

The Tale of Warrior Gene: The Link between the MAOA-upstream Variable Number Tandem Repeat (MAOA-uVNTR) Polymorphism and Aggression, Violence

ABSTRACT

The Monoamine Oxidase A (MAOA) gene has acquired significant attention across the field of behavioral genetics over time due to its association with different adverse impacts it has had on altering human behavior. Research suggests that specific genetic variations of the MAOA gene, particularly the MAOA low allelic variants (MAOA-L alleles), are linked to increased susceptibility to aggression. Due to this association, the low-activity variations of the MAOA gene's upstream Variable Number Tandem Repeat (uVNTR) promoter region have conferred the name "warrior gene." A plethora of neurobiological investigations have revealed that the MAOA gene plays a significant role in the metabolism of neurotransmitters, such as dopamine, serotonin, and norepinephrine, that are implicated in regulating mood, impulse control, and emotional processing. Further, a wealth of research highlights that any form of dysregulation of these neurotransmitter systems, stemming from the genetic variants of the MAOA gene, can contribute to aberrant behavior and lead to aggressive tendencies. However, a negative association between the MAOA low allelic variant and aggressive behavior has recently been presented. Hence, a critical evaluation of available literature is important to retreat the relationship between the MAOA variants and human aggression and violence. This narrative review primarily focuses on the MAOA-uVNTR polymorphism and its influence on antisocial spectrum behaviors like aggression and violence. It also emphasizes the moral, legal, and societal issues that genetically influence human behavior. It is anticipated that the literature compiled herein would provide a critical justification for MAOA-L as a genetic risk factor for humans' aggressive and violent behavioral traits.

Keywords: MAOA, MAOA-uVNTR, Neurotransmitters, Aggression, Violence

1. INTRODUCTION

Perception of the genetic influence on human behavior is complex and multifaceted. Human behavior, ranging from personality traits to susceptibility to a broad spectrum of psychiatric disorders over time, has been studied to be governed by a combination of genetic and environmental factors [1]. Genes do not act in isolation but interact with the environment to produce observable behaviors. Environmental factors such as family upbringing, socioeconomic status, and life experiences can modulate the expression of genetic predispositions, leading to diverse behavioral outcomes [2]. The impact of genetics on the

behavioral patterns of a human being is a fascinating and intricate area of study that continues to evolve with advancements in genetics, neuroscience, and psychology.

Recent studies on brain imaging and molecular genetic analysis have explicated that some specific genes can result in structural and functional brain alterations that subsequently predispose to antisocial spectrum behaviors [3]. One such gene is an X-linked gene that codes for Monoamine Oxidase A (MAOA), which is abundantly available on the mitochondrial outer membranes in neurons, glial cells, and other cells [4]. Monoamine Oxidase enzymes play a significant role in both the Central Nervous System (CNS) and the Peripheral Nervous System (PNS) by regulating the levels of monoamine neurotransmitters such as dopamine, serotonin, norepinephrine, and phenylethylamine [5]. It catalyzes the oxidative deamination of those monoamine neurotransmitters [6]. Monoamine oxidase A gene is located on the X chromosome Xp11.23- 11.4 with a size of 91,911 bases and a plus strand orientation (NCBI gene) [7]. Sabol et al. (1998) [8] identified a functional upstream variable tandem repeat polymorphism (MAOA-uVNTR polymorphism) approximately 1.2 kb upstream of the MAOA coding sequence that consists of a 30-bp repeat sequence present in 2, 3, 3.5, 4, 5, and 6 repeat (R) sequences. These polymorphisms influence the gene transcription and the enzyme activity [7-11]. The 2R, 3R, and 5R are classified as low-activity alleles and exhibit low transcriptional efficiency. Conversely, 3.5R and 4R alleles lead to a more efficient transcriptional activity, and hence, they are classified as high-activity alleles [7-11]. Due to these implications that the MAOA gene has on antisocial behavioral traits of human beings, the MAOA gene earned the nickname "warrior gene" based on experiments conducted using 5R and 6R carrier Rhesus macaque monkeys [12].

The MAOA gene was initially introduced by Dr. Han Brunner in a Dutch family with a history of impulsive aggression in 1993 [13]. In their line of work, they discovered that several male family members were exhibiting "borderline mental retardation and a tendency toward aggressive outbursts." Still, it was not displayed in the female members of that family [13]. Some molecular genetic studies also reiterated the role played by the MAOA gene in various psychopathologies in both adults and children, including antisocial & psychiatric spectral behavior disorders and autism spectrum disorder [14]. The MAOA-L carriers of the MAOA-uVNTR polymorphism have been studied more frequently to be associated with a broad spectrum of antisocial behavioral traits that exhibit higher levels of aggression with violent and delinquent behavior patterns. The MAOA gene's involvement in the degradation of dopamine and serotonin may explain why it has a more significant influence on aggressive behavior than other genes [15]. Reduced MAOA expression, associated with elevated serotonin levels, could influence the brain activity responsible for different societal analyses, evaluations, and emotion regulation, especially during the early stages of neurodevelopment [16]. However, some studies have also presented controversial results [17-20], which could be attributed to true negative associations, small sample sizes, or genetic heterogeneity [16].

This narrative review mainly focuses on the MAOA-uVNTR polymorphism and its influence on antisocial spectral behaviors such as aggression, violence, delinquency, and other behaviors for a better understanding of the genetic mechanism involving MAOA. Further, this review highlights the ethical, legal, and social considerations involved in genetic investigations of psychiatric spectrum disorders. This review is anticipated to unveil MAOA-L as one of the well-supported biological risk factors for aggressive human behavioral traits.

2. MONOAMINE OXIDASE A (MAOA) GENE: THE WORRIER GENE

2.1 MONOAMINE OXIDASES

Monoamine Oxidases are a group of mitochondrial enzymes that catalyze and deaminate several biological amines such as dopamine, norepinephrine, and serotonin [21]. There are two enzymes, MAOA and MAOB, encoded by the MAOA and MAOB genes, respectively, which are present in astrocytes, neurons, and outside of the central nervous system. Their drastic loss of function and the reduction in the enzyme activity and expression of the MAOA were discovered to be altering brain neurotransmitter metabolism [21].

The prominent role of MAOA has been studied, which is to degrade serotonin following its re-uptake by the serotonin transporter from the synaptic cleft. However, it is also capable of degrading both the neurotransmitters norepinephrine and dopamine. Therefore, it plays a very crucial role in the regulation of neurotransmitter activities taking place within the synaptic clefts. Furthermore, the alterations in the MAOA enzyme activity implicated by possession of specific low or high-activity genetic variants and different pharmacological interventions were profoundly causing effects on the behavioral changes under the influence of MAOA inhibitors during the treatment of behavioral disorders, including major depressive disorder [21].

2.2 MAOA GENE AND ITS LOCATION

The MAOA gene and its paralog MAOB gene, which encodes the two MAOA and MAOB isoenzymes, are mapped to the 11.23-11.4 of the short arm of the X chromosome in a tail-to-tail orientation with a 3' coding sequences separated by approximately 50,000bp [7]. Therefore, the conclusion drawn by Dr. Brunner and his team was the possession of an X-linked MAOA genetic mutation within the family members. The specific genetic mutation was found to be a non-conservative C > T substitution in the eighth exon, causing a malfunction due to creating a stop codon instead of a glutamine [7].

As the MAOA gene is X-linked, the MAOA low activity allele male carriers were observed to be MAOA knockouts, where it was observed that the same female carriers maintained a precise optimal level of MAOA enzyme activity where the difference was lied in the number of X chromosomes possessed by the individual [22]. As males have only one copy of the X chromosome, they tend to show the mutated allelic variant affecting the reduced expression of the MAOA gene [22]. Therefore, males show a homozygous state while females show both homozygous and heterozygous statuses as they possess X chromosomes [23]. Hence, the role played by the MAOA gene in its expression could be more unpredictable for females than males [24,25]. MAOA gene expression is more likely affected by testosterone, the sex hormone in males [26,27]. Therefore, there is a higher tendency in males than females to show lower levels of MAOA enzyme activity, thus leading to more aggressive and violent behavioral patterns [27,28].

