory to explain more complex systems. This needs to be improved to move forward in this field of brain science. Cobb [9] points out some important ethical considerations. Some complex ethical and hazardous situations developed in the area of brain stimulation such as being impressive and highly invasive, it has proved to be effective in terms of clinical benefits, including reducing the symptoms of Parkinson's disease. It appears that that so-called deep brain stimulation (neurosurgical procedure that includes a neurostimulator device to send electrical impulses via implanted electrodes to specific targets in the brain, to treat movement disorders including Parkinson's disease), has become much more effective. There are encouraging signs that research in related areas such as controlling machines, is making good progress. This includes the moving of robotic arms in the motor cortex of tetraplegic patients. Next on the agenda is a bionic hand for an amputee, controlled by electrodes implanted in their arm. In addition, translating neuronal activity associated with imagined speech into an artificial voice is under investigation.

Carter [10] asserts that new opportunities are arising in relation to how much we understand of how the human brain works, and what could be done to, for example, enhance the brain's capabilities. There is still a lot more to be discovered, including the development of an artificial brain. The future has already arrived today. Carter reports that some of the available technologies for mind reading, thought control and Artificial Intelligence (AI) have already made a significant difference to develop the human brain of the future. Carter suggests that BMIs are going to revolutionise what human beings can achieve to take the brain's capabilities to the next level. Electrical signals, for example, can be registered by sensors and transmitted wirelessly to electrical devices. Objects can therefore be moved or altered through thought-control. People with nervous system injuries are already benefiting from these developments. This mind-controlled technology provides people with nervous system disabilities to lead a more normal life (artificial limbs, wheel chairs and computers). A major breakthrough appears to have been made in the area of mind reading that has the potential to be developed to allow for B2B communications.

It is now possible to translate the 'picture' of neural activity created by functional magnetic resonance imaging (fMRI) scanning 'into a precise description of what a person is seeing, and, to some extent, what they are thinking' (p. 217). The output from an fMRI scan, whilst someone is looking at an image, is generated via computer software that can translate the whole activity into a visual image. This mind reading is made possible because the neurons in the visual cortex have been stimulated and triggered (horizontal and vertical lines); being indicative of the kind of visual stimuli the neurons appear to be registering. Carter argues that there are still some technical problems that need to be overcome. It appears that 'mapping' is still an issue-not having a sufficient understanding

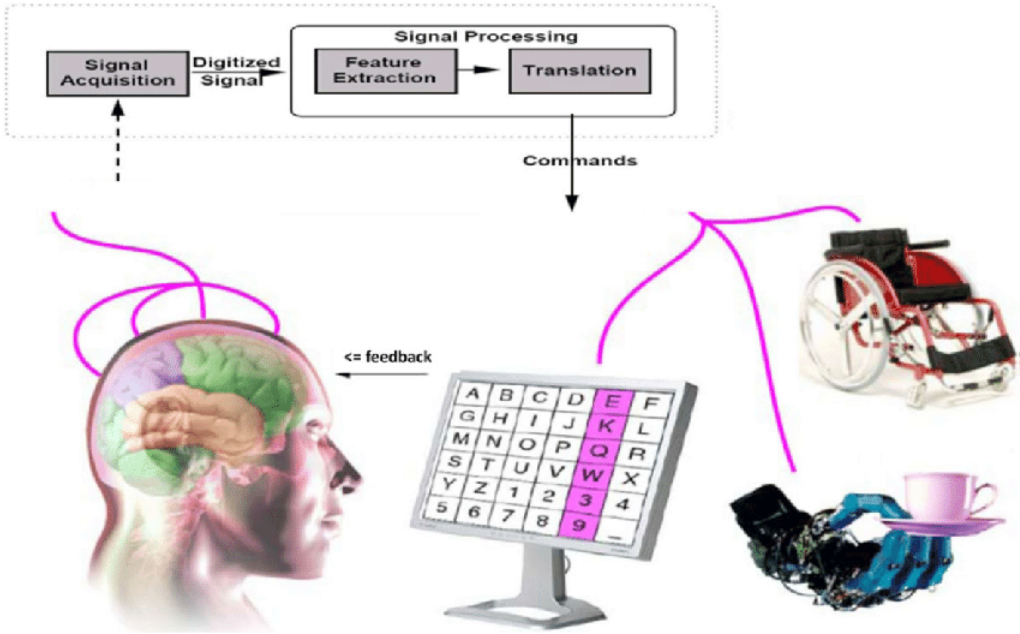

Figure 1: Brain-Machine-Interface Set-up Example (Source: Google, researchgate.net., 2022).

of the complex interconnections between different brain areas. An important consideration for B2B communications.

