# The Cerebellum and Beauty: The Impact of the Cerebellum in Art Experience and Creativity

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**Abstract**

There is growing interest in the cerebellum's contributions to higher order functions of the human brain. When considering specific activities of the human cerebellum related to art, we differentiate two broad areas. Neural activity within different locations of the cerebellum is involved in art perception and in artistic creativity. The cerebellum plays an underappreciated role in neuroaesthetics, including the perception and evaluation of art objects, their appreciation and affective aesthetic experience. Certain areas of the cerebellum presumably are of particular relevance, incorporating cognitive and affective issues within large-scaled neural networks in perceiving and appraising artworks. For art creativity, many investigations report cerebellar implementations. Important areas in these domains are evolutionary younger parts of the cerebellar hemispheres, in particular the lobule VII with its Crus I and II, influencing crucial networks such as the Default Mode Network in optimizing creativity. These structures help guide pattern recognition and in art appreciation as they may play a role in predicting ongoing neural network activities through a crucial frontoparietal axis. In this chapter, we consider how our current neuroscientific understanding of cerebellar functions point to a likely role of the cerebellum in art appreciation and creativity.

**Keywords**

Cerebellum · Art creativity · Art experience · Multiple sensory integration · Internal models

## 14.1 Introduction

One of the most striking species-specific features of *Homo sapiens sapiens* is the ability to create novel ideas and solutions. Creativity is expressed in art, where artists use alternative and innovative ways to depict objects and scenes to convey specific semantic messages through different styles and media. Research on the neural basis of creativity, which has flourished in recent years, attempts to understand the brain mechanisms associated with creative thought (Benedek 2018; Chen et al. 2020). In a similar vein, researchers

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have tried to understand neural processes underlying the perception and appreciation of such artistic creations. In this regard, neuroaesthetics is a growing research field that investigates the neural underpinnings of aesthetic experiences (for reviews: Chatterjee and Vartanian 2014; Nadal and Skov 2015, Pelowski et al. 2017).

Aesthetic experiences are likely to be mediated by a flexible interplay between three main neural systems: the *sensory-motor*, the *emotion-valuation*, and the *meaning-knowledge* systems, the so-called "aesthetic triad" (coined by Chatterjee and Vartanian 2014) (see Fig. 14.1). Accordingly, widely distributed networks of brain regions involved in both low- and high-level processes, spanning from the occipital to frontal lobes are associated with aesthetic judgments about visual stimuli (for a meta-analysis, see Boccia et al. 2016; Chuan-Peng et al. 2020). Creative thinking also relies on dynamic interactions of large-scale brain systems cooperating to support the complex cognitive processes during creative cognition and artistic performance, such as goal-directed memory retrieval, response inhibition, and internally focused attention (Beaty et al. 2016, 2019).

Although cerebellar activity is sometimes observed in neuroimaging studies on creativity (Chamberlain et al. 2014; Saggar et al. 2015; Sunavsky and Poppenk 2020; for reviews, see Beaty et al. 2016; Chen et al. 2020) and aesthetic experience (Ishizu and Zeki 2013, 2014, 2017; Kirk et al. 2009a; Lacey et al. 2011; Vartanian and Goel 2004; for a meta-analysis see Boccia et al. 2016), its role is rarely discussed. More often, the cerebellum is excluded from analysis. Such a gap in our knowledge is surprising given that certain areas of the cerebellum (particularly its posterior lobe) serve as a critical hub of extended brain networks that mediate high-order cognitive, affective, and social processes (Adamaszek et al. 2017; Schmahmann 2019; Van Overwalle et al. 2020) through bidirectional connections with cortical and subcortical structures in the cerebrum (Buckner et al. 2011; Habas 2018; Habas et al. 2009). In this chapter, we provide an overview of the neurocognitive and emotional mechanisms subtending creativity and aesthetic appreciation. We then review empirical findings reporting cerebellar involvement in aesthetic perception and evaluation of artistic visual stimuli and the creative processes involved in art production. Finally, we propose potential mechanisms accounting for the involvement of the cerebellum in the aesthetic experience and how the cerebellum might implement these mechanisms through cortico-cerebellar and limbic-cerebellar networks.

## 14.2 The Cerebellum and Creativity

Most available studies on creativity in the visual arts are based on general views of creativity, which are typically contextualized as the production of both novel and useful forms (Pelowski et al. 2017). Cognitive models of visual creativity propose that creative ideation involves retrieval of semantic associations and their conceptual combination, executive functions including visual imagery, and an evaluation of responses, including inhibition of those that are irrelevant (Abraham 2014; Benedek and Neubauer 2013; Benedek et al. 2014; Sowden et al. 2015). Accordingly, neuroimaging studies on visual creativity report significant recruitment of right prefrontal regions (i.e. inferior and middle frontal gyri), thalamus and fusiform gyrus (for meta-analyses, see Boccia et al. 2015; Gonen-Yaacovi et al. 2013; Pidgeon et al. 2016). Furthermore, as shown by a study conducted on visual artists (Ellamil et al. 2012), the default mode network (DMN)—which is implicated in self-referential processing and is typically suppressed when a person engages with the external environment (Raichle et al. 2001)—contributes to the generation of novel ideas, possibly extracting useful information from memory. Additionally, the executive control network, comprising the dorsolateral prefrontal cortex (dlPFC), inferior frontal gyrus (IFG), and inferior parietal areas, evaluates the efficacy of candidate ideas and modifies them to meet the constraints of the goals of the task at hand. Both networks are connected with subcortical structures such as the striatum. The striatum releases dopamine in computing rewards and integrates information about action plans,

