Tired or Tipsy?

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Imagine Steve, a 38-year-old father of three kids. His wife just had their third baby and she is still on maternity leave. Steve is working extra hours at his job at an accounting firm to help cover the medical bills and support his family. He has been working 70-80 hour weeks for a while now and has been staying up with his new baby when he gets home from work. He's been incredibly sleep deprived but does it all for his family. One Friday night, Steve leaves work around 1:30 AM to drive home, since being at work since 6:00 AM, finishing a big project for the firm in hopes of earning a promotion. Across town, Kevin, a 22-year-old student, just found out he got into law school and has been celebrating at a local bar with his friends. Kevin has been working hard through college as a first generation graduate and is celebrating his hard work finally paying off. Kevin knows he's been drinking a little bit, but doesn't have very far to drive home so he thinks he'll be fine. Kevin leaves the bar around 1:40 am.

Neither Kevin nor Steve make it home that night. They get into a car accident on their routes home. Whose fault is it—Kevin's for being a little tipsy and slightly drifting into the next lane; or Steve's for being too tired and closing his eyes for one second too long at the wheel? When the police show up to the scene, Kevin is unconscious and Steve is in a confused stupor. At the hospital, Kevin's blood alcohol content reads 0.09%, just above the legal limit. Kevin is still unconscious and unable to give a police statement, while Steve is getting treated for mild head trauma and keeps insisting that he wants to talk to the police. Steve tells the police his side of the story and contends that the whole accident was his

fault, even though he can't prove it was the sleep deprivation. He closed his eyes for a second and ran through a red light right into Kevin, who was swerving slightly, but not the cause of this accident.

Everyone knows that drinking and driving is a bad idea, let alone illegal. When you're drunk you have delayed reaction times, impaired decision making, and a slew of other cognitive deficits that make safe driving impossible. This has been proven time and time again, leading to federal laws restricting the amount of alcohol a person can have in their bloodstream so that they do not become a danger to themselves and others around them on the road. However, most people don't realize that we put ourselves under similar cognitive impairments just by staying up late at work or pulling an all-nighter to finish a paper before getting behind the wheel. Staying awake for 17-19 hours straight produces cognitive deficits equal to having a blood alcohol content of 0.05%[1], which equates to about two average drinks within an hour. In comparison, the legal threshold for alcohol impaired driving is only slightly higher at 0.08%[2]. We all think that we know our own bodies and abilities well enough to be able to judge when we should or shouldn't get behind the wheel, but if our cognitive abilities are impaired then we don't have full control over our minds or our bodies. Society is constantly being warned about what drugs and alcohol can do to us and why we should never put ourselves at risk with things such as driving, but sleep has rarely been a part of this discussion.

Sleep is not something we choose to participate in, but rather a biological necessity that has more effects on our bodies and minds than we realize. Knowledge about the importance of sleep and implications of a lack of sleep could lead all of us to make better decisions about when to call it a day, when to call a taxi instead of driving home from work, and even when to stop working on your paper because you're going to sound drunk.

How Are Alcohol Intoxication and Sleep Deprivation Similar?

The physiological and behavioral symptoms as well as the cellular mechanisms of alcohol intoxication and sleep deprivation (a lack of sleep) are fairly similar. Common behaviors that are easily recognizable in people that are heavily intoxicated can be seen in cases of severe sleep deprivation as well. Some of the negative results of either intoxication or lack of sleep will be discussed in following sections, and include decreased cognitive control, slower reaction times, and increased errors in cognitive tasks. Behavioral and personality effects have also been directly analyzed in relation to both alcohol intoxication and sleep deprivation. Based on the cumulative results of various studies, alcohol intoxication can increase impulsivity and aggression while decreasing inhibition, creativity, and abstract thought[3]. Alcohol intoxication and crime rates are also extremely highly correlated. Many different types of crimes are associated with alcohol use and include robbery, sexual assault, aggravated assault, intimate partner violence, child abuse, and even homicide[4]. Of people incarcerated for violent crimes, about 40 percent were significantly under the influence of alcohol at the time of their crime[4]. Interestingly enough, a behavioral study on sleep deprivation and conduct revealed a similar negative effect of lack of sleep on the behavior of the participants. In this study by Barnes *et al.*, multiple behavioral studies were utilized to test the correlation between the amount of sleep and unethical behavior. Unethical behavior was characterized by behaviors such as cheating on survey results or taking credit for others' work[5]. They found a direct correlation between a lack of sleep and an increase in reported unethical conduct in