Nicolelis [11] suggests that so-called brain-machine-interfaces (BMI, Figure 1) will control the physical world in future just by 'thinking'.

It appears that this pioneering work frees the human brain from any constraints imposed by the human body. The long-term vision suggests that people will be able to communicate worldwide, for example, over the Internet through simple thought-control, without typing or speaking a single word. This would be a unique opportunity to free the private brain from its biological body. Nicolelis asserts that neuron populations are very 'plastic' or flexible, particularly when the brain needs to bypass damaged or dead neurons. This can involve changing the 'neurons' physiological, morphological or connectivity make-up' (p. 22). It affects how the brain reacts to tasks and environments, an important insight of earlier developments that aid the evolution of B2B communications. It supports the view that advanced brains like the human brain appear to have become a dynamic system, with its strength lying in its holistic approach, (the sum is greater than the individual parts). This leads Nicolelis to an early conclusion that two living brains can be brought together in direct communication. It could potentially be aided by the application of so-called BMIs. For example, arm movements can be controlled by outside artificial devices such as robotic arms and legs, driven purely by electrical brain activity and through thought-control.

Nicolelis purports that BMIs are considered to be the forerunners of how human beings 'use their computers, drive their cars, and communicate with one another simply by thinking' (p.9). The result would be to set the scene for B2B communication, just one of the many potential future application opportunities to put to practice the ever-growing and widening understanding of how the human brain works but also how it could be made to work.

Nicolelis's longitudinal study confirms that the brain, just as if animals can learn new tasks, is able to incorporate artificial tools via a BMI, acting as an extension of one's self. It is for this reason why a BMI will actually work-the brain does not deliberately make a distinction, for example, between something that has a biological origin compared to a virtual one.

Neuro-engineering at that time developed an ability to link two or more human brains together, based on the contemporary understanding that two simultaneously installed components are needed to make this work (one device that controls signals to an artificial device, another device that provides feedback to the brain). Many new technologies will emerge as time passes. This means that neuroscience departments and brain research institutes will need to adapt to the new environments, at theoretical, practical and simulating levels. If, for example, a brain-net became real, what would be the potential consequences such as being able to feel and perceive within this deep compatibility of opinions and plans between two individuals? In addition, ethical considerations need to be taken into account, based on the premise that every single human life on planet Earth has the right to be treated in accordance with 'high standards of ethical and moral conduct we should devote' (p.317).

Kurzweil [12] suggests that so-called 'reverse engineering' of the human brain will help to understand better how the human brain works. In addition, he considers that the application of this knowledge will enable the creation of even more intelligent machines. Kurzweil investigates how the brain functions and works, the relationship between the human brain and the human mind, and the relationship between increases in human beings' intelligence and the world's problems. His futuristic insights are as relevant today as they were when he completed his research. According to Kurzweil, the human brain (as an organ) is responsible for thought-control, emotion, memory, touch, motor skills, vision, breathing, temperature, hunger and other processes to regulate the human body. In contrast, the mind is made up of a set of faculties (an inherent mental or physical power) responsible for so-called mental phenomena (for example, language, as it creates new forms of attention-they are phenomena that have an inherent object, intentionally, within themselves). It appears that understanding how the neocortex (Figure 2) operates, has enabled human beings to enhance its powers. Understanding the operating principle of the neocortex is of paramount importance. It represents 'all knowledge and skills as well as creating new knowledge' (p. 8). The neocortex covers the completely human brain and its two halves are connected by the corpus callosum (Figure 3).

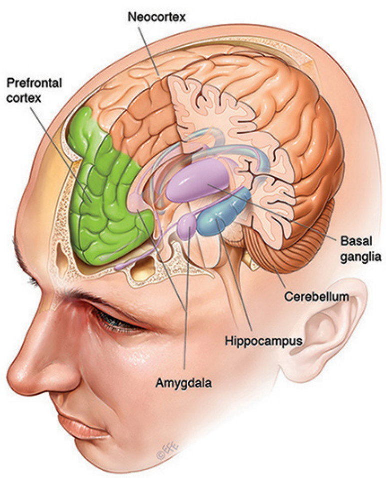

Figure 2: The Human Brain's Neocortex (Source: Google, qbi.uq.edu.au., 2022).