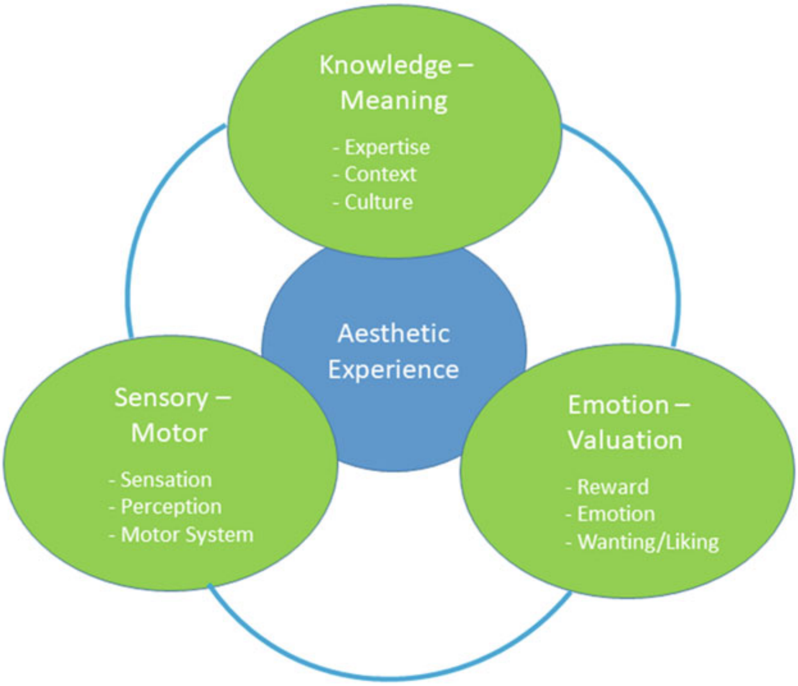

**Fig. 14.1** The aesthetic triad, according to Chatterjee and Vartanian 2014, suggesting a model of three large-scale systems, i.e. the sensorimotor, knowledge-meaning and emotion-valuation, generating aesthetic experiences

motivation, strategy shifts and inhibitory control (Bostan et al. 2018). The balance in the dopaminergic release in these neural networks and the interplay of prefrontal-striatal circuits affect human creativity by increasing cognitive flexibility (Nijstad et al. 2010; Zabelina et al. 2016).

For art creativity, many investigations report cerebellar involvement (Chamberlain et al. 2014; Cogdell-Brooke et al. 2020; Fornazzari et al. 2020; Gao et al. 2017, 2020; Makuuchi et al. 2003; Miall et al. 2009; Ogawa et al. 2018; Saggar et al. 2015; Schlegel et al. 2015; Sunavsky and Poppenk 2020). Most of these studies report an increased involvement of circumscribed locations within the cerebellum accompany specific tasks like the development of drawing skills. Studying morphological features of the brain in art creativity, Chamberlain et al. 2014) reported greater white and gray matter density in the left anterior cerebellum, as well as the supplementary motor area (SMA) was associated with increased skill in drawing. Nevertheless, similar findings of cerebellar involvement were already reported in the early works of Makuuchi et al. (2003) as well as Miall et al. (2009). Makuuchi noted not only a structural, but also a functional increase in neural activity within bilateral posterior cerebellar hemispheres and anterior vermis (Makuuchi et al. 2003). The specific cerebellar findings in these studies were assumed to reflect growing perceptual proficiency following continuous training in drawing. This proficiency might be associated with developments in capturing procedural meaning and enhanced visual perception through the deconstruction and reconstruction of visual scenes as worked out when drawing (Kozbelt and Seeley 2007; Chamberlain et al. 2014), i.e. the integration of external visual cues, internal memory traces, and motor actions. So an artist shows superior skills in visual perception, and fine motor skills (Kozbelt and Seeley 2007), the specific training refines their perception of object details such as size, volume, and bodily space with procedural knowlegde (Rode et al. 2018). They also observed increased functional activities, associated with a structural expansion of the gray matter volume (GMV) in associative cerebral cortex areas such as the SMA and the prefrontal and parietal lobes. This expansion might be the result of increased task activity when subjects train in art creativity. As a result, this increased activitiy is accompanied by perceptual enhancement through specific visuo-motor and visuo-spatial mechanisms. Beyond these primary visual avenues, the observed increased activities of prefrontal-parietal and associated motor cortices might point to involvement of cognitive and affective aspects of visuo-creative perception and thinking, such as elaboration, flexibility, fluency, and originality, guiding spontaneous improvisation and figural creativity along several domains of a large-scaled sketchpad including the central executive and (visual and visuo-spatial) working memory of the drawing person (Baddeley 2003; Saggar et al. 2015). Interestingly, Chamberlain et al. (2014) found more creative thinking in participants after a drawing training course, suggesting that neural plasticity in the cerebellum integrates visual perception and creative action.

Sunavsky and Poppenk (2020), in an exploratory meta-analysis of neuroimaging studies about cognitive and neuroimaging predictors of individual differences in creativity, found multimodal contributions of the cerebellar anterior lobe, as well as less spatially and directionally consistent contributions from lobules VI–VIII, to multiple measures of creativity. Moreover, the anterior cerebellum and the parahippocampal gyrus were reliable predictors of creativity, suggesting two crucial brain sites have specific roles in working and long-term memory relevant to problem solving and imagination. Although cerebellar activations in art creativity had been observed in the right or even bilateral hemispheres, the left cerebellum with its strong connections to the right cerebral areas including the SMA (Schwartze et al. 2012) and posterior parietal cortex (Striemer et al. 2019) is of particular interest because of its possible association to visuo-spatial attention. Additionally, the cerebellum may participate in art creativity through its role in controlling eye movements guiding drawing in art production. Cohen (2005) observed a positive relationship between the frequency of eye fixation switches and the accuracy during the drawing actions of artists, which might indicate an unburdening of working memory. Markey et al. (2019) supported this assumption of a relationship of eye fixation to art perception, finding longer fixations in visual perception tasks for inconsistent objects as indicating an attempt to resolve the inconsistency into the expectations regarding the underlying schematic structure (e.g. the glass is *under* the bar) and/or meaning (e.g. a scene portrays a woman and a dolphin sitting in a car) (Markey et al. 2019). Schlegel et al. (2015) observed that increasing activity in the right anterior cerebellum was associated with motor control, proprioceptive feedback, and coordination between eye and hand movements (Buckner 2013; Floyer-Lea and Matthews 2004; Miall et al. 2001) in relation to subsequent drawing lessons. This activity might account for the dorsal (or vision for action) stream role in spatial awareness and guidance of movements such as the brush stroke. Thus, the cerebellar contribution to multisensory visuo-spatial analysis in creative production and perception might be subserved not only by the connections between the posterior cerebellar lobe and the parietal (in particular the posterior parts) cortex, but also by the supporting eye movements affected by the flocculus–paraflocculus and posterior vermis (Miall et al. 2000; Thier and Ilg 2005; Thier and Markanday 2019; Zeki et al. 2014). Notwithstanding, the specificity of these different cerebellar connections might depend on the task and therefore be involved in high-order domains of creativity, i.e. parallel connections to supplementary motor areas might engage with other sensorimotor learning tasks.

