



Contents lists available at ScienceDirect

Neuroscience and Biobehavioral Reviews

journal homepage: www.elsevier.com/locate/neubiorev

Emotion recognition deficits in Alzheimer's disease: A meta-analysis

Aitor Zamora, Yolanda Balboa-Bandeira^{*}, Javier Peña, Natalia Ojeda

Department of Psychology, Faculty of Health Sciences, University of Deusto, Bilbao, Spain

ARTICLE INFO

Keywords:

Emotion recognition
Alzheimer's disease
Social cognition
Meta-analysis

ABSTRACT

Background: Emotion recognition is a core component of social cognition and is essential for effective interpersonal communication. A growing body of literature suggests that this ability is impaired in Alzheimer's disease (AD), although the magnitude and nature of the deficit remain unclear. This meta-analysis aimed to quantify emotion recognition impairments in individuals with AD relative to healthy older adults (HOA).

Methods: A systematic search identified 24 eligible studies comparing emotion recognition performance in individuals with AD and HOA. Random-effects models were used to calculate pooled effect sizes (Hedges' g). Primary analyses were conducted after influence diagnostics, and sensitivity analyses examined the impact of influential studies. Subgroup analyses examined the role of stimulus modality, while meta-regressions assessed potential moderation by MMSE scores, age, and education. Publication bias analyses were also conducted.

Results: The primary meta-analysis revealed a large and statistically significant impairment in emotion recognition in AD ($g = -1.059$, $p < .0001$). MMSE scores significantly moderated the effect, with higher global cognitive status associated with smaller deficits. Age and education did not significantly influence outcomes. Subgroup analyses showed comparable impairments across facial and non-facial tasks, with no significant differences between stimulus modalities.

Conclusions: Emotion recognition is substantially impaired in AD. Although the magnitude of this deficit is associated with global cognitive status, it is unlikely to be fully explained by it alone. These findings support the relevance of social cognitive dysfunction in AD, highlight the importance of more ecologically valid assessment paradigms, and have implications for person-centred care and everyday interpersonal functioning in dementia settings.

1. Introduction

Alzheimer's disease (AD) is the leading cause of dementia worldwide and is characterised by a progressive decline in multiple cognitive domains, most notably memory (World Health Organization: WHO, 2023). Beyond these core deficits, AD also affects a range of functions that are critical for everyday social interaction, including the ability to interpret and respond to social and emotional cues.

Social cognition refers to the set of processes that enable individuals to perceive, interpret, and respond to the intentions, emotions, and behaviours of others (Adolphs, 2001). Within this domain, emotion recognition constitutes a fundamental component, defined as the ability to identify others' emotional states from facial expressions, vocal prosody, or bodily cues. Importantly, emotion recognition should be distinguished from broader emotional processing, as well as from neuropsychiatric symptoms such as apathy or depression, which are highly prevalent in AD but reflect affective and behavioural

disturbances rather than specific deficits in decoding social signals (Chaudhary et al., 2022). Similarly, emotion recognition is conceptually distinct from phenomena such as emotional enhancement of memory, whereby emotionally salient information may be preferentially retained despite overall cognitive decline (Baran et al., 2014; Boller Farid El Massioui et al., 2002).

Difficulties in emotion recognition have important functional consequences. Impairments in this domain can compromise interpersonal communication, reduce social engagement, and increase caregiver burden (Bucks and Radford, 2004; Demichelis et al., 2020). These deficits are thought to arise from disruption to neural networks involved in social and emotional processing, including frontotemporal and limbic regions such as the amygdala, anterior cingulate cortex, and temporal lobes (Amlerova et al., 2022; Xu et al., 2021). Although these regions are also implicated in memory, their role in social cognition highlights that AD-related impairment extends beyond traditionally assessed cognitive domains.

^{*} Correspondence to: Department of Psychology, Faculty of Health Sciences, University of Deusto, Av. de las Universidades, 24, Bilbao 48007, Spain.
E-mail address: yolandabalboa@deusto.es (Y. Balboa-Bandeira).