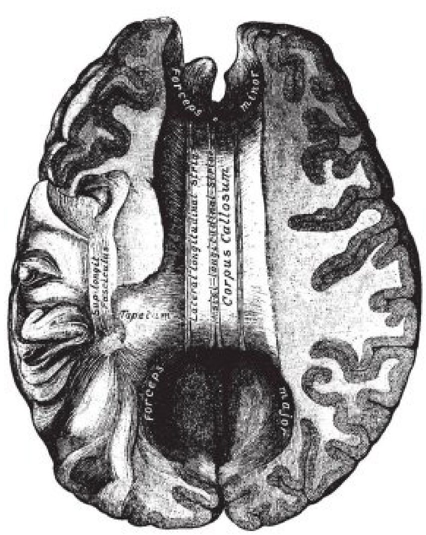

Figure 3: Corpus Callosum Sketch, connecting the two brain hemispheres (Source: Google, en.wikipedia.org, 2022).

Understanding how the neocortex works and operates is essential for human beings' understanding of what language is (generally regarded as thinking). Important knowledge here is that the neocortex is able to deal with patterns of information, in a hierarchical way. This is a crucial factor for consideration in brain-to-brain communication, irrespective of whether a so-called brain-computer-interface (BCI) is applied or not (Figure 4).

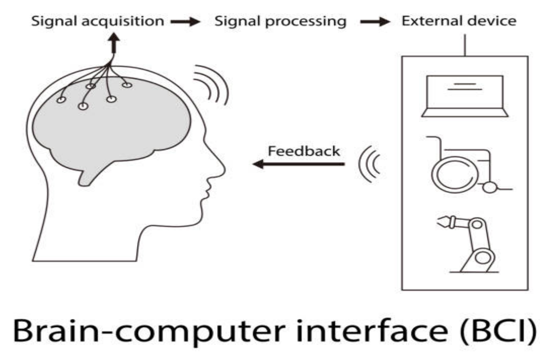

Figure 4: Typical Brain Computer Interface Structure (Source: Google, istockphoto.com, 2022).

This understanding of the guiding principles of communication (language) is paramount to developing a direct brain-to-brain communication system/method. Kurzweil argues that it may be possible to create a synthetic neocortex that will far outweigh the abilities and capabilities of the standard neocortex. This extra capacity of brain potential will bring human beings closer to achieving effective brain-to-brain communications by putting these new capabilities to good effect. Of particular interest is the presence in the neocortex of a hierarchy of pattern recognisers that process actual images of objects, such as an apple. These pattern recognisers deal with the different types, shapes and varieties of apples. This is an important conceptual development, created by the connections between the individual recognisers, for achieving the most effective brain-to-brain communications. Kurzweil suggests that in a biological brain, any imposed parameters are based on the hierarchical brain's own experience. In contrast, so-called artificial intelligence (AI) systems contain hand-coded parameters created by human beings. An important point here for B2B communication: the neocortex is capable of predicting what it expects to experience (such as seeing APPL of the concept of APPLE, and thus predicting what comes next). 'Envisaging the future is one of the primary reasons we have a neocortex' (p.52).

The neocortex is quite flexible, too. The human brain's plasticity makes it possible that people can re-learn the same skills from one part of the brain in another area of the neocortex following, for example, a stroke or an accident. The important point here is that the neocortex can provide substitution between visual and auditory systems where damage has occurred. Kurzweil points out that 'timing appears to be an important factor whether an invention becomes successful or fails many progressive ideas cannot be moved forward. This is not because any gadget/systems do not function but because the timing is wrong. Some necessary enabling factors may not have been in place, were missing or were too late.

According to his own experience, Kurzweil recommends that a so-called 'law of accelerating returns' exists that appears to follow 'amazingly precise exponential trajectories' (p. 255). A possible explanation is that evolution possibly created brains to be able to predict the future. It appears that the latest available technology is used to create an updated version. Before undertaking any in depth development in B2B communications, scientists need to take into consideration that the current human brain has not developed by sheer chance but that 'In the brain every individual structure and neural circuit has been considerably refined by evolution and environmental issues' (p. 271).

