Journal of Educational and Developmental Psychology; Vol. 14, No. 2; 2024
ISSN 1927-0526 E-ISSN 1927-0534
Published by Canadian Center of Science and Education

Hot Executive Function in Autism Spectrum Disorder: A Brief Narrative Review

Evangelia-Chrysanthi Kouklari[1], Antonios I. Christou[2] & Stella Tsermentseli[3]

[1] Department of Child Psychiatry, Aghia Sophia Children's Hospital, School of Medicine, National and Kapodistrian University of Athens, Athens, Greece

[2] Department of Special Education, University of Thessaly, Volos, Greece

[3] Department of Primary Education, University of Thessaly, Volos, Greece

Correspondence: Evangelia-Chrysanthi Kouklari, Department of Child Psychiatry, Aghia Sophia Children's Hospital, School of Medicine, National and Kapodistrian University of Athens, Athens, 11527, Greece. Tel: +30-213-201-3298. E-mail: evakouklar@gmail.com

Received: May 24, 2024 Accepted: June 15, 2024 Online Published: June 24, 2024

doi:10.5539/jedp.v14n2p13 URL: http://doi.org/10.5539/jedp.v14n2p13

Abstract

Executive function (EF), encompassing high-order cognitive processes essential for goal-directed behavior, is often impaired in Autism Spectrum Disorder (ASD). This review addresses the problem of limited understanding regarding the distinction between "cool" and "hot" EF, their respective manifestations, and developmental trajectories in ASD. While cool EF in ASD has been widely investigated, the impairments and development of hot EF are less explored despite potentially also playing a role in ASD's socio-cognitive challenges. The purpose of this narrative review is to synthesize existing literature on hot EF and its development in ASD, particularly in relation to cool EF. Our approach involves a comprehensive examination of current studies to identify gaps and propose directions for future research. The review highlights the scarcity of studies on hot EF in ASD and concludes that targeted interventions should address both cool and hot EF deficits. Future research directions include longitudinal studies, neural investigations, and culturally diverse samples to further elucidate the role of hot EF in ASD. Understanding these distinctions can refine intervention strategies, ultimately enhancing support for individuals with ASD.

Key words: Autism Spectrum Disorder, cool Executive Function, hot Executive Function

1. Introduction

1.1 Executive Function

Autism Spectrum Disorder (ASD) is a multifaceted neurodevelopmental disorder characterized by impairments in social interactions, communication (both verbal and non-verbal), and distinctive patterns of behaviour (i.e., specific mannerisms, intense focus on particular interests, and repetitive actions); *Diagnostic and Statistical Manual of Mental Disorders* [DSM]-5 - TR, American Psychiatric Association, 2022). While these are the primary diagnostic criteria for ASD, research to date has also identified a range of deficient cognitive features that are also commonly seen in individuals with ASD. Among these are impairments in executive function (EF), which refers to a set of high-order, goal-directed cognitive processes involved in problem-solving and engagement with the social world (Diamond, 2013). The organizational structure and arrangement of EF have been the subject of an ongoing debate.

Historically, EF has predominantly been examined from a purely cognitive perspective –despite its diversity– largely neglecting the role of motivation and emotion in its functioning. Research conducted through lesion and neuroimaging studies (for a review see Salehinejad et al., 2021) in the past twenty years suggests that various tasks of EF engage distinct areas of the prefrontal cortex and that EF abilities fluctuate from "hot" to "cool", depending on the emotional or motivational significance of the task (Zelazo, 2020; Zelazo & Carlson, 2012). Cool EF involves cognitive processes that are decontextualized, emotionally neutral, and focus on tasks that are more abstract and cognitive in nature. These functions typically include working memory, inhibitory control, cognitive flexibility, and problem-solving. Cool EF is regulated by the prefrontal cortex and is believed to rely on lateral prefrontal regions, such as the dorsolateral and ventrolateral prefrontal cortex (e.g., Stuss, 2011). Hot EF, on the