2.3 MAOA GENE POLYMORPHISM TYPES

MAOA gene polymorphisms broadly divide into tandem repeats and Single Nucleotide Polymorphism (SNP) [14].

2.3.1 TANDEM REPEATS

The MAOA gene exhibits a series of mini-satellite genetic variations that have been studied to be responsible for a broad range of altered behavioral impacts. There are two variable number tandem repeats (VNTRs) in the MAOA gene within its promoter region: upstream variable number tandem repeat and distal variable number tandem repeat [14]. The locus of the upstream variable number tandem repeat (uVNTR) is about 1000 bp ahead of the gene transcription origin site, while the locus of the distal variable number tandem repeat (dVNTR) is approximately 700bp upstream from the uVNTR and about 1700bp upstream from the transcriptional origin site. Studies such as [29,30] have demonstrated a strong linkage disequilibrium between these two polymorphisms, indicating a synergistic effect of the two VNTRs in regulating the MAOA gene transcriptional activity [14].

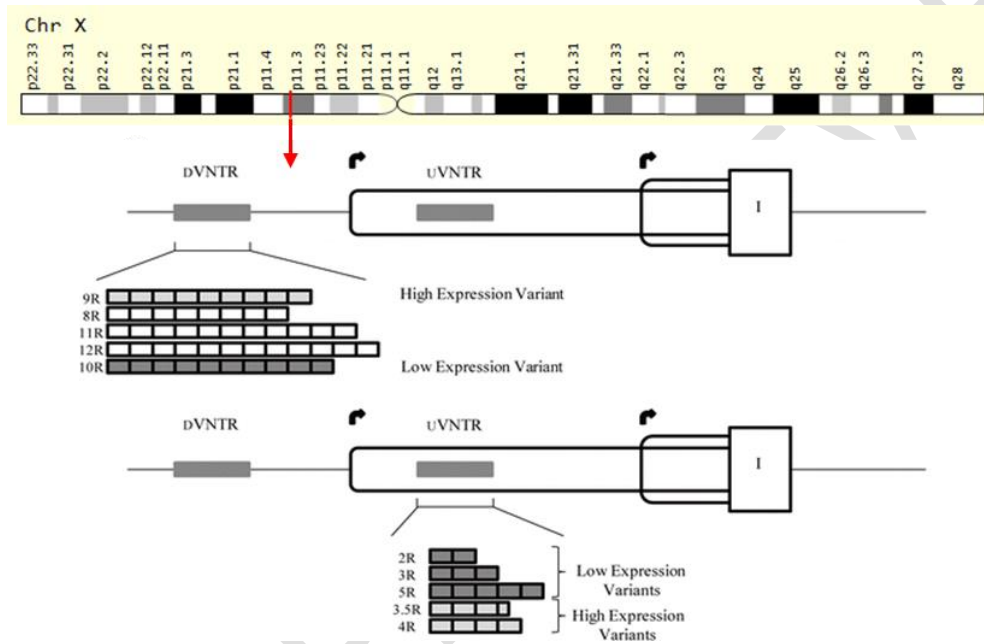


Fig.1. The location of the MAOA gene and the MAOA-uVNTR repeat sequence (Source: Manca et al., 2018).

a) MAOA u-VNTR (Monoamine Oxidase A upstream-Variable Number Tandem Repeats)

As initially described in the study by Sabol et al., 1998 [8], the promoter uVNTR is characterized by a repetitive sequence of 30 base pairs, which is the most well-known MAOA gene variation positioned in the promoter region, roughly about 1142 to 1262 bp [31]. A series of MAOA allelic variants have been identified, comprising 2R, 3R, 3.5R, 4R, 5R, and 6R of the 30 bp repeat sequence [8,10,11,14], as depicted in Figure 1. However, a very rare 1R allelic variant was also reported by Al-Tayie and Ali in 2018 [32] within an Iraqi population, and a 6R allelic variant in a Taiwanese population was identified in a study conducted by Lu and his colleagues in 2002 [33].

The 30-bp repeat sequence (ACC GGC ACC GGC ACC AGT ACC CGC ACC AGT) comprised of five repetitions of a motif of six nucleotides, ACC GCC [8,34], where each of the sequences is precisely followed by a motif of 15bp (ACC GGC ACC GGC ACC) but was not included in the initial phase of the genetic allele nomenclature [14]. In a handful of research

studies, the 4R allelic variant has occasionally been referred to as 4.5R [35,36]. The risk allele of the MAOA-uVNTR, which is the low-activity allelic variant, is linked with antisocial spectral behaviors, violence, and psychiatric disorders, especially in males, as the single copy does not produce the MAOA enzyme effectively [37-39].

b) MAOA-dVNTR (Monoamine Oxidase A distal-Variable Number Tandem Repeats)

In addition to the upstream VNTR polymorphism, another VNTR located further upstream, known as the distal VNTR, has been singled out at around 500bp preceding the upstream VNTR. This distal VNTR polymorphism consists of two varieties of oligonucleotides of size 10bp, which are decamer motifs, namely, decamer A (CCC CTC CCC G) and decamer B (CTC CTC CCC G) [29]. Five major dVNTR variants have been characterized as 8R, 9R, 10R, 11R, and 12R sequences [29]. Among these variants, the most common and prevalent ones are the 9R and 10R allelic variants, whereas the latter exhibit a low expression of transcription [14].

It has been studied to be a linkage disequilibrium between these two upstream and distal VNTR loci, which has caused some haplotypes to be more abundant. As an example, the 4R sequence of the uVNTR is often found together with the 9R sequence of the dVNTR, and the 3R sequence of the uVNTR has been abundantly associated with 9R, 10R or 11R sequences of the dVNTR [30]. This study also has demonstrated that the deletion of dVNTR could have a more pronounced impact on the reduction of MAOA mRNA levels than that of uVNTR [14].

c) Intron 1 polymorphism

Another variable number tandem repeat polymorphism has been identified within the MAOA gene on its intron 1, which is known to be comprised of different repetitions of the 23 bp motif (GAA CTG TGT TTA TAT ATA TAT AT) resulting in a variety of variants as 6R, 7R, 8R, 9R and 10R [14]. Hinds and co-workers 1992 [40] showed that the most common alleles were 7 or 8 copies at an abundance percentage of 33.5 % and 63.1%, respectively. Hence, understanding how the interaction between these polymorphisms regulates MAOA expression remains a critical research goal for enhancing our understanding of MAOA's transcriptional regulation.

2.3.2 SINGLE NUCLEOTIDE POLYMORPHISM (SNP)

Approximately about twenty SNPs (Single Nucleotide Polymorphisms) within the MAOA gene are known to be identified and studied for their functional characteristics. Data from the dbSNP repository indicate the presence of 14,922 distinct polymorphisms (excluding alternative nomenclatures for the same polymorphism) associated with MAOA. Only a few SNPs have been associated with discernible functional effects. Notably, rs6323 and rs1137070 are the two primary SNPs that have been identified thus far to be characterized as compatible polymorphisms distinguishable by the activity of specific restriction endonucleases (FnuHI for rs6323 and EcoRV for rs1137070) [14]. It has been studied that the variant with Guanine of rs6323 encodes for the MAOA enzyme with higher enzyme activity than the enzymatic activity shown by the variant with Thymine in the rs6323 polymorphism. The variant with Thymine of rs1137070 exhibits higher enzyme activity than the Cytosine variant [14].

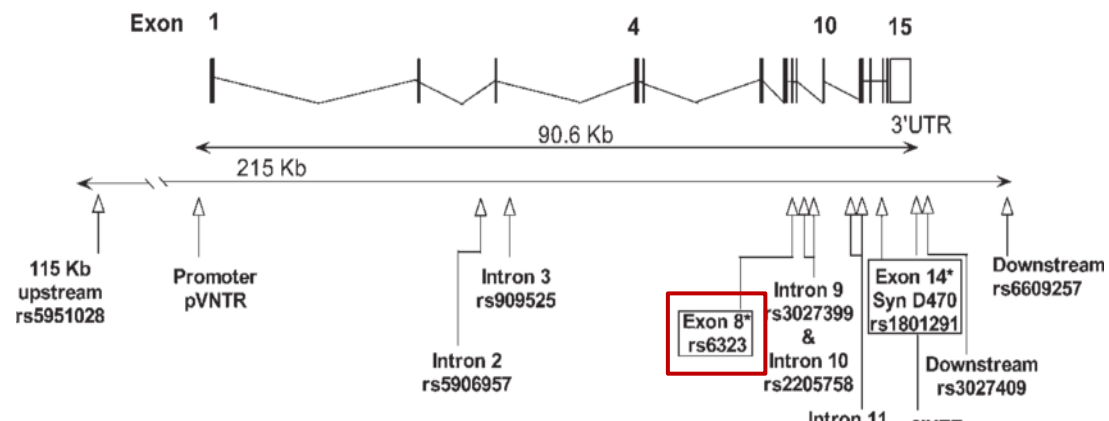


Fig.2.The MAOA-SNP, rs6323 (Source: Pinsonneault et al., 2006).

