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Thermoception in Autism Spectrum Disorder: A Concise Systematic Review

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Abstract

Sensory processing atypicalities have been demonstrated in autism spectrum disorder (ASD). Thermoception, a component of the somatosensory system crucial for survival, can benefit from an overview of the state-of-art in ASD. In this work, a PROSPERO registered (CRD42023412663) systematic review on thermoception in ASD is presented, following PRISMA and MOOSE guidelines. Our search encompassed databases including Pubmed, Scopus, PsycInfo, and Google Scholar (n = 1261). Included articles (n = 9) were written in English, experimental, peer-reviewed documents on thermoception in autism. As the ASD group shows hypo- (n = 3) or hypersensitivity (n = 2) or no discernible difference at times (n = 8) to either warm and/or cold innocuous stimuli, definitive conclusions are difficult to draw. Nevertheless, these aggregated results build cumulative knowledge and guide future research regarding the evaluation of thermoception in autistic individuals which could further increase their quality of life.

Keywords Autism spectrum disorder (ASD), Thermoception, Cold detection threshold, Warm detection threshold, Somatosensation, Systematic review

Declarations

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Declaration of interest

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

Data availability

Not applicable.

Authors' contribution statement

M.R., F.C. and N.C. conceived the theoretical framework. N.C. and F.C. handled the methodological part. M.R., A.C. and F.C. helped supervise the project. N.C. and F.C. wrote the paper with input from all authors. All authors discussed the results and contributed to the final manuscript.

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Abstract

Sensory processing atypicalities have been demonstrated in autism spectrum disorder (ASD). Thermoception, a component of the somatosensory system crucial for survival, can benefit from an overview of the state-of-art in ASD. In this work, a PROSPERO registered (CRD42023412663) systematic review on thermoception in ASD is presented, following PRISMA and MOOSE guidelines. Our search encompassed databases including Pubmed, Scopus, PsycInfo, and Google Scholar (n = 1261). Included articles (n = 9) were written in English, experimental, peer-reviewed documents on thermoception in autism. As the ASD group shows hypo- (n = 3) or hypersensitivity (n = 2) or no discernible difference at times (n = 8) to either warm and/or cold innocuous stimuli, definitive conclusions are difficult to draw. Nevertheless, these aggregated results build cumulative knowledge and guide future research regarding the evaluation of thermoception in autistic individuals which could further increase their quality of life.

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1. Introduction

Autism spectrum disorder (ASD) is a lifelong neurodevelopmental condition associated with social-communicative and behavioural flexibility problems (American Psychiatric Association, APA, 2013; APA, 2022). Its aetiology encompasses genetic variations, environmental exposures (*e.g.,* in-utero), and prematurity. This condition varies along a spectrum of clinical severity which allows to outline inter-individual differences (Lord et al., 2018), classifiable through the amount of needed support (APA, 2013; APA, 2022). It can be diagnosed through its symptomatology as early as 18-24 months of age (Zeidan et al., 2022).

Individuals with ASD are often characterised by sensory-perceptual abnormalities (Baranek et al*.,* 2006; Cascio et al., 2008). These include mild to severe divergent sensory processing (Blakemore et al., 2006; Marco et al., 2011; Robertson & Baron-Cohen, 2017) and a wide range of persistent impairments (Greenspan & Wieder, 1997; Iarocci & McDonald, 2006) and experienced distress (Marco et al., 2011). Clinical evidence supporting these observations dates back to Kanner (1943). Notably, such atypical processing involves various sensory modalities including visual, auditory, olfactory, tactile, taste and proprioceptive senses (O'Neill & Jones, 1997). These sensory processing atypicalities can manifest either as hypo- or hypersensitivity to certain stimuli leading to atypical behavioural responses (Balasco et al., 2020). Moreover, Fiene et al. (2018) reported that 74% of ASD adults experienced interoceptive confusion and that somatosensory bodily signals become clear to them only in extreme intensity, a condition known as alexisomia. For example, some individuals with ASD have experienced paradoxical heat sensations (PHS, Duerden et al., 2015; Fründt et al., 2017; Vaughan et al., 2020) which corresponds to warmth, hot or burning sensation in response to a cool stimulus during a thermal sensory limen (TSL) procedure that consists of alternating warm and cool stimuli (Rolke et al., 2006). In this light, thermoception, defined as the individual's temperature sensation (Prescott & Ratté, 2017), can be impaired in ASD, as partially mentioned in the DSM-5 and DSM-5-TR, in the form of "apparent indifference to pain/temperature" (APA, 2013; APA, 2022).

Thermoception is fundamental for survival (Sherwood & Huber, 2010), as it supports thermoregulation. Thermoregulation is a process that involves neural structures and projections to and from the hypothalamus and the limbic system through the lower brainstem and reticular formation to the spinal cord and sympathetic ganglia (Mackowiak & Boulant, 1996; Mackowiak, 1998). The feedforward and feedback information about body temperature converges in the preoptic area (POA) of the hypothalamus (Tan & Knight, 2018). Supported by massive evidence (Elmquist et al*.,* 1996; Ishiwata et al*.,* 2005; Rothhaas & Chung, 2021; Tan et al*.,* 2016), the POA is believed to be the key site for thermoregulation. Moreover, sensorial afferents myelinated nerve Aδ-fibres respond to innocuous cold stimuli, while unmyelinated C-fibres to innocuous warm stimuli (Seo & Kim, 2021; Vaughan et al., 2020). These thermoreceptors are unevenly distributed within the body and are responsible for temperature sensation and the organism's autonomic and behavioural responses to the environment (Hensel & Schafer, 1984). New evidence supports the existence of a dual (*i.e.,* warm-activated and warm-silenced) sensory model that unambiguously detects skin warming in vertebrates, via a set of polymodal nerve fibres (Paricio-Montesinos et al*.,* 2020). On a molecular level, some transient receptors potential (TRP) channels were found to

be sensitive to innocuous cold stimuli (*e.g.,* TRPM8; Peier et al*.,* 2002) and innocuous warm stimuli (*e.g.,* TRPM2, TRPM8 inhibition, TRPV3 and TRPV4; Green, 2004; Güler et al., 2002; Kashio & Tominaga, 2022; Paricio-Montesinos et al*.,* 2020). According to the review by King and Carnahan (2019), innocuous cold stimuli activate the posterior insula cortex, the secondary somatosensory cortex, the rolandic operculum and the orbital gyrus. Instead, innocuous warm stimuli seem to activate bilaterally the anterior insula, the ventrolateral and dorsolateral prefrontal cortices, the parietal lobe, and the basal ganglia, contralaterally the anterior operculum, the primary and secondary somatosensory cortices and the cingulate cortex (Peltz et al., 2011).

