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Music Theory and Autism Spectrum Disorder: Tuning to the Right Key for Rehabilitation

The following paper seeks to inform how Music Therapy provides individuals with ASD with substantial means for mental and social growth/development. In doing so, it aims to shed light on the unreliability of certain medications used already, advocating the use of Music Therapy as a more appropriate and justifiable alternative.

A simple question, yet hard to answer, "What is music?" has traversed the minds of humans for centuries. In its simplest form, music is the mere organization of sound and silence in time, but as we personalize music, and even objectify it, the definition evolves. For instance, Musicologists typically define music as a "social construct that varies from culture to culture, rejecting cross-cultural quests for universal [connections] underlying diversity," but Biologists usually look at music through a more physiological lens, such as Charles Darwin, who claimed that "[music] must be ranked among the most mysterious with which we are endowed" (Peretz, 2006) (Sacks, 2007). In this quote, Darwin had essentially justified that music is a mysterious form of human activity because it plays no key role in survival, but when thousands of credible music enthusiasts give vastly contrasting definitions of music, who are we to believe? My theory is that music in itself has no definition; it only has the ability to define external elements, particularly people, which use, or embrace it. I have derived this from Edward Elgar, renown composer of the Elgar Cello Concerto and the graduation theme "Pomp and Circumstance," who said "music is in the air, music is all around us, the world is full of it and [we] simply take [in] as much as [we] require". Unlike most music enthusiasts, he leaves us with the idea that music shapes us rather we shape it. So if that is the case, we can't actually define music. Music can only define us.

This viewpoint can be well supported through many lines of evidence, as music represents an immense part of our identity and our culture, and what we choose to listen to has a strong correlation with the outcome of our personalities. After all, we are exposed to music daily, whether it be from hearing a song on the radio, or creating it ourselves by tapping a pen on a desk. We use music it to decrease stress, to induce certain moods in cinema and live performance, to connect with close ones, to vicariously relive our past, and to maintain focus,

amongst other usages (Klosowski, 2011). Perhaps most underestimated however, music can be used as a form of therapy for individuals with mental illnesses. In recent years, music therapy has begun to permeate the medical world as an alternative form of treatment to medicine, and in this article, I will explain how the benefits of music therapy, or MT for short, can outperform the benefits of medicine in the case of treating patients with Autism Spectrum Disorder (ASD)[1].

To start off, although there are various forms and levels of Autism Spectrum Disorder (ASD), ASD is defined as a dysfunctional neural disorder that causes intellectual disabilities, social communication difficulties, delayed motor coordination, and unusual repetitive behaviors (Genes to Cognition Online, 2005). ASD is quite commonly seen in individuals due to environmental toxins and its transmission via various linked genes, and it is more prominently seen during early years of childhood after neural issues have developed (Genes to Cognition Online, 2005). Dismay in regards to ASD has increased in recent years because the diagnostic rates have grown tenfold, where now the average rate for ASD in the United States, excluding ethnic and socioeconomic data, is 1 out of every 88 children (in boys 1 out of every 54, and in girls 1 out of every 252) (Ghasemtabar, 2015).

Many scientists have debated what constitutes the physical network of an Autistic brain, specifically whether or not the cortex contains an overabundance of synapses, but according to an experiment conducted by Columbia University researcher Guomei Tang, this long-debated hypothesis was verified to be true ("Brain Study Finds Evidence that Autism Involves Too Many Synapses," 2014). Tang compared the densities of samples of cortical brain tissue between deceased individuals with ASD and deceased individuals with normal brains, and the brains of the individuals with ASD appeared to be denser, which suggests that via an absence of synapse pruning, too many neurons will clutter the brain, causing neurons to weakly connect and be non-functional **(See Figures at the end for more analysis)**. Thus it is no surprise why people with ASD have abundant mental and physical difficulties, as if too many unnecessary synapses occupy the brain, so much so that the synapses fail to send signals appropriately with another, physical and mental skills can never be developed. In addition to this demystification, Tang also discovered why the lack of pruning might occur in the first place. Her experiments showed that the brain cells of the individuals with ASD lacked access to adequate channels for autophagy, or

[1] I have chosen to capitalize Autism throughout this article because many people who have the disorder think of it as a part of their identity. Moreover, they prefer to be called "individuals with Autism" rather "victims of Autism," because although they may have mental deficits, they do not believe they are suffering, nor do they want others to impose that they are.

self-eating, to occur ("Brain Study Finds Evidence that Autism Involves Too Many Synapses," 2014). If the necessary autophagosomes that break down proteins and organelles for the sake of homeostasis cannot reach their destination, synapses cannot be pruned, and thus the affected brain area will expand into a dense neuron forest with no practical route for neurons to congregate and make the connections needed to develop certain human skills (Autophagy Wikipedia, 2017) ("Brain Study Finds Evidence that Autism Involves Too Many Synapses," 2014).

