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Domains of self-regulation in autism, Down syndrome, and Williams syndrome: Condition-specific or transdiagnostic?

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ABSTRACT

Background: This questionnaire study examined regulatory control in the conditions of autism, Down syndrome, and Williams syndrome by assessing effortful control and executive function across cognitive, emotional, social, and sensory domains.
Method: A bespoke parent-report questionnaire was developed. Parents of children aged 5–13 with these conditions and neurotypical peers participated ($n = 231$). Factor analysis was used to identify regulatory structures across groups, and Bayesian analyses compared group factor scores. Cluster analysis explored whether profiles grouped by diagnosis or regulatory pattern.
Results: Factor analysis identified a four-factor structure of self-regulation comprising Cognitive Regulation, Sensory Regulation, Emotional Regulation, and Social Regulation. Subsequent analyses showed that all neurodiverse children scored lower than neurotypical children on Cognitive Regulation, with no meaningful differences between the neurodiverse groups. All neurodiverse groups also scored lower than neurotypical children on Sensory Regulation, although autistic children scored meaningfully lower than both the Down syndrome and Williams syndrome groups. For Emotional Regulation, autistic children and children with Williams syndrome scored lower than neurotypical children, whereas children with Down syndrome did not; within the neurodiverse groups, the only meaningful difference was that autistic children scored lower than children with Down syndrome. For Social Regulation, only autistic children scored meaningfully lower than neurotypical children. Cluster analysis indicated that children tended to group according to shared patterns of self-regulation rather than by diagnostic category, although some diagnostic clustering was also evident.
Conclusions: These findings highlight both shared and condition-specific challenges, suggesting that diagnosis provides an initial guide to an individual's regulatory profile but should be supplemented by a needs-based assessment to better inform personalized intervention.

1. Introduction

Self-regulation involves the management and modulation of thoughts, feelings, attention, and behavior (Karoly, 1993). It is a key

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skill that can be applied across multiple contexts; indeed, a growing body of research emphasizes the crucial role of self-regulation in fostering positive developmental outcomes. For example, self-regulation serves as a foundation for other key developmental skills, such as theory of mind (Carlson et al., 2004), the ability to comply with environmental demands (Kopp, 1989; Stifter et al., 1999), and general school adaptation (Blair, 2002; Howse et al., 2003), all of which contribute to positive academic outcomes in children (Blair & Razza, 2007). Children with well-developed self-regulation are therefore better able to navigate the complex social, emotional, and academic challenges they face, being more likely to be accepted by their peers, engage actively in learning opportunities, and develop a strong desire to participate in school activities (Bailey & Jones, 2019; Valiente et al., 2012). In contrast, children with lower self-regulation skills often face challenges in school settings. They tend to behave restlessly in the classroom, struggle with maintaining attention, find it harder to become invested in school activities, and have fewer friends (Anderson, 2002; Blair, 2002; McClelland et al., 2007; for a review, see Riggs et al., 2006).

Self-regulation is not only a key skill for neurotypical (NT) children but is also an important developmental factor for neurodiverse individuals, many of whom have difficulties in developing self-regulation skills (e.g., Gardiner & Iarocci, 2018; Hill, 2004; Rhodes et al., 2010; Samyn et al., 2014). The current paper focuses on self-regulation in three conditions – autism, Williams syndrome, and Down syndrome – that have previously been associated with challenges in this broad domain. Autism Spectrum Condition (ASC; the term ASC is used throughout this manuscript in preference to autism spectrum disorder [ASD], reflecting terminology preferred by some autistic individuals and increasingly used within autism research) is a neurodevelopmental condition characterized by significant and persistent difficulties in social communication and interaction, along with restricted and repetitive behaviors (American Psychiatric Association, 2013). Self-regulation challenges have been reported in autistic children as young as 1 year old (Gomez & Baird, 2005). Although regulatory dysfunction is not part of the formal diagnostic criteria, it is frequently observed (Barrett et al., 2013). Williams syndrome is a relatively rare neurodevelopmental condition, with estimates in prevalence rates varying from 1 in 7,000 to 1 in 20,000 (Kozel et al., 2021; Strømme et al., 2002), that is caused by spontaneous genetic deletion of around 25 to 27 genes on chromosome 7 (Tassabehji, 2003). Individuals with Williams syndrome's ability to self-regulate and control their own impulsivity has been researched across social and cognitive contexts (John & Mervis, 2010; Rhodes et al., 2010), with variability in reported findings but generally recognized difficulties in inhibition and self-regulation particularly with social approach behaviors (Little et al., 2013; Lough et al., 2016). Down syndrome is caused by triplication of chromosome 21 (Patterson, 2007), occurring in approximately 15 in 10,000 births (Mai et al., 2019). Issues in cognitive regulation, particularly related to the role of working memory in supporting action, are common in Down syndrome (Doerr et al., 2019). In addition, children with Down syndrome are often reported to be highly social, showing more social-seeking behavior than their peers (Fidler, 2005), and may experience issues in the regulation of negative affect (Jahromi et al., 2008).

The cognitive and social profiles of these groups are often compared to one another, but typically only in studies that include two of these three conditions (Asada & Itakura, 2012; Hamner et al., 2020; Jarrold et al., 1999). In addition, much of the remaining research on self-regulation in a neurodiverse context focuses on autistic individuals. Given this, and what we already know about challenges in self-regulation associated with each of these conditions (see below), they collectively provide an informative context for investigating any diagnosis-specific profiles of self-regulation. At the same time, a key current question in the study of neurodiverse development is the extent to which any strengths and challenges are better understood within a transdiagnostic approach (Apperly et al., 2024; Astle et al., 2022; Michelini et al., 2024). This argues that a diagnosis provides an oversimplified framework in which to understand cognitive and behavioral traits because many such traits are common to more than one condition (e.g., Mareva et al., 2024). In addition, because any particular strength or challenge might not be characteristic of every individual with a given diagnoses, providing tailored interventions based on children's individual profile of needs may be more effective than using the same single intervention for every child with that diagnosis (Hoza & Shoulberg, 2024). The fact that the current study employed three different diagnostic samples therefore allowed us to directly examine the extent to which any particular profile of self-regulation is specific to each condition or whether profiles of need extend beyond diagnostic category labels and are shared by individuals with different conditions. The latter would clearly be more consistent with a transdiagnostic approach and would imply that any support for an individual's self-regulation should be based on their specific profile of need rather than diagnostic-specific assumptions.

A second key innovation was that the current study built on and extended, a recent model of regulation proposed by Bailey and Jones (2019). This is a comprehensive theoretical framework that integrates effortful control (regulation in the context of rewards, desires, and emotionally salient situations, as well as in social interactions) and executive function (regulation in cognitively demanding, often emotionally neutral tasks) to provide a more integrative account of self-regulation. Specifically, Bailey and Jones propose the concept of a "regulatory gestalt", comprising three interrelated domains of self-regulation: cognitive regulation, emotional regulation (emotion regulation), and social regulation. The current study adopted these three domains and further extended the framework by incorporating sensory regulation. This extension was informed not only by prior literature documenting sensory regulatory challenges in neurodiverse populations (e.g., Baranek et al., 2013; Glod et al., 2020; Will et al., 2019), but also by the inclusion of sensory-related behaviors in well-established measures of self-regulation and temperament (e.g., the BRIEF-2; Gioia et al., 2015; CBQ-Short; Putnam & Rothbart, 2006). More specifically, the present study conceptualized sensory regulation as the behavioral aspect of sensory processing, including regulatory responses such as sensory seeking or avoidance. These behavioral responses are thought to reflect adaptive strategies in response to sensory input, for example to prevent sensory overload or to support self-soothing (e.g., MacLennan et al., 2022).

Taken together, Bailey and Jones's (2019) model and previous research on sensory regulation in neurodiverse populations therefore provided the theoretical rationale for the initial selection of the four proposed domains. The following sections provide more detail on the theoretical basis for each of the four domains of regulation within our extended model, and a summary of existing research in these areas with autistic individuals, individuals with Williams syndrome, and individuals with Down syndrome.

1.1. Cognitive regulation

According to Bailey and Jones' (2019) model, cognitive regulation involves managing and modulating thoughts, controlled attention, and related behaviors, such as planning, organizing, problem-solving, and setting goals. This concept closely aligns with the definition of executive function (EF), which encompasses a broad range of processes required for the control and execution of complex behaviors, including metacognitive components such as planning, inhibition, working memory, and cognitive flexibility (Anderson, 2002; Pellicano, 2012). Some definitions of executive control also include the factor of controlled attention, reflecting the strategic allocation of attentional processes to task-relevant rather than task-irrelevant features and processes (Burgoyne et al., 2023; Burgoyne & Engle, 2020; Kane & Engle, 2002).

In autistic children, multiple domains of cognitive control, including inhibition, working memory, cognitive flexibility, planning, and attentional control, have been extensively studied across samples of varying ages, with mixed results (Christ et al., 2007; Demetriou et al., 2018; Geurts et al., 2004; Joseph et al., 2005; Keehn et al., 2013; Luna et al., 2007; Soroor et al., 2022; Steele et al., 2007; Tonizzi et al., 2022; Williams et al., 2005). Large individual differences in executive function have been observed (Pellicano, 2010), along with age-related differences in specific EF components (Van Den Bergh et al., 2014). Both parent reports and a recent review and meta-analysis by Bausela-Herreras (2024) confirmed significant clinical issues in flexibility, inhibition, and global executive functioning among autistic children compared to neurotypical peers. Cognitive regulation is also a commonly studied area in Williams syndrome, with researchers using parent reports and experimental tasks. Parent report measures commonly implicate poorer regulatory abilities than neurotypical individuals (Brawn & Porter, 2018; Commodari et al., 2025; Leyfer et al., 2012). Some experimental studies of inhibition provide support for the view that inhibitory control is a relative difficulty for individuals with Williams syndrome (Menghini et al., 2010; Osorio et al., 2012), although this discrepancy is more often present when comparison groups are matched on chronological age and less common when matching for mental age (Van Jaarsveldt et al., 2026). Individuals with Williams syndrome have also been reported to have difficulties with attentional control and sustained and selective attention compared to neurotypical individuals (Greer et al., 2013; Menghini et al., 2010). Furthermore, experimental assessments of the cognitive regulation skills of individuals with Down syndrome have produced clear evidence of relative challenges in working memory and shifting (Doerr et al., 2019; Lanfranchi et al., 2010), with somewhat more mixed findings regarding tests of inhibition (Fontana et al., 2021) see also (Tungate & Conners, 2021). Similar findings have emerged from studies examining parent- (and, in some instances, teacher-) report measures of cognitive regulation, which document elevated levels of difficulties with working memory and planning; issues in inhibition have sometimes also been observed, but less consistently (Csumitta et al., 2022; Daunhauer et al., 2014; Lee et al., 2011; Van Deusen et al., 2022). Difficulties in attentional control have also been reported in individuals with Down syndrome (Commodari et al., 2025).