Besides the sensorimotor aspects of the cerebellum in art production, its role in higher order domains of art creativity is more intriguing. Functional neuroimaging studies showed that activations of the dorsolateral prefrontal cortex (DLPFC) and the posterior cerebellum covary with the number of solutions in creative processes (Goel and Vartanian 2005), indicating cerebellar involvement within distributed neural network in creativity. Creativity follows a three-level model with each specific neural activation modes, as suggested by Kaufman et al., a claim derived from observations in non-human primates (Kaufman et al. 2011). On this model, one level recognizing novelty relies on hippocampal functions with links to dopamine systems (Kumaran and Maguire 2009). A second level addresses observational learning, which among other structures, involves the cerebellum (Torriero et al. 2011). Finally, a third level processing innovative behavior is mainly instantiated by the prefrontal cortex with a balance between functions of the right and left hemisphere (Aupperle Robin and Martin 2010). For instance, the findings described by Chamberlain et al. (2014) of increased creative thinking associated with structural increase of the left cerebellum and SMA points to the assumption that the cerebellum is subsequently involved in these behavioral levels linking cognitive and affective processing at each level (Petrosini et al. 2015).

Hence creative thinking and action require different solutions: a role for the cerebellum is feasible when considering the cerebellar connections to the lateral and medial prefrontal cortices, parietal cortex, inferior temporal gyrus, and basal ganglia. As Ogawa et al. (2018) assumed, higher creative insight is achieved not only through creative common networks, including the DMN, but also through insight-specific connections such as semantic and cerebral-cerebellar networks (Jung-Beeman et al. 2004; Saggar et al. 2015). Whereas parts of the PFC (OFC, insula with its anterior, dorsal and posterior regions, and the anterior cingulate cortex) involve specific functions of cognitive control, decision making, emotion, autonomic interoception, somatosensory perception, and apprehension of salience which all constitute a comprehensive map of parallel processes in creativity (Liu et al. 2017), i.e. the details of a creative action assembles a broad spectrum of neural information, which is guided by parts of the PFC to gain the appropriate and meaningful synthesis in creative action. The impact of the cerebellum in particular with its crus I, processing the computation of visual information, including inverse kinematic mapping (Taig et al. 2012), is of particular relevance in disentangling mechanisms and their neural connections to crucial areas of the PFC to different degrees in creative process. According to Buckner and colleagues (Buckner et al. 2011), the Crus I and II are major regions coupled to the DMN, emphasizing the need to clarify the role of the Crus I and II in creativity and related cognitive and affective aspects. Since the DMN might initiate insight processing, the associated cerebral-cerebellar networks might be guiding insight-specific information, which modulates insightful problem solving as part of creative thinking.

The cerebellar contribution in creative processing at each level might be relevant to timing, sequencing and modeling of visual and auditory informations of an object that provides rapid and flexible manipulation of motor, cognitive, and affective demands (Vandervert 2017; Bostan and Strick 2010; Koziol et al. 2010; Saggar et al. 2015). This contribution of implicit brain processes might occur through specific parts of the anterior (in particular lobule V) and posterior (in particular lobule VI, VII including Crus I and I, and VIII) cerebellum (Habas et al. 2009; Krienen and Buckner 2009; Buckner 2013; Saggar et al. 2015; Ogawa et al. 2018). In fact, the cerebellum's role in mediating between environmental information and relevant motor, cognitive and affective actions likely apply to the implementation of novel strategies. According to internal models and mechanisms of error-based learning, the cerebellum adapts cerebral cortical activity to the individual context (Ito 2008; Schmahmann 2010). In particular, such influence on associative cortices, specifically at prefrontal sites, might modulate the outcome of ongoing creative processing traces (Petrosini et al. 2015). Therefore, reciprocal connections between the cerebellum and the lateral (DLPFC, IFG) and medial (vmPFC) areas of the PFC could serve as an interactive connection to formulate specific, in some instances new creative outcomes (Pochon et al. 2001; Bellebaum and Daum 2007; Koziol and Lutz 2013), comprising the implicit and explicit processes to problem solving (Ito 2008). These cerebellar contributions to attention and art creativity might interact with several neural networks, including the visual working memory, but also the ventral and dorsal attentional streams in task control with its adaptation and goaldirection mechanisms. Furthermore, cerebellar connections to prefrontal regions, specifically the DLPFC, could identify and clarify novel aspects for systematic storage and retrieval of mental models and representations, which might be relevant to implicit and explicit processes of an ongoing creative acts (Saggar et al. 2015). Implicit processing relies on cerebral-cerebellar interactions along inverse and forward models to facilitate and increase the efficiency of repetitive actions on mental representation (Ito 2008). Indeed, the Aha! effect characterizes the stage of a successive application of implicit processing (via inverse and forward modeling of the sensory informations along the responsible parallel cerebellar-cerebral networks) with an emerging conscious awareness of a solution to the creative task (Ito 2008; Petrosini et al. 2015; Saggar et al. 2015; Argyropoulos et al. 2020). This means, that the cerebellum feeds an internal model directly to a target neural assembly in the cortex, and/or along a parallel cerebellar-cerebral pathway as an inverse signal response. The Aha! effect therefore might represent the summation of a complete neural process within the responsible network, substantially within the PFC. The interactive processing of the highly distributed neural networks between different cerebellar sites and associative cortex areas thus support and therefore guarantee precise, fast and task-dependent execution and control of ongoing creative processing in the human brain. In terms of a more comprehensive view considering the application of internal models, the cerebellum presumably provides several different internal models to solve the demands of motor, cognitive and affective processing traces of the responsible neural networks in specific multimodal task processes, which could be feasible also for processes in creativity. According to several reports of cognitive and emotion impairments in cerebellar damage, the frequent afflicted attentional and executive domains are subject to worsening in quality (Parsons and Fox 1997; Ivry and Fiez 2000; Koziol et al. 2014), which might be relevant to creativity.