Air temperature or objects are sensed in relation to skin temperature, typically around 32°C in humans (Prescott & Ratté, 2017). Rapid temperature changes are sensed to a greater extent compared to slower changes (*e.g.,* slow 31-36° changes are probably perceived less due to the concurrent dilation/constriction of blood vessels; Prescott & Ratté, 2017). On average, innocuous temperature stimuli lie between 15°C and 43°C (Jänig, 2018). A sensation of coolness tends to arise near 31°C, with the sense of cold increasing up to pain near 12°C. Instead, warmth is felt near 36°C and the painful threshold is around 45°C (Prescott & Ratté, 2017).

Experimentally, thermoception can be measured through the method-of-limits which is a time-dependent task where a thermoconducting surface is placed on the subject's body. The surface's temperature is manipulated with increases and decreases at a certain linear rate (*e.g.,* 1°C/s). During a trial, the person presses a button to indicate their perceptual detection of warmth or cold, and the temperature is then adjusted back to baseline. The procedure is repeated and then averaged. Instead, the method-of-levels, also known as forced choice (*e.g.,* staircase algorithm) diverges from the method-of-limits as it allows obtaining a time-independent reaction, where the subject is asked whether the temperature was felt or not (Bakkers et al., 2013). Then, the temperature increases or decreases based on the participant's feedback at a different rate until the precise subject's sensorial threshold is found (Yarnitsky & Sprecher, 1994). Overall, these methods can be employed for thermal quantitative sensory testing (QST) possibly involving parameters such as the cold detection threshold (CDT) and the warm detection threshold (WDT).

As mentioned earlier, sensory systems are often impaired at a behavioural level in ASD, including the sense of touch (Marco et al., 2011; Puts et al., 2014; Robertson & Baron-Cohen, 2017), which allows thermoception. Therefore, thermoception could differ in individuals with ASD. Thermoception abnormalities can have a cascading influence on higher-level functions such as language (Ijzerman & Semin, 2009) or social inference (Williams & Bargh, 2008; although these results have not always been replicated, see Lynott et al., 2014). Concurrently, distress can be provoked by sensory stimuli which may lead to self-injurious and aggressive behaviour in those unable to communicate their discomfort (Marco et al., 2011). Thus, a better knowledge of thermoception in ASD has scientific purposes and could increase the quality of life of the individuals considered.

Based on the provided framework, we intended to conduct a systematic review on innocuous thermoception in ASD which, to the best of our knowledge, has never been carried out before. In this work, we will solely focus on innocuous thermoception, as it appears to be under-researched compared to thermal pain processes, and with only recent studies focusing on ASD somatosensory dysfunctions (Fründt et al*.,* 2017). Hence, this research aims at reviewing the state-of-art of thermoception in ASD (only non-painful sensation with

innocuous stimuli) highlighting general findings, methodological issues, and answering the following questions: do the thermal perception thresholds differ from the allistic (*i.e.,* without ASD) population? Are some methodological protocols more recommended for measuring thermoception in ASD?

2. Methods

This work was previously registered in the International Prospective Register of Systematic Reviews (PROSPERO; CRD42023412663, 10th of April 2023) and follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al*.,* 2021). We further structured our selection criteria and analysis in accordance with the Meta-analysis Of Observational Studies in Epidemiology (MOOSE) guidelines for meta-analyses and systematic reviews of observational studies (Stroup et al*.,* 2000).

2.1 Search strategy

The string used for the database search was: ("QST" OR "Quantitative Sensory Testing" OR "Cold" OR "Cool" OR "Warm" OR "Hot" OR "Thermal" OR "Temperature" OR "Thermoception") AND (("Autism" OR "autism spectrum disorder" OR "Autistic" OR "Asperger") OR ("Pain" AND "Thermal" AND "Autism")). The "pain" keyword was added in the second part of the Boolean sentence to avoid missing articles that measured innocuous thermoception even though primarily focusing on pain. The databases considered were Scopus, PubMed, APA PsycInfo (EBSCO) and Google Scholar, and the search occurred on the 8th of March 2023. The Google Scholar search mostly resulted in non-pertinent articles (for possible explanation see Gusenbauer & Haddaway, 2020). For this reason, we included the first 250 documents from Google Scholar, following the approach of Bramer et al. (2017). Articles met inclusion criteria if they were a) original experimental studies, b) written in English, c) peer-reviewed, and if the protocol d) included individuals with ASD and a control group and e) measured thermoception. Articles presenting pain-based or allistic individual-based studies only were excluded. In studies reported in more than one article, data were extracted from the most recent one. Duplicates were automatically removed from the collective references, resulting in a total of 1261 screened articles. Screening and selection were performed independently by two investigators (NC and FC). Disagreements were discussed with a third investigator (MR).

2.2 Outcome measures and data extraction

When the articles were included (n = 9), the following data were extracted: sample size, type of protocol used in order to measure the individual's thermoception, body site(s), temperature input boundaries, temperature baseline, temperature rate input, temperature rate input to return to baseline temperature, room temperature, age, type of ASD, intelligence quotient (IQ), gender, number of trials for CDT, number of trials for WDT, averaged CDT (C°), averaged WDT (C°), pain measurement (yes/no), number of participants taking neuropsychiatric medications, thermal stimulus surface (cm^2). If data were missing, the corresponding authors were contacted by e-mail.

2.3 Quality assessment

The selected articles were assessed for quality using an adjusted version of the Newcastle Ottawa Scale (NOS) adapted for cross-sectional studies comprehending the categories of selection, comparability and outcomes (Wells et al*.,* 2019). The maximal score obtainable is 9 and cross-sectional studies with a score equal to or above 6 were considered of good quality. Regarding the risk of bias, a third neutral researcher (MR) was consulted in case of non-agreement.

