Clinical Cognitive Sciences

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Abstract. Clinical sciences involved with the mind and brain, including neurology, psychiatry, endocrinology and clinical psychology all frequently deal with cognitive symptoms, side effects, and risk factors. Consequently, there has long been some interaction between those clinical fields and traditional cognitive sciences, focused on computationalist and embodied approaches to understanding natural and machine cognition. Examples include the advances made in understanding the normal cognitive architecture made by studying its breakdown in disease, as well as the enhanced methods of defining and measuring cognitive disorders stemming from understanding the healthy state. Nevertheless, the fields currently fail to fully exploit the potential for mutual advancement. Here we explore the interactions between traditional clinical and cognitive sciences and highlighted strengths of the relationship, and areas that could benefit from greater multidisciplinary emphasis. We argue that original fields of cognitive science (philosophy, linguistics, computer science, anthropology, psychology and neuroscience) remain the core of the multidisciplinary cognitive sciences, but that they can all be applied fruitfully to clinical issues. We explore this in one sample disorder—voice hearing in schizophrenia, showing the potential for clinically applied cognitive sciences. It is our contention that greater achievement is possible, in both academic and applied fields dealing with cognition, if we can foster a mutually symbiotic relationship between the clinical and cognitive sciences.

Keywords: Neurology · Psychiatry · Cognitive disorders · Applied sciences · Hallucinations · Cognitive science

1 Introduction

The endeavor of cognitive science as an interdisciplinary science of the mind is often dated as beginning in earnest in 1956 [26]. Although in the nearly seven decades of progress since then, cognition has become an intensely studied topic, its obvious success is somewhat marred by frequent criticism of the disunity among the many fields that used the cognitive-computational metaphor (see, for example, the review by Nunez and colleagues in 2019 [32]). Although whether a unified cognitive science exists today remains a polemic point, there is no denying that the cognitive perspective has been very popular, particularly within

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psychology and neuroscience. Indeed, the majority of papers published in cognitive science journals nowadays are penned by psychologists. This fact is often lamented, suggesting a failure to balance the contributions from other core areas of the original cognitive science approach (i.e., linguistics, philosophy, anthropology and computer science). However, it has also been argued that despite the dominance of cognitive psychology, cognitive science nevertheless remains more interdisciplinary than either psychology or neuroscience (as judged by the authorship affiliation of study authors in leading journals [7]. Furthermore, Contreras Kallens and colleagues, who performed the audit of author affiliation, argue that "Cognitive science could 'grow into' its many disciplines by embracing new collaborators who inhabit our disciplinary silos, but who have not yet applied their trade to the core questions of our field." [7], p. 643. By this they point out that psychology, though dominant in many ways, is in reality very multidisciplinary, often with people doing linguistics, computation, anthropological work etc. within psychology departments as flags of convenience rather than any mark of being fundamentally psychologists. Though the wider point is simply that potential interdisciplinary links within sciences dealing with cognitive topics, defined broadly, are available and should be exploited more.

In this position paper, we particularly focus on how applied fields could interact more with academic cognitive science in a mutualistic symbiotic relationship. Of course, computer science, particularly artificial intelligence, has a strong applied aspect that contributes to cognitive science. However, we wish to focus on one particular applied topic, which we argue could lead to greater mutual benefits with cognitive science - clinical science. In recent years there has already been much research showing how cognitive biases and heuristic thinking influence clinical decision making. This input from cognitive science is welcome, however, there are many other connections that could be improved. Enhancing interdisciplinary or multidisciplinary work between cognitive and clinical sciences is a daunting task, given the very different approaches and needs of the two broad sciences, and their own heterogeneity. Nevertheless, mutually beneficial interactions, with cognitive studies learning from clinical cases, and the reverse, have a long history with proven examples of mutual benefit. Several examples of this are described in the sections below, so the endeavor can be fruitful. We simply encourage greater interaction. In Sect. 2 we make our basic position for why there exists potential for an applied clinical cognitive science. In Sect. 3 we describe ways in which cognitive and clinical sciences currently interact to mutual benefit, and ways that this could be further developed. In Sect. 4 we explore how clinical sciences fits within the traditional, interdisciplinary approach advocated by cognitive scientists. In the penultimate part, Sect. 5, we present an example of a clinical disorder that is fundamentally within the realm of cognitive science, and give examples of how different component disciplines of cognitive science contribute to understanding it. In Sect. 6, this paper concludes with some final observations and summation of the prospects for the nascent field of clinical cognitive sciences.