An overabundance of neurons certainly creates an issue for individuals with ASD to interpret music, as without proper connections, music may only appear as meaningless sound to the individual, but as we know from the vast array of music enthusiasts who have normal-functioning brains, music can communicate so much more in society. And when music does appear lifeless to the avid listener, severe emotional distress may develop. In his novel "Musicophilia," which explores connections between biographical events of music enthusiasts with the functionality of anatomical structures involved in the perception of music, Dr. Oliver Sacks recounts the story a person who had difficulty in collaborating with other musicians due to hearing distortions from a damaged cochlea, the sensory organ in the ear which produces nerve impulses in response to sound (Sacks, 2007). Normally, sound waves are converted into fluid waves in the inner ear, and vibrations in the cochlea cause inner hair cells, the sensory receptors of the ears, to generate electrical signals, which get transmitted to the brain (Weinberger, 2004). In the case of this man Jacob, who dealt with cochlear amusia after old age disrupted his ability to hear, high pitched sounds appeared grossly out of tune, inhibiting him from being able to compose his music and to conduct without wrongly accusing his orchestra of playing incorrect notes (Sacks, 2007). Moreover, to connect back to synaptic pruning, the out of tune notes which Jacob heard were developed as a result of the "cortical representations" of the neurons responsible for him hearing the correct notes shrinking, meaning that neurons that produced distorted sounds came together to replace damaged ones, causing Jacob to experience such distress (Sacks, 2007).

Although Jacob was never diagnosed with ASD, the inability for him and those with ASD to process music, due to incorrect and/or excessive neural connections, is relayed quite similarly. Ironically however, Dr. Sacks mentions that Jacob had social communication problems, which is one of the core symptoms of ASD (Genes to Cognition, 2005). Social deficits do in fact appear

more central in individuals with ASD than either cognitive or language deficits, thus the struggle to perceive music can be said to greatly affect the ability for an individual with ASD to interact with others if music is the subject matter involved (Ghasemtabar, 2015). An ASD brain study on imbalanced cortical networks provides more insight on this, as experimentations showed that the relative gray matter in auditory and visual networks atypically increases during childhood, resulting in severe socio-communicational deficits (Watanabe, 2016). Since gray matter in the brain consists of the neural cells themselves and synaptic locations, while white matter consists of axons, which connect parts of gray matter together, an overgrowth of gray matter in a brain would suggest that many neural connections are weak and lack functionality if there are not enough axons to connect the neurons together (Dr. Kemp Personal Communication, 2017). But, although they may lack functionality the way they are, an overabundance of neurons means that there is a "stored potential" for connections to be made, so long as the brain can be, in a sense, re-networked. This is where music therapy comes in.

Music Therapy, or MT for short, has gained attention in recent years as an alternative form of treatment of ASD due to its cost-effectiveness, unorthodox yet attractive utilization, ease of use, safety, and minimal side effects. As quoted by the American Association of MT, MT is "the clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship by a credentialed professional who has completed an approved MT program" (Ghasemtabar, 2015). In other words, MT is a psychology-based program that utilizes music as a calm-inducing agent for increased social interactions. Much research provides evidence that MT not only helps patients, whom are typically children, succeed in reaching their social goals, but also helps mediate the disparities of psychosocial, cognitive, and motor behavior with disabilities (Ghasemtabar, 2015). It is thus by these means that I consider MT, at least in the case of individuals with ASD, a more effective form of treatment than medication.

According to MT researchers Sudha Srinivasan and Anjana Bhat, MT is useful for individuals with ASD because of three essential reasons. First, the physical act of musical training can assist in improving core autism deficits such as joint attention, social reciprocity, verbal and nonverbal communication, poor motor performance, and behavioral problems. Second, the introduction to music may foster a greater sense of self-esteem and identity if the individuals are to find learning and understanding music aesthetically pleasing. Third, the instructor has the capability to make the patient feel a non-intimidating emotional connection via

copying their actions and sharing the experience in exploring various instruments (Srinivasan, 2013). Although there are limited studies that explore the correlation between MT and ASD, some studies verify that music-based interventions can improve social skills such as eye contact, engagement, and spontaneous initiation of social interactions in children with ASD.