1.2. Emotional regulation

According to Bailey and Jones (2019), emotional regulation involves managing emotions and behaviors, including emotion knowledge, expression, empathy and perspective-taking; basic emotion knowledge helps children develop empathy and perspective-taking by allowing them to understand others' experiences. More broadly, emotion regulation is the ability to adjust emotions and expressions to achieve personal goals or adapt to social environments (Calkins & Hill, 2007; Eisenberg & Spinrad, 2004).

Research on regulation in emotional contexts in neurodevelopmental conditions is somewhat limited (see Shaffer et al., 2023). However, emotional regulation difficulties are particularly well-documented in autistic children (Jahromi et al., 2012; Loveland, 2005; Prizant et al., 2003). Autistic individuals also often struggle with recognizing and verbalizing their emotions, exhibiting a relative lack of emotional awareness and clarity (e.g., Bormann-Kischkel et al., 1995; Fein et al., 1987; Hobson, 1986; Loveland et al., 1995). Even when they do recognize others' emotions, they may find it hard to grasp their precise meaning or how to adjust their own behavior in response during social interactions (Kamio & Toichi, 1998; Loveland & Tunali, 1991). Individuals with Williams syndrome can struggle with regulation of anxiety-related emotions (Royston et al., 2017) and have difficulties in emotion comprehension and understanding (Ikeda et al., 2023; Ng et al., 2014). Indeed, Greiner de Magalhães et al. (2022) found that individuals with Williams syndrome scored relatively poorly on emotional regulation as measured by the BRIEF-2 (Gioia et al., 2015). Children with Down syndrome also appear to face some challenges in emotional regulation (Shaffer et al., 2023). However, the large number of studies that have presented various versions of the BRIEF to parents of individuals with Down syndrome very consistently find that the Emotional Control subscale of this measure represents an area of relative strength, with no evidence of particular problems relative to age- or ability-referenced norms (e.g., Csumitta et al., 2022; Daunhauer et al., 2014; Miezah et al., 2024; Onnivello et al., 2022).

1.3. Social regulation

Bailey and Jones (2019) argue that social regulation encompasses managing relationships and social interactions, understanding social cues, social problem-solving, and fostering prosocial behavior. It requires not only perceiving and interpreting relevant information about others but also evaluating and adjusting one's own behavior based on this knowledge (Loveland, 2001).

Difficulties in social functioning are a core diagnostic characteristic of autism, marked by ongoing challenges in social communication and interaction (American Psychiatric Association, 2013). Additionally, autistic individuals often find it difficult to regulate their social behavior, particularly in response to mild stressors or unfamiliar environments (Bishop-Fitzpatrick et al., 2015). Research shows that autistic individuals tend to use rigid, rule-based strategies learned from previous experiences when navigating complex social-emotional situations, rather than responding flexibly to each unique circumstance (Hadwin et al., 1996; Yirmiya et al., 1992).

Individuals with Williams syndrome are often considered hypersocial with researchers highlighting evidence of "enhanced empathy" and "indiscriminate social behavior" (Capitão et al., 2011; Karmiloff–Smith & Thomas, 2003). There is also evidence that individuals with Williams syndrome can struggle with understanding and identifying social cues (Davies et al., 1998), such as those that indicate when it is appropriate to enter other people's personal space (Lough et al., 2016). Fisher and Morin (2017) found that the key regulatory skill of socio-communication was self-identified as a particular issue by individuals with Williams syndrome. Some researchers have reported social strengths in children with Down syndrome compared to children with other neurodevelopmental disabilities and relative to their other regulatory skills (Fidler, 2006; Fidler et al., 2008). However, the social regulatory abilities of individuals with Down syndrome may still be compromised to some degree. Guralnick et al. (2009) found that teachers rated children with Down syndrome as less prosocial and more asocial than their age-matched peers. Similarly, Kasari et al. (1995) found that children with Down syndrome engaged in fewer social references in social situations than neurotypical children. Issues of non-compliance with instructions within a social context have also been reported (e.g., Coe et al., 1999).

1.4. Sensory regulation

As an extension of Bailey and Jones' (2019) model, sensory regulation was conceptualized as the behavioral strategies that individuals use to regulate responses to sensory experiences (Dunn, 2002; Dunn, 2014; Piccardi and Gliga, 2022). Sensory processing can occur across multiple levels, including perceptual and emotional responses to sensory input. However, behavioral responses to sensory stimuli also occur (He et al., 2023) and can be understood as forms of regulation in response to sensory input (MacLennan et al., 2022) and its emotional impact on the individual (He et al., 2023). Accordingly, the present study conceptualized sensory regulation as being closely related to the behavioral level of sensory processing.

In autism, recent diagnostic frameworks, such as the DSM-5 (American Psychiatric Association, 2013), recognize sensory atypicalities as core features of the condition. Sensory differences affect nearly 74% of autistic children (Kirby et al., 2022) across various modalities, including taste (Avery et al., 2018), touch (Mikkelsen et al., 2018), audition (Williams et al., 2021), smell (Tonacci et al., 2017), and vision (Little, 2018). A meta-analysis by Ben-Sasson et al. (2019) reported that autistic individuals have more sensory regulatory challenges than neurotypical individuals, reflected especially in over-responsivity (heightened or aversive reactions to sensory input), under-responsivity (reduced or delayed responses to sensory input), and sensory seeking (a strong drive for or fascination with sensory input). There is less research on the sensory profiles of individuals with Williams syndrome, but studies suggest atypical sensory modulation, with hypo- or hyper-responsiveness to sounds being particularly common (John & Mervis, 2010). Furthermore, Powell and Van Herwegen (2022) reported that children with Williams syndrome demonstrated high levels of sensory difficulties across multiple quadrants of Dunn's (1997) framework, with most of the sample showing elevated registration (high threshold, passive behavioral strategy), sensitivity (low threshold, passive behavioral strategy), and avoidance (low threshold, active behavioral strategy), while a smaller but still substantial proportion showed higher-than-typical sensory seeking (high threshold, active behavioral strategy). Although research on sensory processing in children with Down syndrome is similarly limited, existing evidence indicates that they do exhibit sensory regulation difficulties (e.g., Bruni et al., 2010; van Jaarsveld et al., 2016; Will et al., 2019; Wuang & Su, 2011). Indeed, sensory differences in Down syndrome have been observed across multiple modalities, including auditory, tactile, vestibular, and oral processing (Brugnaro et al., 2024).

1.5. The current study

To assess these aspects of regulation, the current study designed and developed a prototype parent-based questionnaire tailored to our specific objectives. In designing this measure, existing instruments such as the CBQ-Short, BRIEF-P/BRIEF-2, and Compscale served as sources of inspiration. The CBQ-Short measures temperament and social behavior across 15 dimensions (Putnam & Rothbart, 2006) and has some focus on sensory regulation. The BRIEF-P includes 63 items assessing five aspects of executive function, with the BRIEF-2 serving as a recent adaptation that uses everyday behaviors reflecting executive functions, categorizing these into behavioral, emotional, and cognitive regulation. The Compscale (Lange & MacKinnon, 1987) contains 27 items rated by parents and teachers, measuring children's mastery of tasks, activities, and social situations. To further explore sensory regulation, additional measures were examined, including the Gilliam Autism Rating Scale-2 (GARS-2, Gilliam, 2006) and the Childhood Autism Rating Scale, Second Edition (CARS2, Schopler et al., 2010).

A preliminary version of the questionnaire consisted of 101 entirely new items developed for this study. These items were piloted with 45 psychology students who rated the extent to which each item reflected cognitive, social, emotional, or sensory regulation. Based on agreement ratings and discrepancy scores, items that were not clearly associated with a single domain were removed, resulting in the final questionnaire administered in the present study, comprising 84 items (20 cognitive, 20 social, 20 emotional, and 24 sensory regulation items) plus three attention-check questions. Subsequent rewording was applied to remove ambiguous terms and ensure relevance across the target sample (see Supporting Information 1 for further details on questionnaire development). Cognitive regulation questions pertained to managing thoughts and controlled attention, social regulation questions addressed interactions with others, emotional regulation questions focused on controlling internal emotional states, and sensory regulation questions were related to modulating responses to sensory input (see Supplementary Table 1 for the complete list of questionnaire items prior to item reduction following EFA). Parents/carers (hereafter, 'parents') were asked to rate each statement based on their child's behavior over the past six months compared to their peers.

In summary, the present study examined self-regulation in autistic children and children with Williams syndrome and Down syndrome using a parent-report questionnaire that was informed by Bailey and Jones' (2019) model of regulation but that additionally

examined sensory regulation. The study was exploratory and comparative in nature, and to that end also recruited parents of neurotypically developing children. Specifically, the study posed two research questions: (1) whether a meaningful multidimensional structure of self-regulation would emerge from the questionnaire, as examined using exploratory factor analysis (EFA), and (2) whether patterns of strengths and difficulties in self-regulation were condition-specific, or reflected a transdiagnostic pattern of being shared across conditions, as examined using cluster analysis.