2 Why Clinical Cognitive Sciences?

Although definitions of what constitutes theory in cognitive sciences vary tremendously, one reasonable one is that "A cognitive theory is a description of mechanisms that explain observed mental phenomena" [46] p.239. The philosopher Paul Thagard argues for this definition because it is consistent with not just what happens in core cognitive sciences, but also with more peripheral fields that deal with cognition, such as clinical medicine. It is a rather obvious fact to mention that clinical impairments of brain function can reveal things about the human mind. That this is so well-known is reflected in the fact the earliest written description of the word 'brain', in the ancient Egyptian Edwin Smith papyrus, also contains the earliest ever description of impaired use of language consequent to brain damage [28]. Though, the extent to which clinical brain health and cognitive ability are intertwined is perhaps not so fully appreciated.

Disorders of the mind are often diagnosed and treated by clinical psychologists. As they are essentially applied psychologists, their interest spans the breadth of mental phenomena, albeit in the context of clinical disorders of the mind or brain. If one takes a more biomedical approach, focused specifically on the nervous system, the two principal medical sciences concerned with the brain are neurology (which deals with disorders defined organically, i.e., affecting the nervous system) and psychiatry (which deals with disorders defined by their impact on mental health- psychopathology). In both neurology [22] and psychiatry [44], the disorders observed usually involve cognitive processing impairments. As clinical psychologists deal with the same patient groups, the same can be said for clinical psychology. Even beyond the boundaries of the nervous system, the activity of many endocrine glands and the hormones that they release into the bloodstream influence brain functioning. Consequently, most disorders seen by clinical endocrinologists also involve alterations to cognitive processing [14]. Clearly, the majority of clinical disorders attended by clinical psychology and clinical neuroscience involve clinical signs, symptoms, side effects etc. that are essentially changes to cognitive ability. Furthermore, cognitive ability, in the form of intelligence, is recognized as a substantial protective factor against a wide range of disorders, a phenomenon known as cognitive reserve [45].

Adding to this, there has been a recent recognition that interoception (i.e., the sensation of signals from bodily organs outside of the nervous system) plays a much more important role in the mind than previously realized. In fact, it has been argued that a wide range of homeostatic mechanisms and bodily sensations are essential drivers of consciousness [10], implying that the whole body (the entire subject of clinical medicine) influences cognition. In addition, the discovery of mirror neurons has demonstrated that the same cells in the brain's premotor cortex that are involved in coordinating actions are also active during observation of actions [37], suggesting that the action system is also involved in perception of actions. It has been theorized that the mirror neuron system is involved in understanding the intentions of others as well as empathy. This latter point presents a strongly embodied perspective, as opposed to the more traditional computationalist approach in cognitive science. Here, we argue that whether or not one accepts an embodied or computationalist approach, it is undeniable that the physiological substrate of human cognition is in the body, and as such, bodily health influences cognitive processing. Following from this, clinical disorders will very frequently have cognitive correlates.

3 Mutual Symbiosis Between Cognitive and Clinical Sciences

In this section we first describe some of the ways in which clinical sciences contribute to understanding cognition. We then explore the reverse: how cognitive sciences contribute to clinical sciences. Here we highlight the mutual symbiosis of such collaborations. Nevertheless, it is likely that, given the differences in paradigms between the fields, and the fundamentally applied nature of medicine, compared to the oft purely academic nature of cognitive studies, that the interaction will be unbalanced. If anything, the benefits of collaboration so far have been reaped more by cognitive science than clinical sciences. This has been due to the revelatory nature of many disorders of the nervous system on cognitive functioning.

3.1 Clinical Disorders as Natural Experiments

As described above, as long as 5,000 years ago it had been noted by Egyptian scholars that aphasia can be caused by brain damage [28]. Relatively more recently, the issue of whether psychological traits, including cognitive abilities, show some level of modularity was famously addressed by the French neurologist Paul Broca in 1865 [2], when he revealed selective impairments of spoken language production in patients with damage to the left frontal lobe of the brain. Since then, damage to the brain has frequently been used as a natural experiment to elucidate the human cognitive architecture. This is known as the lesion-symptom mapping method. Although in one direction it is used to define functions of brain areas (i.e., cognitive neuroscience), it is similarly used to identify and define, at a strictly functional level, cognitive processes. When lesion-symptom mapping is used in this way to study the functional architecture of the mind, irrespective of physiological correlates, it is known as cognitive neuropsychology [6].

Several well-known observations in cognitive science were driven mainly by observations from cognitive neuropsychology, that is, cognitive impairments following brain damage. These include the distinction between procedural and declarative memory (often also known as implicit and explicit memory) first revealed by studies of patients with damage to the hippocampus producing dense amnesia who could nevertheless learn a mirror tracing task [27]. Another clear example being studies of neurological patients that indicated that visual perception for conscious recognition is relatively independent from visual perception for motor transformations [15].