3. Results

3.1 Included studies

A total of nine studies were selected and evaluated with the NOS as good or high-quality and their relevant data were extracted and reported in Table 1. The PRISMA flow diagram (Haddaway et al*.,* 2022) is reported in Figure 1.

(Insert Figure 1 above here)

(Insert Table 1 above here)

3.2 A methodological overview of the investigation of thermoception in ASD

About the sample's statement, only three studies (Fründt et al., 2017; Vaughan et al., 2020; Williams et al., 2019) provided precise information on the use of neuropsychiatric medication in both groups. There appears to be an asymmetrical gender ratio, with a higher percentage of tested males overall. Two studies had a balanced gender ratio (Fründt *et al.*, 2017; Vaughan et al., 2020), while Chien et al.'s (2020) ASD group consisted exclusively of males. Most studies (Cascio et al., 2008; Chien et al., 2020; Fründt et al., 2017; Hoffman et al., 2023; Vaughan et al., 2020) focused on adults, one study on adolescents (Duerden et al., 2015), one on children (Pernon et al., 2007), one on adults and adolescents (Yasuda et al., 2016), and one on adults, children, and adolescents (Williams et al., 2019). With respect to intellectual disability, all included studies except Pernon et al. (2007) reported that IQ of the autistic population was equal or above 70. Pernon et al. (2007) did not specify the IQ of the autistic group but reported the standard Vineland score (M = 37, SD = 17) and the developmental age (M = 2.11, SD = 1.3) using the Vineland Adaptive Behaviour Scale (Sparrow et al., 1984). Geographically, three studies (Cascio et al., 2008; Duerden et al., 2015; Williams et al., 2019) were conducted in the USA.

Methodologically, the most used approach was the method-of-limits (Cascio et al., 2008; Duerden et al., 2015; Fründt et al., 2017; Hoffman et al., 2023; Vaughan et al., 2020; Williams et al., 2019; Yasuda et al., 2016) to compare thermoception in the ASD population with controls. Instead, Chien et al. (2020) used the method-of-levels. In Pernon et al. (2007), a different procedure was employed to measure innocuous thermoception by assessing the pleasantness or unpleasantness in an imposed/offered condition of the stimulus, through the analysis of facial expressions via the Facial Action Coding System (Ekman & Friesen, 1978) and motor-behavioural components in response to a thermal cushion (10 cm^2, 20°C). In this study (Pernon et al., 2007), two conditions were administered, an imposed tactile stimulation, considered as passive touching, and an offered condition, named

active touching. All studies, when specified, have used a 9 cm^2 thermode except for Pernon et al. (2007) and there was no consensus on room temperature across the studies.

3.3 Thermoception in individuals with ASD compared to controls

Results suggest that the thenar palm is more sensitive to warmth compared to the forearm (Cascio et al., 2008), despite the forearm being the most frequently tested body site (Cascio et al., 2008; Duerden et al., 2015; Hoffman et al., 2023; Vaughan et al., 2020; Yasuda et al., 2016) in the included studies.

Six studies did not find significant differences between the groups in terms of WDT and CDT (Cascio et al., 2008; Chien et al., 2020; Fründt et al., 2017; Hoffman et al., 2023; Vaughan et al., 2020; Williams et al., 2019). Concerning WDT only, Yasuda et al. (2016) reported no differences between groups, and Chien et al. (2020) found no significant divergences in most of the experimental group (~75%). Finally, no difference between groups was observed in cool passive stimuli in Pernon et al. (2007).

However, differences between ASD individuals and controls in thermoception have been observed in 5 studies in the form of hyper- or hyposensitivity. Increased sensitivity to cold innocuous stimuli was detected in the autistic population both in Yasuda et al. (2016) and during the active touching condition of Pernon et al. (2007), indirectly manifested via a stronger intensity in positive facial expression. On the other hand, a decreased sensitivity has also been highlighted in adolescents with ASD for warm and cool stimuli (Duerden et al., 2015) and in adults for warmth (Chien et al., 2020; Williams et al., 2019). Regarding trial-to-trial variability, Williams et al. (2019) found a small but significant increase in individuals with ASD compared to controls, as measured by Gini's Mean Difference (GMD, the average absolute difference in temperature between all pairs of trials).

Possible intervening factors, for example, IQ, gender and age were occasionally considered. Concerning IQ, Duerden et al. (2015) reported a strong negative correlation (Pearson Correlation Coefficient, PCC, r = -0.8, $p < 0.001$) between WDT and IQ measured with the Wechsler Abbreviated Scale of Intelligence (WASI, Wechsler, 1999). Williams et al. (2019) also reported a negative correlation *(*Spearman Rank Correlation*, ρ (rho)* = -0.237, $p = 0.006$) between WDT and Performance IQ (PIQ), measured with the WASI-II (Wechsler, 2011).

CDT was also found moderately positively correlated to IQ (Duerden et al., 2015, PCC, r = 0.59, $p = 0.01$) but Williams et al. (2019) found a small negative correlation between PIQ and CDT (ρ = -0.322, $p < 0.001$). To be noted, Williams specified that WDT and CDT were both standardized as the number of Celsius degrees from baseline temperature (effects of the same sign meant the same thing for WDT and CDT). Moreover, Williams et al. (2019) reported no significant difference in the correlations between PIQ scores and thermal thresholds in ASD and controls (WDT: $r_{ASD} - r_{Control}$ = -0.193, 95% CI [-0.512, 0.131]; CDT: $r_{ASD} - r_{Control}$ = -0.159, 95% CI [-0.469, 0.148]). Lastly, no significant correlation was reported between Verbal IQ and thermal detection thresholds in both Fründt et al. (2017), using the German Multiple Word Test (Lehrl, 2005), and Williams et al. (2019), using the WASI-II (Wechsler, 2011).

Concerning gender, Duerden et al. (2015) reported no significant differences between participants' gender and their thermal detection thresholds. However, Williams et al. (2019) reported that males significantly exhibit higher detection thresholds than females, but only after controlling for PIQ. As the authors reported, this could be due to a sampling bias with a large PIQ difference which confounded the gender effect on thresholds.