Kurzweil purports some ethical considerations. He questions whether, for example, a computer that successfully copies the complexity of a human brain, would also have a human consciousness. The assumption is that a mind is a brain that is conscious. In addition, further moral and legal considerations need to be taken into account to ensure that 'conscious entities' are protected. Machines can be designed using the presented principles. Applying reverse engineering will allow for an accelerating iterative design cycle. Although the human brain has some plasticity, it also holds limitations. Its fixed architecture cannot be easily modified and the human brain has a limited capacity.

Grau et al. [13] suggest that the development of so-called brain-computer-interfaces (BCI) has enabled the creation of improved brain-to-brain communications. This includes further advancements in related area of computer-brain-interfaces (CBI). When combined, these two concepts have been responsible for making it possible to establish non-invasive CBI between the brains of two human beings (known as hyper-interaction). Grau et al. achieved the transmission of words through pseudo-random streams encoding between sender and receiver subjects who were separated by a large distance. It appears that this represented the first human brain-to-brain interface. Their results set the scene for the future development of brain-to-brain communication technologies. The outcome of this research further considers that hyper-interaction technologies due to their intense social impact. This may raise some important ethical issues. Their pioneering work provides the foundation for future investigations to explore using closed mind-loops (being able to capture any voluntary brain activity to control other brain elements in the same person, through appropriate external processing).

According to Kaku [14], a few years ago, 'Brain-to-brain interface would make possible not only haptic technology, but also 'Internet of the mind', or brain-net, with direct brain-to-brain contact' (p.87). Kaku quotes Pais et al. [15] who enabled inter-brain communication between rats. The motor cortices of the brains of these groups of rats were connected using a wire via the Internet. This provided evidence that signals between brains could not only be transferred but also correctly interpreted between these brains. This research experimentation provided early evidence that a so-called brain-net could be feasible. It was followed by what appears to have been the first human brain-to-brain communication. One human brain transmitted a message to another human brain, by applying the Internet.

Pais et al. envisaged that human beings, globally, could connect to each other directly through their minds, avoiding the Internet altogether. The advantage of this direct communication is that all mental information can be shared during a conversation, including emotions and reservations. It could be possible for minds to share all their innermost emotions and feelings.

Kaku suggests that this opens up future opportunities such as being able to send emotions and feelings via brain-to-brain communication. Any creation of such a brain net would need to be done step by step. It would include the fitting of nanoprobes into the left temporal lobe (speech governance) and the occipital lobe (vision governance). Computers could then analyse and decode these signals. It would enable the sending of this information via the Internet, using fibre optic cables. Nicolelis considers that the mapping of any involved cortices, such as the hippocampus, is of paramount importance. This would allow for the insertion of 'words, thoughts, memories and experiences into another brain' (p. 89). Nicolelis suggests further that the use of an exoskeleton (outer skeleton) will be possible to be controlled by the human mind of a paralysed person. Kaku argues that 'we may simply give mental commands and our wishes will be silently carried out by tiny chips hidden in the environment (p. 98).

Levitin [16] argues that human genes have not quite developed updates to improve on evolutionary limitations in the way human beings think and make decisions. It appears that this is because the human brain is not quite as organised as people may think. The structure and set up of the human brain incorporate multiple systems, each of these self-controlled. Systems work together haphazardly. There is no guarantee that future evolutionary updates will change any of this. Improved understanding of memory and attention (cognitive neuroscience) will help human beings to understand better the evolution and limitations of the brain. A good understanding of the past will help to develop further knowledge and insights towards the future and provide new avenues for exploring further potential options now this knowledge could be applied to develop, for example, B2B communications further. Although the human brain is capable of processing the collected information, the brain is struggling to separate the trivial from the important. This process leads to tiredness. The conscious human mind has an information-processing limit such as 120 bits per second. Levitin suggests that this speed limit slows down people's ability to pay conscious attention at all times.

This is an important fact to consider in B2B communications. If the brain can process 120 bits per second, 'this means that you can barely understand two people talking to you at the same time' (p. 7). If three people communicated simultaneously, it would not be possible to understand each other. The researcher suggests that this understanding should be considered when developing any B2B communication solution. Levitin asserts that the human brain is able to categorise things in both the physical and mental worlds.

This enables human beings to pay attention and to remember things. In addition, what is most important for human beings to talk about will ultimately be encoded in language.