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the workplace. This increase in unethical conduct also paralleled an increase in cognitive fatigue as a result of sleep deprivation[5]. Based on these studies, sleep deprivation and alcohol appear to have similar effects on behavior, since they both have the ability to draw out an array of various undesirable behaviors in people.

At a more physiological level, both sleep deprivation and alcohol can impair basic functioning of the brain in similar ways. One of the most significant impacts of severe sleep deprivation and alcohol intoxication is on memory. The specific impairments of alcohol on memory are examined in a study by Lister *et al.*[6]. This study utilized various memory tasks within two categories, explicit and implicit memory tasks. Explicit memory is measured through tests that require conscious recollection of information, whereas implicit memory does not rely on conscious recollection of information. A combination of explicit and implicit memory tests were presented to groups of participants who were given various levels of alcohol (0-0.6 g/kg). The results revealed that alcohol decreased performance on explicit memory tasks but not implicit memory tasks[6], meaning that conscious recollection of events and information is more difficult to accomplish under the influence of alcohol. In another study by Van Dongen et al. on sleep deprivation, they used a specific computer task to measure working memory in response to sleep levels of either eight, six, or four hours of sleep for 14 days[7]. Both the six- and four-hour groups experienced decreased working memory from the computer task compared to the eight hour group. The four-hour group exhibited the most significant impairment in memory at levels that were experimentally equal to two nights of complete sleep loss[7]. Both of these studies indicate that the processes of memory within the brain are somehow disrupted by both sleep deprivation and alcohol consumption. This could have many different implications on how we function under both conditions. These data could suggest that pulling an all-nighter to study for an exam, for example, could negatively affect how much you remember for the test the next day compared to getting a good night of sleep instead. This also could help to explain why memory of events that occur during a night of binge tend to get fuzzy.

On the cellular level, similar types of neurological receptors are implicated in sleep and drinking as well. Neural receptors are protein complexes in neurons (brain cells) that bind to different chemicals to elicit a variety of responses throughout the body. Dopamine is one of many different chemical signalers in the brain that binds to specific dopamine receptors. Dopamine is used within the brain in many different regions that control motor activity, cognition, emotion, eating behavior, cardiovascular function, and positive reinforcement[8]. One specific type of dopamine receptor, D2 receptors, are essentially blocked in their function by both alcohol intoxication and sleep deprivation, but in different areas of the brain. In one study by Volkow *et al.*, there was downregulation of D2 receptors after sleep deprivation in human participants, which means that there were fewer receptors available in the dopamine pathway compared to the non-sleep-deprived control group[9]. This occurred in the ventral striatum of the brain, which is involved in motivation, decision-making, and the reward pathway[10]. Alcohol has produced similar disruption of the normal dopamine pathways within the prefrontal cortex, which is the area of the brain responsible for planning complex behavior and cognition[11]. These studies combined illustrate the similarity in cellular response in both sleep deprivation and alcohol intoxication.

Although both alcohol and sleep deprivation appear to significantly disrupt dopamine functions within the brain, sleep itself has also shown indications of disrupting dopamine activity that occurs during wakefulness. In a study using a fly model, sleep mechanisms actually blocked some dopamine signaling in the brain,

which had a positive effect on memory. Without this blockage of dopamine during sleep, the flies had significantly worse memory of motor tasks[12]. This study indicates that normal inhibition of some dopamine pathways during sleep is necessary for normal cognitive functions. However, sleep deprivation causes abnormal inhibition of other dopamine pathways that creates negative effects on cognition. Across various areas of the brain, dopamine is a key player in both alcohol intoxication and sleep deprivation, but in a variety of different processes.

What Does Alcohol Do to Us?