<https://doi.org/10.1016/j.neubiorev.2026.106745>

Received 9 November 2025; Received in revised form 18 March 2026; Accepted 6 May 2026

Available online 9 May 2026

0149-7634/© 2026 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

Despite growing interest in social cognition in AD, findings on emotion recognition remain inconsistent. Many studies report poorer performance in individuals with AD compared to healthy older adults (HOA), yet the magnitude and nature of these deficits vary considerably (Comon et al., 2022; Fernández-Ríos et al., 2021; Jiskoot et al., 2021). Some evidence suggests that recognition of negative emotions is disproportionately impaired relative to positive emotions (McLellan et al., 2008) whereas other studies indicate relative preservation of basic emotions alongside deficits in more complex or subtle expressions (Fischer et al., 2019; Torres et al., 2015). These inconsistencies complicate the interpretation of emotion recognition as a reliable feature of AD.

Several factors may contribute to this heterogeneity. Methodological variability across studies is substantial, including differences in task modality (e.g., static versus dynamic stimuli), stimulus type (faces, voices, or multimodal cues), emotional categories examined, and outcome measures. In addition, clinical heterogeneity—particularly variation in disease severity and diagnostic criteria—may influence observed effects. Notably, reduced awareness of cognitive deficits (anosognosia) is common in AD and may further complicate the interpretation of task performance, as individuals may exhibit intact emotional reactivity or confidence in their responses despite impaired recognition accuracy (Antoine et al., 2013; Latgé-Tovar et al., 2022; Mograbi et al., 2012).

Previous meta-analyses have attempted to synthesise this literature but are now limited by several factors. Earlier work has not incorporated the substantial growth in studies over the past decade, including the use of more diverse and ecologically valid task paradigms. Moreover, prior syntheses have often combined different dementia subtypes or broader social cognitive domains, rather than focusing specifically on emotion recognition in clinically defined AD. In addition, potential moderators such as cognitive severity and task characteristics have not been systematically examined (Klein-Koerkamp et al., 2012; Shi et al., 2025).

Given these limitations, an updated and focused meta-analysis is warranted. The present study aims to quantify the magnitude of emotion recognition deficits in individuals with AD compared to healthy older adults, while explicitly addressing sources of heterogeneity. Specifically, we examine the moderating role of global cognitive status and key methodological features, including task characteristics and outcome measures. By clarifying the extent and variability of emotion recognition impairment, this work seeks to provide a more precise characterisation of social cognitive dysfunction in AD.

2. Methods

2.1. Search strategy

The present meta-analysis was conducted in accordance with the Preferred Reporting Items for Systemic Reviews and Meta Analysis (PRISMA) guidelines (Page et al., 2021) and was registered at the International Prospective Register of Systematic Reviews (number CRD42023440576).

A systematic literature search was conducted between January 2025 and May 2025 across the following databases: PubMed, Web of Science, and Cochrane Library. The search encompassed records published from January 2000 to May 2025. Search terms were combined using Boolean operators and encompassed four concept blocks: 1) Alzheimer Disease/Alzheimer's Disease/AD/dementia; 2) Emotions/Emotion Recognition/Facial Recognition/facial expression/ voice prosody/affective processing; 3) Aged/Healthy Aging/elderly/older adults/healthy controls; 4) Neuropsychological Tests/Task Performance and Analysis/accuracy/reaction time/deficits/moderator/social cognition. These terms were targeted within the title, abstract, and/or keywords of publications. The terms were combined to perform a more comprehensive search. In addition, a supplementary search of grey literature was conducted using general internet search engines, applying the same publication date

limits. Full database-specific search strategies for PubMed, Web of Science, and the Cochrane Library, including Boolean operators, database-specific subject headings where applicable, field tags, truncation, and date limits, are provided in [Supplementary Appendix S1](#).

Duplicates were removed using reference management software ([RefWorks Citation Manager, 2024](#)) and through manual inspection. Title and abstract screening were conducted independently by two reviewers (A.Z. and Y.B.-B.), followed by full-text assessment of potentially eligible studies. Any discrepancies were resolved through discussion or, when necessary, consultation with a third author.

2.2. Eligibility criteria

Studies were eligible if they: (1) compared emotion recognition performance between Alzheimer's disease (AD) participants and healthy older adults (HOA); (2) reported quantitative outcomes (e.g., accuracy, reaction time) for meta-analytical inclusion; (3) were peer-reviewed empirical articles published in English between 2000 and 2025; and (4) contained sufficient statistical information to compute effect sizes for AD vs. HOA group differences.