The strength of these associations between brain impairment and cognitive impairment for elucidating the overall human cognitive system has been in the double dissociation method. This involves the comparison of patients with different cognitive problems, such that a patient can be demonstrated to be impaired on task x, but not task y, and another patient can be shown to have the opposite pattern of impairment and preservation of cognitive task performance. The logic behind the double dissociation is that cognitive processes x and y must be functionally independent if they can be impaired independently within the same overall cognitive system. The methodology allows for discounting of general explanations for the impairments, such as overall task performance being impaired, or global cognitive impairment, and supports the identification of cognitive modularity. A classic example of this has been the identification of patients with either preserved long-term memory (LTM) with impaired short-term memory (STM) and patients with the exact opposite pattern [48]. This double dissociation adds weight to the classic distinction between STM and LTM in Atkinson and Shiffrin's modal model of memory [1] and poses a serious challenge to cognitive theories which propose that there is only one declarative memory system that stores information [9].

Although lesion-deficit association studies still have some weaknesses, and alternative explanations for double dissociation which do not require modularity of function exist, for example from a neural network perspective [34], they undoubtedly have some role in cognitive sciences. The neuropsychologists Shallice and Cipolotti have listed several ways in which the traditional clinical method of studying brain-injured individuals has benefits over other cognitive sciences, including the potential for serendipitous discoveries, and identification of causal efficacy [42].

3.2 Clinical Disorders and Discovery of Cognitive Phenomena

We could also add that many cognitive neuropsychological disorders probably would not be predicted based on other methods in cognitive science. For example, stroke that causes brain damage very frequently produces a disorder in which patients neglect to attend to things to the left side of their body, or, less frequently, to the left side of individual objects. This syndrome, known as hemispatial neglect, appears to be fundamentally a disorder of the control of attention [8]. However, the reverse pattern (of attentional disorder to the right side of the body, or to objects) is much rarer. This suggests that multiple aspects of attention are not only fundamentally lateralized relative to the body of the observer, there is also a substantial lateralized imbalance, again operating left-right, relative to the observer. Further, related to this phenomenon, the clinical observation that stroke patients may show attentional neglect of either the left space (relative to their body) or to the left of the perceived objects, is now interpreted using the cognitive concepts of egocentric and allocentric spatial coding, respectively. This distinction too was first appreciated in clinical cases of brain damage [40].

Another example, also very common after stroke, is ideomotor apraxia—the inability to demonstrate learned actions such as tool use. Cognitive neuropsychological evaluations frequently find much worse performance for actions to verbal command, better performance for imitation, and best performance with the tool held in the hand [39]. This common observation in clinical neurosciences places constraints on cognitive models that aim to explain human tool use.

Evidence from neurological research also encourages the debate on the nature of cognitive architecture. For example, while apraxic patients may be unable to execute action plans related to use of objects, they retain knowledge about their identity, while other brain injured but non-apraxic patients show the reverse pattern [3]. This evidence from double dissociation suggests independent processing between declarative knowledge of object functions and motor-action plans for manipulation of objects. However, other neuropsychological studies show interconnectedness between cognitive abilities and motor systems. In an experiment involving Parkinson's disease patients, Nitiscò and colleagues demonstrated that motor simulation via reading and repeating hand-related action verbs could reduce upper limb tremor, suggesting that language processing of bodily action simulates the experience of action execution [30]. In the case of patients with amyotrophic lateral sclerosis, it has been found that, in addition to motor system impairment, patients had difficulty with action-related verbs [50]. This degradation of action-related knowledge was also associated with neurodegeneration in motor cortices of the brain. In sum, research in clinical disorders often informs cognitive theories and provides a substantive testing ground for hypotheses.

3.3 Selectivity of Cognitive Impairments and Facilitation of Functions

As described above, a multitude of changes to the human nervous system, and body in general, have implications for cognitive processing. Clinical disorders are clearly associated with deficits in cognition. If it were simply a case of illness resulting in some global lack of processing capacity there would be little to learn from their study, from a cognitive perspective. However, that is not the case. Disorders often manifest with relatively specific cognitive changes. The pattern of preservations and losses can therefore be highly informative about the overall cognitive architecture.