In an experiment conducted by scientist Jinah Kim, for example, one group of children joined a 12-week intervention of improvisational music therapy, while another group joined a therapy program where they could engage in toy play. The children in both groups worked individually with a therapist for 30 minutes a few days a week, and by the end, there were significant increases seen in frequency and duration of shared positive affect (eye contact and smiling) and joint attention with the therapist in the music group compared to the control group engaged in toy play (Kim, 2009). In addition to this, another study shows evidence that neurons and anatomical structures within the brain of an individual with ASD can be re-networked. Six-year old children with ASD who received musical training for 15 months demonstrated structural changes in the pre-central gyrus (motor area where pyramidal nerves (nerves that travel from cerebral cortex to the brain or spinal cord) are located), the corpus callosum (the brain's largest track of white matter), and the Heschl's gyrus (a fold within the temporal lobe that contains the primary auditory cortex and is the cortical center for hearing) (Choi, 2015)(Schlaug, 2005)(Transverse Temporal Gyrus Wikipedia, 2017). Similarly, researchers in the field of neurologic rehabilitation have found evidence through magnetic resonance imaging that learning music may effectively strengthen connections in the brain. They discovered that in only a few weeks of piano training, the areas of the brain involving hand control and musical sight-reading became larger and more connected. This suggests that music and MT can effectively increase white matter (which permits the strengthening of neural connections) in individuals with ASD if they are exposed to music for a substantial amount of time (Thaut, 2010); such evidence supports that there are strong links between musical training and activation of anatomical structures in the brain involving mental processing.

In addition to mental treatment, researchers have evidence that music therapy, with a concentration on rhythmic synchronization, can improve physical deficits in individuals with ASD, such as motor ability. Individuals with ASD undeniably have the capability to move muscles, but due to "neuro-atomic abnormalities" in the cerebellum (ex: under/overgrowth of organic tissue in the cerebellar hemispheres, and differences in the structural arrangement of

purkinje neurons), individuals with ASD show signs of poor gait and gross motor skills (Hardy, 2013). Thankfully, MT can aid ASD individuals despite such deficits, because "rhythmicity plays a critical part in learning, development, and performance, as timing of movement is essential in many motor control and cognitive functions" (Hardy, 2013). If rhythmicity is used in the form of external cueing, for example, the cueing will facilitate the ability of individuals with ASD to perform discrete acts because it will provide them with "precise reference intervals" during each stage of movement (Hardy, 2013). A study conducted by Sudha M. Srinisvan and her team of researches supports this theory, because in the experiment, which had children with severe ASD between ages of 4-9 join a biweekly rhythmic program for 8 weeks, signs of increased motor skills were evident (Srinisvan, 2016). The children were engaged in whole-body movement games with a physical therapist, such as beat keeping exercises involving synchronous whole body movements with the adults, and improvisational music making that involved synchronous playing of musical instruments, and changes in motor performance before and after were observed using the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2) (Srinisvan, 2016). The BOT-2 scores for 9 out of 11 children in the experiment increased (Pre-program Average: 32.91/50, Post-program Average: 36.36/50), but all of the children demonstrated a significant decrease in imitation performance errors, the average change going from 35.55% to 16.72% (Srinisvan, 2016). Although studies like this are limited, these positive outcomes should indicate the potential that MT can suppress the intensity of deficits in individuals with ASD.

Besides just helping individuals with ASD, music in itself has significant impacts on human behavior, all of which further justifies why MT should progress to infiltrate society on a more global scale. For example, a collection of multiple studies revealed that listening to music significantly alleviates patient's anxiety when undergoing procedures such as a colonoscopy, Mohs surgery, and other surgeries (Daniel, 2016). Likewise, an experiment utilizing visual analogue scales to calculate the amount of pain during orthodontic treatment when music was used as an intervention showed that those who listened to music experienced less pain than those who did not. Although this experiment contained other variables, the collective conclusion was that music helped comfort the patients (Xu, 2013).