Studies were excluded if they: 1) focused primarily on other dementias (e.g., Parkinson's, Frontotemporal); 2) lacked a healthy older adult control group; 3) were case reports, reviews, meta-analyses, commentaries, or non-empirical articles; or 4) reported data from only a single AD participant.

In relation to diagnostic definitions, studies were eligible only if Alzheimer's disease diagnoses were established using recognised clinical diagnostic frameworks. Across the included literature, diagnoses were most commonly based on NINCDS-ADRDA or DSM-based criteria and were supported by clinical evaluation and neuropsychological assessment. Studies that did not explicitly report diagnostic criteria were included only when a formal clinical diagnosis of probable Alzheimer's disease was clearly stated.

2.3. Quality assessment and risk of bias in the included studies

Methodological quality of the included studies was assessed using the Newcastle–Ottawa Scale (NOS), a validated tool for evaluating non-randomised case-control and cross-sectional studies (see [Supplementary Appendix S2, Table S1](#)) (Wells et al., 2000). The NOS assesses three domains: selection of participants, comparability of groups, and ascertainment of outcomes, with a maximum score of nine points.

Independent evaluations were conducted by A.Z. and Y.B.-B., with disagreements resolved through discussion or third-party adjudication.

2.4. Data extraction

Data extraction was carried out following PRISMA guidelines. Extracted variables included: (1) authorship and publication year; (2) sample size; (3) mean age and standard deviation; (4) demographic variables; (5) years of education; (6) MMSE scores; (7) type of emotion recognition test and stimuli; (8) study design; and (9) principal findings. Data were extracted independently by A.Z. and Y.B.-B.; missing information was requested from corresponding authors.

To ensure statistical independence of effect sizes, a single emotion recognition outcome was selected from each study for inclusion in the primary meta-analysis. When multiple emotion recognition tasks or outcomes were reported, a predefined selection hierarchy was applied. Preference was given to global or composite emotion recognition scores over emotion-specific subscores. Where several tasks were administered, the task most directly assessing emotion recognition—rather than broader social cognitive constructs—and most commonly used across studies was selected.

Accuracy-based outcomes were prioritised over reaction time measures when both were available, in order to maximise comparability across studies. Details regarding the selected outcome, task type, and

stimulus modality are reported in [Supplementary Material Appendix S2 \(Table S2\)](#). The same measures were selected for the sensitivity analyses.

2.5. Statistical analysis

All analyses were conducted using RStudio (R version 4.5.1), employing the *metafor* and *dmatar* packages (Harrer et al., 2019; Viechtbauer, 2010). Effect sizes were calculated as standardised mean differences (SMDs; Hedges' g) between AD and HOA groups and interpreted according to conventional benchmarks (Cumming, 2012).

Given anticipated methodological and clinical heterogeneity, random-effects models were used to estimate pooled effect sizes (Borenstein et al., 2010). Heterogeneity was assessed using Cochran's Q statistic ($p < .05$), the I^2 index (with values of 20%, 50%, and 75% representing moderate, substantial, and considerable heterogeneity, respectively) and the between-study variance estimator τ^2 (Higgins and Thompson, 2002)

Potentially influential studies were identified through a combination of visual inspection of forest plots, examination of confidence interval overlap, and leave-one-out influence diagnostics. Based on convergence across these criteria, three studies (Chainay and Gaubert, 2020; Gressie et al., 2024; Strijkert et al., 2023) showed disproportionately large effect sizes and exerted marked influence on the pooled estimate across these diagnostics. These studies were therefore excluded from the primary meta-analysis to obtain a more stable and conservative estimate of the overall effect size, given the limited number of available studies and the sensitivity of random-effects models to extreme values.

Importantly, the exclusion of these influential studies does not imply that their findings are invalid. Rather, extreme effect sizes may reflect meaningful clinical or methodological differences (e.g., task characteristics, sample composition, or disease severity) that could not be fully modelled within the present meta-analysis. Accordingly, sensitivity analyses were conducted by reintroducing these studies to evaluate the robustness of the primary findings to their inclusion. Results from these sensitivity analyses are reported alongside the primary analyses.