The TG and GG genotypes in this polymorphism correspond to elevated MAOA enzyme activity. At the same time, some studies have revealed associations between the MAOA T941G polymorphism and different behavioral patterns, including borderline personality disorder [41], responses to placebos in individuals with major depression [42], and violent behaviors observed in incarcerated individuals [43].

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3. MAOA LOW ALLELIC VARIANTS AND THE INFLUENCE ON AGGRESSIVE AND VIOLENT BEHAVIORS

Genes have been studied profoundly to explore their underlying mechanisms resulting in violent behavioral patterns. The influences of these genetic factors are carried out through the alterations in the neurotransmitter systems, brain functions, and the regulation of emotions and impulses in a human being [44]. The genes that regulate serotonergic neurotransmission have been highlighted for the genetic predisposition to violence. To be precise, genes such as MAOA (Monoamine Oxidase A), DAT-1 (Dopamine Transporter-1 gene), DRD2 (Dopamine Receptor D2 gene), and DRD4 (Dopamine Receptor D4 gene) have been widely studied to understand the genetic foundation of human violent behavior [45] where MAOA gene has acquired immense attention.

The study by Beaver et al. (2011) [46], which was conducted using 493 participants from the Add Health Study, reported that the MAOA-L allele is associated with elevated levels of anger and hostility, particularly in adverse environments. The study by Cohen et al. (2011) [47] was conducted using a total of 298 male subjects and their parents who were recruited by the Autism Spectrum Disorders Canadian American Research Consortium revealed that the autistic MAOA-L (3R) male carriers exhibited severe sensory behaviors and high aggression. In addition to that, they further demonstrated autistic MAOA-H (4R) male carriers who had 4R homozygous mothers exhibited higher aggression than those with heterozygous mothers.

Simons et al. (2012) [48] is another study that was carried out by recruiting 224 African-American children from the Family and Community Health Study (FACHS). The results showed that the MAOA-L carriers with adverse social environments showed increased aggression levels. The study McDermott et al. (2012) [49] recruited participants from the

National Longitudinal Study of Adolescent to Adult Health (Add Health) and 540 twin pairs from the Virginia Twin Study of Adolescent Behavioral Development (VTSABD) and reported that male carriers of the MAOA-L allele who experienced traumatic early life events were more likely to engage in aggressive behavior during adulthood. Similarly, the study Vehroeven et al. (2012) [50] conducted on 432 Western European students found that MAOA-H females exhibited higher aggression reactivity scores than MAOA-L females carriers. However, this effect wasn't observed in men due to their smaller sample size.

Additionally, the study by Gallardo-Pujol et al. (2013) [51], which was carried out using 57 male college students at the University of Barcelona (Caucasian males with Catalan or Spanish origin), revealed that male MAOA-L carriers scored more than twice as high on measures of aggression compared to male MAOA-H carriers. Hill et al. (2013) [52] conducted a study on 209 infants and found that MAOA-L infants displayed significantly more fussiness and crying behaviors than MAOA-H carriers when raised in deprived environments. The Kuepper et al. (2013) [53] study conducted by recruiting 239 young adults from the University of Giessen with Caucasian ethnicity showed that MAOA-L carriers exhibited increased aggressive reactions.

In addition, the study by El-Din et al. (2014) [54], which was carried out using 150 Egyptian participants (50 controls, 50 offenders, and 50 psychiatric patients), found that psychiatric patients with the 5R MAOA-L allele were at a higher risk of developing aggression. In contrast, the study by Kolla et al. (2014) [20], which was conducted by recruiting 18 violent offenders and 13 non-offenders (Caucasian and Black), reported an association between MAOA-H and proactive aggression. The study by Denson et al. (2014) [55] recruited 38 male undergraduates and presented results showing that the heightened dACC and amygdala activation underlying anger control was observed in MAOA-L carriers. The study by Gorodetsky et al. (2014) [56] observed that within the sample group of 692 Caucasian Italian male prisoners without any physical neglect experiences, MAOA-H carriers exhibited higher levels of aggression. However, a crossover effect was noted, indicating that the elevated aggression scores with physical neglect were more outstanding in MAOA-L carriers than those with the high-activity genotype. The results produced by Lei et al. (2014) [57] demonstrated that lower spontaneous brain activity in the pons of MAOA-L carriers may serve as a neural mechanism underlying impulsivity and aggression, posing a risk factor for these behaviors within a cohort of 60 Han Chinese male adolescents.

The research conducted by Rehan et al. (2015) [58], which was conducted by recruiting 1447 male and 2179 female Finnish twins and their siblings, found no significant interaction between MAOA polymorphism and childhood abuse experiences regarding physical or verbal aggressive behavior in men. However, they observed that the 4R allele of MAOA was associated with physical aggressive behavior in women, and emotionally abused women with the 3R allele of MAOA showed increased aggressive behavior. The study by Holz et al. (2016) [59] showed that MAOA-L male and MAOA-H female carriers exhibited an association between amygdala activity and reactive aggression within a cohort of 125 participants. Similar findings were put forward by the study by Zhang et al. (2016) [60], which was conducted by recruiting 507 healthy Han Chinese male adolescents, revealing that there is a high tendency towards aggression in physically or emotionally abused MAOA-L boys. The study by Zhang et al. (2017) [61] observed within a cohort of 546 healthy Han Chinese male adolescents that there is a high tendency towards aggression in sexually abused MAOA-H and 5-HTTLPR "SS" carriers.

Furthermore, the study Wessels, 2020 [62] conducted on 1036 participants demonstrated that the MAOA-L allele was a predictor of internalizing behavior in both males and females and externalizing behavior only in males. The results produced by Sarwar et al. (2021) [63] within a sample group of 482 Pakistani participants found that the presence of the 3.5R allele in

males and the 4R allele in females of the MAOA-uVNTR polymorphism were significantly linked to aggression. Numerous studies support the notion that antisocial behaviors can escalate from aggression to violence and criminal acts. This escalation is a multifaceted phenomenon influenced by various factors, including biological, psychological, social, and environmental elements.

Table 1. Studies conducted on MAOA-uVNTR polymorphisms and aggressive behavior

Reference	Gene Variant in interest	Environmental Variable	Target Group	Outcome
Beaver et al., 2011	MAOA-uVNTR polymorphism: MAOA-L variant	Aggression and Hostility	493 participants from the Add Health Study	MAOA-L male carriers, compared to MAOA-H male carriers, exhibited high scores on anger and hostility when exposed to risk factors.
Cohen et al., 2011	MAOA uVNTR polymorphism: Both MAOA-L and MAOA-H variants	Autism and Aggression	A total of 298 male subjects and their parents	Autistic MAOA-L (3R) male carriers exhibited severe sensory behaviors and high aggression. Autistic MAOA-H (4R) male carriers who had 4R homozygous mothers showed higher aggression than ones with heterozygous mothers.
Simons et al., 2012	MAOA-uVNTR polymorphism: MAOA-L variant	Aggression	224 African-American children	The MAOA-L carriers with adverse social environments showed increased aggression levels.
McDermott et al., 2012	MAOA-uVNTR polymorphism: MAOA-H variant	Aggression	Participants from the National Longitudinal Study of Adolescent to Adult Health (Add Health) and 540 twin pairs from the Virginia Twin Study of Adolescent Behavioral Development (VTSABD) participants.	The traumatized MAOA-L male carriers had an increased likelihood of participating in aggressive behavior as adults.
Verhoeven et al., 2012	MAOA-uVNTR polymorphism: Both MAOA-L and MAOA-H	Aggressive Behavior	432 western European students	Females with the MAOA-H allele exhibited elevated scores in aggression reactivity compared to those with the MAOA-L allele but not males.