other hand, involves cognitive processes that are elicited in emotional and motivational situations. Hot EF processes involve affective decision-making (i.e., the process of selecting among different options under risk), delay of gratification (i.e., the ability to delay an immediate reward in exchange for a larger reward at a later designated time), and delay discounting (i.e., propensity to devalue delayed rewards; Reynolds et al., 2002). Brain regions including the orbitofrontal cortex and ventromedial prefrontal cortex are implicated in these processes (Stuss, 2011). The conceptualization of EF is continually evolving as understanding the distinct features of cool and hot EF is essential for comprehending their neurocognitive underpinnings and their impact on various aspects of social behavior. Zelazo and colleagues have been at the forefront of this research and have investigated the evolution of cool and hot EF in typically developing children along with the neurocognitive mechanisms that underlie these processes. One of their key focus was the further understanding of the hot EF development (versus cool) which led them to suggest that the two aspects develop at different rates, and likely follow different trajectories (e.g., Zelazo & Carlson, 2012). While cool and hot EF processes are perceived as distinct, they are considered to cooperate as components of a larger adaptive function, adapting to the demands of each task (Zelazo, 2020).

Evidence regarding the hot EF manifestation and developmental progression (along with the cool one) in ASD is very scarce to date. The relevance of delineating between hot and cool EF in the context of ASD lies in the unique socio-cognitive challenges faced by individuals on the spectrum. While deficits in cool EF have been well-documented within the spectrum (e.g., Demetriou et al., 2018), recent data suggest that impairments in affective hot EF, may also play a significant role in socio-cognitive abilities of the ASD phenotype (e.g., Kouklari et al., 2019; Kouklari et al., 2023). Understanding the distinction between hot and cool EF in ASD may have important implications for designing interventions and support strategies tailored to the specific needs of ASD, especially considering the emotional and motivational/rewarding aspects of cognitive processes (i.e., hot EF).

It should be noted at this point that there is a disagreement in the literature in terms of whether Theory of Mind (ToM) should be treated as a process of the hot EF domain. Certain authors suggest that socio-cognitive abilities like ToM, emotion regulation, emotional intelligence, or moral judgment could be included in the category of hot EF (e.g., Anderson et al., 2008; Zimmerman et al., 2016), while others suggest that such capabilities are closely linked to, but do not belong to hot EF (e.g., Kouklari et al., 2017, 2018, 2019; Yu et al., 2021; Zelazo et al., 2005). ToM might be connected to emotional regulation and social behavior in certain situations, particularly when individuals need to respond to the mental states of others. Nevertheless, it is generally treated as a socio-cognitive variable rather than a hot EF aspect. The current review thus primarily centers its attention on the examination of core hot EFs, specifically affective decision-making, delay of gratification, and/or delay of discounting, which are explicitly linked to the processing of emotional and motivational impulses.

Considering the evolving conceptualization of EF, and its distinction into “hot” and “cool” domains, this narrative review endeavors to synthesize existing literature to investigate the manifestation and trajectory of progression of hot EF in the autism spectrum (relative to cool EF). Our review seeks to provide further insight into understanding the expression of hot EF deficits and development in ASD which could likely inform the implementation of targeted interventions and identify areas for further exploration.

1.2 Development of hot EF in Typical Development

EF emerges around the age of 2 years and experiences significant and rapid development from 3 to 6 years of age (e.g., Carlson, 2005; Jones et al., 2003). In typical development, in middle childhood, age-related improvements have been observed mostly for cool EF (for a systematic review see García et al., 2021), while hot EF development presents mixed results. Longitudinal evidence from middle childhood (Almy et al., 2018; Lensing & Elsner, 2018) for “hot” affective decision-making has shown that the enhancements associated with age persisted throughout middle childhood and beyond but conversely, it has also been reported that progression for affective decision-making may stabilize by 8 years old (Audusseau & Juhel, 2015).