Subgroup analyses were conducted to examine whether effect sizes differed according to stimulus modality, comparing studies using facial emotion recognition tasks with those employing alternative formats (e.g., videos, drawings, or body-based cues). To further explore potential sources of heterogeneity, meta-regressions were conducted using age, MMSE scores, and years of education as moderators, each examined independently. In addition, an interaction between MMSE and stimulus modality (facial vs. non-facial) was tested to assess whether cognitive status moderated the relationship between task format and emotion recognition performance. Prior to meta-regression analyses, collinearity diagnostics were performed using variance inflation factors (VIFs) and correlation matrices to ensure that multicollinearity did not compromise the validity of parameter estimates.

Finally, publication bias was evaluated through visual inspection of funnel plots and Egger's regression test, based on standard error and sampling variance.

Finally, publication bias was assessed through visual inspection of funnel plots and Egger's regression test, using standard error and sampling variance to evaluate asymmetry in the distribution of effect sizes.

3. Results

3.1. Study selection and characteristics of the studies

A preliminary search yielded 1490 articles of which 861 were selected for the screening process after the removal of duplicated ones. From the information provided by the title and abstract, 63 studies passed the selection criteria and were considered eligible for more in-depth analysis. After a review of the full text, 40 articles were excluded (reasons for exclusion stated in [Fig. 1](#)) leaving a total sample of 23 studies for inclusion in further meta-analytic processes. On the other hand, one article was included from records identified via other methods and was included to the other 23 included studies via databases, being a total of 24 studies eligible for quantitative synthesis (see [Fig. 1](#)).