Gallardo-Pujol et al., 2013	MAOA-uVNTR polymorphism: Both MAOA-L and MAOA-H	Aggression	57 male college students	MAOA-L carriers exhibited higher aggression than MAOA-H carriers.
Hill et al., 2013	MAOA-uVNTR polymorphism: Both MAOA-L and MAOA-H	Aggression and Irritability	209 infants	MAOA-L infants were strongly associated with negative emotionality than MAOA-H carriers as an early risk for the development of antisocial behavior disorders during later stages of life.
Kuepper et al., 2013	MAOA-uVNTR polymorphism: MAOA-L variant	Aggression	239 Caucasian young adults	MAOA-L carriers exhibited increased aggressive reactions.
El-Din et al., 2014	MAOA-uVNTR polymorphism: Both MAOA-L and MAOA-H variants	Aggression	150 Egyptian participants	Psychiatric patients with the 5R MAOA-L allele are at a higher risk of developing aggression.
Kolla et al., 2014	MAOA-uVNTR polymorphism: MAOA-H variants	Aggression	18 violent offenders and 13 non-offenders	MAOA-H carriers showed high proactive aggression traits.
Denson et al., 2014	MAOA-uVNTR polymorphism: Both MAOA-L and MAOA-H variants	Aggression	38 male undergraduates	The heightened dACC and amygdala activation underlying anger control was seen in MAOA-L carriers.
Gorodetsky et al., 2014	MAOA-uVNTR polymorphism: MAOA-L variant	Aggression	692 Caucasian Italian male prisoners	Non-neglected MAOA-H carriers and physically neglected MAOA-L carriers showed high aggression scores.
Lei et al., 2014	MAOA-uVNTR polymorphism: MAOA-L variant	Aggression and Impulsivity	60 Han Chinese male adolescents	MAOA-L with lower spontaneous brain activity in the pons showed a risk for impulsivity and aggression.
Rehan et al., 2015	MAOA-uVNTR polymorphism: Both MAOA-L and MAOA-H	Aggressive Behavior	1447 male and 2179 female Finnish twins and their siblings.	MAOA-H and emotionally abused MAOA-L showed high physical aggressive and aggressive behavioral traits, respectively.
Holz et al., 2016	MAOA-uVNTR polymorphism: Both MAOA-L and MAOA-H variants	Aggression	125 participants	MAOA-L male and MAOA-H female carriers exhibited an association between amygdala activity and reactive aggression.
Zhang et al., 2016	MAOA-uVNTR polymorphism: MAOA-L variant	Aggression	507 healthy Han Chinese male adolescents	A high tendency towards aggression was shown by physically or emotionally abused MAOA-L boys.

Zhang et al., 2017	MAOA-uVNTR polymorphism: MAOA-H variant	Aggression	546 healthy Han Chinese male adolescents	A high tendency towards aggression was shown by sexually abused MAOA-H and 5-HTTLPR "SS" carriers.
Wessels, 2020	MAOA-uVNTR polymorphism: MAOA-L variant	Externalizing Behavior	1036 participants	The MAOA-L allele was a predictor of internalizing behavior in males and females and externalizing behavior only in males.
Sarwar et al., 2021	MAOA uVNTR polymorphism: Both MAOA-L and MAOA-H variants	Aggression	482 Pakistani participants	MAOA-H (3.5R male and 4R) female carriers displayed high aggression traits.

The study by Tikkanen et al. (2010) [17] observed within a study population of 174 Finnish male alcoholic offenders that the MAOA-H carriers with childhood abuse and alcohol consumption are at high risk for severe recidivistic impulsive violent crimes. The study by Beaver et al. (2010) [64] recruited 2196 participants from the Add Health study and reported that the MAOA-L male carriers tend to be gang members, and once they become gang members, they tend to use weapons in fights. The study by Watts and McNulty (2014) [65], which was carried out by recruiting 3610 adolescent males from the National Longitudinal Study of Adolescent Health, showed that the participants with the 2R or 3R alleles of MAOA (MAOA-L) and the 10R/10R allele of DAT1 are more inclined to participate in increased criminal behaviors when they encounter strained parent-child relationships. Several studies, including those by Stetler et al. (2014) [10] with a study population of 89 male prisoners (49 violent and 40 non-violent male Caucasian and African-American convicts) and Armstrong et al. (2014) [38] with a study population consisting of 99 male prisoners (59% were African American, 25% Hispanic, 12% White, and 4% reported their race as 'Other'), all support the same notion that the low allelic variants of the MAOA-uVNTR polymorphism, specifically the 2R and 3R variants, are strongly associated with criminal violent behavior. The study by Beaver et al. (2013) [66] analyzed data on 2574 samples of males drawn from the National Longitudinal Study of Adolescent Health and discovered that African-American males with the 2R variant (MAOA-L) are more prone to be involved in shooting and stabbing incidents. Similarly, the systemic review by Hernandez et al. (2015) [67] reported findings consistent with previous studies, indicating that individuals with the MAOA-L variant allele were more predisposed to criminal violence compared to those with the MAOA-H gene.

Moreover, the studies by Tiihonen et al. (2015) [68] with a study population of 794 Finnish prisoners and 114 members of a cohort of homicide offenders and the review by Kolla & Bortalato (2020) [14] underscored a strong correlation between MAOA-L carriers and violent offenders, drawing from substantial sample sizes. The study by Wells et al. (2017) [69] with a study population of 267 university students and 1294 participant data from the Add Health study elaborated that proximal life stress contributes to a rise in criminal activity and delinquent behavior among MAOA-L carriers, especially those who have also endured distal stress. The study by Kolla et al. (2017) [70], which was carried out by recruiting 38 participants (18 violent offenders and 20 controls), elucidated that the Antisocial Personality Disorder (ASPD) MAOA-L violent offenders with psychopathic traits exhibit decreased surface area in the right basolateral amygdala nucleus. Similarly, findings from studies by Prasad et al. (2020) [7] with a study cohort of 67 Indian male inmates and the review by Jarrette et al. (2023) [71] emphasized the predominant presence of the MAOA-uVNTR polymorphism in instances of criminal violence. In evident to all above, these findings collectively solidify the extensive involvement of the MAOA-uVNTR polymorphism in antisocial behavior and the broader

spectrum of antisocial tendencies, which encompasses a range of behaviors from impulsivity and aggression to conduct disorder and criminal behavior. On the contrary, the study by Lu et al. (2016) [72] conducted by recruiting 569 American male adolescents revealed that the MAOA high-risk allele (MAOA-L allelic variant) could mitigate the influence that interaction with delinquent peers exerts on the progression of adult criminal conduct.

Table 2. Studies conducted on MAOA-uVNTR polymorphisms and violent and criminal violent behavior

Reference	Gene Variant in interest	Environmental Variable	Target Group	Outcome
Tikkanen et al., 2010	MAOA-uVNTR polymorphism; MAOA-H variant	Violent Recidivism	174 Finnish male alcoholic offenders	MAOA-H carriers with childhood abuse and alcohol consumption are at high risk for severe recidivistic, impulsive, violent crimes.
Beaver et al., 2010	MAOA-uVNTR polymorphism: MAOA-L variant	Weapon Use	2196 participants from Add Health.	MAOA-L male carriers tend to be gang members, and such members use weapons in fights.
Beaver et al., 2013	MAOA-uVNTR polymorphism: Both MAOA-L and MAOA-H	Shooting and stabbing behaviors	The 2574 samples of males were drawn from the National Longitudinal Study of Adolescent Health.	African-American males with the 2R variant (MAOA-L) are more prone to be involved in shooting and stabbing incidents.
Watts and McNulty, 2014	MAOA-uVNTR polymorphism: MAOA-L DAT-1 polymorphism	Criminal Violence	3610 adolescent males from the National Longitudinal Study of Adolescent Health.	Individuals with the 2R or 3R alleles of MAOA (MAOA-L) and the 10R/10R allele of DAT1 are more inclined to participate in increased criminal behaviors when encountering strained parent-child relationships.
Stetler et al., 2014	MAOA-uVNTR polymorphism: MAOA-L variant	Criminal Violence	89 male prisoners	An association was observed between MAOA-L allelic variants and the commission of violent crimes.