2. Method

2.1. Participants

The study initially recruited 246 parents of children aged 5–13 years, comprising 124 parents of neurodiverse children (42 parents of autistic children, 41 parents of children with Williams syndrome, and 41 parents of children with Down syndrome) and 122 parents of neurotypical children. Recruitment of approximately 40 participants per neurodiverse group reflected the feasibility of recruiting

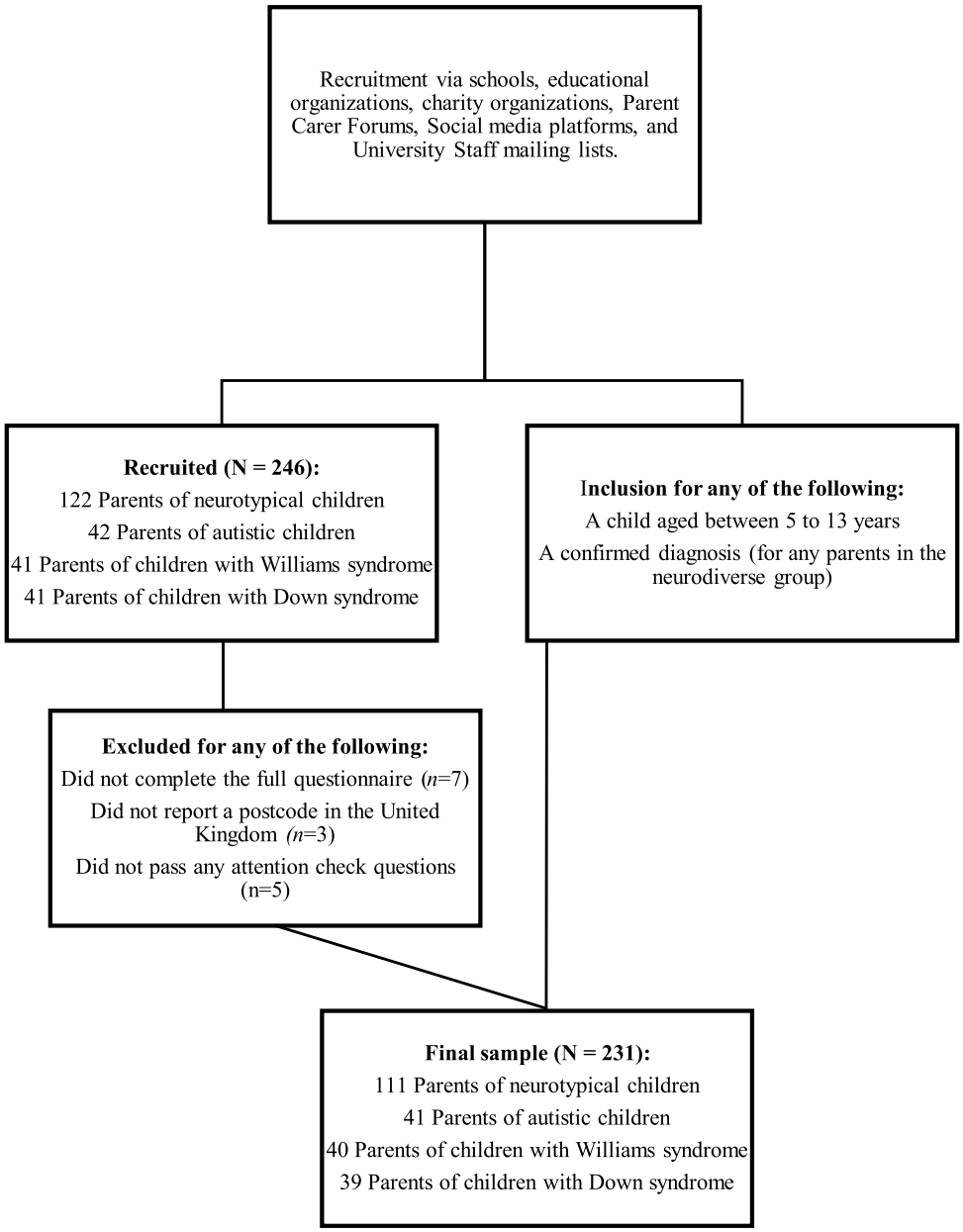


Fig. 1. Participant recruitment, inclusion, and exclusion flow diagram.

relatively low-incidence populations while maintaining comparable sample sizes for comparisons across neurodevelopmental groups. The neurotypical group was recruited to be broadly equivalent in size to the combined neurodiverse sample, allowing comparisons between neurotypical and neurodiverse participants. Sample sizes were consistent with the factor analytic and cluster analytic approaches described below. Although ideal participant-to-item ratios of 5–10 participants per item have been suggested for factor analysis (Nunnally, 1978; Pett et al., 2003), recommendations also emphasize absolute sample size, with total samples of approximately 200–300 considered adequate when communalities are acceptable and factors are well defined (Comrey & Lee, 2013; Kline, 2014; Tomchek & Dunn, 2007). For exploratory clustering approaches, although universally agreed upon sample size thresholds do not exist, recent methodological guidance suggests that approximately 20–30 participants per expected subgroup may be sufficient (Dalmaijer et al., 2022). Furthermore, the sample sizes were considered adequate for the planned Bayesian analyses examining group differences across the derived factor scores, as Bayesian approaches do not impose strict *a priori* sample size requirements (e.g., Berger & Wolpert, 1988; Van Doorn et al., 2021, see also sensitivity analyses reported in the Analysis Plan section).

The inclusion criteria were as follows: For all groups, participants were required to have a child between the ages of 5 to 13 years old, to be living in the United Kingdom, and be fluent in English. Parents of neurodiverse children were asked to confirm that their child had a formal diagnosis. Participants were not excluded if their child had any additional co-occurring diagnosis, rather they were asked to disclose any such co-occurrences.

The exclusion criteria were as follows: data from participants who failed to complete the full questionnaire ($n = 7$), reported postcodes that were not in the United Kingdom ($n = 3$), or failed any of the three attention-check questions ($n = 5$) were excluded, resulting in final sample sizes of 111 parents of neurotypical children, 41 parents of autistic children, 40 parents of children with Williams syndrome, and 39 parents of children with Down syndrome (see Fig. 1). Full demographic information for the sample is presented in Table 1.

Parents of autistic children were reached through local schools and educational institutions for autistic children, as well as organizations including Bristol Autism Support, Bath and North East Somerset Council's Specialist Autism Support Service, and the Bristol Parent Carer Forum. Parents of children with Williams syndrome were recruited through the Williams Syndrome Foundation. Being a member of the Williams Syndrome Foundation requires that the member or their child must have an official diagnosis of Williams syndrome. Parents of children with Down syndrome were contacted via organisations supporting Down syndrome families, including the Down Syndrome Association. Parents of neurotypical children were recruited through email outreach to local schools in the Bristol area, local parenting Facebook groups and through the University of Bristol staff mailing list. This study received ethical approval from the School of Psychological Science Human Research Ethics Committee at the University of Bristol under the approval code 15054.

2.2. Measures

This study utilized a parent-based self-regulation questionnaire, developed by the researchers, to assess self-regulation in both neurodiverse and neurotypical children. The questionnaire consisted of 84 items; each rated on a 0 to 10 scale. Reverse coding was applied to 59 items (e.g., a score of 10 was recoded to 0, 9 to 1, and so on), as those questions were phrased such that higher scores indicated greater difficulties with regulation (for more information see Supplementary Table 1). This adjustment ensured that higher scores consistently represented greater self-regulation across all items, maintaining uniformity and facilitating accurate interpretation of the results.

2.3. Procedure

The questionnaire was completed online via a Qualtrics link sent to participants. Participants were asked to answer each statement regarding their child's self-regulation in the past 6 months. Completion of the questionnaire took approximately 15 minutes.

Table 1
Demographic information for participants' children including age (Years:months), sex, ADHD co-occurrence, ASC co-occurrence, and socio-economic status z-scores.

Group	Age (years: months)		Sex			Co-occurring diagnosis		SES	
	M	*SD*	Male	Female	Unreported	ADHD	ASC	*M*	*SD*
NT	9:01	2:10	37	12	63	6	0	-0.35	0.96
ASC	9:06	2:10	28	8	4	11	NA	0.03	1.16
WS	9:09	2:05	22	16	2	4	4	-0.09	1.16
DS	9:05	2:06	17	13	10	5	2	-0.12	0.94

Note: NT = neurotypical, ASC = autism spectrum condition, WS = Williams syndrome, DS = Down syndrome. Socio-economic status (SES) information was derived from the participant's reported postcode and transformed into a z-score relative to the national distribution using the multiple deprivation index. This index ranks postcode areas within the UK across the seven weighted domains of income, employment, education, health, crime, housing, and living environment. This was then reverse coded meaning that a higher z-score corresponds to lower socio-economic status.

2.4. Analysis plan

A confirmatory factor analysis (CFA) was first conducted on the full sample to examine whether the four-factor structure proposed during questionnaire development could be confirmed. Given the poor fit of this model, an exploratory factor analysis (EFA) was subsequently performed to identify the underlying factor structure of the data. Internal consistency was then assessed for the final set of retained items and for each resulting subscale. Following identification of the factor structure and confirmation of the reliability of the resulting scales, the resultant factor loadings were used to calculate factor scores for each participant.

These factor scores were subsequently used to examine group differences in self-regulation across neurotypical, autistic, Williams syndrome, and Down syndrome groups using a Bayesian repeated-measures ANOVA (BANOVA). To further examine the pattern of group differences across factor scores, follow-up Bayesian independent-samples *t*-tests were conducted for all pairwise group comparisons within each factor score. Compared with traditional null-hypothesis significance testing (NHST) approaches, a Bayesian framework offers several advantages, including the ability to obtain evidence in favor of the null hypothesis and, in turn, distinguish between "absence of evidence" and "evidence of absence", allowing quantification of evidence for and against effects (Dienes, 2014; Keysers et al., 2020; Van Doorn et al., 2021). Following Jeffreys (1939), Bayes factors (BFs) between 1 and 3 were considered to indicate weak evidence for a given hypothesis, BFs between 3 and 10 to indicate moderate evidence, and BFs greater than 10 to indicate strong evidence.