Across the included studies, the total sample comprised 1358

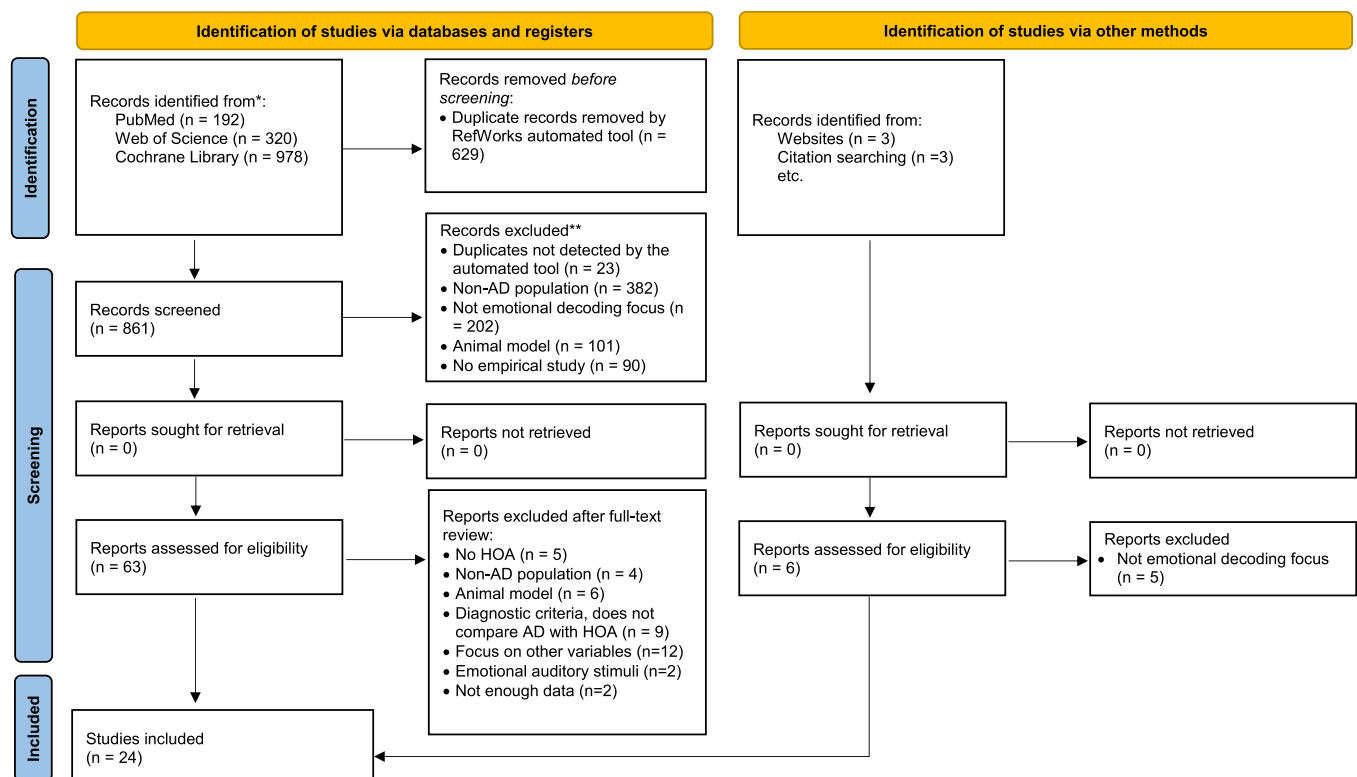


Fig. 1. PRISMA summary of identified studies included in the study.

participants: 626 individuals diagnosed with Alzheimer's disease (mean age = 73.53 years; mean MMSE = 22.95) and 732 healthy older adults (mean age = 70.96 years; mean MMSE = 29.12). Detailed characteristics of the included studies, including task type and stimulus modality, are presented in Table 2.

3.2. Emotion recognition performance: Overall effect

A random-effects meta-analysis was conducted on 21 studies assessing emotion recognition performance in individuals with AD compared to HOA (). The pooled effect size calculated using Hedges' *g*, indicated a large and statistically significant deficit in the AD group

Table 2
Summary of the reviewed studies for emotion recognition measures in HOA and AD patients.