In addition, Levitin suggests that the human brain is preconfigured to enable it to create categories and classifications automatically, without any conscious human intervention. There are two related mind states present in the human mind: the mind-wandering mode that allows disparate thoughts and ideas to connect, without any barriers between senses and concepts. This mind state stands in contrast to the other mind state, known as the central executive, a kind of stay-on-the-task mode. Only one mode can work at a time. The central executive's main role is to ensure that engaged tasks are completed without interruption. Levitin argues that there are four parts of the human brain that form the so-called human attentional system: prefrontal cortex, orbital cortex, insula and anterior angulate (Figure 5). The human brain's ability to organise information lies at its centre.

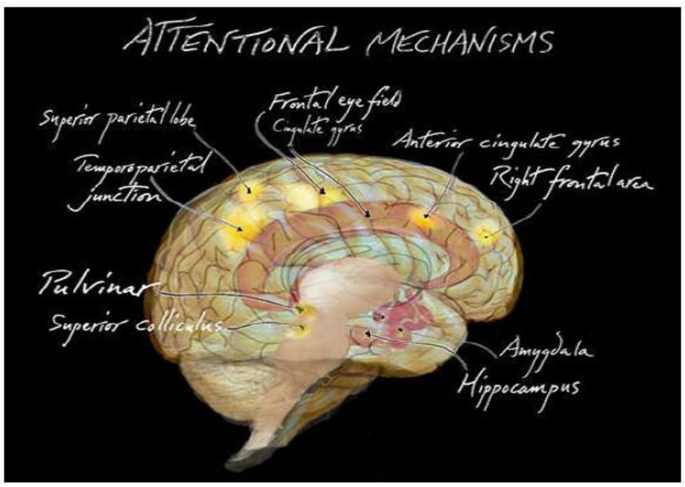

Figure 5: Human Brain Attentional System (Source: Google, AIMS Press, 2022).

Recent Developments and Considerations (Post-2015)

According to Farisco and Evers, an improved understanding of the human brain's cerebral activity has enabled the development of new technology that allows communication to take place without the need for associated behaviour or speech to take place beforehand. It appears that further insights relating to how the human brain works, has shed new light on the human being's communicative abilities and practices in terms of language and communication. Farisco and Evers raise the fundamental question of whether it is feasible to read or interpret what an individual thinks or feels through the method of direct brain-to-brain communication. Their research, with the help and support of numerous other researchers in this field, focuses primarily on the interface between technology and speechless subjects. An important point to consider in brain-to-brain communications is the concept of informed consent. Any person involved must be in a position to make an informed decision, considering all risks and benefits, and this decision must be free from external influences.

What happens in the brain in terms of decision-making? According to Alan Turing (British mathematician, 1912-1954), the brain's three principles of decision-making [17] are based on Turing's algorithm as follows:

1. Neurons in the visual cortex receive information from the retina. Reflected are the neuron's quantity and direction of movement for each moment, but does not entail an accumulation of these observations.
2. Sensory neurons are connected to other neurons in the parietal cortex, collecting this information over time. The neural circuits of the parietal cortex then encode changes between the predisposition and the potential changes whilst making the decision.
3. As more information becomes available that confirms in favour of one option, the appropriate responsible parietal cortex increases its electrical activity. When this activity reaches a certain threshold, the basal ganglia (circuit of neurons deep in the brain) will initiate a corresponding action and thus makes room for the next decision to be made).

Carrillo et al. [18] argue that B2B communication as a concept has experienced an enormous interest boost. Linked to research conducted in the area of brain interfaces, it appears that knowledge has been advanced in this field by 'extracting neuro-information from the signals representing neuronal activities in the human brain' (Abstract). Some recent research proposes that direct B2B communications are feasible between animals, the potential for new scenarios for wireless communications between human beings are possible. Using an illustration method, the neural signals from a sender's brain are digitised and delivered, to a receiver's brain. Although subject interactivity has been minimal, this approach is still in its infancy. New advances in this area since 2019 confirm that it is now possible for two senders and one receiver to 'brain communicate' between them. This includes the exploration of the application of functional magnetic resonance imaging (fMRI). It will enhance the bandwidth of data transmitted via BCIs.

Dingman [19] reports that a most recent phenomenon has been the linking of human brains with computers, also known as the brain--computer-interface (BCI). This enables direct communication to take place between a brain and a computer. For the time being, this is possible through a wired connection. Whilst the primary focus of attention has been on helping paralysed patients move again, it can also be applied in setting up direct communications between, for example, two human brains. How can this be accomplished? The BCI records associated brain activities from the motor cortex (devoted to movement, better understanding what was primarily gained through electrical stimulation). This led to an early indication and realisation that many of the pathways that travel from the motor cortex, allow the brain to control movement. The BCI keeps records of brain activities from the motor cortex, usually achieved via a number of electrodes in or on the brain. These electrodes record/detect electrical activities and then send these details to a computer. The computer is paramount to translate the signals (the intention of the patient). If the patient wishes to control the hand, for example, the signal can be utilised to control a robotic arm. It is thus possible to treat patients who suffer from paralysis, due to a number of different causes.