Furthermore, Steinbeis et al. (2016) demonstrated noteworthy advancements associated with age in a “hot” delay discounting task, followed though by a diminished inclination in middle childhood to devalue rewards of high value that entail prolonged waiting periods. Hao (2017) and Wilson et al. (2018) did not observe age-related advancements in their studies and, instead, reported a ceiling effect by the age of seven years when utilizing a delay of gratification task akin to the Marshmallow task. Developmental data from adolescence report enhancements in hot EF more consistently (e.g., Crone & van der Molen, 2007; Hooper et al., 2004; Poon, 2018; Prencipe et al., 2011). It is important to note that adolescents often do not perform at ceiling levels on measures of hot EF, suggesting ongoing development throughout adolescence and beyond (e.g., Prencipe et al., 2011; Hooper et al., 2004). Contrary to cool EF’s linear age improvements during the transition from childhood to adolescence, hot EF

somewhat seems to present nonlinear changes beyond childhood. For example, Poon (2018) documented a bell-shaped curve exhibiting an ascending trajectory during early adolescence, a peak during middle adolescence (around ages 14 and 15), and a declining trend from middle to late adolescence (at age 17) for hot EF (used gambling tasks for "hot" delay aversion and affective decision-making). In early childhood, EF appears to exhibit a relatively more unidimensional nature, but as development advances, it may undergo specialization into two distinct functions (Casey, 2015; Zelazo & Carlson, 2012). However, as the development of hot EF seems to depend on the types of tasks used to assess them, results should be interpreted with caution.

1.3 Hot EF Deficits and Development in ASD

Prior to delving into the discussion of hot EF in ASD, it is paramount to present a brief overview of cool EF deficits and development within the spectrum. This sequential approach is essential for elucidating their distinct features within ASD. The vast majority of studies investigating EF in ASD have primarily focused on cool EF and consistently report deficient cool EF compared to typically developing peers (for a meta-analysis see Demetriou et al., 2018). Studies on the developmental trajectory of cool EF in children and adolescents with ASD have indicated either a delayed progression throughout development (e.g., Chen et al., 2016; Happé et al., 2006) or persistent impairments that do not reach the performance levels of controls, even though some age-related improvements have been reported (e.g., Andersen et al., 2015a; Fossum et al., 2021; Kouklari et al., 2018, 2019; Luna et al., 2007; Ozonoff & McEvoy, 1994). These observations might indicate that while cool EF seems to remain impaired throughout ASD development, the maturation processes from childhood to adolescence may manifest certain preservation. Nevertheless, it is worth noting that there have been studies that reported no discernible improvement or even performance deterioration with increasing age for some cool EF (i.e., working memory) in childhood and adolescence in ASD (e.g., Andersen et al., 2015b; Kouklari et al., 2018).

Deficits in hot EF have direct clinical implications for children with ASD, as they may associate with challenges in socio-cognitive and adaptive functioning (due to the affective nature of hot processes). By gaining a better understanding of these deficits, clinicians can tailor interventions to address specific socio-emotional and socio-cognitive difficulties in ASD. To date, only a few studies have attempted to explore hot EF within the ASD population. Results have shown impairments in affective decision-making in children and adolescents with ASD (e.g., Kouklari et al., 2017, 2019; Yechiam et al., 2010) but for delay of gratification/discounting results are mixed. Some studies (e.g., Antrop et al., 2006; Demurie et al., 2012) found no impairments contrary to more recent ones that consistently report deficient performance in delay of discounting or delay of gratification in ASD (e.g., Chantiluke et al., 2014; Faja & Dawson, 2015; Warnell et al., 2019). Exploring the association between hot EF impairments and ASD symptomatology (e.g., difficulties in social communication and repetitive behaviors), could shed more light on the underlying mechanisms driving the heterogeneity of ASD manifestations. This understanding is crucial for developing targeted interventions that address the unique needs of children with ASD.