Armstrong et al., 2014	MAOA-uVNTR polymorphism: MAOA-L variant	Criminal Violence	99 male prisoners (59% were African American, 25% Hispanic, 12% White, and 4% reported their race as 'Other')	The abused MAOA-L carriers showed severe criminal activity.
Tiihonen et al., 2015	MAOA-uVNTR polymorphism: Both MAOA-L and MAOA-H	Violence, Impulsivity, and Psychopathy	794 Finnish prisoners and 114 members of a cohort of homicide offenders.	The MAOA-L carriers exhibited violent offending acts among members of the discovery cohort.
Hernandez et al., 2015	MAOA-uVNTR polymorphism: Both MAOA-L and MAOA-H	Criminal Violence	A systemic review	MAOA-L carriers are more prone to criminal violence than MAOA-H carriers.
Lu et al., 2016	MAOA-uVNTR polymorphism: MAOA-L variant	Criminal Behavior	569 American male adolescents	The MAOA high-risk allele could mitigate the influence that interaction with delinquent peers exerts on the progression of adult criminal conduct.
Wells et al., 2017	MAOA-uVNTR polymorphism: MAOA-L variant	Criminal Violence	267 university students and 1294 participants data from the Add Health study.	Proximal life stress contributes to a rise in criminal activity and delinquent behavior among MAOA-L carriers, especially those who have also endured distal stress.
Kolla et al., 2017	MAOA-uVNTR polymorphism: MAOA-L variant	Criminal Violent Behavior	38 participants (18 violent offenders and 20 controls)	ASPD MAOA-L violent offenders with psychopathic traits exhibit decreased surface area in the right basolateral amygdala nucleus.

Kolla & Bortalato, 2020	MAOA-uVNTR polymorphism: MAOA-L variant	Aggression, ASB, and Violence	A systemic Review	The progression from abuse to dependence, as well as involvement in violent behavior, was observed in MAOA-L carriers.
Prasad et al., 2020	MAOA uVNTR polymorphism: MAOA-H variant	Criminal Violence	67 Indian male inmates	3.5 R allele carriers (MAOA-H) exhibited an association in contributing aggression and violence in recidivist violent offenders.
Jarrett et al., 2023	MAOA uVNTR polymorphism	Criminal Violence	A systemic review	MAOA-uVNTR polymorphism is a prominent genetic determinant for criminal violence.

4. LEGAL AND ETHICAL CONSIDERATIONS OF BEHAVIOURAL GENETICS

Based on these research findings, the legal systems in many countries, particularly those with trial by jury, have considered the criminal liability and the weight given to evidence suggesting the impact of genetic influences on behavior. Countries like the United States of America, United Kingdom, Canada, and The Netherlands have already shown an upward trend in using genetic findings in criminal cases where only a meager number of experts have introduced evidence of an accused's unique genetic risk in relation to their crime, most commonly a low expression of the MAOA gene (possession of MAOA-L allelic variants), which has been linked to aggressive and antisocial behavior leading to criminal violence [73]. Therefore, in both the USA and Europe, criminal cases involving MAOA low activity have been introduced in criminal trials as standalone evidence or combined with socio-environmental factors. From 1995 up to 2016, the evidence of the MAOA-L genotype has been included in 11 criminal cases, where nine were in U.S. and the rest were in Italy [73].

Table 3. Legal Proceedings with Evidence of MAOA-L Genotype from 1995 to March 1, 2016

Case (Year) Court	Country	Presence of MAOA-L	Reason for Test	Outcome
Mobley (1995)	U.S.	N/A	Murder	No sentencing reduction; death penalty
Bayout (2009)	Italy	+	Murder	Appeal upheld; 9 years reduced to 8 years.

Waldroup (2011)	U.S.	+	Murder Attempted Murder	Charge reduction: first-degree murder reduced to voluntary manslaughter
Albertani (2011)	Italy	+	Murder Attempted Murder (2)	Appeal upheld; life reduced to 20 years
Bourassa (2012)	U.S.	+	Murder	Sentenced to life; spared death penalty
Adams (2014)	U.S.	+	Murder (3) Attempted Murder	No sentencing reduction; death penalty
Duran (2014)	U.S.	N/A	Attempted Murder	Appeal dismissed; 15 years
Driskill (2015)	U.S.	+	Murder (2)	No sentencing reduction; death penalty
Colbert (2015)	U.S.	+	Murder	No sentencing reduction; life sentence
Yepez (2015)	U.S.	+	Murder	Evidence inadmissible; second-degree murder
Bathgate (2016)	U.S.	N/A	Murder	Habeus corpus dismissed; evidence procedurally defaulted

Note. + = MAOA-L genotype carrier
N/A – Not Applicable

Therefore, the first instance of such a case where a genetic defense was permitted to mitigate a sentence for a convicted criminal occurred in Italy. In this particular case, Abdelmalek Bayout, an Algerian citizen residing in Italy, confessed to the killing of Walter Perez, a Colombian. Bayout's sentence was reduced by one year on appeal after it was revealed that he had low MAOA enzyme levels [73,74]. As mentioned earlier, many research has indicated that individuals with the MAOA-L genotype, particularly when coupled with childhood maltreatment, have an increased likelihood of engaging in criminal activities [73,75-79].

Related to ethical issues that arise during the discussion of these genetic findings in criminal courts can be emphasized as follows. Some of the prominent issues at hand are how reliable and valid the genetic evidence is, how often these genetic findings will be used as an excuse for criminal behavior or reducing individual responsibility, and the potential of misusing genetic information for strategic and manipulative purposes to support a specific narrative.

5. CONCLUSION

The MAOA gene, even referred to as the "warrior gene," has been the subject of extensive research due to its significant association with aggressive, violent, and criminal behavior, especially with its low activity variants. The studies have demonstrated a correlation between the presence of the MAOA-L variants and an increased propensity towards aggressive and

violent behavior, particularly when coupled with environmental factors such as adverse childhood experiences, childhood maltreatment, and trauma. Therefore, it emphasizes the criticality of acknowledging the complexity of human behavior shaped by the collective impact of the interplay of genetic, environmental, and social influences.

The MAOA-L genetic variants tend to have lower levels of MAOA enzyme activity, leading to higher concentrations of these neurotransmitters such as serotonin, dopamine, and norepinephrine. As these neurotransmitters play pivotal roles in mood and behavior regulation, the fluctuations from the optimal level of the neurotransmitters have been studied to contribute to aggressive and violent tendencies. Research highlights the importance of considering gene-environment interactions when evaluating the impact of MAOA-L variants on human behavior, as MAOA low allelic variants are not solely the determinant of these behavioral changes. Therefore, developing effective preventative and intervention plans requires a comprehensive strategy incorporating genetic data and environmental and psychological aspects. Socioeconomic stress, traumatic childhood events, and other environmental factors can intensify the behavioral characteristics linked to the MAOA-L genetic variants, which can be lessened by encouraging surroundings and constructive social interventions, highlighting the possibility of changing behavior through therapeutic and environmental approaches.

Moreover, incorporating information on the MAOA-L genetic variants and the consequences of trauma to legal interventions provides strategies to develop more humane and successful crime prevention tactics. The criminal justice system can more effectively rehabilitate offenders and safeguard communities by concentrating on the underlying causes of criminal conduct and offering tailored help. Future research works are recommended to explore the multifaceted interactions between genetics, environment, and behavior to foster a more comprehensive understanding of the factors contributing to aggression and violence to mitigate their escalations.