According to Kounte et al., a BMI enables communication between the human brain and various machines, such as a mobile chair or a robotic arm, via thought-control. The researchers developed a real-time BMI that can be applied for surveillance and monitoring of the location. Put simply, BMI is a machine-based system 'that acquires brain signals, analyses them, and translates them into commands that are relayed to an output device to carry out a desired action' (p. 245). The main purpose of the BMI is to comprehend the brain signals that deal with the intentions and thoughts of the user. The interface translates these brain signals into real-time commands. As, for example, the mobile chair user 'thinks', a direct communication link is created between the BMI ad the mobile chair. The mobile chair user can thus exercise control over the external device, based on the strength of the electrical signals emanating from the human brain. The created link, it appears, is thereby used to 'guide' the mobile chair based on user requirements. Typical areas of application include automotive and medical environments.

Szczupak et al. [20] report that bi-directional communications can be conducted between the corpus callosum (CC), the anterior (AC) and posterior commissures (the principal arousal fibre bundle pathway that connects the two brain hemispheres). Although their research was primarily concerned with mice, the results suggest that the understanding of interhemispheric brain communication has been improved. The part of the human brain known as thalamus has been confirmed to be the driver behind inter-hemispherical connectivity. It provides an opportunity to readdress and reinterpret brain plasticity within the context of axonal reinforcement and pruning. It provides new research opportunities to identify some relation structures in human beings.

Kwai and Zhong point out that it is vital to understand information-processing mechanisms in the human brain if human-like intelligence it to be realised. It appears that so-called brain informatics is a fast-growing mechanism for harvesting and applying brain-related data, information and knowledge, emanating from the research approach that relates to in-depth brain investigation. Of paramount importance is the understanding of how the many and varying techniques work together to address resulting brain computing challenges. Existing computing power improves all the time, leading to the development of some supercomputing power. As a direct result, researchers will be in a position to apply these new technologies more effectively to reach new conclusions about the human brain. In turn, this will lead to further progress being made to enhance the human level Artificial Intelligence (AI). Kwai and Zhong suggest that the closer bringing together of AI with brain science has enabled brain informatics to develop further, particularly with inputs from research fields such as neuroscience, cognitive science, artificial intelligence and information and communication technologies [21,22]. Kwai and Zhong developed a new brain-computing framework called data brain. This model improves the step-by-step understanding of the 'biological characteristics and information-processing mechanisms within the human brain' (p.2). It integrates the cross-study viewpoints of the areas of cognitive science, neuroscience and artificial intelligence. It appears that stronger computing power is needed in the areas of software technologies and hardware platforms [23], such as neuroimaging (ultra-high spatial and temporal solutions). It should also be noted that 'current technologies (such as data masking, transforming and modifying sensitive information and data encryption) do not fully guarantee the absolute security of the data in an environment where all people can participate' (p.3).

Main Research Questions

The main questions for this research are:

1. What is known about (direct and indirect) B2B communication? Are there any considered limitations?
2. How can this knowledge be used for practical application?
3. How does the concept of brain informatics relate to B2B communication? What is its relevance?
4. What are the considered ethical and privacy principles that need to be taken into account such as privacy, informed consent and potential for harm?

Research Methodology

The researcher considered that a structured literature review was most appropriate to establish what is already known about the topic under investigation. This methodological tool was an enabler to provide answers to the research questions within the chosen qualitative and constructivist interpretivist research paradigm. The researcher's intention was to evaluate known theory and supportive evidence within the chosen research subject area (B2B communication). New thinking and fresh approaches were produced by the a priori results from the research. In addition, the researcher conducted a critical systematic review of the validity and accuracy of reviewed theories and competing theories [24]. This research approach was narrow in that it investigated the relationship between two specific topics (direct and indirect B2B communication). It was applied to ascertain what the current state of knowledge is in the topics under investigation. It provided an overview of the identified research problem/current issue (Introduction). As such, this research's primary focus was on the development of theory in direct and indirect B2B communication.