In terms of the hot EF development within ASD, there is very limited research, but it seems to suggest that the developmental trajectory of hot EF differentiates to cool EF. Exploring the developmental trajectories of hot EF in ASD could establish a foundation for clarifying, primarily on a theoretical level, whether there are delays, deviance, or persistent deficits across development, identifying thus critical periods for intervention and support. By recognizing the developmental nuances of hot EF deficits, timely and effective interventions could be implemented to support individuals with ASD across the lifespan. To the best of our knowledge, only three studies to date (Kouklari et al., 2018; Kouklari et al., 2019; Kouklari et al., 2023) have investigated the hot EF development in childhood and adolescence within the autism spectrum. One of the first cross-sectional studies (Kouklari et al., 2018), reported that for hot EF abilities (i.e., affective decision-making and delay discounting) there were no statistically significant differences between children and adolescents with ASD, indicating a lack of improvement with age. These two hot EF abilities exhibited interruptions in development, diverging from the majority of cool EF trajectories, which demonstrated alterations in adolescence. A later longitudinal study (Kouklari et al., 2019) indicated that hot affective decision-making was improved after a year in children (7-11 years) with ASD. However, it should be noted that their performance remained deficient compared to controls at both time points. Hot delay discounting presented no statistically significant developmental improvements in children with ASD. Finally in a more recent examination (Kouklari et al., 2023) it was indicated that the cross-sectional trajectory of hot affective decision-making declined from middle childhood to early adolescence but subsequently improved by mid-adolescence. Similarly, hot delay discounting presented a non-linear developmental pattern characterized by three distinct phases of advancement and deterioration in its trajectory. These limited findings suggest variable developmental trajectories for cool and hot EF in ASD and highlight the need for further investigation.

Comprehending how hot and cool EF developmental trajectories evolve over time in ASD (relative to typical development) can identify critical periods of vulnerability, potential developmental delays, or atypical patterns that may contribute to the behavioral phenotype of ASD. By pinpointing specific developmental stages or domains where deficits in hot EF emerge or exacerbate, interventions can be tailored to address these areas effectively.

1.4 The Hot-Cool EF Distinction Model in ASD

In an up-to-date comprehensive review (Moriguchi and Phillips, 2023), authors analyzed data from conceptual distinction, factor analysis, cognitive complexity, and neuroimaging research – regarding the evaluation of the cool and hot EF distinction model in typical development – and concluded that cool EF may differentiate relative to hot EF during childhood; however, this differentiation may not always be consistent or evident.

Such an in-depth analysis regarding the hot-cool EF distinction in ASD has not yet been carried out. To date, findings from limited research (e.g., Kouklari et al., 2018, 2019; Kouklari et al., 2023) arise mainly from neuropsychological data, suggesting that the developmental trajectory of hot EF may differ from cool EF, both in terms of age and time in ASD. Moreover, Kouklari et al. (2018) conducted correlational analysis in ASD which revealed no significant relations between hot and cool EF. Subsequently, Kouklari et al. (2019) reported differing predictive patterns for each domain in a longitudinal study. Specifically, hot and cool EF aspects were observed to predict distinct social and developmental outcomes in ASD. For instance, early cool EF was found to predict later ToM false belief in both typical development and ASD, whereas early hot delay discounting predicted later ToM mental state/emotion recognition only in ASD (Kouklari et al., 2019). Taken together, these findings suggest a preliminary indication of separate hot and cool aspects in ASD. Nevertheless, further longitudinal studies spanning the lifespan are necessary to provide deeper insights into the neural underpinnings of cool and hot EF in ASD (Welsh & Peterson, 2014). Validating the cool-hot EF distinction model in ASD can contribute to refining diagnostic criteria and enhancing diagnostic precision. By delineating distinct profiles of cool and hot EF deficits in ASD, clinicians can more effectively differentiate ASD from other neurodevelopmental disorders, identify potential early markers of deficits and predict long-term outcomes and trajectories.

2. Directions for Future Research

Future directions for research on hot EF in ASD should prioritize several key areas:

Firstly, investigating the neural underpinnings of hot EF through neuroimaging techniques is crucial in order to determine how hot EF deficits may contribute to core symptoms of the spectrum, such as difficulties in emotion recognition/understanding and/or social behavior. For example, studying the interaction between brain regions implicated in hot EF and those affected in ASD, such as the social brain network (see Sato and Uono, 2019), could provide valuable insights, especially with regards to the involvement hot EF may have in adaptive/social functioning of individuals with ASD. Understanding the impact hot EF deficits have on these areas can inform intervention strategies and support systems.

Secondly, given the complexity of studying cool and hot EF, researchers should also prioritize the development of more appropriate tasks that can facilitate a more accurate identification of hot EF and elucidate the processes encompassed by “hot processes”.