Finally, given our emphasis on a transdiagnostic approach to strengths and challenges in regulation across neurodiverse populations, an exploratory cluster analysis was conducted using the EFA-derived factor scores.

All analyses were conducted using JASP (version 0.19.3; JASP Team, 2023), with the exception of cluster stability analyses and follow-up Bayesian independent-samples *t*-tests for pairwise group comparisons, which were conducted in R (version 4.3.1; R Core Team., 2023). Bayesian analyses used the default JASP prior scales ($r = 0.5$ for fixed effects, $r = 1.0$ for random effects, and $r = 0.354$ for covariates). Sensitivity analyses using alternative prior scales for fixed effects ($r = 0.25$, 0.707, and 1.0) yielded highly similar results, indicating that the conclusions were robust to prior specification.

3. Results

3.1. Confirmatory factor analysis

CFA was conducted on the sample of data from all parents to assess the fit to the four-factor model which the questionnaire was designed to test. The chi-square test was significant, $\chi^2(3396) = 7249.826$, $p < .001$, indicating that the hypothesized model did not provide an exact fit to the observed data. The comparative fit index (CFI), the Tucker-Lewis index (TLI), and the goodness-of-fit index (GFI) values were also examined to assess the fit to the model; CFI, TLI, and GFI have a range of 0–1 and values closer to 1 indicate a better fit. The resultant values (CFI = 0.696, TLI = 0.688, GFI = 0.506) were below the commonly accepted threshold of ≥ 0.90 (≥ 0.95 for a good fit), suggesting poor model fit. The CFA indicated that the original four-factor item structure did not fit the data well under the strict constraints imposed by CFA (i.e., items loading only on their designated factor and no substantial cross-loadings; Brown, 2015; Kline, 2023). Consequently, this model was not supported and a further EFA was conducted.

3.2. Exploratory factor analysis

An EFA was conducted on the data provided by all parents. Prior to conducting the EFA, the suitability of the data for factor analysis was assessed using Bartlett's test of sphericity and the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy. The results of Bartlett's test of sphericity, $\chi^2(3486) = 14081.316$, $p < .001$, indicated that the correlation matrix was not an identity matrix, making the data suitable for an exploratory factor analysis. The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was.933, which is considered excellent and exceeds the minimum criterion of.60, although three individual items had KMO values below .60 (between .50 and .60), suggesting potential issues with those specific variables. The item-to-item correlations of the self-regulation questionnaire ranged from low to high (−.40 to –.79), indicating meaningful relationships among items without evidence of excessive multicollinearity. Following confirmation that the correlation matrix was factorable, EFA was conducted. The number of factors was determined using parallel analysis based on principal components. Factor extraction was performed using principal axis factoring, with an oblique Promax rotation applied to allow for correlated factors. Missing data were handled using listwise deletion, and factor loadings $\geq .40$ were interpreted. Fit was acceptable according to RMSEA (.053, 90% CI [.051,.057]) and SRMR (.043), although TLI (.822) and CFI (.844) were slightly below the conventional threshold of.90.

Item reduction followed a stepwise iterative procedure (following Samuels, 2017). First, items with low communalities (<.20; corresponding to uniqueness >.80) were removed one at a time, with the analysis re-run after each removal. Six items were removed at this stage. Second, items that did not load substantially on any factor (i.e., no factor loading exceeded.40) were removed, resulting in the removal of a further seven items. Finally, items demonstrating problematic cross-loadings (i.e., loadings ≥.40 on multiple factors with cross-loadings > 75%) were evaluated for removal; however, no items met these criteria. In total, 13 items were removed, resulting in a final solution comprising 71 items (See Appendix A for the final 71-item questionnaire retained following exploratory factor analysis).

Following item removal, parallel analysis based on principal components supported retaining four factors: the fourth observed eigenvalue exceeded the corresponding simulated mean (3.199 vs. 2.054), whereas the fifth did not (1.933 vs. 1.977). The scree plot and interpretability of the factor solution were also considered. Collectively, these criteria resulted in the retention of four factors,

which were subsequently extracted. The first factor, identified as "Cognitive Regulation", encompassed 25 items loading ≥ .40 on this factor and primarily captured challenges in executive functioning and executive attention. These items had communalities ranging from.26 to.71 and an eigenvalue of 25.84. The second factor, identified as "Sensory Regulation", consisted of 21 items relating to sensory behaviors of avoidance and seeking. These items yielded communalities ranging from.34 to.70 and an eigenvalue of 3.77. The third factor, identified as "Emotional Regulation", included 14 items concerning emotional intensity, difficulties regulating emotions, and challenges modulating emotional responses. These items yielded communalities ranging from.202 to.706 and an eigenvalue of 3.20. Finally, the fourth factor, identified as "Social Regulation", comprised 11 items relating to social engagement, social initiation, and interpersonal functioning. These items yielded communalities ranging from.24 to.60 and an eigenvalue of 2.69. This four-factor solution explained 49.3% of the cumulative variance (see Supporting Information 2 for the questions and their loadings on each of the four factors derived from the EFA). Correlations among the four identified factors are presented in Supporting Information 3.

3.3. Internal reliability

Following the identification of the final factor structure through EFA, the internal consistency of the overall scale and each resulting subscale was examined. The internal consistency of the entire 71-item scale was excellent (α = 0.969, 95% CI [0.964, 0.974]; ωt = 0.971, 95% CI [0.967, 0.976]).

The reliability of each subscale was also calculated. Internal consistency was excellent for Factor 1 (Cognitive Regulation; α = 0.932, 95% CI [0.921, 0.942]; ωt = 0.946, 95% CI [0.936, 0.955]), Factor 2 (Sensory Regulation; α = 0.944, 95% CI [0.933, 0.954]; ωt = 0.945, 95% CI [0.935, 0.955]), and Factor 3 (Emotional Regulation; α = 0.895, 95% CI [0.876, 0.912]; ωt = 0.907, 95% CI [0.889, 0.924]). Factor 4 (Social Regulation) demonstrated good internal consistency (α = 0.859, 95% CI [0.834, 0.886]; ωt = 0.864, 95% CI [0.837, 0.888]). Item–rest correlations were calculated within each subscale. One item within the Emotional Regulation factor (Item 71, emotional: "They feel sad and disheartened when they cannot finish a task") showed a lower item–rest correlation (−0.264) but was retained due to its conceptual relevance. One item within the Social Regulation factor (Item 56, emotional: "They become excited about future treats, e.g. park after school or dessert after dinner") showed an item–rest correlation of.27; however, this item was also retained due to its meaningful factor loading within the EFA.

3.4. Factor scores and group comparisons

Having established the reliability of the EFA-derived scales, factor scores were calculated and used to examine group differences in self-regulation across neurotypical, autistic, Williams syndrome, and Down syndrome groups. The final 71 items retained from the EFA were used to calculate weighted factor scores.

Participant's item scores were first converted to z-scores using the mean and standard deviation of each item. These standardized scores were then weighted by their respective factor loadings and summed to produce factor scores for each participant. Descriptive statistics for the resulting factor scores are presented in Table 2.

To examine group differences in the resulting factor scores, a Bayesian repeated-measures ANOVA (BANOVA) was conducted on the data represented in Table 2, with group (neurotypical, autism, Williams syndrome, Down syndrome) as a between-participants factor, factor score (cognitive regulation, sensory regulation, emotional regulation, and social regulation) as a within-participants factor, and age included as a covariate.

Based on the results of this analysis, the best-supported model included group, age, and the group × factor score interaction ($BF_{10} = 5.821 \times 10^{63}$ relative to the null model, which included subject, random slopes, and factor score; Factor score was included in the null model because scores were standardized across the full sample, $M = 0$, $SD = 1$). Subsequent analysis of effects revealed extreme evidence for the inclusion of group ($BF_{incl} = 2.429 \times 10^{19}$) and the factor score × group interaction ($BF_{incl} = 1.570 \times 10^{44}$; see Fig. 2), indicating that the profile of relative difficulties across the four factor scores varied across groups. There was also strong evidence supporting the inclusion of age in the model ($BF_{incl} = 18.60$).

To further examine the potential influence of age, separate Bayesian ANCOVAs were conducted for each factor score, with group entered as a fixed factor and age as a covariate. Evidence for including age was weak for Cognitive Regulation (BFincl = 2.08), Emotional Regulation (BFincl = 1.10), and Social Regulation (BFincl = 0.54), and only exceeded the conventional threshold of 3 for Sensory Regulation (BFincl = 71.08). In contrast, there was evidence against including the age × group interaction in all analyses (BFincls = 0.018–0.119), suggesting that the observed group differences were not moderated by age. Furthermore, when age was included as a covariate and incorporated into the null model, evidence for group differences remained strong across all factor scores (BFincls = 4.37×10^{8} to 1.30×10^{26}), indicating that the findings were robust to the inclusion of age.

Table 2
Descriptive statistics for factor scores by group.

Group	Cognitive Regulation	Sensory Regulation	Emotional Regulation	Social Regulation
TD	8.79 (11.60) [6.60, 10.98]	5.58 (10.92) [3.52, 7.64]	2.69 (7.01) [1.37, 4.02]	1.95 (4.91) [1.02, 2.88]
ASC	-7.02 (8.49) [-9.70, −4.34]	-9.61 (7.49) [-11.97, −7.24]	-5.54 (5.05) [-7.13, −3.95]	-5.57 (4.39) [-6.95, −4.18]
WS	-10.41 (7.65) [-12.85, −7.96]	-3.73 (8.17) [-6.35, −1.12]	-2.55 (6.64) [-4.68, −0.43]	0.63 (4.31) [-0.74, 2.01]
DS	-7.51 (7.48) [-10.00, −5.01]	-2.31 (7.88) [-4.94, 0.32]	0.47 (6.01) [-1.54, 2.47]	-0.40 (4.97) [-2.06, 1.25]

Note. Values are presented as Mean (SD) [95% credible interval]. Credible intervals were obtained from Bayesian descriptive analyses.