## 14.3 The Cerebellum and Art Perception

Aesthetic appreciation is the result of a dynamic interaction between different cortical and subcortical neural networks (for review, see Boccia et al. 2016; Chatterjee and Vartanian 2014). The extent to which a visual stimulus is preferred modulates neural responses at the level of low- and mid-visual processing of stimuli in regions in the ventral and dorsal visual pathways (Calvo-Merino et al. 2008; Chatterjee et al. 2009; Lacey et al. 2011; Vartanian and Goel 2004), likely reflecting the influence of bottom-up factors related to the salience of stimuli's perceptual features and top-down processes related to voluntary attention. Similarly, activation in cortical and subcortical motor-related regions is influenced by preferences (Calvo-Merino et al. 2008, 2010; Cazzato et al. 2016; Ishizu and Zeki 2013), possibly associated with implicit responses to the stimulus. These responses contributing to aesthetic evaluation may underpin a perceiver's empathic response toward visual art (Leder et al. 2012; see also Ticini et al. 2014, 2015). Moreover, implicit mechanisms related to motor preparation may also be at play, such as approach/avoidance behavior elicited by the perceived beauty or ugliness in the stimulus (Faust et al. 2019; Kawabata and Zeki 2004; see also Di Dio et al. 2007). Critically, aesthetic judgments are tightly linked to affective processes as demonstrated by the activations in both subcortical (i.e. striatum, amygdala, putamen) and prefrontal limbic and reward-related regions when viewing beautiful stimuli (e.g. Cupchik et al. 2009; Ishizu and Zeki 2013; Vessel et al. 2012). Furthermore, recent evidence suggests that the DMN might also be critically engaged when one finds an artwork especially moving (Belfi et al. 2019; Vessel et al. 2019). Indeed, activity patterns from the DMN can predict aesthetic appeal across visual stimuli, such as artworks, landscapes, or architecture (Vessel et al. 2019), possibly by monitoring the observer's internal state during continued engagement with aesthetically pleasing experiences, as well when disengaging from non-pleasing stimuli (Belfi et al. 2019).

Art perception and appreciation is the counterpart of the cerebellar contribution to creativity and may share similar mechanisms through reciprocal connections between associative cortices and certain parts of the cerebellum (Saggar et al. 2015; Ogawa et al. 2018). Nevertheless, the cerebellar involvement in art perception and appreciation is tied to the lateral hemispheres of the cerebellum, perhaps reflecting less motor and more cognitive and affective domains in art experience.

In contrast to neuroimaging and electrophysiological evidence for a cerebellar role in perception and processing of visual art, there are no relevant clinical data. Notwithstanding, previous clinical investigations of cerebellar involvement in emotion processing as reported by Schmahmann and Sherman (1998) and Adamaszek et al. (2013, 2014), might be relevant to cerebellar-cerebral involvement, especially feedforward connections to prefrontal, temporal, and parietal cortex and subcortical areas, in cognitive and affective cue perception and recognition. These findings may elucidate the cerebellar role in domains of emotion processing as applied to art perception and appreciation. A first approach arises from the close relationship between the aforementioned cerebral areas of emotion recognition of salient stimuli, such as the perception and discrimination of emotional facial expressions, for which cerebellar involvement is clear from clinical and neurophysiological observations (Adamaszek et al. 2013, 2015; Schutter and van Honk 2009; Ferrucci et al. 2012; Ferrari et al. 2018a). Indeed, the cerebellum appears to be a crucial hub in regulating one's emotional states (Adamaszek et al. 2017) and is a fundamental component of mentalizing network by which people read another individuals' mind (intentions, goals, emotions, thoughts, beliefs) (Van Overwalle et al. 2020). The posterior cerebellum has bidirectional anatomical and functional connections with cortical and subcortical regions involved in emotional processing (Buckner et al. 2011; Habas et al. 2009; Habas 2018; Sang et al. 2012). Based on the cerebellar role in recognizing emotions in facial expressions, the question arises whether the cerebellum also assigns aesthetic value through recognition and discrimination of emotions in art images. In an ongoing study, Adamaszek et al. (2021) postulate such a function for the cerebellum based on interim data analysis. In the study, similar to Melcher and Bacci (2013), patients with circumscribed injury to the cerebellum, predominantly in the posterior lobe, as well as healthy subjects of comparable age, were presented with art images with varying levels of valence and arousal. Participants assessed pictures from different art periods (fifteenth to twentieth centuries) with different emotions depicted (joyful, fearful, sad, angry, disgusted, neutral). The interim evaluation suggests that patients categorized the emotional valence of fewer pictures correctly. A separate test of affect discrimination of art pictures, i.e. the assignment of one presented art picture with a predominant basic emotion (i.e. joyful, fearful, sad, or angry) to a matching emotion of a disctinct art picture among a separate selection of four presented art pictures with different predominating basic emotion, remained without statistically significant effect. These provisional results suggest a cerebellar function of emotion recognition of visual stimuli that extends to art image representations (see also Ferrari et al. 2018b).

Despite these reasonable considerations of cerebellar functions in art perception, few studies have pursued this line of inquiry. Several neuroimaging studies report cerebellar activations in aesthetic perception, although most of these studies do not properly consider these activations. Indeed, many neuroimaging studies in cognitive and affective neuroscience are cortico-centric, and omit or do not include the entire cerebellum. Furthermore, disadvantages in MRI quality result in low cerebellar signal-to-noise ratio, and different cellular functions of the cerebellum without aerobic glycolysis (Vaishnavi et al. 2010) contribute to weak or even absent cerebellar activations when assessed by blood oxygenation levels (Marek et al. 2018). Finally, the cerebellum, in contrast to the cerebral cortex, has high individual variability, which further complicates its measurement in aesthetic paradigms. Therefore, it seems appropriate to study the neural underpinnings of aesthetic engagement by analysing resting state functional connectivity (RSFC). Williams et al. (2018) found the cerebellum involved with the right striatum and the ventral attention network, suggesting a cerebellar role in attention and processing of sensory information including engagement with the DMN. Further neuroimaging findings of the cerebellum in visual perception and analysis of aesthetic objects are reported by Ishizu and Zeki, who found expected activity in medial parts of the OFC, different parts of the cingulate cortex, the basal ganglia, and also in the cerebellar lobule VII with its Crus I and II (Zeki et al. 2014; Ishizu and Zeki 2014, 2017). The cerebellar findings are of particular interest, as the circumscribed activations of the lobule VII for different visually perceived aesthetic stimuli, i.e. for displayed mathematical formulas, images of beauty and ugly scene expressions, and images of different emotion valence such as joyful and sorrowful. Moreover, the activations of the Crus I and II differed in part according to emotion category of the stimuli, i.e. the Crus I was more responsive to negative, and Crus II more responsive to positive valence, which might be due to specific role of the activated parts of the lobule VII for the domain of emotion expressions in visual perception (Ishizu and Zeki 2017). The different patterns of functional connectivity of the cerebral areas such as the mOFC might be relevant to two specialized systems, i.e. a reward-related and an empathy-related system. These systems could relate to differently engaged nodes of the large-scaled networks associated with positive or negative emotional valence in visual perception and analysis also in art, as the mOFC (in particular A1) involvement for the experience of beauty is positive, rewarding, and pleasurable (Ishizu and Zeki 2017). Indeed, the cerebellum may act as a bridge between emotion and cognition, becoming activated by various tasks involving emotion judgments, empathy, and information updating relative to reward (Melcher and Bacci 2013).