In a specific study of the effects of alcohol on behavior and physiology of the body, participants were given different doses of alcohol and performed tests of reaction time, arithmetic, standing steadiness, and physiological recordings (electroencephalography, electro-oculography, and eye movement). This study concluded that performance on most performance tasks declined as blood alcohol content increased[13]. Another more recent study conducted by Bailey *et al.* (2014) also examined the cognitive effects of alcohol using electroencephalography (EEG) recordings, which show changes in the brain in response to different tasks over time[14]. They gave the participants alcohol and using the EEG recordings, were able to quantify their relative amount of cognitive control and response time as they performed a basic computer task. The results of this physiological study showed both a longer reaction time and a decrease in cognitive control from the alcohol. Both of these specific studies, as well as many others, have similar results indicating that drinking alcohol affects your physical abilities as well as mental control.

The direct physiological effects of alcohol on the brain are well established. Alcohol is classified as a depressive drug, meaning it directly decreases stimulation of the brain. Alcohol activates multiple types of chemical receptors in the brain including GABAA and NMDA receptors. Alcohol molecules bind a specific portion of the GABAA receptor protein, opening the ion channel, as shown in Figure 1. When GABAA is opened, there is a negative flow of chloride ions into the neurons of the brain, which decreases the signaling rate of these neurons to other neurons in the brain. Ethanol molecules also have the opposite effect on another prevalent receptor type in the brain, NMDA. NMDA is a type of glutamate receptor, which indicates that the molecule glutamate is necessary to activate or open up the receptor. Glutamate binds to one of the protein subunits of an NMDA receptor, just as ethanol does to GABAA receptors in Figure 1. When glutamate binds and the cell membrane reaches an ideal charge, the receptor opens and allows positively charged calcium ions to enter the cell. The positive charge of the calcium ions increases the overall charge of the neuron and activates the neuron by allowing it to send signals to other neurons in the brain[15]. However, when alcohol is involved, the ethanol molecules bind to the NMDA receptor and blocks the binding of glutamate, therefore keeping the receptor closed. Both mechanisms of ethanol on GABAA and NMDA receptors keep the neurons from firing and sending a normal amount of signals to other neurons in the brain, which causes the symptoms associated with alcohol intoxication.

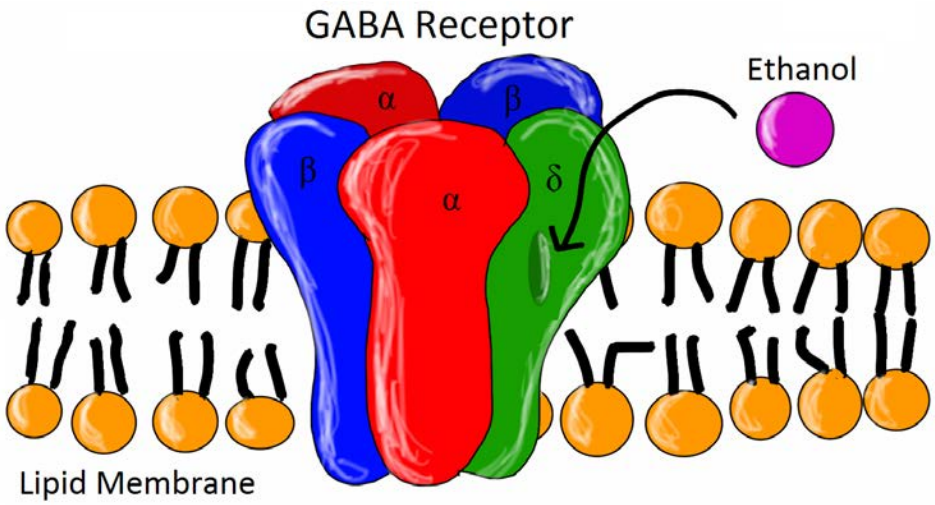

Figure 1: "Alcohol Binding to GABA Receptor" on Wikipedia Commons

Alcohol has many common effects on the functions of the body and brain as well. Moderate alcohol intoxication causes noticeable physical symptoms including general disorientation, slurred speech, loss of coordination, and impaired attention and memory[16]. Severe alcohol intoxication can cause stupor, slow breathing, hypothermia, and rapid heart rate[17]. When you are drunk, you also have delayed detection times to changes in your body position and therefore delayed response times[18]. Sleep comparatively follows a very different mechanism of action on the brain.