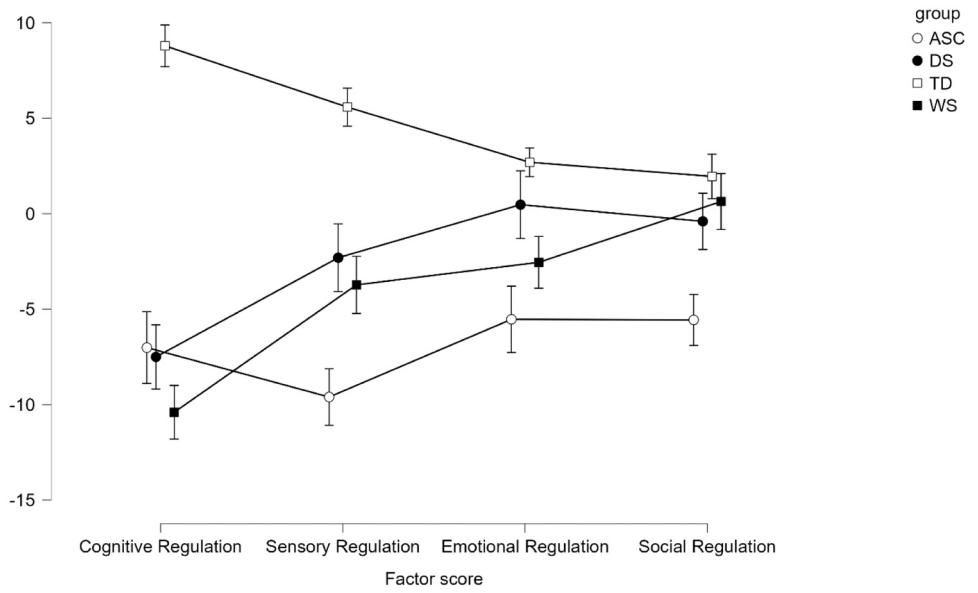


Fig. 2. Descriptive profiles of factor scores across diagnostic groups (error bars represent 95% credible intervals).

To clarify the pattern underlying the group × factor score interaction, follow-up Bayesian independent-samples *t*-tests were conducted in R (version 4.3.1; R Core Team., 2023) for all pairwise group comparisons and separately for Cognitive Regulation, Sensory Regulation, Emotional Regulation, and Social Regulation. Table 3 reports the resulting Bayes factors (BF_{10}), Cohen's d values, and 95% confidence intervals.

3.5. Cluster analysis on factor scores derived from the EFA

To explore any distinguishable self-regulation profiles within the sample, fuzzy c-means clustering was conducted in JASP (version 0.19.3; JASP Team, 2023) using the four standardized factor scores (Cognitive Regulation, Sensory Regulation, Emotional Regulation, and Social Regulation). The "Scale Features" option was enabled to ensure all factor scores contributed equally to the clustering solution. Solutions ranging from 2 to 10 clusters were evaluated using the default fuzzy c-means settings, with the maximum number of iterations increased to 1000. Cluster selection was based on multiple criteria, including the Bayesian Information Criterion (BIC), Akaike Information Criterion (AIC), within-cluster sum of squares (WSS), average silhouette coefficients, cluster sizes, and interpretability of the resulting profiles. Inspection of the model comparison plot showed that the rate of improvement in WSS diminished beyond approximately four clusters, while the lowest BIC was obtained for the four-cluster solution.

Accordingly, the optimal solution consisted of four clusters (see Fig. 3). The four-cluster solution explained 71.3% of the variance (R^2 =.713), produced relatively balanced cluster sizes (n = 54–64), and yielded an average silhouette coefficient of.280 (cluster-specific silhouette coefficients ranged from.20 to.41), indicating some overlap and moderate differentiation between clusters.

To assess robustness, additional sensitivity analyses were conducted by varying the fuzziness parameter (m = 1.5–2.5) and the maximum number of iterations (100–10,000), which produced highly similar solutions. Cluster stability was further evaluated in R

Table 3
Pairwise group comparisons for each factor score.

Comparison	Cognitive Regulation	Sensory Regulation	Emotional Regulation	Social Regulation
ASD vs DS	BF_{10}= 0.235; d= 0.04 [-0.40, 0.48]	BF_{10}= 501.9; d= -0.97 [-1.44, −0.51]	BF_{10}= 4781; d= -1.12 [-1.59, −0.65]	BF_{10}= 3152; d= -1.10 [-1.57, −0.63]
ASD vs TD	BF_{10}= 1.95×10^{19}; d= -1.46 [-1.86, −1.07]	BF_{10}= 7.62×10^{19}; d= -1.51 [-1.91, −1.11]	BF_{10}= 6.37×10^{7}; d= -1.27 [-1.65, −0.88]	BF_{10}= 6.60×10^{11}; d= -1.58 [-1.98, −1.18]
ASD vs WS	BF_{10}= 1.07; d= 0.42 [-0.02, 0.86]	BF_{10}= 26.81; d= -0.75 [-1.20, −0.30]	BF_{10}= 2.15; d= -0.51 [-0.95, −0.06]	BF_{10}= 9.86×10^{5}; d= -1.42 [-1.91, −0.94]
DS vs TD	BF_{10}= 3.10×10^{19}; d= -1.51 [-1.91, −1.11]	BF_{10}= 339.4; d= -0.77 [-1.14, −0.39]	BF_{10}= 0.645; d= -0.30 [-0.67, 0.06]	BF_{10}= 3.82; d= -0.48 [-0.85, −0.11]
DS vs WS	BF_{10}= 0.920; d= 0.40 [-0.04, 0.85]	BF_{10}= 0.323; d= 0.19 [-0.25, 0.64]	BF_{10}= 2.09; d= 0.51 [0.06, 0.96]	BF_{10}= 0.355; d= -0.22 [-0.66, 0.22]
TD vs WS	BF_{10}= 3.68×10^{14}; d= 1.80 [1.39, 2.22]	BF_{10}= 7750; d= 0.92 [0.54, 1.29]	BF_{10}= 357.3; d= 0.76 [0.39, 1.14]	BF_{10}= 0.556; d= 0.28 [-0.08, 0.64]

Note. BF_{10} values were obtained from Bayesian independent-samples *t*-tests. Cohen's d values are accompanied by 95% confidence intervals. BFs of 1–3, 3–10, and > 10 indicate weak, moderate, and strong evidence, respectively.

using bootstrap resampling. Jaccard coefficients ranged from.83 to.90 (M =.86), indicating that the identified clusters were reliably recovered across resamples.

The standardized cluster means across the four factor scores and the corresponding contingency table are presented in Fig. 4 and Table 4, respectively; Table 4 additionally shows the number of participants from each group in each cluster.

Cluster 1 ($n = 55$) was characterized by consistently negative scores across all four factors, particularly Factor 4 (Social Regulation). The cluster consisted of 49% autistic participants, 18% participants with Down syndrome, 15% participants with Williams syndrome, and 18% neurotypical participants. Cluster 2 ($n = 54$) displayed the highest positive scores across all four factors and consisted of 93% neurotypical participants, 6% participants with Down syndrome, and 2% participants with Williams syndrome. Cluster 3 ($n = 64$) was characterized by low-to-moderate negative scores on Factors 1–3 and a slightly positive score on Factor 4 (Social Regulation). This cluster consisted of 34% participants with Williams syndrome, 30% neurotypical participants, 22% participants with Down syndrome, and 14% autistic participants. Cluster 4 ($n = 58$) showed modestly positive scores across all four factors and consisted of 55% neurotypical participants, 21% participants with Down syndrome, 16% participants with Williams syndrome, and 9% autistic participants.

4. Discussion

This study aimed to explore differences in self-regulation, as reported by parents of children with neurodevelopmental conditions, using an extended version of a recent model of regulation proposed by Bailey and Jones (2019). In Bailey and Jones' model, self-regulation is divided into three domains: cognitive, emotional, and social. However, we further added a fourth domain of sensory regulation. This decision was informed by the observation that measures of executive functioning and effortful control often include items relating to sensory experiences or responses. It was also motivated by growing evidence that behavioral responses to sensory input, such as sensory seeking and avoidance, can serve important regulatory functions for neurodiverse individuals in response to differences in their sensory perceptual and emotional experiences (He et al., 2023; MacLennan et al., 2022; Robertson & Simmons, 2015; Verhulst et al., 2022). Using this framework, we developed a prototype questionnaire by generating a pool of items inspired partly by previous executive function and effortful control measures. This questionnaire was then given to parents of neurotypical children and parents of children with the neurodevelopmental conditions of autism, Williams syndrome, and Down syndrome. A key aim was to determine the extent to which self-regulatory profiles were specific to different diagnostic groups, or whether different profiles of regulation were common across conditions. While the first possibility is often assumed in the existing literature, the latter would be more in line with a transdiagnostic account of the development of self-regulation.

Confirmatory factor analysis on the questionnaire data from the full sample failed to provide support for the hypothesized four distinct regulation domains (cognitive, emotional, social, and sensory). However, exploratory factor analysis conducted on the same sample revealed a four-factor solution that was broadly consistent with the extended Bailey and Jones (2019) theoretical framework. This suggests that, although the strict CFA model was not supported when all items were constrained to load exclusively onto their originally proposed domains, the underlying structure of the questionnaire nevertheless reflected the expected regulatory constructs. Given the strict assumptions of CFA, including the requirement that items load only onto their designated factors and exhibit minimal cross-loadings (Brown, 2015; Kline, 2023), this finding is perhaps not surprising for a newly developed measure. Following a standardized EFA item reduction and refinement procedure (Samuels, 2017), four interpretable factors emerged, corresponding to Cognitive Regulation, Sensory Regulation, Emotional Regulation, and Social Regulation, providing preliminary evidence for the multidimensional nature of self-regulation.