Data Collection and Interpretation

The researcher considered one approach to obtain and collect appropriate research data to answer the research questions: a literature review (Section 1.2.2) within an associated constructivist interpretivist research paradigm. The results from this applied research contributed to answer the main questions. The findings from this research approach focused on an evidential analysis and interpretation of the collected research data. All data was analysed by subject matter to designate some meaning to the data to arrive at a relevant conclusion. The adopted data interpretations process included 1. Collect data 2. Develop findings 3. Develop conclusions 4. Develop recommendations.

Predictive analysis was applied to postulate about potential and likely future approaches ('What is likely to happen' scenario). Although this approach often generates some extrapolative guesswork, it had the potential to contribute towards accurate predictions. The data interpretation and analysis covered the eras pre- and post-2015, in chronological order (Table 1). In addition, Table 2 presents a summary of the considered potential ethical issues associated with B2B communication, based on the number of occurrences within the literature review.

Table 1: Data Analysis Summary: BCI/BMI and B2B Communication (pre- and post-2015).

Brain Computer Interface/Brain Machine Interface (BCI/BMI) Pre-2015	**Brain-to-Brain (B2B) Communication Pre-2015**
Development of AI (make computers as intelligent as possible).	Development of imagined speech to artificial voice.
Increased understanding of the brain interconnections, leading to the production of electronic versions of sensory processing).	Communications via thought-control over the Internet established.
Development of thought-controlled artificial limbs, wheelchairs and computers.	Brain's plasticity concept linked to B2B communication.
Development of software that can translate activity into an image.	Revelation that the brain does not differentiate between biological and virtual origins.
Evolving reverse engineering to create machines that are more intelligent.	First mentioned that a so-called brain net could potentially replace the Internet in future.
Further expansion of Computer Brain Interface (CBI).	Improved understanding of how the neocortex works, particularly how it manages information hierarchically and how a synthetic neocortex could be produced to achieve B2B communication.
Maturity of the concepts of haptic technology (to stimulate the sense of touch) and the introduction of exoskeletons (to overcome injuries or biological capacities).	Development of the understanding of insertion of words, thoughts, memories and experiences inter-brain.
Brain Computer Interface/Brain Machine Interface (BCI/BMI) Post-2015	**Brain-to-Brain (B2B) Communication Post-2015**
Further developments in the area of BCI: paralysed people are able to move again. Direct communications between human beings via BCI.	Further explorations of brain's decision-making abilities.
	Wireless communications established between animals, same potentially possible between human beings.
	Increased knowledge of the brain's attentional system in the context of B2B communication.
	Inter-hemispheric brain communication reported.
	Brain informatics established and further understanding of the concept of a 'data brain', with particular emphasis on the brain's processing capabilities.

Table 2: Summary of Ethical Considerations (B2B Communication).

B2B Communication: Ethical Considerations	**Ranking** (0=Not important, 1=Neutral, 2=Important, 3=Very Important)
Being impressive, highly invasive	2
High standards of ethical and moral conduct	3
Protection of conscious entities (moral and legal considerations)	3
Informed consent	2
Free from external influences decisions	2
Data Security	3

Results

The outcome of this research confirmed that significant progress has been made during the last ten years to understand better how the human brain works and functions, and how this new knowledge could be applied practically in the area of brain communication, both direct and through an interface device. Gaining further insights of sensory and brain interconnections has led to the discovery of solutions to improve the lives of wheel-chair bound people or amputees. Increased capabilities of computer brain interfaces (CBI) provide individuals with higher levels of autonomy in terms of being actively involved, making decisions and experience the physical and social environments autonomously.

It appears that these early developments have been the key drivers for advancing the concept of B2B communication. Vital research conducted in the area of brain plasticity produced further conclusive evidence that the human brain is sufficiently flexible to allow the operational activation of B2B communication. An essential discovery in this context confirmed that the human brain does not differentiate between biological and virtual origins of information. This facilitates the creation of potential options to create B2B applications that will work in reality.

A potential limitation issue has been identified in this context. The human brain may not be able to read or evaluate what an individual thinks or feels. Research is ongoing to establish if there is a necessary relationship between technology and direct speechless communication. Work conducted in this area so far has accelerated an understanding how the generated brain data (information and knowledge) could be collected, analysed and applied in future (brain informatics). Of paramount importance, is the capture of how the varying techniques work together to address and resolve brain-computing challenges? It appears that a wireless communication approach will make B2B communication possible via digitisation of the neural signals from the sender's brain to the receiver's brain. Similar to the way in which a BCI approach maintains a record of, for example, brain activities from the motor cortex, allowing the brain to control movement, it may be possible for the brain to apply the same principle to achieve direct B2B communication.