Thirdly, future longitudinal studies with more than two-time points are required to explore the developmental trajectories of hot EF in ASD. These studies should utilize structural equation modeling and factor analysis techniques for a comprehensive examination. By understanding how hot EF skills develop from childhood to adolescence and into adulthood in ASD (i.e., investigating whether it constitutes a unitary or multidimensional construct, along with cool EF), researchers can gain insights into individual differences and identify critical developmental periods of vulnerability for interventions.

Finally, it should be highlighted at this point that as recommended by Moriguchi and Phillips (2023), future hot EF work could be also conducted in non-WEIRD (Western, Educated, Industrial, Rich, and Democratic) countries. Most research is still heavily based on participants from WEIRD countries, while it is still unknown whether and how the cool-hot EF model is differentiated in non-WEIRD backgrounds, let alone in individuals with ASD from such backgrounds. Including diverse samples can provide a more global perspective on the development and manifestation of hot EF in ASD.

3. Clinical and Practical Implications

Implications for clinical practice should focus on assessment and intervention. The vast majority of previous research on EF assessments and interventions has mainly investigated cool EF aspects. However, it is crucial to consider the unique challenges faced by individuals with ASD, particularly their specific deficits in hot EF.

3.1 Assessment and Evaluation

Assessment protocols should incorporate evaluations of hot EF functioning in ASD, in order to provide insights into an individual's ability to make adaptive decisions in emotionally and motivationally charged situations. Thus, recognizing the specific deficits in hot EF is vital as it can lead to implementing interventions designed to improve such abilities as well as socio-cognitive functioning, a critical area often impacted in individuals with ASD.

3.2 Intervention Strategies

Interventions should adopt a holistic approach that simultaneously targets both cool and hot EF. This means integrating strategies that improve cognitive processes like working memory, inhibitory control, and cognitive flexibility (cool EF) alongside those that enhance affective decision-making, delay of gratification, and delay discounting (hot EF). By addressing both domains, the intervention can support a comprehensive improvement in EF. Exploring the use of technology-based interventions, such as virtual reality (VR) and computer-based training programs, can offer engaging and immersive platforms to target hot EF deficits. VR environments can simulate real-life emotionally charged cognitive situations, providing a safe space for individuals with ASD to practice and develop their hot EF skills. These interventions can be tailored to individual needs, offering personalized and adaptive training opportunities that gradually increase in complexity as the individual's skills improve, enhancing the ability of individuals with ASD to navigate emotionally charged cognitive and socio-cognitive situations effectively.

4. Conclusions

As the study of hot EF presents unique challenges, continued investigation in this area is warranted in order to enhance our understanding of the emotional/ motivational factors of cognitive processes in ASD. By exploring the hot EF deficits and their distinct developmental trajectories (relative to cool EF), tailored interventions can be devised to address the specific needs of ASD. Further research into the neural basis of hot EF, longitudinal studies, and cross-cultural investigations are essential for refining intervention strategies. In essence, ongoing research in this domain is crucial for advancing our understanding of hot EF in ASD and enhancing support for individuals across the spectrum.

Funding

None.

Informed Consent

Not applicable.

Provenance and Peer Review

Not commissioned; externally double-blind peer reviewed.

Data Availability Statement

Not applicable.

Competing Interests Statement

The authors declare that there are no competing or potential conflicts of interest.

References

Almy, B., Kuskowski, M., Malone, S. M., Myers, E., & Luciana, M. (2018). A longitudinal analysis of adolescent decision-making with the Iowa Gambling Task. *Developmental psychology*, *54*(4), 689-702. https://doi.org/10.1037/dev0000460

American Psychiatric Association. (2022). *Diagnostic and statistical manual of mental disorders (5th ed. TR)*. Author.