Furthermore, some clinical disorders are associated with better, not impaired cognition. For example, attempts at suicide and other acts of self-harm by patients with schizophrenia are more common in people with relatively good performance on word pronunciation tasks, compared to patients who do not self-harm [36]. Similarly, there are a range of clinical observations of enhanced cognitive performance on specific tasks after brain damage. These include better ability to detect deception from faces by people with aphasia and enhanced face detection in complex visual scenes in patients with visual agnosia (inability to recognize objects by sight), and recovery of attentional bias caused by a right hemisphere lesion, after a second lesion, this time to the left hemisphere [18]. Enhanced attention to detail, visuospatial activities, and perhaps even artistic ability is seen in some forms of dementia, and may even be useful in distinguishing between different forms of the disease [25]. Also, the observation that patients with schizophrenia develop better reading and spelling ability than education-matched control participants [19]. The many observations of enhanced cognition associated with clinical disorder undoubtedly have a wide-range of causes, which require deep understanding of how cognition is molded and enacted in the brain to explain them. As such, traditional approaches in clinical neuroscience, which implicitly use a disorders-cause-deficits paradigm, are generally insufficient [35]. What is needed is a greater appreciation, within clinical sciences, of the cognitive sciences.

3.4 Cognitive Science and Clinical Assessment

To take a task-based example, we can examine the Towers of Hanoi task. This involves three pegs and a set of disks of varying diameter. The task is to move the tower of disks from one peg to another, one disk at a time, with certain restrictions, such as never to place a larger disk on top of a smaller disk. This task, originally developed in mathematics, has attracted the attention of artificial intelligence, because of its multiple task versions and easily definable problem space [13]. It has also been used extensively in clinical neuropsychology, to measure cognitive planning ability in patients with neurological or psychiatric illness. In fact, it was selected for that purpose as a test that would particularly load on non-routine planning ability, and was hypothesized to be particularly sensitive to impairments of top-down cognitive control after damage to the frontal lobes of the brain [41].

The problem is that there are multiple ways to complete the Towers of Hanoi task. This has been demonstrated with various iterative, recursive and other algorithms in computer science [13]. Herbert Simon also demonstrated, from a cognitive science perspective, that humans who attempt the Towers of Hanoi have a wide range of strategies that they can use to successfully complete the task. Some strategies are transferable between different tasks, and some are not, and some require substantial use of working memory to represent sub-goal states, while others do not [43]. He emphasized that because so many different performance strategies and learning effects are involved, it is essential to examine performance on a subject-by-subject basis in order to estimate the cognitive mechanisms being used. Furthermore, cognitive science studies on choice of strategies in reasoning tasks have shown that they tend to vary across cultures [31], and even within cultures, reasoning strategy employed in tasks such as physics problems, varies by level of expertise on the material [21].

From a cognitive science perspective, Simon referred to these different ways of solving the same problems as *functional equivalence*. This parallelism between cognitive strategies used is also recognized in cognitive neuroscience. At the biological level, many cognitive processes show degeneracy, that is, the same behavioral outcome, such as word reading, or action imitation, can be achieved by different pathways within the brain [35]. Importantly, some of these degenerate pathways can become damaged, and others preserved, in the same patient, in which case no deficit will be observed. Thus, appreciation of functional equivalence / degeneracy is essential to recognizing clinical impairments of function.

Current clinical methods to evaluate top-down cognitive control use versions of the Towers of Hanoi task, but compare performance of individual clinical patients to average performance, regardless of strategies used. For example, the most-developed, commercially available test of top-down cognitive control for use in clinical practice is the Delis-Kaplan Executive Function System [11]. This includes a version of the Towers of Hanoi task, with scoring of performance primarily based on the number of moves made within time limits (fewer moves give higher scores). Other versions of the Towers of Hanoi use the same basic approach to scoring performance [41]. There are two main problems with this approach. The first problem is that patients are clinically evaluated for executive function impairments based on how well they perform the task (defined as lowest number of moves). Importantly, although they are told to use as few moves as possible, they are not told that they must complete it quickly. Hence, steady and careful planning could actually be penalized. Furthermore, those patients who promptly identify and apply one of the iterative strategies will be able to score highly, while patients who use different, but equally effective strategies will receive low scores, and perhaps be defined as cognitively impaired. The second problem is that individual performance is not evaluated in the subject-by-subject manner advised by Simon [43], rather, individual patients are compared to the average performance of a large group of healthy control participants. Thus, the control sample performance average will be calculated from task performance scores achieved using many of the different strategies that can validly complete the task.

Although many theoretical and experimental fields dealing with brain sciences, such as experimental neuropsychology, do often consider error types, and step-changes between trials that indicate changes in strategy (see e.g., [42]), this is often not the case in clinical neurosciences. Clinical sciences that deal with brain impairments often lack the sophistication of understanding of information processing present in the core cognitive sciences.