Authors	Healthy Older Adults (HOA)					Alzheimer Disease patients (AD)					Test & tasks	Main Results
	N	Age (M ±SD)	Education (M±SD)	Sex (F/M)	MMSE (M±SD)	N	Age (M ±SD)	Education (M±SD)	Sex (F/M)	MMSE (M±SD)		
Bertoux et al. (2015)	30	67.2 ± 8.7	10.7 ± 3.7	15 F/ 15 M	29 ± 0.9	28	70.3 ± 11.1	11 ± 3.6	12 F/ 16 M	24.3 ± 2.7	FERT Mini-SEA	AD < HOA (faces)
Chainay and Gaubert (2020)	33	72.6 ± 6.1	-	22 F/ 11 M	29.1 ± 0.94	28	74.4 ± 7.9	-	17 F/ 11 M	25.1 ± 2.4	Facial expression recognition (MSFDE)	AD < HOA (faces)
Dodich et al. (2022)	20	73.6 ± 4.7	11.0 ± 4.6	11 F/ 9 M	29.7 ± 0.5	16	73.5 ± 6.7	12.1 ± 4.7	8 F/ 8 M	26.1 ± 1.9	Ekman 60-Faces Test	AD < HOA (faces)
Duclos et al. (2018)	20	77.3 ± 5.9	10.8 (±4.2)	15 F/ 5 M	29 ± 1.1	20	79.4 ± 5.1	10.2 ± 3.6	11 F/ 9 M	21.9 ± 2.1	Peter and Mary emotion tasks battery – Face task	AD < HOA (faces)
Garcia-Cordero et al. (2021)	38	70.55 ± 7.30	13.8 ± 3.92	24 F/ 14 M	-	27	74.04 ± 7.66	11.89 ± 4.21	15 F/ 12 M	-	FERT Mini-SEA	AD < HOA (faces)
Goodkind et al. (2015)	24	67.51 ± 6.13	-	17 F/ 7 M	29.33 ± 1.13	23	60.65 ± 8.69	-	11 F/ 12 M	22.04 ± 5.09	Emotion recognition in films	AD = HOA (film clip)
Gressie et al. (2023)	90	65 ± 5.4	13.5 ± 2.7	44 F/ 46 M	-	76	65 ± 8.4	12.1 ± 3.4	30 F/ 46/M	-	FAST	AD < HOA (faces)
El Haj et al. (2015)	30	74.4 ± 6.02	10.03 ± 3.15	19 F/ 11 M	28.37 ± 1.35	27	76.59 ± 5.81	9.04 ± 2.87	18 F/ 9 M	21.67 ± 1.54	Emotion recognition task (pictures from Ebner et al.'s FACES database)	AD < HOA (association of faces)
Hazelton et al. (2023)	19	64.16	-	-	-	21	75.2	-	-	-	FAST	AD < HOA (faces)
Heitz et al. (2016)	16	68.3 ± 10.5	11.9 ± 3.2	9 F/ 7 M	29.3 ± 0.9	15	70.9 ± 11.1	13.5 ± 3.6	7 F/ 8 M	27.2 ± 1.8	Ekman's FERT, Reading the Mind in the Eyes (RME)	AD = HOA (faces)
Henry et al. (2009)	20	80.5 ± 5.95	10 ± 2.01	13 F/ 7 M	28.8 ± 1.11	20	81.8 ± 4.23	9.7 ± 2.01	14 F/ 6 M	17.2 ± 4.33	RME	AD = HOA (emotions of eye pictures)
Insch et al. (2015)	15	73.13 ± 5.21	14.33 ± 2.67	8 F/ 7 M	29.47 ± 0.64	15	75.25 ± 6.46	13.93 ± 4.54	8 F/ 7 M	23.87 ± 2.97	Biological motion emotion recognition task	AD < HOA (body emotion)
Maki et al. (2013)	17	76.8 ± 3.5	-	-	-	12	81.1 ± 9.2	-	-	-	FER (Japanese woman, six emotions)	AD = HOA (faces happiness) AD < HOA (faces other emotions)
Mariano et al. (2020)	23	64.7 ± 10	11 ± 2.6	15 F/ 8 M	29 ± 0.9	20	71.3 ± 9	13 ± 4	10 F/ 10 M	24.7 ± 2	FERT Mini-SEA	AD = HOA (faces)
Martinez et al. (2018)	25	62.05 ± 13.3	NA	14 F/ 8 M	-	25	73.2 ± 10.7	-	15 F/ 10 M	-	TASIT-EET	AD < HOA (video clips)
Moura et al. (2021)	23	68 ± 10	11 ± 2.6	15 F/ 8 M	29 ± 0.9	20	74 ± 9	13 ± 4	10 F/ 10 M	24 ± 2	FERT Mini-SEA	AD = HOA (faces)
Mulet-Perreault et al. (2025)	20	74.6 (5.0)	14.4(3.7)	10 F/ 10 M	NA	20	74.2 (7.3)	14.4(3.7)	7 F/ 13 M	-	FERT Mini-SEA	AD = HOA (faces)
Wiechetek Ostos et al. (2011)	12	70.5 ± 6.0	-	10 F/ 2 M	29.7 ± 0.5	12	80.6 ± 6.3	-	7 F/ 5 M	23.4 ± 3.2	Multimodal Emotion Recognition Test	AD < HOA (faces)
Park et al. (2017)	33	70.97 ± 6.45	12.27 ± 3.19	22 F/ 11 M	27.91 ± 1.96	32	76.75 ± 8.47	9.50 ± 3.94	17 F/ 15 M	19	FERT based on Ekman 60 Faces Test - Korean version	AD < HOA (faces)
Phillips et al. (2010)	30	72.97 ± 7.51	12.12 ± 3.20	21 F/ 9 M	29.4 ± 1.04	27	74.37 ± 9.03	11 ± 2.70	15 F/ 12 M	22.07 ± 4.19	FEEST battery	AD < HOA (faces)
Sava et al. (2019)	21	74.33 ± 8.47	9.04 ± 2.62	14 F/ 7 M	29.04 ± 0.82	17	78.82 ± 3.24	10.87 ± 1.6	7 F/ 10 M	24.4 ± 2.05	Emotional expressions attribution task (drawings)	AD < HOA (associating emotions to drawings)
Sheardova et al. (2014)	42	71.55 ± 4.95	15.79 ± 2.59	17 F/ 25 M	28.54 ± 1.44	29	74.41 ± 8.44	12.59 ± 2.21	12 F/ 17 M	19.79 ± 3.26	Ekman's FERT	AD < HOA (faces)
Strijkert et al. (2022)	60	66.9 ± 1.4	5.1 ± 0.1	32 F/ 28 M	29.4	45	71.6 ± 1.2	4.8 ± 0.2	22 F/ 23 M	24.9	Ekman 60 Faces Test	AD < HOA (faces)
Strijkert et al. (2023)	60	66.9 ± 11.2	5.1 ± 1.1	28 F/ 32 M	30 (28–30)	31	71.1 ± 8.4	4.7 ± 1.6	16 F/ 15 M	25 ± 20–30	Ekman 60 Faces Test	AD < HOA (faces)