The consideration of different specialized systems in relation to reward and empathy as two domains of multiple processing pathways of aesthetic experience in human brain leads to the request of disentangling the cerebellum and its subdivided regions in cognitive and affective aspects of aesthetic experience. Indeed, the processing emotional cues in art is likely to be complex, involving cortical areas such as the ACC, OFC, the insula, and the IFG, but apparently involving also certain areas of the cerebellum (Wang et al. 2014; Hoche et al. 2016), which are in turn connected with aforementioned cortical areas of the PFC. These regions can be viewed as a bridge between emotion and cognition, becoming activated in various tasks involving emotion judgments, empathy, and information updating relative to reward (Melcher and Bacci 2013). Moreover, the cerebellar involvement in various emotions, e.g. subjective emotion of plesantness and unpleasantness (Kühn and Gallinat 2012; Pujol et al. 2018), facial expressions Ferrucci et al. 2012; Schutter and van Honk 2009; Adamaszek et al. 2015; Ferrari et al. 2018a), voices (Adamaszek et al. 2014; Thomasson et al. 2019) and language (Keulen et al. 2017), and in various cognitive domain, e.g. executive functions (in particular set-shifting, abstract reasoning, working memory, visuo-spatial organization) (Schmahmann and Sherman 1998; Ito 2008; Marek et al. 2018), should be candidates for cerebellar contributions to the cerebral processing pathways of aesthetic perception and evaluation. Whereas the phylogenetically older parts of the cerebellum, in particular the vermal structures, are thought to be involved in basic affective response mechanisms with little or no access to conciousness (in particular for short-looped circuits processing rapid responses for threating or strong unpleasant emotions), the relatively younger parts within the expanded lateral hemispheres are frequently tied to more elaborated processing of emotions, which are coupled to processings of associated cognitive domains (Buckner 2013). In this view, the cerebellar lobule VII with its Crus I and II may function as a central hub in diverse large-scaled neural networks of aesthetic processing and across different stimulus categories (e.g. faces, paintings, music, architectures, moral judgments, mathematical equations (e.g. Kühn and Gallinat 2012; Vartanian et al. 2013; Zeki et al. 2014).

Aesthetic experiences can be subdivided into processing stages from the early perception of an object, followed by late stages involving cognitive top-down mechanisms (Pelowski et al. 2017). According to a recent proposed model of Pelowski et al. (2017), which closely follows previous developed models of art experience such as those proposed by Chatterjee (2004) with a focus on visual interactions in art experience and Leder and Nadal (2014) with a emphasis of cognitive aspects, perceptual analysis, implicit memory integration and explicit classification represent earlier art processing, while cognitive mastery including the check of self-relevance and schema congruence and stages guiding art evaluation are tied to later stages. Affective processing occurs in parallel with cognitive processing, e.g. the evaluation of emotional valence when processings both content and form.

The principle observation that object perception and evaluation have early, intermediate, and late stages of are typical in cognitive neurophysiology. In fact, early signals elicited by emotion-laden task are reflected in bottom-up processes, whereas subsequent top-down processes are predominately reflected by ongoing intermediate and late stages of affective stimulus evaluation (Sabatinelli et al. 2013). While these observations are typically ascribed to cortical networks, the involvement of the cerebellum in modality-specific perception and processing across different stages is also evident from neurophysiological studies. Adamaszek et al. (2013, 2015) and Styliadis et al. (2015) reported that cerebellar structures are involved in early, intermediate, and late recognition and processing of salient stimuli as demonstrated using affectively loaded images of the IAPS. More precisely, both studies applying event-related potentials (ERP) paradigms with emotion-ladened IAPS images showed that the cerebellum, in particular the Crus I and II of the cerebellar hemispheres, were associated with the early and late stages of the responsible cerebral networks along the temporo-occipital as well as the frontoparietal networks of emotion processing. Moreover, a different time course of early and late reflecting temporal delineations were found for valence (positive and negative) and arousal (high low), indicating segregated involvement of the cerebellum to different affective ingredients of emotion processing. Accordingly, these studies emphasize not only the functional feedforward connections between the cerebellum and parietal and prefrontal cortex, but also its temporal attributes, which might apply to timing in art perception (Jacobsen 2013; Markey et al. 2019). In fact, such neurophysiological patterns of early and late ERP reflecting specific encoding of emotion and cognitive cues have been described in two electrophysiological studies by Jacobsen and Höfel (2001, 2003). In these studies, an aesthetic judgment elicted a fronto-central located negative deflection (around 300 and 400 ms) after stimulus onset, reflecting impression formation in the brain, and a late positive potential (LPP), reflecting evaluative categorization of the perceived aesthetic stimuli (Cacioppo et al. 1994). Sustained analysis of symmetry, in contrast, resulted in a longer lasting, late-onset ERP deflection with a posterior distribution. In another electrophysiological investigation of aesthetic evaluation in paintings (Markey et al. 2019), the authors used digital reproductions of surrealistic paintings, containing semantic or syntactic inconsistencies. The obtained ERP associated with the semantic and syntactic aesthetic discrimination showed different time courses, i. e. an early phase around 400 ms poststimulus predominated by a neural signal evolution for semantic, followed by a late phase around 600 ms for syntactic aspects in aesthetic discrimination. The latter observations are of interest since Adamaszek et al. (2013) identified cerebellar contributions to syntax processing in a linguistic paradigm. The cerebellum also contributes to semantic processing (Jacob et al. 2019), perhaps through a principal cerebellar connection to frontoparietal networks that guiding internal models of semantic and syntactic order and meaning in paintings and lyrics.

Studies comparing brain circuits involved in the aesthetic evaluation of visual artworks and non-artistic stimuli (e.g. photographs or altered versions of original paintings) report specific activations for the artworks in occipital regions (Di Dio et al. 2007; Lutz et al. 2013; Mizokami et al. 2014), as well as limbic and reward-related structures, such as the insula, ventral striatum and caudate nucleus (Di Dio et al. 2007, 2011; Lacey et al. 2011; Vartanian and Goel 2004). A few of these studies also report cerebellar activations in the right lobule VI and bilateral lobule VIIb, for the aesthetic evaluation of artworks, but not with the same judgment for non-artistic stimuli (Di Dio et al. 2011; Mizokami et al. 2014; Vartanian and Goel 2004; but see Di Dio et al. 2007; Lutz et al. 2013). These findings suggest that the cerebellar contribution might be modulated by the artistic status of stimuli, thus suggesting that artworks, representing more salient (emotional) stimuli, may trigger greater cerebellar activations (Moreno-Rius 2018; Pierce and Péron 2020).