Andersen, P. N., Skogli, E. W., Hovik, K. T., Egeland, J., & Øie, M. (2015a). Associations Among Symptoms of Autism, Symptoms of Depression and Executive Functions in Children with High-Functioning Autism: A 2 Year Follow-Up Study. *Journal of autism and developmental disorders*, *45*(8), 2497-2507. https://doi.org/10.1007/s10803-015-2415-8

Andersen, P. N., Skogli, E. W., Hovik, K. T., Geurts, H., Egeland, J., & Øie, M. (2015b). Working memory arrest in children with high-functioning autism compared to children with attention-deficit/hyperactivity disorder: results from a 2-year longitudinal study. *Autism: the international journal of research and practice*, *19*(4), 443-450. https://doi.org/10.1177/1362361314524844

Anderson, V., Anderson, P. J., Jacobs, R., and Smith, M. S. (2008). Development and assessment of executive function: from preschool to adolescence. In V. Anderson, R. Jacobs, and P. J. Anderson (Eds.), *Neuropsychology, Neurology, and Cognition. Executive functions and the Frontal Lobes: A Lifespan Perspective* (pp. 123-154). Taylor & Francis.

Antrop, I., Stock, P., Verté, S., Wiersema, J. R., Baeyens, D., & Roeyers, H. (2006). ADHD and delay aversion: the influence of non-temporal stimulation on choice for delayed rewards. *Journal of child psychology and psychiatry, and allied disciplines*, *47*(11), 1152-1158. https://doi.org/10.1111/j.1469-7610.2006.01619.x

Audusseau, J., & Juhel, J. (2015). Working memory in children predicts performance on a gambling task. *The Journal of genetic psychology*, *176*(1-2), 38-54. https://doi.org/10.1080/00221325.2014.1002749

Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology, 28*(2), 595-616. https://doi.org/10.1207/s15326942dn2802_3.

Casey B. J. (2015). Beyond simple models of self-control to circuit-based accounts of adolescent behavior. *Annual review of psychology*, *66*, 295-319. https://doi.org/10.1146/annurev-psych-010814-015156

Chantiluke, K., Christakou, A., Murphy, C. M., Giampietro, V., Daly, E. M., Ecker, C., …, & Rubia, K. (2014). Disorder-specific functional abnormalities during temporal discounting in youth with Attention Deficit Hyperactivity Disorder (ADHD), Autism and comorbid ADHD and Autism. *Psychiatry research*, *223*(2), 113-120. https://doi.org/10.1016/j.pscychresns.2014.04.006

Chen, S. F., Chien, Y. L., Wu, C. T., Shang, C. Y., Wu, Y. Y., & Gau, S. S. (2016). Deficits in executive functions among youths with autism spectrum disorders: an age-stratified analysis. *Psychological medicine*, *46*(8), 1625-1638. https://doi.org/10.1017/S0033291715002238

Crone, E. A., & van der Molen, M. W. (2007). Development of decision making in school-aged children and adolescents: evidence from heart rate and skin conductance analysis. *Child development*, *78*(4), 1288-1301. https://doi.org/10.1111/j.1467-8624.2007.01066.x

Demetriou, E. A., Lampit, A., Quintana, D. S., Naismith, S. L., Song, Y. J. C., Pye, J. E., … & Guastella, A. J. (2018). Autism spectrum disorders: a meta-analysis of executive function. *Molecular Psychiatry*, *23*(5), 1198-1204. https://doi.org/10.1038/mp.2017.75

Demurie, E., Roeyers, H., Baeyens, D., & Sonuga-Barke, E. (2012). Temporal discounting of monetary rewards in children and adolescents with ADHD and autism spectrum disorders. *Developmental science*, *15*(6), 791-800. https://doi.org/10.1111/j.1467-7687.2012.01178.x

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135-68. https://doi.org/10.1146/annurev-psych-113011-143750

Faja, S., & Dawson, G. (2015). Reduced delay of gratification and effortful control among young children with autism spectrum disorders. *Autism: the international journal of research and practice*, *19*(1), 91-101. https://doi.org/10.1177/1362361313512424

Fossum, I. N., Andersen, P. N., Øie, M. G., & Skogli, E. W. (2021). Development of executive functioning from childhood to young adulthood in autism spectrum disorder and attention-deficit/hyperactivity disorder: A 10-year longitudinal study. *Neuropsychology, 35*(8), 809-821. https://doi.org/10.1037/neu0000768