How Does Sleep Occur?

Sleep is a naturally occurring physiological process induced by the brain. Throughout the day, we are in a constant state of wakefulness, during which time our brains are being constantly stimulated. While we are awake, our brains are also producing a type of sleep-inducing chemical called adenosine. Adenosine accumulates in our brains throughout the day and the longer we are awake, the more adenosine is being produced. By the time we go to sleep, we have enough adenosine buildup to inhibit neurons, put our bodies to sleep, and let our brain rest[15].

There are multiple phases of sleep that we go through every night. We transition from being awake to being in slow-wave sleep to eventually falling into rapid eye movement (REM) sleep. There are five distinct stages of sleep, within these broad categories. These stages represent the different types of brain activity (as shown on an electrophysiological recording) that occur during sleep. Figure 2 represents a typical cycle of sleep stages over the course of seven hours. Both slow-wave and REM sleep serve different purposes for the brain. During slow-wave sleep, the brain is relaxing and recovering from the day. Specific patterns of brain waves called sleep spindles during this phase also indicate consolidation of memories. The specific functions of REM sleep are not as well understood. There is some evidence for REM sleep playing a role in brain development and learning. However, we do know that REM sleep is vital to the brain for survival. When it's time to wake up from a night of sleep, our brain induces an arousal mechanism to take us out of a sleeping state. This mechanism of wakefulness includes an assortment of chemicals that are released in different parts of the brain. These chemicals are all neurotransmitters released by neurons to send a signal to other neurons in the brain. Each of these five chemicals are produced and distributed in different parts of the brain to constitute an overarching arousal of the entire brain[15].

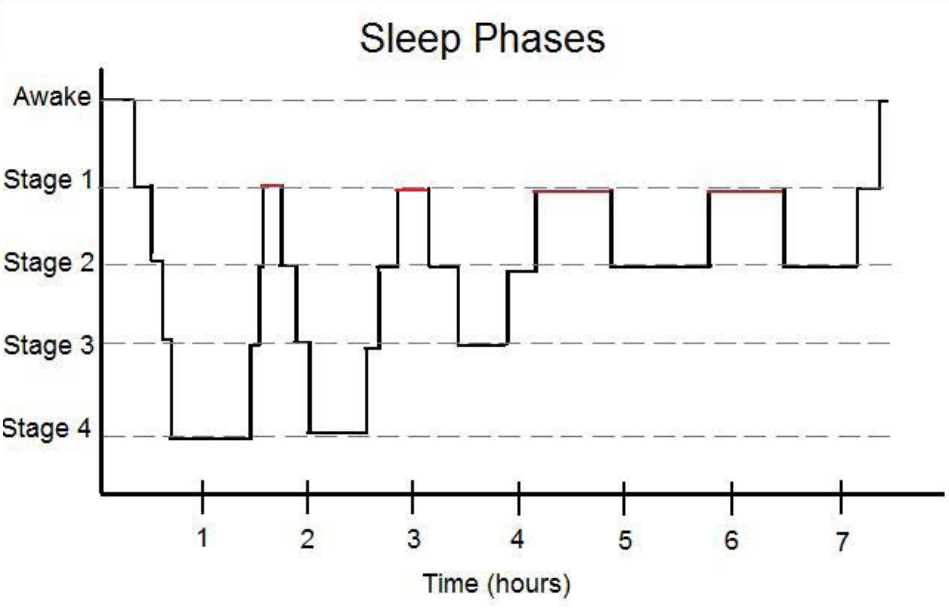

Figure 2: Adapted from "Simplified Sleep Stages". On Wikipedia Commons.

What Happens When We Don't Get Enough Sleep?