## 14.4 Functional Aspects of the Cerebellum in Art Experience

A critical and comprehensive understanding of the cerebellum in neuroaesthetics faces the challenge of mapping the growing neuroscientific knowledge about art perception and processing to an increasingly differentiated understanding of cerebellar involvement in higher order functions of the brain. The cerebellum is essential for cognitive and emotional processings that are pertinent to empathy, theory of mind, moral judgment and action, and in all likelihood aesthetic evaluation. These psychological functions are embedded in complex systems consisting of neural circuits that operate as modules in a decentralized, highly parallel fashion selectively engaged by environmental demands to produce adaptive behavior. The cerebellum is suited to regulate these distributed systems to modulate behavior automatically and optimize states around a homeostatic baseline adapting to the relevant context (Leiner et al. 1986; Ivry and Fiez 2000; Demirtas-Tatlidede and Schmahmann 2013; Argyropoulos et al. 2020).

Neuroscientific research into the cerebellum has mapped the cerebellar connections to association networks of the cerebral cortex, including central executive control networks (in particular DLPFC) and the DMN (Parsons and Fox 1997; Habas et al. 2009; Krienen and Buckner 2009; Brady et al. 2019). The underlying neural organization of the cerebellar-cerebral connections constituting large-scale feedforward pathways is a focus of contemporary research into cerebellar contributions to high-order neural networks (Benagiano et al. 2018; Guell and Schmahmann 2020; Sereno et al. 2020). The intracerebellar neural organization of functional modules and the cerebello-thalamo-cerebro-cortical circuits (CTCC) might be considered main structural elements (see also Fig. 14.2), whereby the CTCCs of the posterior cerebellar hemispheres, i.e. lobule VI up to VIII, are segregated and progressively interconnected associative cognitive brain areas such as the prefrontal and parietal lobes, the amygdala, hippocampus, temporal lobe, hypothalamus, septal nuclei, basal ganglia including the nucleus accumbens (Heath and Harper 1974; Haines et al. 1997; D'Angelo and Casali 2013; Palesi et al. 2020). Lobules VII through X, as non-motor areas of the cerebellum, are linked to the dentate nuclei in cognitive, and to the midline fastigial nucleus in limbic functions (Schmahmann 2010). Interestingly, the sensorimotor functions are linked to the anterior cerebellum, but also in part to lobule VIII (and parts of lobule VI), whereas the cerebral associations areas are heavily linked to lobule VII (Crus I and II), with spread to lobule VI (Krienen and Buckner 2009; O'Reilly et al. 2010). The crus I and II is a special hub, as suggested in a meta-analysis by Keren-Happuch et al. (2014), which outlined a topographically organized cerebellar parcellation with the crus I and II for executive functions, emotion, language, and working memory. This topography underpins the observations of the cerebellar role in cognitive domains of executive and default mode networks such as abstract reasoning, problem solving, and self-reference (Schmahmann 2010; Vandervert 2017; Steward et al. 2019; Argyropoulos et al. 2020).

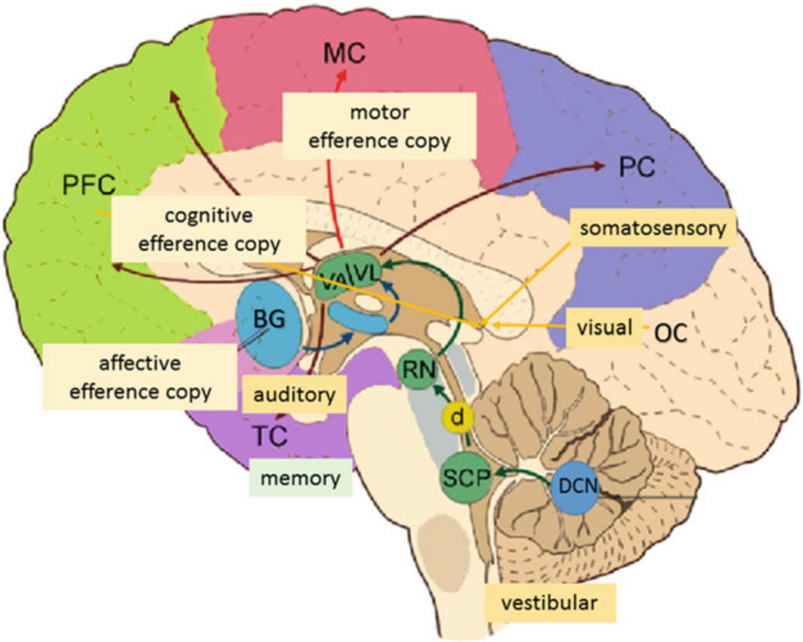

**Fig. 14.2** Overview of cerebellar-cerebral connections of eloquent sensory or associative cortex areas. According to the main connection lines, cerebral information enters the appropriate areas within the cerebellum via the pons, whereas outgoing signals go along the superior peduncle to the thalamus via the deep cerebellar nuclei and the dentate nucleus and further to the responsible areas, mainly of the prefrontal cortex. Abbreviations: *PFC* prefrontal cortex, *MC* motor cortex, *PC* parietal cortex, *TC* temporal cortex, *OC* occipital cortex, *BG* basal ganglia, *VA/VL* ventroanterior/ventrolateral thalamus, *RN* ruber nuclei, *SCP* superior cerebellar peduncle, *DCN* deep cerebellar nucleus. Under permission of Palesi et al., Brain Funct Struct (2014)