Factor 1, labelled *Cognitive Regulation*, primarily reflected difficulties in the executive functions of working memory, inhibition, and planning, as well as in executive attention. Although the factor also included a small number of items from the social domain, these items were mainly related to social awareness and the cognitive monitoring of social situations rather than social behavior itself. For example, such items included "They often invade personal space without being aware of it" and "They laugh along with others even if they do not understand what is funny". This is consistent with evidence suggesting that executive functioning facilitates the cognitive

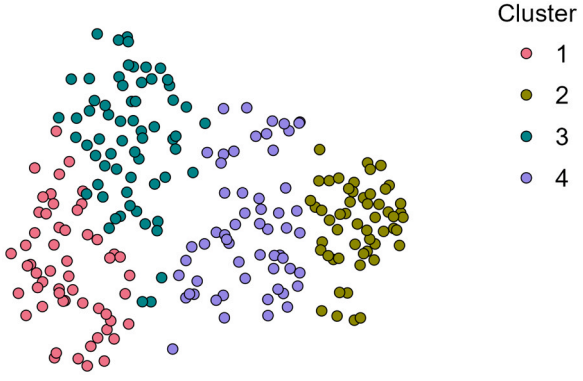


Fig. 3. t-SNE cluster plot of participants based on EFA-derived factor scores.

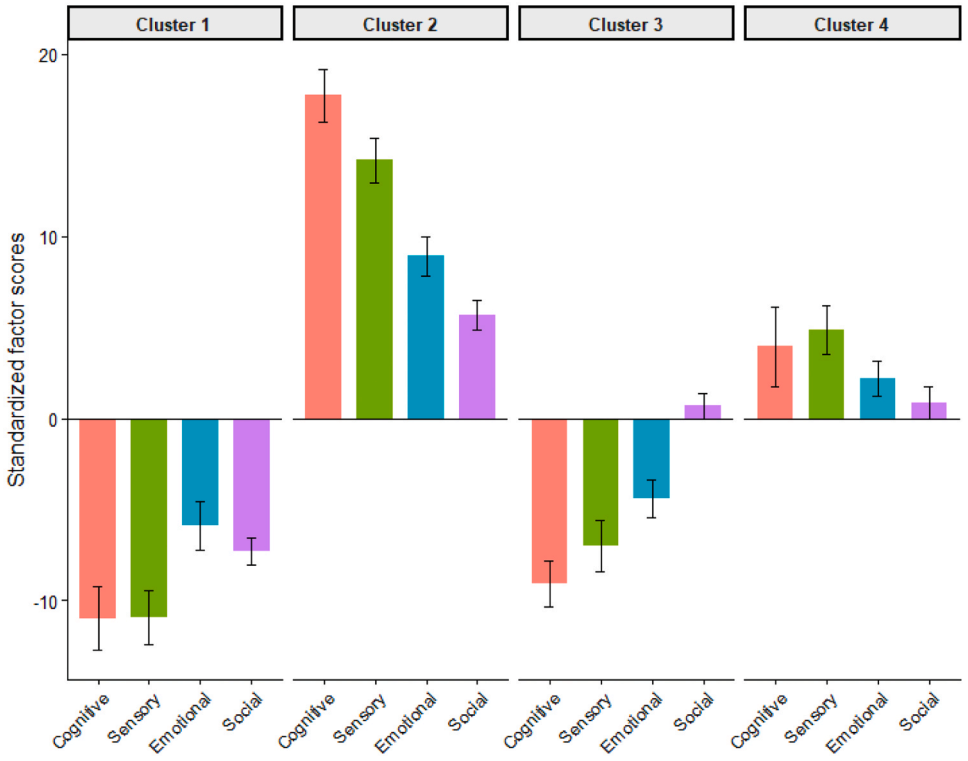


Fig. 4. Standardized cluster profiles across the four self-regulation domains (error bars represent 95% confidence intervals).

Table 4
Participant distribution by group across the four clusters.

Group	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Neurotypical	10	50	19	32
Autism	27	0	9	5
Williams syndrome	8	1	22	9
Down syndrome	10	3	14	12

skills required for successful social interaction (e.g., Moriguchi, 2014). Factor 2, labelled *Sensory Regulation*, mainly captured sensory regulatory behaviors in the form of sensory seeking and avoidance. Sensory regulatory behaviors are typically understood as behavioral responses to differences in sensory perception and the emotional experiences associated with sensory input (He et al., 2023), which should be distinguished from stereotyped or repetitive behaviors, which may arise from a range of underlying mechanisms beyond sensory factors alone (He et al., 2023). Factor 3, labelled *Emotional Regulation*, captured emotional intensity, difficulties regulating emotions, and challenges modulating emotional responses as expected. This factor also included only one sensory item, which clearly reflected sensory experiences at an emotional level ("They are sensitive to small injuries"). Factor 4, labelled *Social Regulation*, captured difficulties in social engagement, initiating social interactions, and broader interpersonal functioning, again as predicted by our theoretical framework. Although primarily reflecting social regulation, this factor also included two social-emotional items (originally conceptualised as emotional regulation items), consistent with evidence that emotional and social regulatory processes are closely intertwined and jointly contribute to social competence (e.g., Calkins, 1994; Denham et al., 2003).

The fact that the expected factor structure emerged from our prototype questionnaire, albeit via exploratory rather than confirmatory factor analysis, allows for a clear test of whether profiles of strengths and challenges across these four domains of regulation are condition-specific among the three neurodevelopmental conditions that were the focus of this study. Bayesian analysis of variance of resultant factor scores showed that, for Cognitive Regulation, all three neurodiverse groups scored meaningfully lower than the neurotypical group reflecting challenges in executive and attentional aspects of cognitive self-regulation. This finding aligns with previous evidence of executive functioning and attentional control difficulties in autism (e.g., Demetriou et al., 2018; Keehn et al., 2013), Down syndrome (Commodari et al., 2025; Lanfranchi et al., 2010), and Williams syndrome (e.g., Commodari et al., 2025; Costanzo et al., 2013). However, the absence of any meaningful differences in Cognitive Regulation factor scores among these three groups provides initial evidence of a shared pattern of challenges in cognitive self-regulation across these neurodiverse groups (e.g., Otterman et al., 2019; Sadozai et al., 2024).

All three neurodiverse groups in this study scored meaningfully lower than the neurotypical group on Sensory Regulation, which, given the items loading on this factor, indicates greater use of sensory regulatory behaviors. However, the autism group scored meaningfully lower than both the Down syndrome and Williams syndrome groups, which is consistent with evidence that sensory processing differences are a more prominent and pervasive feature of autism than other neurodevelopmental conditions (Ben-Sasson et al., 2019; Isralowitz et al., 2023; Willfors et al., 2024). Although sensory regulatory behaviors (seeking and avoidance behaviors) are sometimes viewed as maladaptive in neurotypical populations, where sensory-perceptual and emotional difficulties may be less prevalent, they are increasingly conceptualized as attempts to regulate sensory perceptions, emotional responses to sensory input, and levels of arousal in neurodiverse individuals (He et al., 2023; MacLennan et al., 2022). For example, autistic adults report using avoidance strategies, such as leaving overwhelming environments or using earplugs and sunglasses, to manage sensory overload, while sensory seeking behaviors involving preferred sensory experiences may be used in response to sensory or emotional needs (MacLennan et al., 2022; Robertson and Simmons, 2015; Verhulst et al., 2022). The current data are therefore consistent with the suggestion that individuals with Down syndrome and Williams syndrome both experience a degree of sensory challenge that leads to sensory regulation behavior, but with this pattern being more marked among autistic individuals.

For Emotional Regulation, autistic children and children with Williams syndrome scored meaningfully lower than the neurotypical group, whereas the children with Down syndrome did not. However, although the autism group scored meaningfully lower than the Down syndrome group, there was no meaningful evidence for differences between the Down syndrome and Williams syndrome groups or between the Williams syndrome and autism groups (see Fig. 2). This pattern is broadly consistent with the (somewhat limited) previous literature on emotional regulation within neurodiverse populations (England-Mason, 2020; Samson et al., 2022). Emotional regulation difficulties are well documented in autistic children (Jahromi et al., 2012; Loveland, 2005; Prizant et al., 2003), while individuals with Williams syndrome have been reported to experience difficulties regulating anxiety-related emotions and understanding emotions (Greiner de Magalhães et al., 2022; Ikeda et al., 2023; Royston et al., 2017). In contrast, although some emotional regulation challenges have been reported in Down syndrome (Shaffer et al., 2023), emotional control is often identified as a relative strength in this population (Csumitta et al., 2022; Daunhauer et al., 2014; Miezah et al., 2024; Onnivello et al., 2022).

Difficulties in Social Regulation were most pronounced in the autism group, with autistic children showing substantially greater social regulation difficulties than the Down syndrome, Williams syndrome, and neurotypical groups. In contrast, the Williams syndrome and neurotypical groups showed comparable levels of social regulation, while the Down syndrome group showed only modest difficulties relative to the neurotypical group. These findings are broadly consistent with previous work on this construct in these neurodiverse groups. Social regulation is consistently found to be particularly affected in autism (e.g., Hadwin et al., 1996; Knott et al., 2006; Mundy, 1995; Travis et al., 2001), in line with diagnostic criteria (e.g., American Psychiatric Association, 2013; Lord et al., 2020). In contrast, more nuanced or selective social difficulties have been reported in individuals with Down syndrome and Williams syndrome (Capitão et al., 2011; Fidler, 2006; Fidler et al., 2008; Karmiloff–Smith and Thomas, 2003; Lough et al., 2016). Although, in a potential contrast to the current findings, preschoolers with Down syndrome have previously been reported to show stronger social communication abilities than those with Williams syndrome (Thurman & Mervis, 2013), individuals with Williams syndrome are often described as demonstrating relative strengths in social motivation and social engagement (Capitão et al., 2011). Together, these characteristics may contribute to the modest differences observed between these two groups on the current Social Regulation factor.