A final motive for the need for greater cooperation between clinical sciences and cognitive sciences comes from the cognitive models applied in clinical assessment. Often, the models used are outdated and misinterpreted. As an example, the Wechsler Memory Scale [49], widely used to define amnesic disorders in clinical practice, is overtly based around the modal model of memory proposed by the psychologists Atkinson and Shiffrin in 1968 [1]. Most cognitive scientists would see that as an outdated theory. Furthermore, the distinction between STM and LTM operationalized in that memory assessment, is that recall within 'several minutes' of stimuli exposure assesses STM, while recall after 25-30 minutes assesses LTM. That simplistic interpretation ignores most of what is known from cognitive sciences of the strategies for transfer from transient to long-term storage of information, and the intermediate stages of processing between them [4,5].

Clinical brain sciences could gain much from closer links to cognitive sciences. Related to this, is the emerging need for consistent cognitive ontologies. Many cognitive constructs, particularly in clinical sciences, are derived from common sense interpretations, or from general application of cognitive concepts, such as dysexecutive syndrome to describe a wide-range of impairments of cognitive and emotional control. However, there are now numerous attempts to harmonize the terms used across clinical and cognitive sciences [16]. Cognitive science is ideally placed to improve ontologies used in clinical practice and research regarding the brain.

4 The Place of Clinical Sciences within Cognitive Science(s)

Cognitive science is often conceived of as being composed of contributions from at least six different fields: philosophy, linguistics, anthropology, neuroscience, computer science, and psychology. A report in 1978 represented these as a hexagon, with each discipline at one of the vertices [26]. This is shown in Fig. 1.

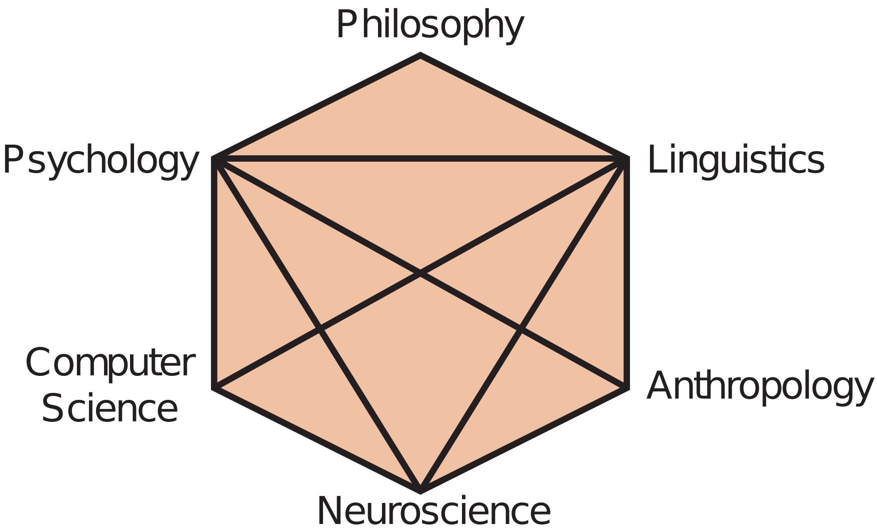

Fig. 1. The cognitive science hexagon, as envisaged in 1978, showing core cognitive fields and their viable interactions (shown as inter-connecting lines).

At that time of presentation in the late 1970's, only some of the fields were seen as having viable interdisciplinary subfields, for example, computer science was seen as interacting productively with psychology, neuroscience and linguistics, but not with philosophy or anthropology. This is shown by the 11 lines of the hexagon that connect them. It has since been argued that all of the interconnections have been achieved, and now, for example, it is reasonable to suggest that there is a philosophy of computer science, hence the newer version of the hexagon has all combinations of fields connected. The philosopher Paul Thagard, and George Miller [26,46], the originator of the hexagon, and arguably a founding father of cognitive science, concur. The revised version of the cognitive science hexagon (with 15 different interconnections) is shown in Fig. 2.