REFERENCES

1. Plomin R, DeFries JC, Knopik VS, Neiderhiser JM. Top 10 Replicated Findings from Behavioral Genetics. *Perspectives on psychological science: A journal of the Association for Psychological Science*. 2016;11(1):3–23. <https://doi.org/10.1177/1745691615617439>
2. Taylor SE, Way BM, Seeman TE. Early adversity and adult health outcomes. *Development and Psychopathology*. 2011;23(3):939–954. <https://doi.org/10.1017/S0954579411000411>
3. Viding E, McCrory E, Baskin-Sommers A, De Brito S, Frick P. An 'embedded brain' approach to understanding antisocial behavior. *Trends in Cognitive Sciences*. 2024;28(2):159–171. <https://doi.org/10.1016/j.tics.2023.08.013>
4. Yeung AWK, Georgieva M, Atanasov AG, Tzvetkov N. Monoamine Oxidases (MAOs) as Privileged Molecular Targets in Neuroscience: Research Literature Analysis. *Frontiers in Molecular Neuroscience*. 2019;12. <https://doi.org/10.3389/fnmol.2019.00143>
5. Setini A, Pierucci F, Senatori O, Nicotra A. Molecular characterization of monoamine oxidase in zebrafish (*Danio rerio*). *Comparative Biochemistry and Physiology B*. 2005;140(1):153–161. <https://doi.org/10.1016/j.cbpc.2004.10.002>

6. Guo G, Ou X, Roettger ME, Shih JC. The VNTR 2 repeat in MAOA and delinquent behavior in adolescence and young adulthood: associations and MAOA promoter activity. *European Journal of Human Genetics*. 2008;16(5):626–634. <https://doi.org/10.1038/sj.ejhg.5201999>
7. Prasad MS, Vardhanan YS, Prabha SPS, Joseph JK, Aneesh EM. MAOA-uVNTR polymorphism in male recidivist violent offenders in the Indian population. *Archiwum Medycyny Sądowej i Kryminologii*. 2020;70(4):242–250. <https://doi.org/10.5114/amsik.2020.104863>
8. Sabol SZ, Hu S, Hamer DH. A functional polymorphism in the monoamine oxidase A gene promoter. *Human Genetics*. 1998;103(3):273–279. <https://doi.org/10.1007/s004390050816>
9. Kolla NJ, Malcolm C, Attard S, Arenovich T, Blackwood N, Hodgins S. Childhood Maltreatment and Aggressive Behavior in Violent Offenders with Psychopathy. *The Canadian Journal of Psychiatry*. 2013;58(8):487–494. <https://doi.org/10.1177/070674371305800808>
10. Stetler DA, Davis C, Leavitt K, Schriger I, Benson K, Bhakta S et al. Association of low-activity MAOA allelic variants with violent crime in incarcerated offenders. *Journal of Psychiatric Research*. 2014;58:69–75. <https://doi.org/10.1016/j.jpsychires.2014.07.006>
11. Ouellet-Morin I, Côté SM, Vitaro F, Hébert M, Carbonneau R, Lacourse E et al. Effects of the MAOA gene and levels of exposure to violence on antisocial outcomes. *British Journal of Psychiatry*. 2016;208(1):42–48. <https://doi.org/10.1192/bjp.bp.114.162081>
12. Gibbons A. AMERICAN ASSOCIATION OF PHYSICAL ANTHROPOLOGISTS MEETING: Tracking the Evolutionary History of a "Warrior" Gene. *Science*. 2004;304(5672):818a. <https://doi.org/10.1126/science.304.5672.818a>
13. Brunner HR, Nelen MR, Breakefield XO, Ropers H, Van Oost B. Abnormal Behavior Associated with a Point Mutation in the Structural Gene for Monoamine Oxidase A. *Science*. 1993;262(5133):578–580. <https://doi.org/10.1126/science.8211186>
14. Kolla NJ, Bortolato M. The role of monoamine oxidase A in the neurobiology of aggressive, antisocial, and violent behavior: A tale of mice and men. *Progress in Neurobiology*. 2020;194:101875. <https://doi.org/10.1016/j.pneurobio.2020.101875>
15. Waltes R, Chiocchetti AG, Freitag CM. The neurobiological basis of human aggression: A review on genetic and epigenetic mechanisms. *American Journal of Medical Genetics Part B Neuropsychiatric Genetics*. 2015;171(5):650–675. <https://doi.org/10.1002/ajmg.b.32388>
16. Fowler T, Langley K, Rice F, Van Den Bree MB, Ross K, Wilkinson LS et al. Psychopathy trait scores in adolescents with childhood ADHD: the contribution of genotypes affecting MAOA, 5HTT, and COMT activity. *Psychiatric Genetics*. 2009;19(6):312–319. <https://doi.org/10.1097/ypg.0b013e3283328df4>
17. Tikkanen R, Auvinen-Lintunen L, Ducci F, Sjöberg RL, Goldman D, Tiihonen J et al. Psychopathy, PCL-R, and MAOA genotype as predictors of violent reconvictions.

Psychiatry Research. 2011;185(3):382–386.
<https://doi.org/10.1016/j.psychres.2010.08.026>

18. Lee SS. Deviant Peer Affiliation and Antisocial Behavior: Interaction with Monoamine Oxidase A (MAOA) Genotype. *Journal of Abnormal Child Psychology*. 2010;39(3):321–332. <https://doi.org/10.1007/s10802-010-9474-2>
19. Pardini M, Krueger F, Hodgkinson CA, Raymont V, Ferrier C, Goldman D et al. Prefrontal cortex lesions and MAO-A modulate aggression in penetrating traumatic brain injury. *Neurology*. 2011;76(12):1038–1045. <https://doi.org/10.1212/wnl.0b013e318211c33e>
20. Kolla NJ, Attard S, Craig G, Blackwood N, Hodgins S. Monoamine oxidase A alleles in violent offenders with antisocial personality disorder: High activity associated with proactive aggression. *Criminal Behavior and Mental Health*. 2014;24(5):368–372. <https://doi.org/10.1002/cbm.1917>
21. Craig IW, Halton K. Genetics of human aggressive behavior. *Human Genetics*. 2009;126(1):101–113. <https://doi.org/10.1007/s00439-009-0695-9>
22. Pimentel T, Valvoda J, Maudsley RH, Zmigrod R, Williams A, Cotterell R. Information-Theoretic probing for linguistic structure. *arXiv (Cornell University)*. 2020. <https://doi.org/10.48550/arxiv.2004.03061>
23. Buades-Rotger M & Gal lardo-Pujol D. The role of the monoamine oxidase A gene in moderating the response to adversity and associated antisocial behavior: a review. *Psychology Research and Behavior Management*. 2014;185. <https://doi.org/10.2147/prbm.s4045>
24. Carrel L, Willard HF. X-inactivation profile reveals extensive variability in X-linked gene expression in females. *Nature*. 2005;434(7031):400–404. <https://doi.org/10.1038/nature03479>
25. Pinsonneault JK, Papp AC, Sadee W. Allelic mRNA expression of X-linked monoamine oxidase A (MAOA) in the human brain: dissection of epigenetic and genetic factors. *Human Molecular Genetics*. 2006;15(17):2636–2649. <https://doi.org/10.1093/hmg/ddl192>
26. Sjöberg RL, Ducci F, Barr CS, Newman TS, Dell'Osso L, Virkkunen M et al. A Non-Additive interaction of a functional MAO-A VNTR and testosterone predicts antisocial behavior. *Neuropsychopharmacology*. 2007;33(2):425–430. <https://doi.org/10.1038/sj.npp.1301417>
27. Wagels L, Votinov M, Kellermann T, Konzok J, Jung S, Montag C et al. Exogenous testosterone and the monoamine-oxidase A polymorphism influence anger, aggression, and neural responses to provocation in males. *Neuropharmacology*. 2019;156:107491. <https://doi.org/10.1016/j.neuropharm.2019.01.006>
28. Weeland J, Overbeek G, De Castro BO, Matthys W. Underlying Mechanisms of Gene-Environment Interactions in Externalizing Behavior: A Systematic review and search for theoretical Mechanisms. *Clinical Child and Family Psychology Review*. 2015;18(4):413–442. <https://doi.org/10.1007/s10567-015-0196-4>