In this sample, these findings from the analysis of group differences in factor scores therefore provide some support for the view that self-regulatory profiles are condition-specific when considered at the group level (see Fig. 2). In particular, although autistic children face challenges in cognitive regulation that are comparable to those experienced by the Down syndrome and Williams syndrome groups, they have more issues in emotional regulation and social regulation, and show more sensory regulation behaviors than these other two groups. Conversely, individuals with Down syndrome and Williams syndrome show a broadly comparable profile when considered at the group level, with more issues relative to neurotypical individuals in cognitive and sensory regulation and somewhat fewer, though still measurable, issues in emotional and social regulation. One might argue that the absence of meaningful differences from neurotypical individuals for i) emotional regulation among individuals with Down syndrome, and ii) social regulation among individuals with Williams syndrome, reflects distinguishable strengths in these two neurodevelopmental conditions. While this possibility deserves further investigation in future research, it is also important to note that there was no good evidence for a meaningful difference between the Down syndrome and Williams syndrome groups on any of the four regulatory factors in the current study (see Table 3).

In addition to analyzing factor scores at the group level, our cluster analysis allowed us to examine the extent to which individuals *within* a given group showed a consistent profile of regulation that was distinct from that seen in individuals with a different diagnosis. Again, this analysis presented a mixed picture, with some clear condition-specific patterns but also considerable overlap between individuals across clusters. For example, Cluster 2, which was associated with relative strengths in regulation across the board (see Fig. 4) consisted almost entirely of neurotypical individuals. At the same time, fewer than half of the neurotypical group belonged to this cluster. Indeed, while a good proportion of the other neurotypical individuals belonged to Cluster 4, who also had better than average regulatory abilities in all domains, there were also reasonable numbers of neurotypical children in the remaining two clusters.

In a somewhat similar vein, while two-thirds of autistic individuals belonged to Cluster 1 – a cluster associated with regulatory challenges in all domains but particularly in social regulation relative to the other clusters – some autistic individuals belonged to Clusters 3 or 4. Furthermore, Cluster 1 was not autism-specific, and instead included individuals from all four groups. Finally, individuals with Down syndrome and Williams syndrome were reasonably evenly distributed across Clusters 1, 3, and 4. The broad similarity in distributions across clusters of these two samples mirrors the comparable profiles described at the group level above. Having said this, there was also some suggestive evidence that individuals with Williams syndrome were relatively more likely to

belong to Cluster 3, a cluster associated with issues in Cognitive, Sensory, and Emotional Regulation, but not Social Regulation.

5. Theoretical, clinical, and educational implications

Taken together, these results indicate that certain traits are more likely to be associated with certain diagnoses, perhaps most notably the association of autism with particular issues of social regulation. However, even within the group of autistic individuals this profile was not universally observed, nor were particular issues of social regulation restricted to individuals with autism. Indeed, there was substantial overlap between the three neurodiverse samples across each of Clusters 1, 3, and 4. In addition, issues in cognitive regulation appeared to be comparable for all three groups (see Fig. 2). This latter set of findings is therefore more consistent with a transdiagnostic analysis. As outlined initially, this rejects the assumption that a diagnostic label provides a definitive indication of a given individual's traits and argues that patterns of strength or of challenge in a particular trait may well be common to many conditions. As noted, aspects of the current data are consistent with both of these points, as are other findings. For example, Ros and Graziano (2020) identified four regulatory profiles in autistic children and children with ADHD that transcended these two diagnostic categories. While some condition-specific differences were observed (e.g., EF-predominant challenges in autism vs. ER-predominant challenges in ADHD), their study highlighted that dimensional self-regulation profiles were stronger predictors of functional outcomes than categorical diagnoses.

It might well be the case that particular regulatory challenges (in emotional regulation for example) are inherently transdiagnostic, perhaps by virtue of arising from developmental interactions with caregivers and peers that are shaped by factors common to many neurodiverse conditions (Karmiloff-Smith, 2009). It could also be that an individual's level of intellectual disability is an over-arching factor that acts as a general moderator of some of the regulatory behaviors assessed in our questionnaire. In particular, given the close association between cognitive regulation and IQ (e.g., Arffa, 2007; Hocking et al., 2015; Tassé et al., 2016), it is possible that an individual's ability to engage cognitive regulation is constrained by their level of intellectual functioning. As we emphasize below, IQ was not assessed in this study, but could usefully be included in future work that seeks to further explore the extent to which self-regulation skills in the four domains investigated here are transdiagnostic.

Our findings therefore suggest that diagnosis-associated and transdiagnostic aspects of self-regulation can occur simultaneously. Certain strengths and challenges might be broadly associated with certain diagnoses, to an extent that might vary depending on the particular condition. At the same time, we have observed a degree of shared strengths and challenges in regulation across autism, Down syndrome, and Williams syndrome. This nuanced summary has important applied implications for educational or clinical interventions that might seek to support regulatory skills in neurodiverse conditions. Specifically, it suggests that a child's diagnosis could be a useful starting point for considering which interventions might be both needed and effective, perhaps particularly in clinical settings where a specific challenge is being targeted. Indeed, the current data imply that autistic individuals are very likely to face challenges in social regulation, and might well benefit from autism-specific interventions that seek to address the particular issues (perhaps in theory of mind, e.g., Begeer et al., 2011; Fletcher-Watson et al., 2014; Ma et al., 2023) that could give rise to these regulatory challenges. However, another key implication of the current work is that too much weight should not be placed on diagnosis-driven assumptions, as they clearly do not apply to every individual. The current data do not directly indicate which interventions are likely to have broad, cross-condition utility, but they do support the view that an individual needs-based analysis would be extremely important when supporting a child with a neurodevelopmental condition, perhaps particularly so when providing educational support in areas that might draw on multiple regulatory domains. In addition, a further important implication is that such an analysis could usefully be based on the four-domain framework of cognitive, sensory, emotional, and social regulation that formed the basis of our prototype questionnaire. For example, in educational settings these four domains could help teachers and other school staff identify which demands of a classroom activity are likely to be difficult for an individual child; for instance, following multi-step instructions, managing sensory input, coping with frustration, or navigating group work. Educational support could then be tailored to the child's identified needs, rather than based solely on their diagnosis.

6. Strengths and limitations

We would argue that our study has a number of key strengths that allow for a certain amount of confidence in our conclusions. These include the fact that our prototype questionnaire was based on a coherent theoretical framework of self-regulation that was supported by our exploratory factor analysis (although we note that the stricter confirmatory factor analysis was not a good fit, indicating the potential need for further questionnaire development). While a number of previous studies have contrasted some of the aspects of self-regulation assessed here in two neurodiverse populations, this work included three different neurodevelopmental conditions as well as data on a larger sample of neurotypical children within a single analytical framework. The study also used an innovative combination of exploratory factor analysis, Bayesian statistics, and cluster analysis. In turn this allowed us to go further than just including 'traditional' analyses of diagnostic group differences to also examine whether regulatory profiles transcended diagnostic boundaries, in line with current views on the potential benefits of a transdiagnostic approach. Our Bayesian approach to comparing group factor scores represents better statistical practice than null hypothesis significance testing, not least because it tests the evidence both for and against meaningful group differences.

However, given the partly exploratory nature of the factor and cluster analyses, the resulting factor structure and regulatory profiles should be interpreted as preliminary. It is also important to acknowledge several other limitations of the current study. The first of these is the use of parental report to measure children's self-regulation. Some previous studies have reported discrepancies between parent report indices and other informant reports of self-regulation as well as experimental tasks (DeCamp et al., 2025; Toplak

et al., 2008). However, Fisher et al. (2014) argued that among adults with Williams syndrome, parent reports may be more reliable than self-reports. In addition, parent-report measures of regulatory functioning are well-established, and include widely-used instruments such as the BRIEF. Indeed, Daunhauer et al. (2017) found moderate correlations between task-based and parent report measures of executive functioning among 42 young children with Down syndrome. Moreover, parent ratings were stronger predictors of adaptive functioning than task performance, suggesting that parental report captures ecologically meaningful variance in regulatory behavior. Nevertheless, future research should aim to use multiple methods as well as multi-informant designs for measuring self-regulation to fully understand children's self-regulation profile.

Second, our study characterized children's self-regulation ability at a single timepoint, but did not examine how self-regulation ability emerges, stabilises, or fractionates over time (Doebel, 2020). The cross-sectional nature of the current study also precludes causal interpretations of the observed group differences and regulatory profiles. Some literature suggests that there are age-related differences in self-regulation in neurodiverse populations (Guralnick et al., 2009; Van Den Bergh et al., 2014) and the age range of the children assessed in the current study spanned a considerable period of potential self-regulation development. However, other parent-report measures of regulation, including well-established instruments such as the BRIEF, span a similar age range. Additionally, the four groups assessed here had comparable means and standard deviations for age (see Table 1), suggesting that age-related variation is unlikely to drive any group differences in self-regulation ability; in addition, age was included as a covariate in our analyses. Nevertheless, future longitudinal work should include age as a continuous predictor in order to model developmental trajectories in self-regulation.

A third limitation concerns the relatively high reported co-occurrence of an ADHD diagnoses within the current sample across all four groups (see Table 1). ADHD is independently associated with regulatory difficulties (Ros and Graziano, 2020; Shiels and Hawk, 2010) and its presence, particularly within the ASC group where co-occurrence rates were highest, may have influenced the clusters of self-regulation (see Supporting Information 4). Future research should therefore directly examine the influence of co-occurring diagnoses or phenotypes to understand their effects on self-regulation profiles.

A fourth, related, issue is that no standardized measure of cognitive ability, developmental level or adaptive functioning was included in the current study. As a result, any group differences in factor scores cannot be solely attributed to diagnosis-specific self-regulation issues, and might instead be driven, in part at least, by any group differences in general cognitive functioning. Indeed, children with Down syndrome and Williams syndrome frequently present with intellectual disability of varying severity (e.g., Greiner de Magalhães et al., 2022; Mervis & John, 2010; Roizen & Patterson, 2003), and autism can also, though need not be, associated with intellectual disability (e.g., Brugha et al., 2016; Rydzewska et al., 2018; Zeidan et al., 2022). As noted above, Cognitive Regulation factor scores might be expected to be particularly sensitive to level of intellectual ability, and this might account for the lack of group difference on this factor among the neurodiverse groups. Additionally, cluster membership could be affected by cognitive level, not least because some clusters – most notably Clusters 2 and 4 – appear to be differentiated by general degree of overall regulatory ability. Future research should therefore incorporate standardized measures of cognitive or developmental level, so that reports or measures of self-regulation can be interpreted in the light of this additional factor.