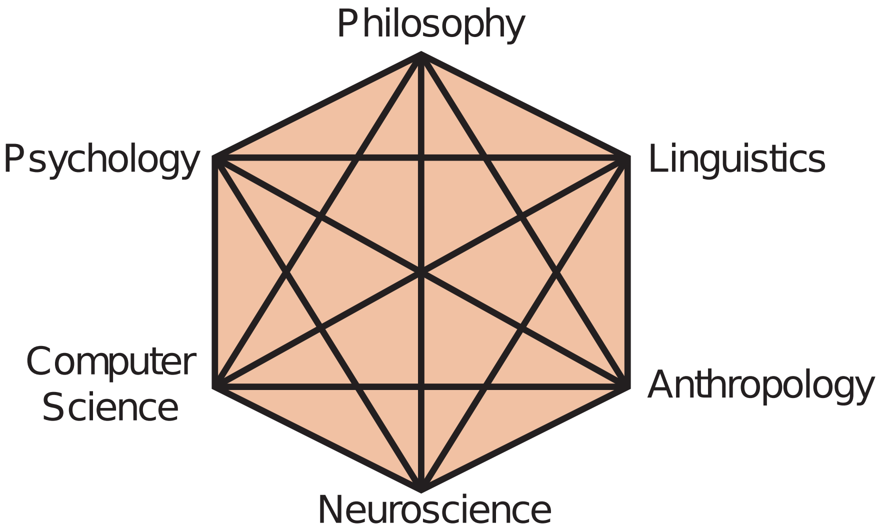

Fig. 2. The revised cognitive science hexagon, showing core cognitive fields with all connected by lines, indicating their potential for fruitful interactions.

Whether the six vertices can be considered to be working as an interdisciplinary cognitive science (singular), as originally envisaged, is debatable. The concept of interdisciplinarity suggests that research in each discipline is integrated and harmonized into a singular endeavor, with each field contributing more or less equally, but analysis of research output in cognitive science journals suggests that this is not the case [7,32]. Many researchers, including George Miller, now see the study of cognition as being more multidisciplinary [26], with disciplines focused on similar concepts, but having their own agendas, hence the increasing use of the term cognitive sciences (plural). As this term is said to indicate more multidisciplinarity [26,32], it seems appropriate for it to be used when applied to clinical matters.

One could easily argue that other endeavors could now be considered contributing fields to cognitive science, such as the emerging areas of cognitive design, cognitive history, and cognitive engineering. Indeed, some versions of the hexagram now include education (but shown as a heptagon). Although it is undeniable that cognitive approaches to understanding phenomena have expanded into many fields, it is debatable whether these additional fields have cognitive principles as core aspects. For this reason, we suggest that applied areas of cognitive science, such as education, should perhaps remain conceived of in terms of the original six vertices of the hexagon, but seen as applications of them. We demonstrate this idea graphically in Fig. 3. In the foreground we have the core cognitive sciences, and in the background their applications to diverse fields, such as educational, and most relevant to the current study—clinical cognitive sciences.

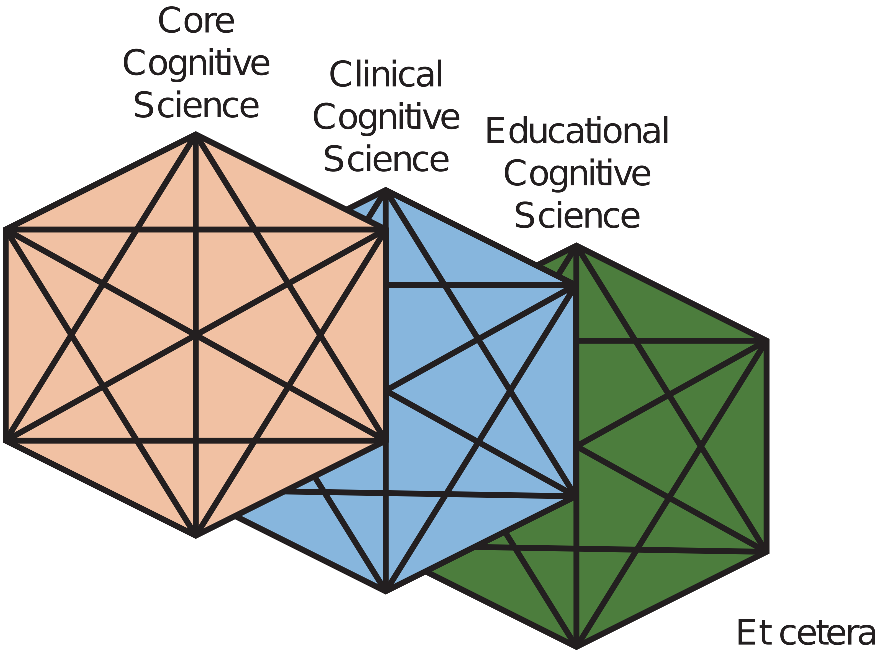

Fig. 3. A proposed scheme to think about the position of applied fields that interact substantially with the core cognitive sciences.