García, L. S., Merchán, A. P., Phillips-Silver, J., & González, M. J. G. (2021). Neuropsychological Development of Cool and Hot Executive Functions Between 6 and 12 Years of Age: A Systematic Review. *Frontiers in Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.687337

Hao, J. (2017). Do Children with Better Inhibitory Control Donate More? Differentiating between Early and Middle Childhood and Cool and Hot Inhibitory Control. *Frontiers in psychology*, *8*, 2182. https://doi.org/10.3389/fpsyg.2017.02182

Happé, F., Booth, R., Charlton, R., & Hughes, C. (2006). Executive function deficits in autism spectrum disorders and attention-deficit/hyperactivity disorder: examining profiles across domains and ages. *Brain and cognition*, *61*(1), 25-39. https://doi.org/10.1016/j.bandc.2006.03.004

Hooper, C. J., Luciana, M., Conklin, H. M., & Yarger, R. S. (2004). Adolescents' performance on the Iowa Gambling Task: Implications for the development of decision making and ventro-medial prefrontal cortex. *Developmental Psychology*, *40*, 1148-1158. https://doi.org/10.1037/0012-1649.40.6.1148

Jones, L. B., Rothbart, M. K., & Posner, M. I. (2003). Development of executive attention in preschool children.

Developmental Science, *6*(5), 498-504. https://doi.org/10.1111/1467-7687.00307

Kouklari, E. C., Tagkouli, E., Tsermentseli, S., Ntre, V., Pehlivanidis, A., & Papanikolaou, K. (2023). Cross-sectional Developmental Trajectories of Executive Function and Relations to Theory of Mind in Autism Spectrum Disorder. *Journal of Pediatric Neuropsychology*, *9*, 157-174. https://doi.org/10.1007/s40817-023-00148-2

Kouklari, E. C., Thompson, T., Monks, C. P., &Tsermentseli, S. (2017). Hot and cool executive function and its relation to theory of mind in children with and without autism spectrum disorder. *Journal of Cognition and Development*, *4*(18), 399-418. https://doi.org/10.1080/15248372.2017.1339708

Kouklari, E. C., Tsermentseli, S., & Monks, C. P. (2018). Hot and cool executive function in children and adolescents with autism spectrum disorder: cross-sectional developmental trajectories. *Journal of Child Neuropsychology*. https://doi.org/10.1080/09297049.2017.1391190

Kouklari, E. C., Tsermentseli, S., & Monks, C. P. (2019). Developmental trends of hot and cool executive function in school-aged children with and without autism spectrum disorder: links with theory of mind. *Development and Psychopathology*, 1-16. https://doi.org/10.1017/S0954579418000081

Lensing, N., & Elsner, B. (2018). Development of hot and cool executive functions in middle childhood: Three-year growth curves of decision making and working memory updating. *Journal of experimental child psychology*, *173*, 187-204. https://doi.org/10.1016/j.jecp.2018.04.002

Luna, B., Doll, S. K., Hegedus, S. J., Minshew, N. J., & Sweeney, J. A. (2007). Maturation of executive function in autism. *Biological psychiatry*, *61*(4), 474-481. https://doi.org/10.1016/j.biopsych.2006.02.030

Moriguchi, Y., & Phillips, S. (2023). Evaluating the Distinction between Cool and Hot Executive Function during Childhood. *Brain sciences*, *13*(2), 313. https://doi.org/10.3390/brainsci13020313

Ozonoff, S., & McEvoy, R. E. (1994). A longitudinal study of executive function and theory of mind development in autism. *Developmental Psychopathology*, *6*(3), 415-31. https://doi.org/10.1017/S0954579400006027

Poon, K. (2018). Hot and Cool Executive Functions in Adolescence: Development and Contributions to Important Developmental Outcomes. *Frontiers in psychology*, *8*, 2311. https://doi.org/10.3389/fpsyg.2017.02311

Prencipe, A., Kesek, A., Cohen, J., Lamm, C., Lewis, M. D., & Zelazo, P. D. (2011). Development of hot and cool executive function during the transition to adolescence. *Journal of Experimental Child Psychology*, *108*, 621-637. https://doi.org/10.1016/j.jecp.2010.09.008