29. Philibert RA, Wernett P, Plume J, Packer H, Brody GH, Beach SRH. Gene-environment interactions with a novel variable Monoamine Oxidase A transcriptional enhancer are associated with antisocial personality disorder. *Biological Psychology*. 2011;87(3):366–371. <https://doi.org/10.1016/j.biopsycho.2011.04.007>
30. Manca M, Pessoa V, Lopez AI, Harrison PT, Miyajima F, Sharp H et al. The regulation of monoamine oxidase a gene expression by distinct variable number tandem repeats. *Journal of Molecular Neuroscience*. 2018;64(3):459–470. <https://doi.org/10.1007/s12031-018-1044-z>
31. Zhu QS, Grimsby J, Chen K, Shih JC. Promoter organization and activity of human monoamine oxidase (MAO) A and B genes. *Journal of Neuroscience*. 1992;12(11):4437–4446. <https://doi.org/10.1523/jneurosci.12-11-04437.1992>
32. Al-Tayie S, Ali A. Allelic Diversity of VNTR polymorphism in Monoamine Oxidase A (MAOA) gene in Iraqi population. 2018. Accessed July 27 2024. Available: <https://jpsr.pharmainfo.in/Documents/Volumes/vol10Issue12/jpsr10121816.pdf>
33. Lu R, Lee J, Ko H, Lin W, Chen K, Shih JC. No association of the MAOA gene with alcoholism among Han Chinese males in Taiwan. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*. 2002;26(3):457–461. [https://doi.org/10.1016/s0278-5846\(01\)00288-3](https://doi.org/10.1016/s0278-5846(01)00288-3)
34. Huang Y, Cate SP, Battistuzzi C, Oquendo MA, Brent DA, Mann JJ. An Association between a Functional Polymorphism in the Monoamine Oxidase A Gene Promoter, Impulsive Traits and Early Abuse Experiences. *Neuropsychopharmacology*. 2004;29(8):1498–1505. <https://doi.org/10.1038/sj.npp.1300455>
35. Das M, Bhowmik AD, Sinha S, Chattopadhyay A, Chaudhuri K, Singh M et al. MAOA promoter polymorphism and attention deficit hyperactivity disorder (ADHD) in Indian children. *American Journal of Medical Genetics Part B Neuropsychiatric Genetics*. 2006;141B(6):637–642. <https://doi.org/10.1002/ajmg.b.30385>
36. Edwards AC, Dodge KA, Latendresse SJ, Lansford JE, Bates JE, Pettit GS et al. MAOA-uVNTR and early physical discipline interact to influence delinquent behavior. *Journal of Child Psychology and Psychiatry and Allied Disciplines*. 2010;51(6):679–687. <https://doi.org/10.1111/j.1469-7610.2009.02196.x>
37. Byrd AL, Manuck SB. MAOA, Childhood Maltreatment, and Antisocial Behavior: Meta-analysis of a Gene-Environment Interaction. *Biological Psychiatry*. 2014;75(1):9–17. <https://doi.org/10.1016/j.biopsych.2013.05.004>
38. Armstrong TD, Boutwell BB, Flores SK, Symonds M, Keller S, Gangitano D. Monoamine oxidase A genotype, childhood adversity, and criminal behavior in an incarcerated sample. *Psychiatric Genetics*. 2014. <https://doi.org/10.1097/ypg.0000000000000033>
39. Galán CA, Choe DE, Forbes EE, Shaw DS. The interaction between monoamine oxidase A and punitive discipline in the development of antisocial behavior: Mediation by maladaptive social information processing. *Development and Psychopathology*. 2016;29(4):1235–1252. <https://doi.org/10.1017/s0954579416001279>

40. Hinds HL, Hendriks RW, Craig IW, Chen Z. Characterization of a highly polymorphic region near the first exon of the human MAOA gene containing a GT dinucleotide and a novel VNTR motif. *Genomics*. 1992;13(3):896–897. [https://doi.org/10.1016/0888-7543\(92\)90181-q](https://doi.org/10.1016/0888-7543(92)90181-q)
41. Ni X, Sicard T, Bulgin N, Bismil R, Chan K, McMains S et al. Monoamine Oxidase A gene is associated with borderline personality disorder. *Psychiatric Genetics*. 2007;17(3):153–157. <https://doi.org/10.1097/ypg.0b013e328016831c>
42. Leuchter AF, McCracken JT, Hunter AM, Cook IA, Alpert JE. Monoamine Oxidase A and Catechol-O-Methyltransferase Functional Polymorphisms and the Placebo Response in Major Depressive Disorder. *Journal of Clinical Psychopharmacology*. 2009;29(4):372–377. <https://doi.org/10.1097/jcp.0b013e3181ac4aaf>
43. Wang M, Li H, Deater-Deckard K, Zhang W. Interacting Effect of Catechol-O-Methyltransferase (COMT) and Monoamine Oxidase A (MAOA) Gene Polymorphisms, and Stressful Life Events on Aggressive Behavior in Chinese Male Adolescents. *Frontiers in Psychology*. 2018;9. <https://doi.org/10.3389/fpsyg.2018.01079>
44. Canli T, Sivers H, Whitfield SL, Gotlib IH, Gabrieli JDE. Amygdala response to happy faces as a function of extraversion. *Science*. 2002;296(5576):2191. <https://doi.org/10.1126/science.1068749>
45. Hunsaker MR. Comprehensive neurocognitive endophenotyping strategies for mouse models of genetic disorders. *Progress in Neurobiology*. 2012;96(2):220–241. <https://doi.org/10.1016/j.pneurobio.2011.12.001>
46. Beaver KM, Nedelec JL, Wilde M, Lippoff C, Jackson D. Examining the association between MAOA genotype and incarceration, anger, and hostility: The moderating influences of risk and protective factors. *Journal of Research in Personality*. 2011;45(3):279–284. <https://doi.org/10.1016/j.jrp.2011.02.007>
47. Cohen I, Liu X, Lewis M, Chudley A, Forster-Gibson C, Gonzalez M et al. Autism severity is associated with child and maternal MAOA genotypes. *Clinical Genetics*. 2011;79(4):355–362. <https://doi.org/10.1111/j.1399-0004.2010.01471.x>
48. Simons RL, Stewart EA, Brody GH, Beach SRH, Philibert RA, Gibbons FX. Social adversity, genetic variation, street code, and aggression. *Youth Violence and Juvenile Justice*. 2011;10(1):3–24. <https://doi.org/10.1177/1541204011422087>
49. McDermott R, Dawes C, Prom-Wormley E, Eaves LJ, Hatemi PK. MAOA and aggression. *Journal of Conflict Resolution*. 2012;57(6):1043–1064. <https://doi.org/10.1177/0022002712457746>
50. Verhoeven FEA, Booij L, Kruijt A, Cerit H, Antypa N, Van Der Does W. The effects of MAOA genotype, childhood trauma, and sex on trait and state-dependent aggression. *Brain and Behavior*. 2012;2(6):806–813. <https://doi.org/10.1002/brb3.96>
51. Gallardo-Pujol D, Andrés-Pueyo A, Maydeu-Olivares A. MAOA genotype, social exclusion, and aggression: an experimental test of a gene-environment interaction. *Genes, Brain and Behavior*. 2012;12(1):140–145. <https://doi.org/10.1111/j.1601-183x.2012.00868.x>