Similarly, the cerebellum may prioritize, process, and coordinate emotional experience along bottom-up- and top-down pathways (D’Angelo and Casali 2013). In a recent brief overview by Habas (2017), the “emotional” cerebellum might include several specific and non-specific areas, whereby these topographically divided areas occur in two main clusters. More precisely, one cluster, substatiated by vermal and paravermal areas in association to deep cerebellar nuclei (especially the fastigial nuclei) with a prominent role of lobules VI-VII, may take part in primary emotion processing of salient cues. This “medial limbic” part of the cerebellum may belong to the salience network, including the insula, frontal operculum, anterior cingulate and medial prefrontal cortices, but maybe also include the amygdala and hippocampus (Habas 2017). The other cluster involves the laterally located lobules VI–VIII, especially crus I and II, as parts of the executive cerebellum with its connections to the dentate nucleus, and regions of the prefrontal cortex including cingulate cortex, but also the hypothalamus, may be recruited by cognitive aspects of emotion processing (working memory, attention allocation, emotion evaluation, response selection) or associative learning, constituting a phylogenetically more recent “limbic” area within the cerebellum. Both clusters (medial and lateral “limbic” cerebellum) seems to be not only involved in experience of emotion, but also in the control and coordination of autonomic, cognitive, and appropriate behavioral responses along salience and executive networks (Habas 2017). These topographical distinctions point to specific contributions of cerebellar areas with its feedforward actions to the large-scaled networks, supporting the control, organization, and comprehension of complex sequences involved in different technical and social intelligence (Barton

2013) including language and visual displays such as facial expressions, gestures, and presumably arts. These functions subserved by the cerebellum in attentional, but also executive and default mode networks of the prefrontal cortex (PFC) and the posterior parietal cortex (PPC) along a precise timing of sensory predictions, including visuo-spatial integration (Ivry and Fiez 2000; Schmahmann 2010; Buckner 2013), and a specific cerebellar involvement in probalistic reasoning of external events (Vandervert 2018), which are integrated in fast and unconscious automatic processing.

The neuroanatomical and neurofunctional connections of cerebellar areas to cerebral networks of high-order domains strengthen the hypothesis that the cerebellum interfaces with information sequencing and the temporal characteristics of cognitive and affective cues. One crucial mode of providing such high-order processes is represented by the specific cerebellar actions in sensory encoding as it has been emphasized to attention (Allen et al. 1997; Courchesne et al. 1994; Breska and Ivry 2020). The specific impact of distinct cerebellar areas on these sensory attention modes is to guide incoming information from the environment, thus manipulate objects and forward this detailed information for further integration, facilitating the efficiency of sensory systems with its connections to motor and non-motor areas, including autonomic neural systems (Gao et al. 1996; Parsons and Fox 1997; Ivry and Fiez 2000). The cerebellum provides feedback to cerebral activity in ongoing behavior, including adaptation to subsequent or even future sequelae, pointing to a predictive interface in task-dependent neural networks in error-based corrective mechanisms. This means that the cerebellum compares the signals of stimulus-activated neural networks for a predictive match, forming anticipatory adjustments to signals from the cerebral cortex and therefore supporting optimal outcomes (Courchesne and Allen 1997; Paulin 1997; Ivry and Fiez 2000; Ito 2008; Schmahmann 2010). These predictive functions of the cerebellum are presumably related to the internal model of Ito (2008), which explain feedforward cerebellar-cerebral modes in guiding sequential and temporal information of ongoing visual or acoustic task-related cognitive and affective processing most effectively (Ivry and Keele 1989; Moberget and Ivry 2016; Bares et al. 2019). Accordingly, the cerebellum function as a versatile supervised learning machine of spatiotemporal information that constructs or generates internal models for the control and adaptation of behavior across contexts (Koziol et al. 2014). This role outlines the cerebellar relevance to executive networks in face of increasing situational complexity (D'Angelo and Casali 2013). This assumption fits observed clinical findings of disturbed motor and non-motor functions in cerebellar disorders, indicating a blurring of time-dependent fine-graded signal of motor and non-motor coordination (Ivry and Keele 1989; Ito 2008; Schmahmann 2010; Argyropoulos et al. 2020) as has been found in a variety of perceptual tasks across different sensory modalities such as audition (Ivry and Keele 1989; Mangels et al. 1998), vision (Ivry and Diener 1991; Nawrot and Rizzo 1995), somatosensation (Grill et al. 1994), and speech (Ackermann et al. 1999). A principal feature of an internal model is the harmonious tracking and control of interrelated activities between a perceived object (including sensory and attentional domains) and following stages of object processing (Ito 2008) that involves manipulation of mental representation and behavioral decision such as the analysis and computation of specific sensory modalities to suitable motor, cognitive, and affective behavior outcome (O'Halloran et al. 2016). This specific cerebellar mode in generating internal models may be particularly critical for art perception and evaluation. The context under which stimuli are viewed influences aesthetic appreciation by modulating the individuals' predictions regarding the sensory and emotional reactions within art engagement (Chatterjee and Vartanian 2014) and the associated neural activity in the OFC and medial prefrontal cortex (Kirk et al. 2009b), which suggests that activity within emotional and reward neural circuitry is biased by subjects' prior expectations about the likely hedonic value of stimuli according to their source.

An interesting model directly relates the aesthetic experience within a predictive coding framework (Kesner 2014; Van de Cruys and Wagemans 2011; Wagemans 2017; see also Wolf 2020). According to this model, a temporary state of unpredictability (i.e. prediction error) is important for the emergence of perceptual pleasure when encountering a work of art. Within this framework, to engage with a work of art, viewers must adapt their prediction mechanisms to recognize art as a specific class of objects whose nature is ambiguous. Moreover, viewers sustain a flow of predictions, from low-level sensory predictions required for object recognition, to more abstract semantic, conceptual, and affective inferences aimed at grasping the meaning of the artwork (Kesner 2014). Aesthetic pleasure is experienced when the perceiver succeeds in solving the prediction error and moves from an initial state of high uncertainty that captures attention (higher prediction errors), to a final state of the models' refinement (higher predictability and a reduction of the prior prediction errors). Critically, the process of minimizing prediction errors is further, and perhaps decisively, affected by the viewer's access to external facts, extra-pictorial information, such as artwork captions or titles, that cannot be gathered from the visible configuration of the image itself. Still, the observer's mindset, like personality traits, affective style, art expertise, as well as the momentary psychosomatic state, determines which top-down expectations and predictions are generated, and form priors that operate in the perception of art (Kesner 2014). The cerebellum may play a role in these predictive mechanisms.