Reynolds, B., De Wit, H., & Richards, J. B. (2002). Delay of gratification and delay discounting in rats. *Behavioural Processes*, *59*(3), 157-168. https://doi.org/10.1016/S0376-6357(02)00088-8

Salehinejad, M. A., Ghanavati, E., Rashid, M. H. A., & Nitsche, M. A. (2021). Hot and cold executive functions in the brain: A prefrontal-cingular network. *Brain and Neuroscience Advances*, *5*. https://doi.org/10.1177/23982128211007769

Sato, W., & Uono, S. (2019). The atypical social brain network in autism: advances in structural and functional MRI studies. *Current opinion in neurology*, *32*(4), 617-621. https://doi.org/10.1097/WCO.0000000000000713

Steinbeis, N., Haushofer, J., Fehr, E., & Singer, T. (2016). Development of Behavioral Control and Associated vmPFC-DLPFC Connectivity Explains Children's Increased Resistance to Temptation in Intertemporal Choice. *Cerebral cortex*, *26*(1), 32-42. https://doi.org/10.1093/cercor/bhu167

Stuss, D. T. (2011). Functions of the frontal lobes: relation to executive functions. *Journal of the International Neuropsychological Society: JINS*, *17*(5), 759-765. https://doi.org/10.1017/S1355617711000695

Warnell, K. R., Maniscalco, S., Baker, S., Yi, R., & Redcay, E. (2019). Social and delay discounting in autism spectrum disorder. *Autism research: official journal of the International Society for Autism Research*, *12*(6), 870-877. https://doi.org/10.1002/aur.2085

Welsh, M., & Peterson, E. (2014). Issues in the conceptualization and assessment of hot executive functions in childhood. *Journal of the International Neuropsychological Society*, 20, 152-156. https://doi.org/10.1017/S1355617713001379.

Wilson, J., Andrews, G., Hogan, C., Wang, S., & Shum, D. H. K. (2018). Executive function in middle childhood and the relationship with theory of mind. *Developmental neuropsychology*, *43*(3), 163-182. https://doi.org/10.1080/87565641.2018.1440296

Yechiam, E., Arshavsky, O., Shamay-Tsoory, S. G., Yaniv, S., & Aharon, J. (2010). Adapted to explore: reinforcement learning in Autistic Spectrum Conditions. *Brain and cognition*, *72*(2), 317-324. https://doi.org/10.1016/j.bandc.2009.10.005

Yu, Y. T., Li, H. J., Tsai, C. H., Lin, C. H., Lai, S. S., & Chen, K. L. (2021). Cool Executive Function and Verbal Comprehension Mediate the Relation of Hot Executive Function and Theory of Mind in Children with Autism Spectrum Disorder. *Autism research: official journal of the International Society for Autism Research*, *14*(5), 921-931. https://doi.org/10.1002/aur.2412

Zelazo, P. D. (2020). Executive Function and Psychopathology: A Neurodevelopmental Perspective. *Annual review of clinical psychology*, *16*, 431-454. https://doi.org/10.1146/annurev-clinpsy-072319-024242

Zelazo, P. D., & Carlson, S. M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives*, *6*, 354-360. https://doi.org/10.1111/j.1750-8606.2012.00246.x

Zelazo, P. D., Qu, L., & Müller, U. (2005). Hot and cool aspects of executive function: Relations in early development. In W. Schneider, R. Schumann-Hengsteler, & B. Sodian (Eds.), *Young children's cognitive development: Interrelationships among executive functioning, working memory, verbal ability and theory of mind* (pp. 71-95). Lawrence Erlbaum Associates.

Zimmerman, D. L., Ownsworth, T., O'Donovan, A., Roberts, J., & Gullo, M. J. (2016). Independence of Hot and Cold Executive Function Deficits in High-Functioning Adults with Autism Spectrum Disorder. *Frontiers in human neuroscience*, *10*, 24. https://doi.org/10.3389/fnhum.2016.00024

Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/4.0/).