As stated in the previous section, sleep is necessary for basic cognitive functioning. On average, most people need about seven to eight hours of sleep per night[19]. Below this amount, people begin to have symptoms of sleep deprivation. Many studies have been conducted to measure the specific impairments on physical, behavioral, and mental performance from sleep deprivation. One study by Van Dongen *et al.* controlled the amount of sleep in participants at incremental levels of eight, six, and four hours for a total of 14 days and measured cognitive ability over the course of the experiment[7]. The participants of both the four- and six-hour groups performed worse than the eight-hour group on the cognitive tests. Complete sleep deprivation (for 88 hours) in this same study resulted in more severe cognitive dysfunction in the participants, specifically impairing their processes of attention and memory. In another study, ultra-marathoners were monitored for physiological effects of sleep deprivation during a 168 kilometer race. Some of the athletes exhibited physical symptoms of hallucinations, extreme tiredness, loss of balance, and partial amnesia. The cognitive impairments of this combined sleep deprivation and extreme physical activity were measured by pre- and post-race tests. After the race, participants had increased reaction times, reaction time lapses, and number of errors, denoting impaired cognitive function[20]. In this specific study, there is no way to differentiate between the effects of the race itself or the sleep deprivation caused by the race, but the general

"Doze" by dannyworking on pixabay

decline in cognitive performance is consistent with other complete sleep deprivation studies as well.

There are various neurological disorders that directly affect sleep patterns. One of the more common sleep disorders is insomnia, which affects about 25 percent of people at some point in their life[15]. People with insomnia have issues either falling asleep or staying asleep for the whole night, which causes prolonged sleep deprivation for the duration of the disorder. After long bouts of insomnia, people can be at an increased risk for other health issues as a result of prolonged sleep deprivation including obesity, cardiovascular disease, and diabetes[15]. The most severe form of this sleep disorder is fatal familial insomnia. As the name suggests, this disorder is a version of insomnia that is genetically influenced and always fatal. This disorder is an incredibly rare form of insomnia with and average onset of 49 years of age, in which people completely lose the ability to sleep. Individuals with fatal familial insomnia first experience a decrease in slow-wave and REM sleep in the early stages of the disease. In later stages, any form of sleep is minimal and more severe cognitive symptoms occur including hallucinations, deficits in memory and attention, stupor, and coma at the terminal stage. This disease generally lasts for about 12-13 months from the onset of symptoms to the terminal stage[21]. The disease is the direct cause of death, but the specific mechanism remains unknown and untreatable.

What are the Implications of All of This?

If alcohol intoxication and sleep deprivation both present with very similar behavioral, cognitive, and even cellular deficits, then why do we have strict laws around drinking but not sleeping? In the state of Ohio, common penalties for driving with a blood alcohol content above 0.08% for someone over 21 years old, over 0.04% for a commercial driver, or over 0.02% for someone under 21 years old include fines ($375-$20,000), time in prison/jail (3 days-15 years), suspension of the driver's license, mandated alcohol treatment programs, and more[22]. However, sleep deprivation can cause the same driving impairment as alcohol, can pose the same safety risks, and can cause you to get pulled over for impaired driving. The differences between alcohol impaired driving and sleep deprivation impaired driving have been investigated by Fairclough and Graham in a behavioral study[23]. After a full night without sleep, the number of lane crossings was comparable to legal levels of alcohol intoxication (0.08% BAC), but four hours of sleep during the night produced the highest number of near lane crossings. Moreover, both amounts of sleep deprivation resulted in a significantly lower amount of steering activity compared to the unimpaired control and the alcohol impaired participants[23]. This single study exemplifies direct comparisons of driving under the influence of alcohol versus driving while sleep deprived, and shows that sleep deprivation is just as dangerous to driving ability as alcohol.

Knowledge of the importance of sleep and the implications of a lack of sleep is the first step in preventing harmful and dangerous situations caused by sleep deprivation. Although Steve, our sleep deprived example from the beginning was only trying to support his family, he still put himself and others at risk. Steve had the best intentions but didn't know the consequences of his actions. Kevin, similarly put others at risk by driving while intoxicated, but made that decision knowingly. If Steve had known that he was essentially driving while impaired, would he have gotten behind the wheel? Is there any way to judge or quantify sleep deprivation if it isn't detectable like alcohol?