Accordingly, as Thach (1998, 2007) and also Schmahmann (2010) outlined, the cerebellum is linked to cognitive activities, presumably by regulating the speed, smootheness, capacity, consistency, and appropriateness or otherwise accuracy of the underlying processes in cerebral cortex and therefore as a skillfull execution of mental acts including embodied affective constituents (Leiner et al. 1986; Thach 1998; Ito 2008; Schmahmann 2010). In regard to the requested mode of the cerebellum in visual art, the findings in several clinical and neuroimaging trials for supporting neural networks in imagery tasks are quite intriguing in approaching a comprehensive view of the cerebellum in visual perception and analysis of art objects (Decety et al. 1990; Parsons et al. 1997; Sergent et al. 1992). Different domains of the working memory are active for many aspects of art creativity and perception by retrieving and monitoring specific informations including the anticipation of sequences along executive, spatial, and tonal function levels, as it has been also proposed for music practice (Chen et al. 2008; Schulze and Koelsch 2012). The cerebellar efficacy to specific art training, whether in painting or music performance, is probably due to a discrete neuroplasticity and the resulting cerebro-cerebellar improvement of the central executive functions of working memory. Moreover, as it has been argued for music training (Lee and Noppeney 2011), cerebellar-premotor circuitries deem to work on a forward model mapping integrating, i.e. blending or binding visual, auditory, and tactile information. According to Ito (1997) and Vandervert (2015), the improvement of the crucial working memory here can be understood as the result of the learning of error-driven cerebellar internal models, whereby these error-driven adaptive cerebellar internal models progressively increase the speed, consistency, and appropriateness of the central executive (and other components) of working memory in different, among others, visuo-spatial domains (Thürling et al. 2012). The cerebellum provides moment-to-moment, unconscious, very short time-scale, anticipatory information (Akshoomoff et al. 1997) for cognitive, emotional, and motor integration, and, thereby, for voluntary control also of art creation and perception. Interestingly, Yomogida et al. (2004) suggested a critical involvement of the cerebellum in mental visual synthesis, assuming that this visual synthesis consists of taking part of various personal conceptions and combining them to give new forms and images more selective (Vandervert 2015). This consideration might be of particular interest when applying the approach of the development of creativity in modern art to new forms and gestures, such as Picasso elaborating his artistic virtuosity in the paintings of the middle creative periods (see example in Fig. 14.3), which might be also a result of blending of internal models within old and new visuo-spatial contexts as provided by responsible areas of the prefrontal and parietal, but also the cerebellum (Lee and Noppeney 2011). In fact, as Picasso was driven by a cognitive-emotional intent concerning his concept of the purpose of art, this cognitive-emotional intent and conception arising in the cerebral cortex drives the blending of cerebellar internal models (Imamizu et al. 2007) learned during acquisition of his skills of art composition and during his real-time professional renderings. Accordingly, these cerebellar internal models are sent to and blended in the cerebral cortex before and during the rendering of his art, with each painting feeding back in a positive feedback loop to his ongoing artist development. As this ongoing development takes place in this positive feedback loop the art would become increasingly "abstract" (Vandervert 2022).

Nevertheless, the cerebellum in association with the parietal, in particular PPC, and the strong connections to lateral (dorsolateral) and medial (ventromedial and orbitofrontal) areas of PFC, are likely to be involved in feedforward control (Ito 2008; Schmahmann 2010; Buckner et al. 2011), which is emphasized by the elaborated growth of these brain regions in human evolution (Ito 2008; Schmahmann 2010; Buckner 2013; Neubauer et al. 2018; Marek et al. 2018). The evolution of cerebello-cerebral connections to these prefrontal, parietal, and temporal areas underpins the presumed cerebellar involvement to the frontoparietal networks with its broad processing in high-order domains such as creativity and art experiences (Zaidel 2013). As Marek et al. (2018) suggested, the lateral and posterior parts of the cerebellum are disproportionately expanded in the human brain, co-activating with the cortex across a vast array of control-related functions supported by the frontoparietal network (Marek and Dosenbach 2018), including error processing (Dosenbach et al. 2006; Fiez 1996), task switching (Monsell 2003), and language (Mariën and Borgatti 2018). The functional development of the parietal cortex to orientation, attention, cue perception, sensomotoric processing and visuo-spatial integration, fits cerebellar developments in visuo-spatial processing, working memory, social cognition and also affective processing. A prominent growth of these brain parts is therefore fairly representative for the increasing need for human communication to meet the demands of adapting between the internal conditions to specific external conditions of the environment (Neubauer et al. 2018; Marek et al. 2018). In addition to cerebellar coding of motor and sensory patterns, cognitive and affective-behavioral patterns come into question here in order to map external events as well as artistically designed mapping of experiences and assumptions, reality and imagination in the respective contexts in the best possible way and to derive decisions or plans of action (Ivry and Fiez 2000; Zaidel 2013). The cerebellum is indeed active, i.e. its posterior parts, especially lobule VII with crus I and II, in cognitive and affective tasks, but also vermis with its phylogenetically older parts in connection with limbic networks, in the acquisition of emotional information (Koziol et al. 2014). Since these areas are also active in simple as well as complex action decisions, cerebral-cerebellar connections are assumed to process incoming sensory signals within visual neuronal process pathways in the form of art representations in detail and assign multimodally to the cognitive and affective as well as motor and autonomic reaction or action levels.

## 14.5 Conclusion

Since the proposal of the Cerebellar Cognitive Affective Syndrome or otherwise Schmahmann's syndrome (Schmahmann and Sherman 1998) that described executive functioning, language, visuo-spatial deficits and anomalous affective behaviors following cerebellar dysfunction, a growing number of studies focused their investigations on the cerebellar role in high-order domains of our behavior. This new research led to a more comprehensive appreciation of the cerebellum as a critical node of extended networks allocated to

**Fig. 14.3** Woman in a fish hat, Picasso 1942. Under permission of http://freepicture24.blogspot.com

high-level and more abstract cognitive and affective processing, through anatomical and functional connections with both cortical and subcortical structures in the cerebrum (Buckner et al. 2011; Habas 2018; Habas et al. 2009; Sang et al. 2012).

Notwithstanding the advance of our knowledge about high-level cerebellar functions, the contribution of the cerebellum to art experiences, and in particular to art creativity and art appreciation, has been almost completely neglected. The findings reviewed in the present chapter suggest that posterior cerebellar regions, predominantly in lobule VII with its Crus I and I as well as the vermis comprising cortico-cerebellar and limbic-cerebellar networks, should be considered of particular interest in diverse large-scale neural networks of aesthetic processing, including art perception and appreciation as well as creative thinking. Considering the cerebellar role in context-based predictions and the involvement of predictive mechanisms in driving aesthetic pleasure as well as improvisation and creativity, the cerebellar functional significance in neuroaesthetics may rely on its ability to implicitly implement and coordinate both low-level sensorimotor predictive mechanisms and higher-level inferences requiring the appraisal of the cognitive and affective salience of stimuli. Future research is needed to disentangle the specific role of the cerebro-cerebellar networks in different facets of aesthetic experiences.

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