One could argue perhaps, that clinical disorders are already covered within the cognitive sciences under various investigations within neuroscience or psychology. But an important point is that fields such as those are primarily interested in the healthy state. There is a need for cognitive analyses that focus on the clinical issues. Furthermore, some issues that are important clinically, are of only tangential connection to psychology or neuroscience. A case in point is anosognosia, a state frequently seen in psychiatry and neurology, in which patients clearly have disease or disability, but because of their disorders are unable to recognize it [29]. For example, a dementia patient may be unaware that they have dementia, precisely because of their cognitive impairment, or a stroke patient with limb paralysis may be unaware of their paralysis. This is a clinical disorder that has substantial implications for understanding cognition, particularly from an embodied perspective. Anosognosia is important clinically due to the implications, such as compliance with treatment or care. In other words, clinical research could provide information related to construct validity of the cognitive theories. For example, the bottom-up approach to embodied cognition could be tested in the context of cognitive behavioral therapy (CBT) focusing on sensory-motor stimulation, while the top-down approach could be tested via CBT focusing on abstract mental representation of action knowledge [33].

5 Core Cognitive Science Contributions to a Sample Clinical Disorder

In the following section, we explore how the six original disciplines of cognitive science can individually contribute to understanding of clinical disorders. To do this we take as an illustration the hearing of voices within one's mind, that are not recognized as one's own. Such auditory hallucinations are a cardinal symptom of schizophrenia, but occur in many other medical states, and indeed, many people without any clinical disorder experience them too. Nevertheless, they can be very distressing, and as a symptom of schizophrenia, they are a core indicator of psychosis and are frequently treated with major tranquilizers. They are also fundamentally a cognitive phenomenon.

5.1 Philosophy and Cognition of Hearing Voices

That philosophy has a strong contribution to cognitive science is well established [46]. This often involves foundational issues such as the core theory of cognitive science. However, philosophy has also contributed substantially to understanding the phenomena of voice hearing in schizophrenia and other disorders. The clinical symptom of not recognizing voices within one's head as one's own has been particularly of interest to philosophers interested in understanding phenomenology. From this perspective, it has been argued that voices should not be considered as disorders at all, as neither a purely biological nor psychological explanation can account for their meaning. Instead, they can be thought of as embodied cognitive experiences, embedded in cultures which influence how voices are interpreted [47].

5.2 Cognitive Anthropology Approaches to Hearing Voices

The philosophical approach to voice hearing, drawing on the writings of phenomenological theorists, is broadly supported by cognitive research from anthropology. This field has examined how people describe their experiences of auditory hallucinations (which are usually voices). There appears to be a very wide range of experiences, not limited to clear voices. These include scratching, murmuring, whispering, with vague or clear contents, which can be psychologically located by the hearer either outside or inside their own heads. The anthropologist Tanya Luhrmann and colleagues have compared the experiences of auditory hallucinations in people with schizophrenia reported across cultures [23]. In California, they found that voice hearers tend to report diagnostic labels from psychiatry and refer to being 'crazy', and they uniformly disliked the voices that they heard. But this psychiatric vocabulary was very rare for patients in Accra, Ghana, or Chennai, India. Instead, the Ghanaian patients were likely to interpret the voices positively, while the Indian patients interpreted the voices as providing guidance. The anthropologists interpreted this by suggesting the people in the USA tend to interpret minds as being bounded, and thus unwanted voices must be pathological. In contrast the Ghanaian folk concept of mind is that it is porous- emotions seep into the world and can cause harm. Their interpretation of the voices was therefore supernatural, that voices and feelings were being controlled by God. In contrast, the Indian voice hearers interpreted the voices in terms of how older people provide guidance for people, often recognizing the voices as being kind or Hindu avatars.

To explain these differences, Luhrmann and colleagues suggested a form of 'social kindling' that alters how auditory hallucinations form. Drawing on cognitive psychology they argue that, due to cultural influences, people developing psychosis selectively attend to different aspects of their sensations. They cite evidence that this attentional focus then shapes how the auditory hallucination unfolds.

5.3 Cognitive Linguistics Approaches to Hearing Voices

The approach from psycholinguists concurs with that from anthropology, supporting the suggestion that how auditory experiences are interpreted influences their clinical presentation. Linguists particularly study the structure of language, when applied to auditory hallucinations this can include the content of the voices heard. However, the way that people with schizophrenia who hear voices describe their experiences is also important. One psycholinguistic study reported on the metaphors that patients use to describe their voices. This revealed that there was a remarkable consistency in the phenomenology of the voices, in that similar metaphors were used by all participants to indicate location and movement of the voices. However, the metaphors varied in terms of how distressed the patients were. Distressed patients described the voices using metaphors suggesting violence and lack of control (e.g., "it's like trying to fight with one hand behind your back" [12] p. 20. This association between distress and interpretation of heard voices is revealed through cognitive-psycholinguistic analysis.