Regarding the age factor, no significant association with the thermal thresholds was found by Duerden et al. (2015). In Williams et al. (2019) no significant relation was detected in WDT as well, but they found age to be a significant predictor with older age associated with higher WDT when controlling for intra-individual variability, in a hierarchical multiple regression with the following predictors: diagnosis, age, gender, counterbalance order and GMD. Lastly, a significant small negative association was found between age and CDT in Williams et al. (2019, PCC, r_s = -0.176, p = 0.038).

Lastly, pain was part of the research subject in most of the included studies (88.9%), except for Williams et al. (2019).

4. Discussion and conclusion

The objective of this work was to draw an overview of the state of art of research measuring innocuous thermoception in individuals with ASD, as sensory processing impairments are common in ASD (Baranek et al., 2006). Thermoception, being part of the sensorial system, allows thermoregulation which is fundamental for survival (Sherwood & Huber, 2010). A systematic analysis of the literature showed that only 9 studies had investigated thermoception in autism, with variability in the methods, recruitment criteria and aim. Unsurprisingly, the results are not unequivocal. Although, based on previous knowledge it was conjecturable that alterations should have existed.

The hyposensitivity (Chien et al., 2020; Duerden et al., 2015; Williams et al., 2019) might be reflecting alterations in the peripheral processing of thermal stimuli (*e.g.*, functional alteration of small-fibre sensory nerves; Chien et al., 2020) or in the cortical somatosensory system. As suggested by Duerden et al. (2015), other factors (shift attention, fatigue, anxiety or presence of the parents) should be taken into account to explain the thermoception differences. In this light, anxiety could be taken into consideration to explain the sensorial hypersensitivity (offered condition in Pernon et al., 2007; Yasuda et al., 2016). Somatosensory dysfunctions may correlate with anxiety levels (Orefice, 2020) and sensory processing in individuals with ASD and allistics (Normansell-Mossa et al., 2021). We speculate that anxiety symptoms could act as a moderator in ASD and sensory hypo- or hypersensitivity, similar to Duerden et al. (2015), specifically on innocuous thermal thresholds. In this case, anxiety would modify/amplify or dampen the relationship between thermal threshold; for example, individuals with autism and high levels of anxiety may exhibit pronounced changes in thermal detection threshold compared to those with low anxiety. The conflictual results obtained from the included studies could be attributed to not controlling for this or other possible factors (*e.g.,* various symptoms) or differences in the methodology, even within the same method (*i.e.,* method-of-limits), but also to the sampling (*e.g.,* gender unbalance, PIQ polarity) and lack of pertinent statistical procedure.

Regarding IQ, a probable moderate-weak association between IQ and thermal detection thresholds in ASD subsists. The differences found in the studies of Willliams et al. (2019) and Duerden et al. (2015) in the correlations between CDT and P/IQ are both in sign and power. However, the sign difference is meaningless and explained by differences in the measure operationalization (standardization), while the absolute magnitude difference is probably due to the use of different statistical approaches (PCC *vs.* Spearman Rank correlation, with the PCC inflating the estimate, especially, in skewed distributions) (Bishara & Hittner, 2015) and the sample size.

The method-of-limits protocol has been the most widely employed and is generally considered suitable (Heldestad et al., 2010). However, Yarnitsky and Sprecher (1994) suggest that the methods-of-levels shall be preferred over the method-of-limits. This is particularly relevant for autistic individuals as they tend to be resistant to uncertainty and may respond earlier to avoid it (Moore, 2015). Concerning Pernon et al. (2007), their distinctive approach found that autistic children expressed more positive outcomes in the active thermal touching condition. However, this result could be confounded by a less anxiety-inducing thermal condition. We suggest to further control the subject's role of control and their perceived predictability regarding the sensory experiences. Investigating the interplay between sensory processing and cognitive factors represents a valuable avenue for research by providing insight into the complex sensory experiences of individuals with ASD. This line of research has the potential to contribute to the development of interventions that address the sensory needs of this population, ultimately improving their overall well-being.

Regarding the choice of body sites for the application of the thermal stimulus, the thenar palm is preferable to the feet (Yarnitsky & Sprecher, 1994) and more sensitive than the forearm (Cascio et al., 2008) but an extensive search of optimal body sites has never been conducted in innocuous thermal stimuli in ASD. The room temperature shall be controlled, to assess its potential impact on the results. Moreover, there appears to be a lack of research focusing on the ASD population with intellectual disability as, seemingly, almost all included studies examined participants with an IQ equals or above 70, hence further investigation within this subgroup is needed.

About the research reliability, GMD and power analysis were only computed by Williams et al. (2019). GMD, an inequality measure, shall be calculated to further confirm the increased trial-to-trial variability in thermoception in ASD (Williams et al., 2019). A power analysis should be run to estimate the reliability of the results.

Lastly, given the potentially different underlying dimensions of thermoception, it is uncertain whether the conclusions from the selected experiments, using the available set of methods, can generalize the functioning characteristics of thermal thresholds in ASD. For example, the phenomenon of alexisomia demonstrated in ASD (Fiene et al., 2018) raises the question: the differences in thermal thresholds could be proportional to (or explained by) the degree of alexisomia, which represents an uncontrolled factor up to the present time, together with anxiety, or other symptomatology? Additional studies are needed to control confounding variables using more standardised, rigorous and innovative methodology in larger samples and with the inclusion of autistic individuals with intellectual disabilities.

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). American Psychiatric Publishing.

American Psychiatric Association. (2022). *Diagnostic and statistical manual of mental disorders* (5th ed., text rev.). American Psychiatric Publishing.