52. Hill J, Breen G, Quinn JP, Tibu F, Sharp H, Pickles A. Evidence for interplay between genes and maternal stress in utero: monoamine oxidase A polymorphism moderates effects of life events during pregnancy on infant negative emotionality at 5 weeks. *Genes, Brain and Behavior*. 2013;12(4):388–396. <https://doi.org/10.1111/gbb.12033>
53. Kuepper Y, Grant P, Wielpuetz C, Hennig J. MAOA-uVNTR genotype predicts interindividual differences in experimental aggressiveness as a function of the degree of provocation. *Behavioral Brain Research*. 2013;247:73–78. <https://doi.org/10.1016/j.bbr.2013.03.002>
54. Galal El-Din AMM, Ali NH, Swelim HH, Amr KS, El-Din Effat LK. Monoamine oxidase A (MAOA) gene polymorphism in offenders and psychiatric patients in an Egyptian Study. *IOSR Journal of Pharmacy and Biological Sciences*. 2014;9(2):38–42. <https://doi.org/10.9790/3008-09273842>
55. Denson TF, Dobson-Stone C, Ronay R, Von Hippel W, Schira MM. A functional polymorphism of the MAOA gene is associated with neural responses to induced anger control. *Journal of Cognitive Neuroscience*. 2014;26(7):1418–1427. <https://doi.org/10.1162/jocn.a.00592>
56. Gorodetsky E, Bevilacqua L, Carli V, Sarchiapone M, Roy A, Goldman D et al. The interactive effect of MAOA-LPR genotype and childhood physical neglect on aggressive behaviors in Italian male prisoners. *Genes, Brain and Behavior*. 2014;13(6):543–549. <https://doi.org/10.1111/gbb.12140>
57. Lei H, Zhang X, Di X, Rao H, Ming Q, Zhang J et al. A functional polymorphism of the MAOA gene modulates spontaneous brain activity in PONs. *BioMed Research International*. 2014;1–6. <https://doi.org/10.1155/2014/243280>
58. Rehan W, Sandnabba NK, Johansson A, Westberg L, Santtila P. Effects of MAOA genotype and childhood experiences of physical and emotional abuse on aggressive behavior in adulthood. *Nordic Psychology*. 2015;67(4):301–312. <https://doi.org/10.1080/19012276.2015.1026922>
59. Holz NE, Boecker R, Buchmann AF, Blomeyer D, Baumeister S, Hohmann S et al. Evidence for a Sex-Dependent MAOA \times Childhood stress interaction in the neural circuitry of aggression. *Cerebral Cortex*. 2014;26(3):904–914. <https://doi.org/10.1093/cercor/bhu249>
60. Zhang Y, Ming Q, Wang X, Yao S. The interactive effect of the MAOA-VNTR genotype and childhood abuse on aggressive behaviors in Chinese male adolescents. *Psychiatric Genetics*. 2016;26(3):117–123. <https://doi.org/10.1097/ypg.0000000000000125>
61. Zhang Y, Ming Q, Yi J, Wang X, Chai Q, Yao S. Gene-Gene-Environment interactions of serotonin transporter, monoamine oxidase A and childhood maltreatment predict aggressive behavior in Chinese adolescents. *Frontiers in Behavioral Neuroscience*. 2017;11. <https://doi.org/10.3389/fnbeh.2017.00017>
62. Wessels SH. The prevalence of the MAOA μ VNTR alleles and their relationship to childhood behavior and personality within a South African cohort (Doctoral dissertation).

63. Sarwar S, Shabana N, Hasnain S. Association of the variable number of tandem repeats (VNTR) and T941G polymorphism of monoamine oxidase (MAO-A) gene with aggression in Pakistani subjects. *African Health Sciences*. 2021;21(1):180–188. <https://doi.org/10.4314/ahs.v21i1.24>
64. Beaver KM, DeLisi M, Vaughn MG, Barnes J. Monoamine oxidase A genotype is associated with gang membership and weapon use. *Comprehensive Psychiatry*. 2010;51(2):130–134. <https://doi.org/10.1016/j.comppsy.2009.03.010>
65. Watts SJ, McNulty TL. Genes, Parenting, Self-Control, and Criminal Behavior. *International Journal of Offender Therapy and Comparative Criminology*. 2014;60(4):469–491. <https://doi.org/10.1177/0306624x14553813>
66. Beaver KM, Wright JP, Boutwell BB, Barnes J, DeLisi M, Vaughn MG. Exploring the association between the 2-repeat allele of the MAOA gene promoter polymorphism and psychopathic personality traits, arrests, incarceration, and lifetime antisocial behavior. *Personality and Individual Differences*. 2013;54(2):164–168. <https://doi.org/10.1016/j.paid.2012.08.014>
67. Hernandez J, Highsmith J, Madrigal S, Mercado M. Nature (MAOA) and nurture in a criminal. *UC Merced Undergraduate Research Journal*. 2015;8(1). <https://doi.org/10.5070/m481029475>
68. Tiihonen J, Rautiainen M, Ollila HM, Repo-Tiihonen E, Virkkunen M, Palotie A et al. Genetic background of extreme violent behavior. *Molecular psychiatry*. 2015;20(6):786–792. <https://doi.org/10.1038/mp.2014.130>
69. Wells J, Armstrong T, Boisvert D, Lewis R, Gangitano D, Hughes-Stamm S. STRESS, GENES, AND GENERALIZABILITY ACROSS GENDER: EFFECTS OF MAOA AND STRESS SENSITIVITY ON CRIME AND DELINQUENCY*. *Criminology*. 2017;55(3):548–574. <https://doi.org/10.1111/1745-9125.12147>
70. Kolla NJ, Patel R, Meyer JH, Chakravarty MM. Association of monoamine oxidase-A genetic variants and amygdala morphology in violent offenders with antisocial personality disorder and high psychopathic traits. *Scientific Reports*. 2017;7(1). <https://doi.org/10.1038/s41598-017-08351-w>
71. Jarrett AL, Jarrett AF, Shreve M. Causal factors of serial killers. *International Journal of Educational Reform*, 105678792311635. 2023. <https://doi.org/10.1177/10567879231163545>
72. Lu Y, Menard S. The interplay of MAOA and peer influences in predicting adult criminal behavior. *Psychiatric Quarterly*. 2016;88(1):115–128. <https://doi.org/10.1007/s11126-016-9441-3>
73. McSwiggan S, Elger BS, Appelbaum PS. The forensic use of behavioral genetics in criminal proceedings: Case of the MAOA-L genotype. *International Journal of Law and Psychiatry*. 2017;50:17–23. <https://doi.org/10.1016/j.ijlp.2016.09.005>
74. Aluja A, García LF, Blanch Á, Lorenzo D, Fibla J. Impulsive-disinhibited personality and serotonin transporter gene polymorphisms: Association study in an inmate's sample. *Journal of Psychiatric Research*. 2009;43(10):906–914. <https://doi.org/10.1016/j.jpsychires.2008.11.008>

75. Sohrabi S. The criminal gene: the link between MAOA and aggression (REVIEW). BMC Proceedings. 2015;9(S1). <https://doi.org/10.1186/1753-6561-9-s1-a49>
76. Caspi A, McClay JL, Moffitt TE, Mill J, Martin J, Craig IW et al. Role of Genotype in the Cycle of Violence in Maltreated Children. Science. 2002;297(5582):851–854. <https://doi.org/10.1126/science.1072290>
77. Kim-Cohen J, Caspi A, Taylor AM, Williams B, Newcombe RG, Craig IW et al. MAOA, maltreatment, and gene-environment interaction predicting children's mental health: new evidence and a meta-analysis. Molecular Psychiatry. 2006;11(10):903–913. <https://doi.org/10.1038/sj.mp.4001851>
78. Williams LM, Gatt JM, Kuan SA, Dobson-Stone C, Palmer D, Paul RH et al. A Polymorphism of the MAOA Gene is Associated with Emotional Brain Markers and Personality Traits on an Antisocial Index. Neuropsychopharmacology. 2009;34(7):1797–1809. <https://doi.org/10.1038/npp.2009.1>
79. Fergusson DM, Boden JM, Horwood LJ, Miller JS, Kennedy MA. MAOA, abuse exposure, and antisocial behavior: a 30-year longitudinal study. British Journal of Psychiatry. 2011;198(6):457–463. <https://doi.org/10.1192/bjp.bp.110.086991>

DEFINITIONS, ACRONYMS, ABBREVIATIONS

MAOA	Monoamine Oxidase A
MAOB	Monoamine Oxidase B
MAOA-uVNTR	Monoamine Oxidase A-upstream Variable Number Tandem Repeat
MAOA-L	MAOA low activity
MAOA-H	MAOA high activity
CNS	Central Nervous System
PNS	Peripheral Nervous System
2R	2 Repeat Sequence Of MAOA-uVNTR Polymorphism
3R	3 Repeat Sequence Of MAOA-uVNTR Polymorphism
3.5R	3.5 Repeat Sequence Of MAOA-uVNTR Polymorphism
4R	4 Repeat Sequence Of MAOA-uVNTR Polymorphism
4.5R	4.5 Repeat Sequence Of MAOA-uVNTR Polymorphism
5R	5 Repeat Sequence Of MAOA-uVNTR Polymorphism
6R	6 Repeat Sequence Of MAOA-uVNTR Polymorphism
SNP	Single Nucleotide Polymorphism
DAT-1	Dopamine Transporter-1
DRD2	Dopamine Receptor D2
DRD4	Dopamine Receptor D4