5.4 Cognitive Psychology Approaches to Hearing Voices

Psychologists are primarily concerned with the normal functioning of the mind, and when applied to disorders, generally to explain the phenomenon in terms of breakdown of the normal system. One important contribution from psychology towards understanding auditory hallucinations has been the recognition that many people, not just people with clinical disorders, hear voices as auditory hallucinations. In fact, about one in ten healthy people will experience hearing voices in their lifetime, and consequently it is now considered as a phenomenon on a continuum from healthy to psychotic [24]. Drawing on this, it is argued that healthy people recognize that the experiences are generated internally, but people who experience the hallucinations as clinical symptoms, and often experience distress, may be failing to apply top-down executive control. This theory suggests that the voices are in fact normal perceptual processes related to auditory cognition. The reason that they may be misrepresented as being voices of strangers, being due to a failure of top-down inhibitory control, and this produces a strong attentional shift to the voice. This theory, based firmly in experimental psychology, is supported by experiments that use dichotic listening tasks [17]. These tasks present auditory stimuli, such as different syllables, to both ears simultaneously. The participant is asked to report what they hear. A right-ear advantage emerges in healthy individuals, thought to indicate the contralateral processing of auditory information in the left temporal lobe (specialized for phonology). Experimental evidence suggests that top-down executive control (hypothesized to the brain's prefrontal region) is limited in patients who hear voices due to functional disconnection from bottom-up processing in language centers (hypothesized to be in the brain's temporal region).

5.5 Cognitive Neuroscience Approaches to Hearing Voices

Studies on brain structure in people with schizophrenia who hear voices reach similar, but obviously more physiologically based conclusions. Reduced gray matter volume in auditory and language processing regions of the left temporal lobes of patients with schizophrenia is correlated with severity of their hallucinations, and when patients who hallucinate voices are compared to healthy individuals, the patients are found to have reduced gray matter volumes in the prefrontal cortex [38]. As gray matter volume indicates mainly neuronal cell bodies and dendrites (where synapses are present), it suggests reduced processing capability in those two regions, and disconnection between them, correspond to the language processing and inhibitory control modules suggested by experimental psychology.

5.6 Computer Science and Cognitive Modeling Approaches to Hearing Voices

Finally, research from computer science and artificial neural networks (ANNs) supports both the disconnection and inhibition approaches to understanding auditory hallucinations [20]. ANNs that are trained and then have disconnections induced, by extra pruning of connections to mimic the pruning of synapses, produce output suggestive of hallucinations. Similarly, relatively reduced levels of inhibitory connections in ANNs leads to confusion between bottom-up and top-down information, which could also be seen as hallucinatory and akin to hearing one's own internal voice as being not one's own, which is essentially the same as the psychological explanation for voice hearing in schizophrenia. These phenomena are currently receiving substantial attention within computer science, as it is becoming clear that 'hallucinations' are a common, and perhaps even inevitable feature of large language models such as ChatGPT.

5.7 Summary of the Cognitive Science of Auditory Hallucinations

Thus, the six fields that represent the core cognitive sciences have produced substantially overlapping ideas to help understand why people with schizophrenia frequently hear voices in their heads that they do not recognize as their own. Voice hearing like this would not usually be a topic in cognitive sciences, were it not that it is such a common clinical symptom. Furthermore, the analyses provided enrich the core of the cognitive endeavor. Voice hearing is but one example of cognitive disorders that can benefit from interaction with the field of cognitive sciences. While it may remain arguable whether the different fields work in an interdisciplinary way, it is clear that there is much to be gained from at least multidisciplinary application of the cognitive sciences to clinical problems.

6 Conclusions

The clinical sciences that deal with the mind and brain, including neurology, psychiatry, endocrinology and clinical psychology, already value the usefulness of applying cognitive principles to understanding disorders. And in the other direction, cognition has been frequently informed by clinical studies. However, greater integration would bring benefits to all sides. Nevertheless, the clinical and cognitive sciences have different basic paradigms, stemming from their strong emphases on biological and computational methods, respectively. This may, at times, present a barrier to cooperation. However, these need not be an insurmountable barrier, as the recent success in the fields of computational neuroscience and cognitive neuroscience have shown.

By identifying clinical cognitive sciences as an important applied parallel to the core academic cognitive sciences, we have attempted to bring greater attention to the mutually symbiotic relationship between clinical and cognitive sciences. In the spirit of applied technology, we would like to quote the industrialist Henry Ford: "Coming together is a beginning. Keeping together is progress. Working together is success". We feel that achievements so far are from cognitive and clinical sciences coming together, and keeping together. But much greater success is achievable from actively working together, in a mutually symbiotic relationship.

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