Bakkers, M., Faber, C. G., Peters, M. J., Reulen, J. P., Franssen, H., Fischer, T. Z., & Merkies, I. S. (2013). Temperature threshold testing: a systematic review. *Journal of the Peripheral Nervous System*, doi:10.1111/jns5.12001

Balasco, L., Provenzano, G., & Bozzi, Y. (2020). Sensory Abnormalities in Autism Spectrum Disorders: A Focus on the Tactile Domain, From Genetic Mouse Models to the Clinic. *Frontiers in psychiatry*, doi:10.3389/fpsyt.2019.01016

Baranek, G. T., David, F. J., Poe, M. D., Stone, W. L., & Watson, L. R. (2006). Sensory Experiences Questionnaire: discriminating sensory features in young children with autism, developmental delays, and typical development. *Journal of Child Psychology and Psychiatry*, doi:10.1111/j.1469-7610.2005.01546.x

Bishara, A. J., & Hittner, J. B. (2015). Reducing Bias and Error in the Correlation Coefficient Due to Nonnormality. *Educational and Psychological Measurement*, doi:10.1177/0013164414557639

Blakemore, S. J., Tavassoli, T., Calò, S., Thomas, R. M., Catmur, C., Frith, U., & Haggard, P. (2006). Tactile sensitivity in Asperger syndrome. *Brain and Cognition*, doi:10.1016/j.bandc.2005.12.013

Bramer, W. M., Rethlefsen, M. L., Kleijnen, J., & Franco, O. H. (2017). Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study. *Systematic Reviews*, doi:10.1186/s13643-017-0644-y

Cascio, C., McGlone, F., Folger, S., Tannan, V., Baranek, G., Pelphrey, K. A., & Essick, G. (2008). Tactile Perception in Adults with Autism: a Multidimensional Psychophysical Study. *Journal of Autism and Developmental Disorders*, doi:10.1007/s10803-007-0370-8

Chien, Y. L., Chao, C. C., Wu, S. W., Hsueh, H. W., Chiu, Y. N., Tsai, W. C., Gau, S. S., & Hsieh, S. T. (2020). Small fiber pathology in autism and clinical implications. *Neurology*, doi:10.1212/WNL.0000000000010932

Duerden, E. G., Taylor, M. J., Lee, M., McGrath, P. A., Davis, K. D., & Roberts, S. W. (2015). Decreased Sensitivity to Thermal Stimuli in Adolescents With Autism Spectrum Disorder: Relation to Symptomatology and Cognitive Ability. *The Journal of Pain*, doi:10.1016/j.jpain.2015.02.001

Ekman, P., & Friesen, W. (1978). *Facial Action Coding System: A Technique for Measurement of Facial Movement.* Consulting Psychologist's Press, Palo Alto, CA.

Elmquist, J. K., Scammell, T. E., Jacobson, C. D., & Saper, C. B. (1996). Distribution of Fos-like immunoreactivity in the rat brain following intravenous lipopolysaccharide administration. *The Journal of Comparative Neurology*, doi:10.1002/(SICI)1096-9861(19960715)371:1<85::AID-CNE5>3.0.CO;2-H

Fiene, L., Ireland, M. J., & Brownlow, C. (2018). The Interoception Sensory Questionnaire (ISQ): A Scale to Measure Interoceptive Challenges in Adults. *Journal of Autism and Developmental Disorders*, doi:10.1007/s10803-018-3600-3

Fründt, O., Grashorn, W., Schöttle, D., Peiker, I., David, N., Engel, A. K., Forkmann, K., Wrobel, N., Münchau, A., & Bingel, U. (2017). Quantitative Sensory Testing in adults with Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, doi:10.1007/s10803-017-3041-4

Green, B. G. (2004). Temperature perception and nociception. *Journal of Neurobiology,* doi:10.1002/neu.20081

Greenspan, S. I., & Wieder, S. (1997). Developmental Patterns and Outcomes in Infants and Children with Disorders in Relating and Communicating: A Chart Review of 200 Cases of Children with Autistic Spectrum Diagnoses. *Journal of Developmental and Learning Disorders*, 1, 87-141

Güler, A. D., Lee, H., Iida, T., Shimizu, I., Tominaga, M., & Caterina, M. (2002). Heat-evoked activation of the ion channel, TRPV4. *The Journal of neuroscience: the official journal of the Society for Neuroscience,* doi:10.1523/JNEUROSCI.22-15-06408.2002

Gusenbauer, M., & Haddaway, N. R. (2020). Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of Google Scholar, PubMed, and 26 other resources. *Research synthesis methods*, doi:10.1002/jrsm.1378

Haddaway, N. R., Page, M. J., Pritchard, C. C., & McGuinness, L. A. (2022). PRISMA2020: An R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis. *Campbell Systematic Reviews*, doi:10.1002/cl2.1230

Heldestad, V., Linder, J., Sellersjö, L., & Nordh, E. (2010). Reproducibility and influence of test modality order on thermal perception and thermal pain thresholds in quantitative sensory testing. *Clinical Neurophysiology*, doi:10.1016/j.clinph.2010.03.055

Hensel, H., & Schafer, K. (1984). Thermoreception and Temperature Regulation in Man. In E. F., Ring, & B., Phillips (Eds), *Recent Advances in Medical Thermology* (pp. 51-64). New York: Springer.

Hoffman, T., Bar-Shalita, T., Granovsky, Y., Gal, E., Kalingel-Levi, M., Dori, Y., Buxbaum, C., Yarovinsky, N., & Weissman-Fogel, I. (2023). Indifference or hypersensitivity? Solving the riddle of the pain profile in individuals with autism. *Pain*, doi:10.1097/j.pain.0000000000002767

Iarocci, G., & McDonald, J. (2006). Sensory Integration and the Perceptual Experience of Persons with Autism. *Journal of Autism and Developmental Disorders*, doi:10.1007/s10803-005-0044-3

Ijzerman, H., & Semin, G. R. (2009). The thermometer of social relations: mapping social proximity on temperature. *Psychological Science*, doi:10.1111/j.1467-9280.2009.02434.x

Ishiwata, T., Saito, T., Hasegawa, H., Yazawa, T., Kotani, Y., Otokawa, M., & Aihara, Y. (2005). Changes of body temperature and thermoregulatory responses of freely moving rats during GABAergic pharmacological stimulation to the preoptic area and anterior hypothalamus in several ambient temperatures. *Brain Research*, doi:10.1016/j.brainres.2005.04.027

Jänig, W. (2018). Peripheral thermoreceptors in innocuous temperature detection. In A. A. Romanovsky (Ed.), *Handbook of clinical neurology* (pp. 47–56). Elsevier.