Fifth, the current study was conducted exclusively within the United Kingdom. Diagnostic practices, educational systems, availability of specialist support, and sociocultural contexts vary across national settings, all of which may influence the development and expression of self-regulatory behaviors in both neurotypical and neurodiverse children. Indeed, access to support varies by country for neurotypical individuals, including between countries with advanced economies such as Australia. Australian adults report more barriers to access compared to the UK (Schoen & Doty, 2004). Therefore, replication across diverse cultural contexts should be conducted to strengthen the generalisability of our study's findings. A related point concerns our use of convenience sampling through specialist organizations, charities, and schools. This may also limit the representativeness of the sample, as participating families may differ systematically from the wider populations from which they were drawn. Furthermore, whether the findings of this study would extend to other neurodevelopmental conditions beyond those of autism, Down syndrome, and Williams syndrome, remains to be examined.

An additional sixth potential issue relates to diagnostic status being confirmed through parental report. Parents were recruited via organizations, charities, and schools specialising in support for individuals with Williams syndrome, Down syndrome, and autism. Although recruitment through these specialist communities provides some confidence in the accuracy of these reported diagnoses, formal independent verification was not conducted. Future research should consider incorporating diagnostic screening procedures such as review of diagnostic documentation or standardized diagnostic instruments in order to further strengthen diagnostic verification.

A seventh potential limitation concerns our cluster analysis, where the silhouette coefficient indicated some overlap between clusters. This suggests that the boundaries between clusters may not be entirely distinct and that some participants may share characteristics of multiple clusters. However, the selected solution was supported by multiple indicators of fit and stability (see above). The identified profiles therefore appear robust, but should still be interpreted with an appropriate degree of caution.

A final limitation relates to the psychometric validation of our questionnaire. Although questionnaire items were informed and inspired by well-established measures of self-regulation to ensure conceptual relevance to the constructs of interest, and although the resulting EFA yielded a four-factor structure broadly consistent with the proposed domains of self-regulation, providing some evidence of construct validity, convergent and discriminant validity were not directly assessed. Future research should therefore examine convergent validity against established measures of self-regulation as well as measures relevant to each factor, such as performance-based measures of executive functioning for the Cognitive Regulation factor, and evaluate discriminant validity through comparison with theoretically distinct constructs. In addition, future research should test whether the four-factor structure replicates in larger, independent samples, including within each of the participant groups assessed here. Accordingly, the present questionnaire should be

considered a prototype tool requiring further validation, and the current findings should be interpreted as providing encouraging preliminary evidence of the multidimensional structure of self-regulation rather than definitive confirmation of these regulatory domains.

7. What this paper adds?

In this study, parent-reported self-regulation differed across the neurodivergent groups (autism, Down syndrome, and Williams syndrome) and the neurotypical group. The prototype questionnaire used to examine these differences may serve as a valuable starting point for future research, as it has the potential to provide a comprehensive picture of strengths and challenges across a theoretically-motivated set of regulatory domains. The findings indicate that some aspects of regulation are more commonly associated with specific conditions, offering a starting point for exploring support needs. However, they also underscore the importance of a transdiagnostic approach—looking beyond diagnostic labels to focus on individual profiles. As a result, while diagnosis can provide an initial guide to a child's self-regulation profile, it should be complemented by an individualized, needs-based assessment to inform more personalized and effective intervention strategies.

CRediT authorship contribution statement

Yasamin Rahmati: Writing – review & editing, Writing – original draft, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Imogen E. M. van Jaarsveldt:** Writing – review & editing, Writing – original draft, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Christopher Jarrold:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal interests that could have appeared to influence the work reported in this paper.

Appendix A. : List of questions from the newly developed questionnaire

Note. In the original questionnaire, items from the Social, Emotional, Cognitive, and Sensory domains were presented in a mixed order and were not grouped by domain. Unless indicated by an asterisk (*), all items were reverse coded prior to scoring.

1. **Social**: They enjoy playing activities with other children, e.g., Tag.
2. **Sensory**: They like gentle repetitive activities, e.g. they rock back and forth.
3. **Emotional**: They overreact when minor events occur (e.g. they cry for a long time when a toy breaks, or they get overly angry when they do not win in a game).
4. **Social**: In conversations they do not understand social etiquette e.g. taking turns to speak.
5. **Cognitive**: They only remember the first instruction when they are given multiple instructions.
6. **Emotional**: When they are told it is their bedtime, they throw a temper tantrum/get angry and refuse to go to bed.
7. **Sensory**: They tune out other senses or their surroundings because they are so focused on one sensation.
8. * **Cognitive**: They are self-starter when doing activities or tasks.
9. **Emotional**: They get overly excited and enthusiastic when doing things.
10. **Social**: They are unaware of social boundaries (e.g., they talk or play too loudly in a café/restaurant or the cinema).
11. **Sensory**: They are easily overstimulated during day-to-day activities, e.g. too many different smells in a supermarket, different people talking in a room.
12. **Cognitive**: They forget what they are doing during an activity.
13. * **Cognitive**: They can draw associations between concepts.
14. **Emotional**: They become easily upset and frustrated when they are stopped from doing what they want.
15. **Sensory**: When they encounter an unwanted external stimulus, e.g. a loud noise, they will often make repetitive, unusual body movements or noises.
16. * **Emotional**: When they are upset, they can quickly feel better by changing what they are thinking of.
17. **Social**: They prefer to play alone (e.g. toys, videogames).
18. * **Cognitive**: They attempt tasks that are challenging.
19. **Sensory**: They are unwilling to eat foods that they are not familiar with e.g., they will avoid trying new textures or flavours.
20. **Social**: They laugh along with others even if they do not understand what is funny.
21. **Emotional**: They struggle to control their emotions after an exciting activity.
22. **Sensory**: They notice even very quiet sounds that others do not.
23. * **Social**: They ask others for help.
24. **Cognitive**: They finish tasks/activities quicker than expected.
25. * **Emotional**: They convey their feelings effectively.
26. * **Social**: They happily ask other children to play with them.

27. **Sensory**: They try to avoid bright lights.
28. **Cognitive**: They make obvious mistakes during tasks/activities that are within their ability.
29. **Sensory**: They seek oral stimulation and will often put inedible foods in their mouth. For example, they will eat or lick playdough.
30. * **Social**: They can competently handle conversations and interactions with others.
31. **Social**: They are unable to adjust to new people.
32. **Sensory**: They are sensitive to small injuries.
33. **Cognitive**: They continuously make the same mistakes; despite being given support.
34. **Emotional**: After a minor injury, they become overly emotional.
35. * **Cognitive**: They are able to concentrate on extended tasks/activities (e.g. puzzles and boardgames).
36. **Sensory**: They seek out physical stimulation, for example they like the pressure from a blanket tightly wrapped around them.
37. * **Cognitive**: They easily think of multiple strategies to solve problems when they are stuck.
38. **Social**: They often invade personal space without being aware of it.
39. **Emotional**: They react with more intensity.
40. **Sensory**: They avoid where possible certain textures.
41. **Cognitive**: They are unable to set goals and do not try as hard as they are capable of
42. * **Social**: They like to help others e.g. they help to tidy up toys after play time, tidying in the kitchen after baking.
43. **Sensory**: They try to avoid loud sounds.
44. **Social**: They are rejected by other children when they play carelessly or recklessly.
45. **Cognitive**: They find it difficult to finish tasks/activities they have started.
46. **Sensory**: They seek out the vestibular sensation, e.g. jumping and spinning, and they find this soothing.
47. **Emotional**: They become so excited and out of control that they act reckless.
48. **Sensory**: They try to avoid specific smells.
49. * **Cognitive**: They are able to complete tasks/activities independently.
50. **Cognitive**: They struggle to follow instructions.
51. **Emotional**: They are usually unable to control their feelings and emotions, e.g. when they are angry they struggle to stop being angry and/or when excited they struggle to stop being excited.
52. **Sensory**: They take note of the textures of objects more than other children, e.g. they notice how rough a new T-shirt is.
53. **Emotional**: They experience constant mood swings.
54. **Emotional**: Following a problem, they are upset and are unable to be easily soothed for over 10 minutes.
55. * **Social**: They start social encounters with other children.
56. * **Emotional**: They become excited about future treats e.g. park after school or dessert after dinner.
57. **Sensory**: They will seek out visual stimulation, for example staring at flashing LED lights and spinning objects.
58. **Sensory**: They will seek out auditory stimulation through making noises or sounds themselves, e.g., humming.
59. * **Social**: They actively engage in group activities e.g. afterschool clubs.
60. **Cognitive**: They have difficulty planning and following multi-step activities/tasks.
61. **Emotional**: When they do not get their own way, they throw temper tantrums/get angry.
62. * **Cognitive**: They develop new activities and tasks to keep themselves interested.
63. **Sensory**: They are obviously fascinated with certain items e.g., soft blankets.
64. **Cognitive**: They get easily distracted when completing an activity/task (e.g. when reading a story).
65. **Emotional**: They hardly ever laugh during comedies (e.g. tv shows or movies).
66. **Sensory**: They seek out olfactory stimulation and will often smell objects we do not usually smell, e.g. a rubber/eraser.
67. * **Social**: They work well with others.
68. **Cognitive**: They struggle to remember something even after a short amount of time.
69. * **Social**: They are good at sharing things with friends and family e.g. toys.
70. **Sensory**: They have an under reaction to touch or pain, e.g., they may fall over but have no reaction.
71. **Emotional**: They feel sad and disheartened when they cannot finish a task.

Appendix B. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ridd.2026.105390.

Data availability

we have shared the link to our data.
Domains of Self-Regulation in Autism, Down Syndrome, and Williams Syndrome: Condition-Specific or Transdiagnostic? (OSF)

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