MT in itself has credibility because other than the potential for it to be ineffective in some cases, there is virtually no evidence to suggest that it can have any major negative impacts on

anyone. The only potential downsides that exist come in the form of context by which music is being used, as the use of aggressive music to calm patients with Acute Stress Disorder would certainly increase the intensity of symptoms, and at the same time one can experience joy and comfort from listening to music, mental deficits may cause individuals to have false memories, confusion, and anxiety in response to the music they hear (Swayne, 2014). For example, the film "Alive Inside" features a man named Henry with Alzheimer's, who is "brought to life" upon hearing music from an IPod intended for therapeutic purposes, but the information he gives afterwards is misleading (Rossato-Bennett, 2014). Henry claimed that his favorite song is "I'll be home for Christmas," by Bing Crosby, but he identifies Cab Calloway as the artist. Of course, due to old age, he may be unsure of certain information, but as Henry's situation suggests, the context of how music (and MT) is being used and who is listening to it would justify a sense of confusion as the listener attempts to make sense of the disjuncture between a song heard right now and a recollection of where and when he or she might have heard the song before (Swayne, 2014). Nonetheless, despite such minor shortcomings, the overall benefits of MT reckon it a trustworthy source for treatment of mental illnesses.

Despite all of this evidence that supports the effectiveness of MT, it is important to realize that medicine can have positive effects on ASD as well, although I will argue how it is inferior to MT later. Although the Food and Drug Administration (FDA) has not approved of any medication that deals directly with the core symptoms of ASD all at once, drugs can be administered to individuals with ASD that regulate certain behaviors which can thus indirectly treat the core symptoms ("Medicines for Treating Autism's Core Symptoms," Autism Speaks). For example, selective serotonin re-uptake inhibitors (SSRI's), which are marketed under various names like Fluoxetine and Vilazodone, can treat internal problems that may arise from chemical imbalances, and may reduce the frequency and intensity of repetitive behaviors as well as improve eye contact ("Medicine Treatment," National Institute of Health). Likewise, tricyclics, a type of anti-depressant, can treat depression and may reduce obsessive-compulsive behaviors, sometimes even more effectively than SSRI's can ("Medicine Treatment," National Institute of Health).

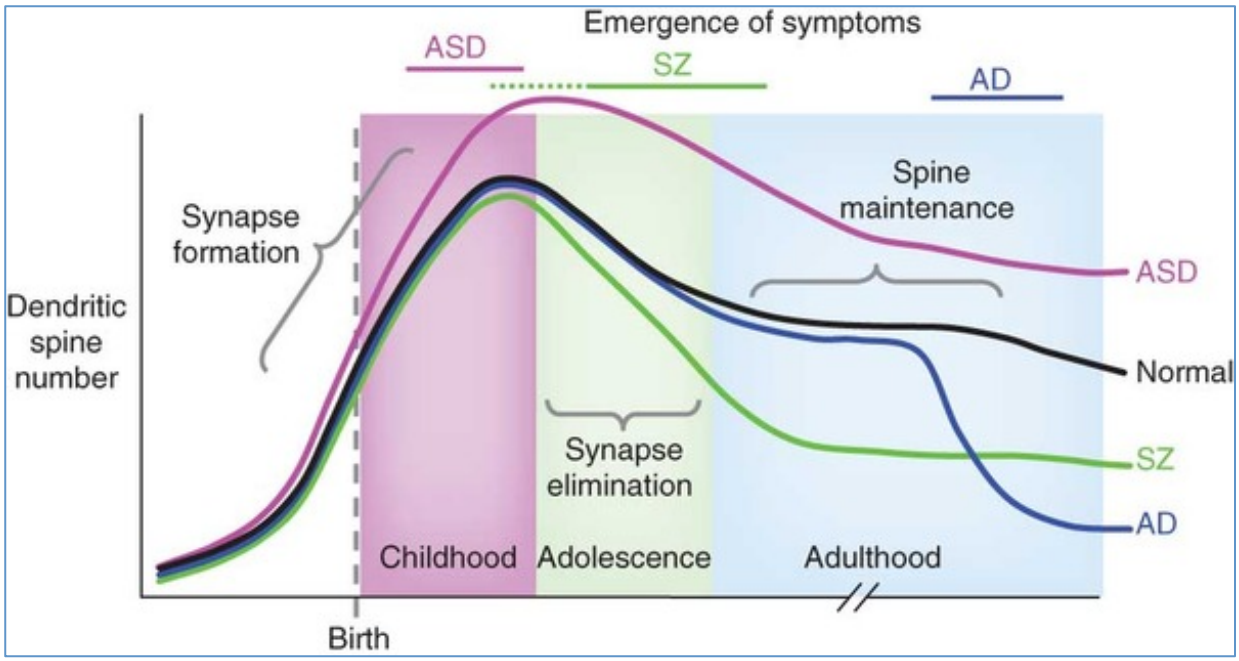
Unfortunately, however, there are various effects that may arise if an individual with ASD takes medication, and due to the distressing dual possibility that any given drug may react well or poorly (since humans do not react the same way to certain drugs) with the individual, the use