Kanner, L. (1943). Autistic disturbances of affective contact. *Nervous Child*, 2, 217-250

Kashio, M., & Tominaga, M. (2022). TRP channels in thermosensation. *Current Opinion in Neurobiology*, doi:10.1016/j.conb.2022.102591

King, M., & Carnahan, H. (2019). Revisiting the brain activity associated with innocuous and noxious cold exposure. *Neuroscience and Biobehavioral Reviews*, doi:10.1016/j.neubiorev.2019.06.021

Lehrl, S. (2005). *Mehrfachwach-Wortschatz-Intelligentztest MWT-B* (5th ed.). Balingen: Spitta Verlag.

Lord, C., Elsabbagh, M., Baird, G., & Veenstra-Vanderweele, J. (2018). Autism spectrum disorder. *Lancet*, doi:10.1016/S0140-6736(18)31129-2

Lynott, D., Corker, K. S., Wortman, J., Connell, L., Donnellan, M. B., Lucas, R. E., & O'Brien, K. (2014). Replication of "Experiencing physical warmth promotes interpersonal warmth" by Williams and Bargh (2008). *Social Psychology*, doi:10.1027/1864-9335/a000187

Mackowiak, P. A., & Boulant, J. A. (1996). Fever's glass ceiling. *Clinical Infectious Diseases: an official publication of the Infectious Diseases Society of America,* doi:10.1093/clinids/22.3.525

Mackowiak, P. A. (1998). Concepts of fever. *Archives of Internal Medicine*, doi:10.1001/archinte.158.17.1870

Marco, E. J., Hinkley, L. B., Hill, S. S., & Nagarajan, S. S. (2011). Sensory Processing in Autism: A Review of Neurophysiologic Findings. *Pediatric research*, doi:10.1203/PDR.0b013e3182130c54

Moore D. J. (2015). Acute pain experience in individuals with autism spectrum disorders: A review. *Autism*, doi:10.1177/1362361314527839

Normansell-Mossa, K. M., Top, D. N., Jr, Russell, N., Freeston, M., Rodgers, J., & South, M. (2021). Sensory Sensitivity and Intolerance of Uncertainty Influence Anxiety in Autistic Adults. *Frontiers in psychology*, doi:10.3389/fpsyg.2021.731753

O'Neill, M., & Jones, R. S. (1997). Sensory-Perceptual Abnormalities in Autism: A Case For More Research? *Journal of autism and developmental disorders*, doi:10.1023/a:1025850431170

Orefice, L. L. (2020). Peripheral Somatosensory Neuron Dysfunction: Emerging Roles in Autism Spectrum Disorders. *Neuroscience*, doi:10.1016/j.neuroscience.2020.01.039

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, doi:10.1136/bmj.n71

Paricio-Montesinos, R., Schwaller, F., Udhayachandran, A., Rau, F., Walcher, J., Evangelista, R., Vriens, J., Voets, T., Poulet, J. F. A., & Lewin, G. R. (2020). The Sensory Coding of Warm Perception. *Neuron*, doi:10.1016/j.neuron.2020.02.035

Peier, A. M., Moqrich, A., Hergarden, A. C., Reeve, A. J., Andersson, D. A., Story, G. M., Earley, T. J., Dragoni, I., McIntyre, P., Bevan, S., & Patapoutian, A. (2002). A TRP channel that senses cold stimuli and menthol. *Cell,* doi:10.1016/s0092-8674(02)00652-9

Peltz, E., Seifert, F., DeCol, R., Dörfler, A., Schwab, S., & Maihöfner, C. (2011). Functional connectivity of the human insular cortex during noxious and innocuous thermal stimulation. *NeuroImage*, doi:10.1016/j.neuroimage.2010.09.012

Pernon, E., Pry, R., & Baghdadli, A. (2007). Autism: tactile perception and emotion. *Journal of Intellectual Disability Research*, doi:10.1111/j.1365-2788.2006.00931.x

Prescott, S. A., & Ratté, S. (2017). Somatosensation and Pain. In P. M. Conn (Ed.), *Conn's Translational Neuroscience* (pp. 517-539). Elsevier.

Puts, N. A., Wodka, E. L., Tommerdahl, M., Mostofsky, S. H., & Edden, R. A. (2014). Impaired tactile processing in children with autism spectrum disorder. *Journal of Neurophysiology*, doi:10.1152/jn.00890.2013

Robertson, C. E., & Baron-Cohen, S. (2017). Sensory perception in autism. *Nature Reviews Neuroscience*, doi:10.1038/nrn.2017.112

Rolke, R., Baron, R., Maier, C., Tölle, T. R., Treede, R.-D., Beyer, A., Binder, A., Birbaumer, N., Birklein, F., Bötefür, I. C., Braune, S., Flor, H., Huge, V., Klug, R., Landwehrmeyer, G. B., Magerl, W., Maihöfner, C., Rolko, C., Schaub, C., Scherens, A., Sprenger, T., Valet, M., & Wasserka, B. (2006). Quantitative sensory testing in the German Research Network on Neuropathic Pain (DFNS): Standardized protocol and reference values. *Pain,* doi:10.1016/j.pain.2006.01.041

Rothhaas, R., & Chung, S. (2021). Role of the preoptic area in sleep and thermoregulation. *Frontiers in Neuroscience*, doi:10.3389/fnins.2021.664781

Seo, Y., & Kim, J. H. (2021). Differential Cutaneous Thermal Sensitivity in Humans: Method of Limit vs. Method of Sensation Magnitude. *International Journal of Environmental Research and Public Health*, doi:10.3390/ijerph182312576

Sherwood, S. C., & Huber, M. (2010). An adaptability limit to climate change due to heat stress. *Proceedings of the National Academy of Sciences of the United States of America*, doi:10.1073/pnas.0913352107

Sparrow, S. S., Balla, D. A., & Cicchetti, D. V. (1984). *Vineland Adaptive Behavior Scale*. Circle Pines, MN: American Guidance Service.