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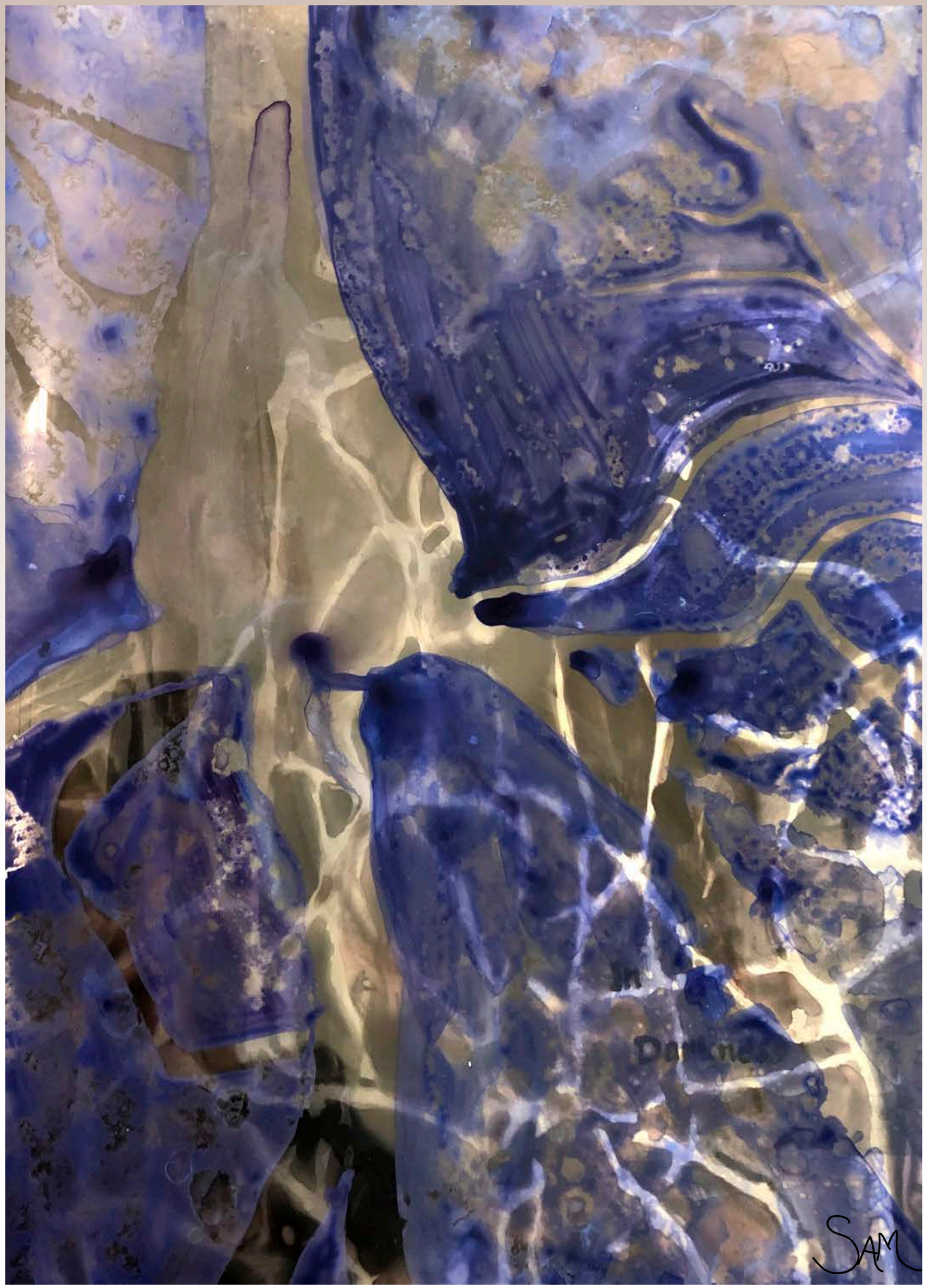

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