There are some ethical issues and moral concerns related to brain communication. Direct communication between two human brains could make it possible for people to not just sense but also feel what another person is thinking or planning to do. A number of researchers raised concerns about privacy and informed consent implications. Other concerns include data protection and people not being able to make decisions without being influenced.

Discussion

This research established that there is a relationship between direct and indirect B2B communication. The pioneering work of the past few years created valid and reliable solutions such as BCI, CBI and BMI that enabled users to control machinery such as robotic arms and exoskeletons through thought-control. Direct B2B communication is the next logical and challenging step as a basis to further develop the recent exploratory work in direct communication between two human brains, without applying an interface device.

Research approaches do not assume that brains are computers-they all focus on the plasticity of the human brain. Scientific research is at the brink of progressing further breath-taking discoveries and therapeutic challenges. According to Cobb, it will be difficult to predict how well human beings will ultimately understand the brain. It should be noted that many new technologies now provide valid and reliable research data that has strengthened the outputs and outcomes of brain experiments. In addition, generally speaking, scientists have become increasingly precise in their predictions what the human brain is or will be able to do in future. A sense of realism has also developed that confirms that human beings are not even close yet to fully understand how the brain works. This has been summarised well by one of the leading world neuroscientists [25]: 'Neuroscience still largely lacks organising principles or a theoretical framework for converting brain data into fundamental knowledge and understanding'.

Recently conducted research established that wireless communication is possible, for example, between animals. This revelation has the potential to pave the way for successful direct B2B communication between human beings. More knowledge and understanding have been created in other vital related areas: the human brain's attentional system, communication between two different human brain hemispheres and the brain is processing capabilities. More work needs to be done but there is clear evidence that it is just a matter of time when an acceptable solution will be developed that allows for direct B2B communication. It is not possible yet to make a judgement when this will be accomplished. In addition to working out how this task could be achieved in reality some ethical considerations must be addressed before a universal solution can be applied safely.

Accomplished research and related trials involving computer brain interface (CBI) and brain machine interface (BMI) applications in the area of brain communication created opportunities to further explore options to develop a realistic, achievable and acceptable B2B communication solution. This is not a short-term engagement. It will be necessary to be open-minded about considering suggested solutions and adopt or adapt potential improvements that endeavour to make direct brain communication possible. So-called 'sanitary checks' need to be administered to examine what the associated ethical, moral and legal implications are. A comprehensive and reliable integrated holistic approach (systems thinking), if applied, has a good chance to direct the complexity of the workload and deliver a suitable solution.

Depending on cultural differences, issues such as privacy, informed consent and legal issues must be taken into consideration. The reviewed literature reveals that this appears to be a major concern for many researchers. It is not possible to draw concrete conclusions if the considered approaches to achieve direct B2B communication can be achieved through the suggested options. Further research needs to be conducted to enhance the current knowledge, strive for other potential alternative solutions and not be afraid to enter uncharted territory.

Conclusions and Recommendations

Direct B2B communication has the potential to become the de facto standard for brain communications. There is strong evidence that it captured the interest and attention of a fast-growing audience. The research synthesis of what is known about direct and indirect brain communications has made significant contributions to integrate the latest thinking in both approaches. Applying a non-predetermined and non-directed research process produced new insights that enabled the researcher to develop the following conclusions:

- The human brain's plasticity is a key player in the further development of direct B2B communication
- A synthetic neocortex with increased brain potential needs to be developed to achieve higher levels of effective inter-brain communications
- Replace the wired communication link (BCI) with a pure thought-control solution (for patients who suffer from paralysis), based on an improved understanding that many motor cortex pathways allow the human brain to control movement
- Concept of data brain established and a better understanding of the brain's processing capabilities has led to the creation of so-called brain informatics

More work needs to be done in the area of ethics and privacy to address raised concerns. The focus should be on introducing high standards of ethical and moral conduct, together with a review of any potential associated legal issues, including informed consent.

Further research is suggested to generate more knowledge and insights in the area of direct B2B communication at practitioner level, by conducting a series of face-to-face interviews together with a focus group meeting.

The researcher confirms that the research questions from Section 1.2.2 have been answered.

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