Stroup, D. F., Berlin, J. A., Morton, S. C., Olkin, I., Williamson, G. D., Rennie, D., Moher, D., Becker, B. J., Sipe, T. A., & Thacker, S. B. (2000). Meta-analysis of observational studies in epidemiology: a proposal for reporting. *JAMA*, doi:10.1001/jama.283.15.2008

Tan, C. L., Cooke, E. K., Leib, D. E., Lin, Y. C., Daly, G. E., Zimmerman, C. A., & Knight, Z. A. (2016). Warm-Sensitive Neurons that Control Body Temperature. *Cell*, doi:10.1016/j.cell.2016.08.028

Tan, C. L., & Knight, Z. A. (2018). Regulation of Body Temperature by the Nervous System. *Neuron*, doi:10.1016/j.neuron.2018.02.022

Vaughan, S., McGlone, F., Poole, H., & Moore, D. J. (2020). A Quantitative Sensory Testing Approach to Pain in Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, doi:10.1007/s10803-019-03918-0

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence (WASI)*. San Antonio, TX: Psychological Corporation.

Wechsler, D. (2011). *Wechsler Abbreviated Scale of Intelligence* (2nd ed.). Pearson.

Wells, G. A., Shea, B., O'Connell, D., Peterson, J., Welch, V., Losos, M., & Tugwell, P. (2019). *The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses*. The Ottawa Hospital Research Institute. https://www.ohri.ca/programs/clinical_epidemiology/oxford.asp. Accessed 2 May 2023.

Williams, L. E., & Bargh, J. A. (2008). Experiencing physical warmth promotes interpersonal warmth. *Science*, doi:10.1126/science.1162548

Williams, Z. J., Failla, M. D., Davis, S. L., Heflin, B. H., Okitondo, C. D., Moore, D. J., & Cascio, C. J. (2019). Thermal Perceptual Thresholds are typical in Autism Spectrum Disorder but Strongly Related to Intra-individual Response Variability. *Scientific Reports*, doi:10.1038/s41598-019-49103-2

Yarnitsky, D., & Sprecher, E. (1994). Thermal testing: normative data and repeatability for various test algorithms. *Journal of the Neurological Sciences,* doi:10.1016/0022-510x(94)90239-9

Yasuda, Y., Hashimoto, R., Nakae, A., Kang, H., Ohi, K., Yamamori, H., Fujimoto, M., Hagihira, S., & Takeda, M. (2016). Sensory cognitive abnormalities of pain in autism spectrum disorder: a case-control study. *Annals of General Psychiatry*, doi:10.1186/s12991-016-0095-1

Zeidan, J., Fombonne, E., Scorah, J., Ibrahim, A., Durkin, M. S., Saxena, S., Yusuf, A., Shih, A., & Elsabbagh, M. (2022). Global prevalence of autism: A systematic review update. *Autism Research*, doi:10.1002/aur.2696

Figure 1 top

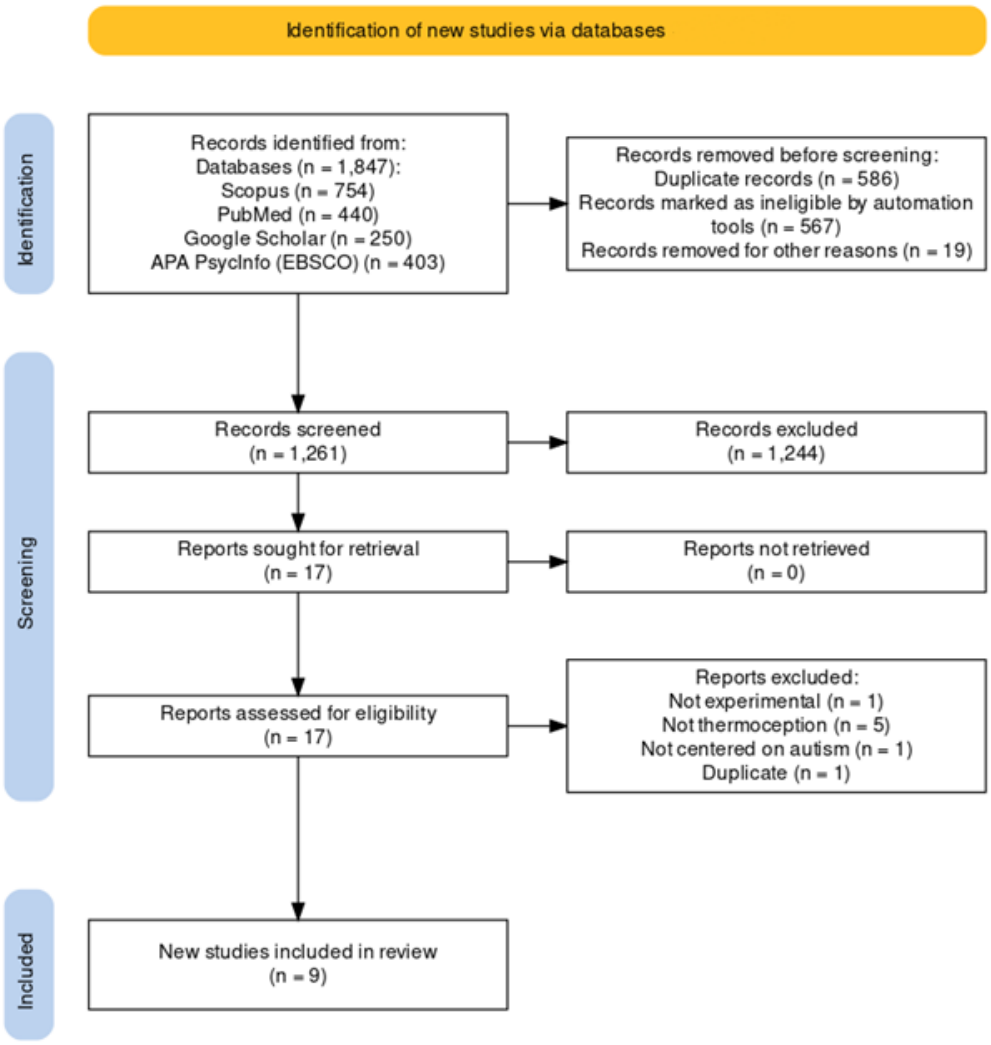
Identification of new studies via databases
Identification
Records identified from:
Databases (n = 1,847):
Scopus (n = 754)
PubMed (n = 440)
Google Scholar (n = 250)
APA PsycInfo (EBSCO) (n = 403)
Records removed before screening:
Duplicate records (n = 586)
Records marked as ineligible by automation tools (n = 567)
Records removed for other reasons (n = 19)
Screening
Records screened
(n = 1,261)
Records excluded
(n = 1,244)
Reports sought for retrieval
(n = 17)
Reports not retrieved
(n = 0)
Reports assessed for eligibility
(n = 17)
Reports excluded:
Not experimental (n = 1)
Not thermoception (n = 5)
Not centered on autism (n = 1)
Duplicate (n = 1)
Included
New studies included in review
(n = 9)