medication as a means of treatment is rendered overly complicated and untrustworthy. In fact, although limited in publications, there is evidence to suggest that the medications that are prescribed for individuals with ASD for the purpose of rehabilitation do not always guarantee positive results. For example, although fluvoxamine has been efficient in reducing aggression and repetitive behaviors in adults with ASD, it has limitations, because it is poorly tolerated in children who have ASD symptoms ("Medicines for Treating Autism's Core Symptoms," Autism Speaks). In a double-blind placebo experiment, where 34 children (aged 5-18) were given fluvoxamine purely for its psychological benefits without preconceived notions as to how the drug many influence them, clinical improvement was only seen in one child, while 14 children experienced adverse effects, and the rest were unaffected (Doyle, 2012). In addition, clomipramine, another type of SSTI, may be effective in reducing aggression and hyperactivity in children with ASD, but it too has the potential for adverse effects. In a trial involving five children aged 7-12, all experienced a reduction in movement disorders and compulsions, but three of the children exhibited extreme agitation and aggression that required hospitalization (Doyle, 2012). Besides SSTI's, supplementations such as w-3 (n-3) fatty acid can show adverse effects too, as a group participants (all children with ASD) out of 183 total tested with the Behavioral Assessment System for Children showed significant signs of worsened external behavior and social skills after consuming the supplement (Horvath, 2017).

Given such evidence, the validity of MT as a reliable form of treatment, even more so than drugs and medication, should be indubitable. As researchers have claimed, and as I will now, the use of MT (and the publication of its analyses) is highly limited, and the comparison in net gain improvement between MT and medicine specifically for any deficits that ASD may bring is virtually nonexistent from the biological research world. Experiments comparing these two forms of treatment with ASD individuals need to be performed in order to truly make a definite claim, but until then, the credibility of MT over medicine should speak for itself. As previously stated, the dual possibility of medicine working well or poorly contributes to its downfall as a form of treatment for individuals with ASD, and since the medication must continuously be replaced after it is consumed, one can conclude that the amount of medicine needed to suppress the intensity of ASD deficits requires more resources than MT does. Moreover, drug industries already devote substantial time to developing medication for other purposes, thus I believe by

incorporating MT – a simplistic, safe, and exciting musical program – as a new form of treatment for individuals with ASD, we would be doing the economy a huge favor.

Figure A: Dendritic Spine Number vs. Mental Illness (Penzes, 2011)