Figure Captions

Fig. 1. *The Flow Diagram Reporting the Selection Process of the Studies*

Authors, year	Experimental group (ASD) n, sex, age, IQ	Control group (Allistic) n, sex, age, IQ	Innocuous Thermoception Protocol	Summary of findings	NOS result
Pernon et al. 2007	n = 30 children (28 males, 2 females) Age = 7.11 ± 1.4 IQ (Non-Available, NA)	2 control groups (n1, n2) n1 = 16 allistic children but with other condition (14 males, 2 females, including 4 with Intellectual Disability, ID) Age = 7.3 ± 3, IQ (NA) n2 = 30 children without ID (28 males, 2 females) Age = 2.11 ± 1.3 IQ (NA)	10 cm² thermal cushion at 20°C in an offered active (*i.e.*, stimulus on the table with no instruction) *vs.* imposed passive condition (*i.e.*, stimulus applied directly on the subject's hand), analysis of facial expressions and motor-behavioural components	No significant difference between the groups for the imposed passive touching condition. In the offered active touching condition, a higher intensity in their positive facial expressions was reported compared to the control groups	6
Cascio et al., 2008	n = 8 adults (7 males, 1 female) Age = 29.3 ± 10.5 IQ ≥ 70	n = 8 allistic adults (7 males, 1 female) Age = 29 ± 9.7	Method-of-limits	No significant difference between the groups was reported for thermal detection thresholds	7
Duerden et al., 2015	n = 20 adolescents (15 males, 5 females) Age = 14.6 ± 1.9 IQ = 104.1 ± 18.27 or 104.4 ± 16.9 (3 missing values, 3 NA)	n = 56 Typically Developing (TD) adolescents (27 males, 29 females; 1 subject was discarded) Age = 15.7 ± 1.1	Method-of-limits	The ASD group was less sensitive to warm and cool stimuli than the control group	8
Yasuda et al., 2016	n = 15 (male/female = 2/3) Age = 25.8 ± 9.2 Full-scale IQ (3 different tests used) = 101.8 ± 14.3	n = 15 (male/female = 2/3) Age = 26.3 ± 7.5 IQ (NA)	Method-of-limits	The ASD group was more sensitive to cool stimulus. But no difference between the groups for warm detection threshold	7
Trindt et al., 2017	n = 13 adults (7 males, 6 females) Age = 31.7 ± 8.2 Verbal IQ (1 NA) = 111.6 ± 16	n = 13 TD adults (7 males, 6 females) Age = 32.1 ± 7.1 Verbal IQ = 110.2 ± 17.3	Method-of-limits	No significant difference between the groups for thermal detection thresholds	9
Williams et al., 2019	2 experimental groups (n1, n2) n1 = 51 children & adolescents (41 males, 10 females) Age_{Median} = 10.03 Full-scale IQ_{Median} (1 NA) = 103.29, Performance IQ $(PIQ)_{Median}$ (1 NA) = 103.47, Verbal IQ $(VIQ)_{Median}$ (1 NA) = 100.21 n2 = 32 adults (21 males, 11 females) Age_{Median} = 25.5 Full-scale IQ_{Median} (2 NA) = 104.61, PIQ_{Median} (2 NA) = 107.98, VIQ_{Median} (2 NA) = 101.14	2 control groups (n1, n2) n1 = 35 TD children & adolescents (26 males, 9 females) Age_{Median} = 9.21 Full-scale IQ_{Median} = 114.16, PIQ_{Median} = 114.01, VIQ_{Median} = 110.74 n2 = 24 TD adults (14 males, 10 females) Age_{Median} = 29.76 Full-scale IQ_{Median} (1 NA) = 107.44, PIQ_{Median} (1 NA) = 106.26, VIQ_{Median} (1 NA) = 105.81	Method-of-limits	No significant difference between the groups was reported for other than adults with ASD being less sensitive to warmth than controls. Regarding trial-to-trial variability, a small but significant increase was found in individuals with ASD, for both stimuli (cool, warm)	9
Chen et al., 2020	n = 27 adults (27 males) Age = 25.86 ± 5.03 IQ ≥ 70	NA	Method-of-levels	Approximately 25% of the individuals with ASD showed to be insensitive to warm stimuli. No significant difference between the ASD group and previous authors' reference data for CDT	7
Vaughan et al., 2020	n = 13 adults (7 males, 6 females) Age = 27.22 ± 9.19 IQ > 70	n = 13 allistic adults (7 males, 6 females) Age = 27.08 ± 8.13	Method-of-limits	No significant difference between the groups for thermal detection thresholds	8
Hoffman et al., 2023	For both groups (experimental, control) 84 males, 20 females; aged 18 to 50 (median = 25.5) years old n = 52 adults (4 discarded subjects) Total IQ_{Median} = 114, PIQ_{Median} = 116, VIQ_{Median} = 113.5	n = 52 TD adults Total IQ_{Median} (1 NA) = 114, PIQ_{Median} (1 NA) = 118, VIQ_{Median} (1 NA) = 108	Method-of-limits	No significant difference between the groups for thermal detection thresholds	8

Table 1. *Studies Included in the Current Review.* Information on the experimental and control group are reported together with the innocuous thermoception protocol, the summary of findings and the NOS results for each included studies.

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