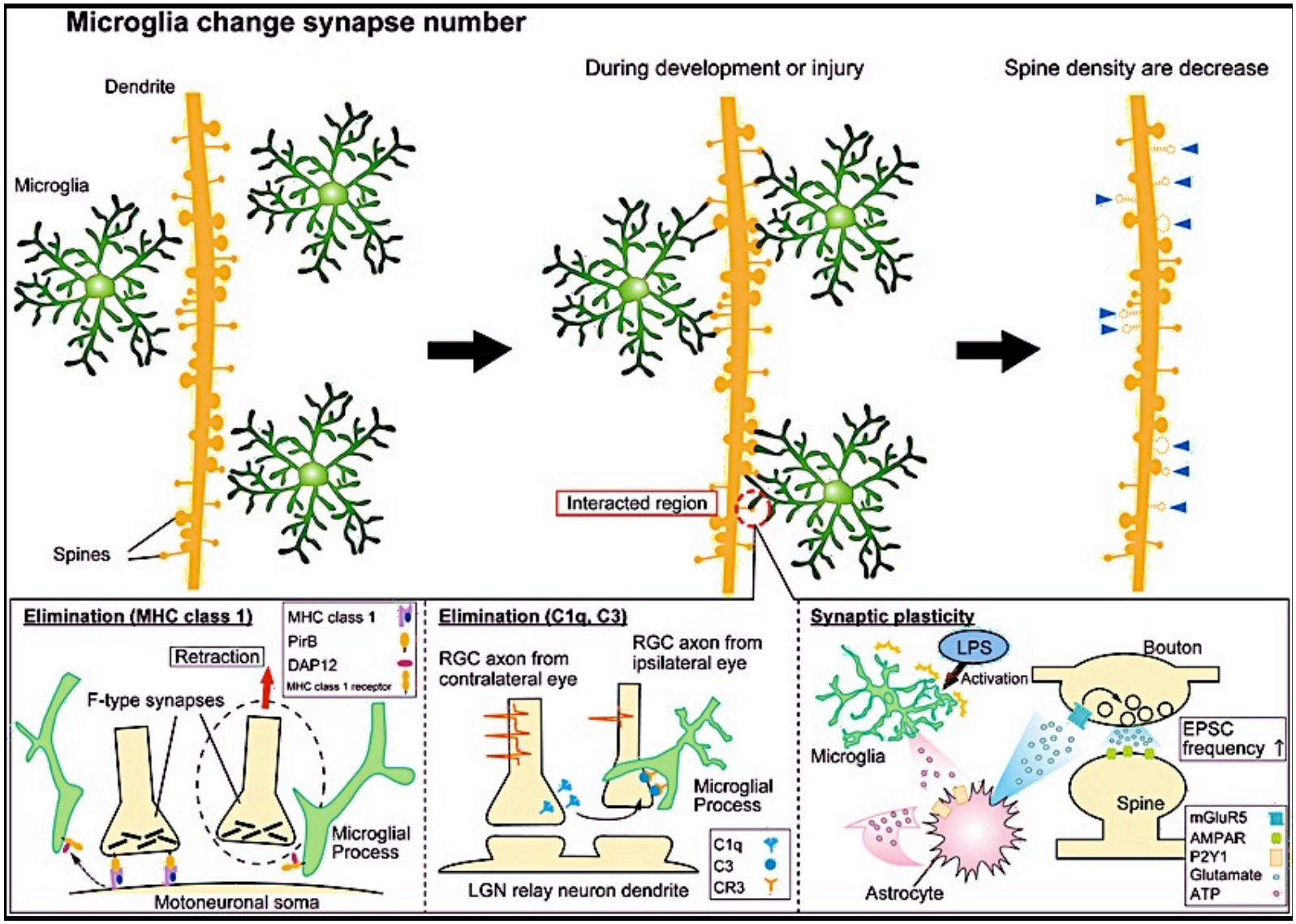
Straight lines at the top indicate the period for which symptoms are most likely to be seen

* **Dendritic spines** are small membranous protrusions from a neuron's dendrite that typically receive input from a single axon at the synapse*

This figure shows the relative distribution of dendritic spine numbers across time, and their correlation to various mental illnesses (Autism Spectrum Disorder, Schizophrenia, and Alzheimer's Disease, respectfully). It is typical to have a abundance of dendritic spines, or synapse signal receptors, leading into adolescence, but if the number grows too high, ASD symptoms may develop, and if too many synapses decrease after childhood, symptoms of SZ or AD may develop (Penzes, 2011).

Figure B: Microglia's effect on Synaptic Pruning (Neurowiki, 2014)

Synaptic pruning refers to a neurological regulatory process in which productive changes in neural structure are facilitated by reducing the overall number of neurons or connections. It is an essential process of development because the brains of newborn babies are flooded with information, and the only means by which they can process sensory information is by creating neural connections for brain transmission, thereby reducing the amount of synapses, or synaptic pathways ("Synaptic Pruning" Wikipedia, 2016).



Synapses have variations in strength based on which ones are used most often, and it is natural for weaker synapses to be pruned in order to allow stronger ones to dominate (Neurowiki, 2014). Although only expressing 2 possible theories as to how synapses are pruned (the third expressing plasticity), the diagram above illustrates how stronger synapses prevail in more detail. In order for pruning to occur, the green star like structures, called microglia, must bind to a receptor on a synapse (in the interacted region), and depending on the reaction taken place, the synapse may either be retracting or degraded. The first scenario depicts a microglia identifying pruning targets utilizing the multiple histocompatibility complex (MHC I) when bound to the immune receptor PirB, and here the microglia physically retracts the synapse, thereby allowing the axon to regenerate (Cebrián, 2014). In the second scenario, an astrocyte (not shown) activates C1q, an immune response starter, which in turn activates C3, which binds to neurons and marks them for degradation. The microglia would then proceed to interact with C3 and stimulate degradation via a CR3 receptor (Neurowiki, 2014). And finally, although the last scenario, which illustrates that following the activation of ATP release and PY21 receptors on astrocytes, microglia are stimulated to produce glutamate which bind to the receptor mGluR5s thereby increasing pre-synaptic release and strengthening synapses, one could propose that a deprivation of ATP or a malfunctioning astrocyte may also contribute to synapse pruning, that is assuming no other reactions take place to counteract the fixed level of pre-synaptic releases (Gursharan, 2015) (Neurowiki, 2014).

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