compared to HOA: $g = -1.059$, 95% CI $[-1.219, -0.899]$, $t(21) = -13.79$, $p < .0001$ (see Fig. 2). The negative direction of the standardised mean difference reflects consistent evidence across studies that individuals with AD exhibit reduced accuracy in identifying emotional expressions. The 95% prediction interval $[-1.376, -0.742]$ suggests that future studies are also likely to report substantial impairments in the same direction, reinforcing the clinical relevance of the effect.

Between-study heterogeneity was moderate to substantial ($I^2 = 53.3\%$, $\tau^2 = 0.0179$), although Cochran's Q test did not reach statistical significance ($Q(21) = 26.72$, $p = .1804$).

3.3. Subgroup Analyses by Stimulus Type

To examine whether stimulus modality moderated emotion recognition performance, subgroup analyses compared studies using facial stimuli ($k = 16$) with those employing alternative modalities ($k = 6$), including drawings and video clips. Both subgroups yielded large and statistically significant pooled effect sizes in the same direction, indicating consistently poorer performance in AD relative to HOA regardless of stimulus type.

For studies using facial stimuli, the pooled effect size was $g = -1.0290$, 95% CI $[-1.2173, -0.8407]$, with a τ^2 of 0.0184 and an I^2 value of 23.2%, indicating low-to-moderate heterogeneity. Studies using non-facial stimuli showed a slightly larger pooled effect ($g = -1.1596$, 95% CI $[-1.5809, -0.7383]$), accompanied by slightly greater heterogeneity ($\tau^2 = 0.0341$, $I^2 = 23.9\%$). However, the test for subgroup differences was not statistically significant, $Q(1) = 0.49$, $p = .4830$, suggesting no reliable evidence that stimulus modality altered the magnitude of the effect.

3.3.1. Meta-regression analyses

To further explore sources of heterogeneity among effect sizes, a series of univariate meta-regressions were conducted using key study-

level characteristics as potential moderators. Mean age ($k = 22$) did not yield a significant moderation effect, $F(1, 20) = 0.6373$, $p = .4341$, with a non-significant regression coefficient ($b = -0.0124$, 95% CI $[-0.0448, 0.0200]$). This indicates that chronological age did not account for variability in emotion recognition deficits across studies.

In contrast, MMSE score emerged as a significant moderator of effect sizes ($k = 17$), $F(1, 15) = 11.10$, $p = .0046$. The positive regression coefficient ($b = 0.0794$, 95% CI $[0.0286, 0.1303]$) suggests that higher cognitive functioning in the AD group was associated with smaller group differences in emotion recognition performance.

Years of education did not significantly moderate effect sizes, either in the AD group ($F(1, 15) = 1.81$, $p = .1990$; $b = 0.0392$, 95% CI $[-0.0230, 0.1013]$) or in the HOA group ($F(1, 15) = 0.0069$, $p = .9351$; $b = -0.0024$, 95% CI $[-0.0631, 0.0584]$).

Finally, a combined model including an interaction between MMSE score and stimulus modality ($k = 17$) yielded a significant overall test, $F(3, 13) = 3.43$, $p = .0491$. However, none of the individual coefficients reached statistical significance, and the MMSE \times stimulus interaction term was non-significant ($b = 0.0291$, $p = .5951$), indicating no evidence that the moderating effect of cognitive status differed as a function of stimulus type.

3.4. Sensitivity analysis

Sensitivity analyses were conducted to assess the robustness of the primary findings to the inclusion of three studies identified as influential due to disproportionately large effect sizes (Chainay and Gaubert, 2020; Gressie et al., 2024; Strijkert et al., 2023). When these studies were reintroduced into the analysis ($k = 25$), the pooled effect size remained large and statistically significant ($g = -1.1387$, 95% CI $[-1.4156, -0.8617]$, $p < .0001$).

Although the inclusion of these studies increased the magnitude of the pooled effect and heterogeneity estimates, the direction and

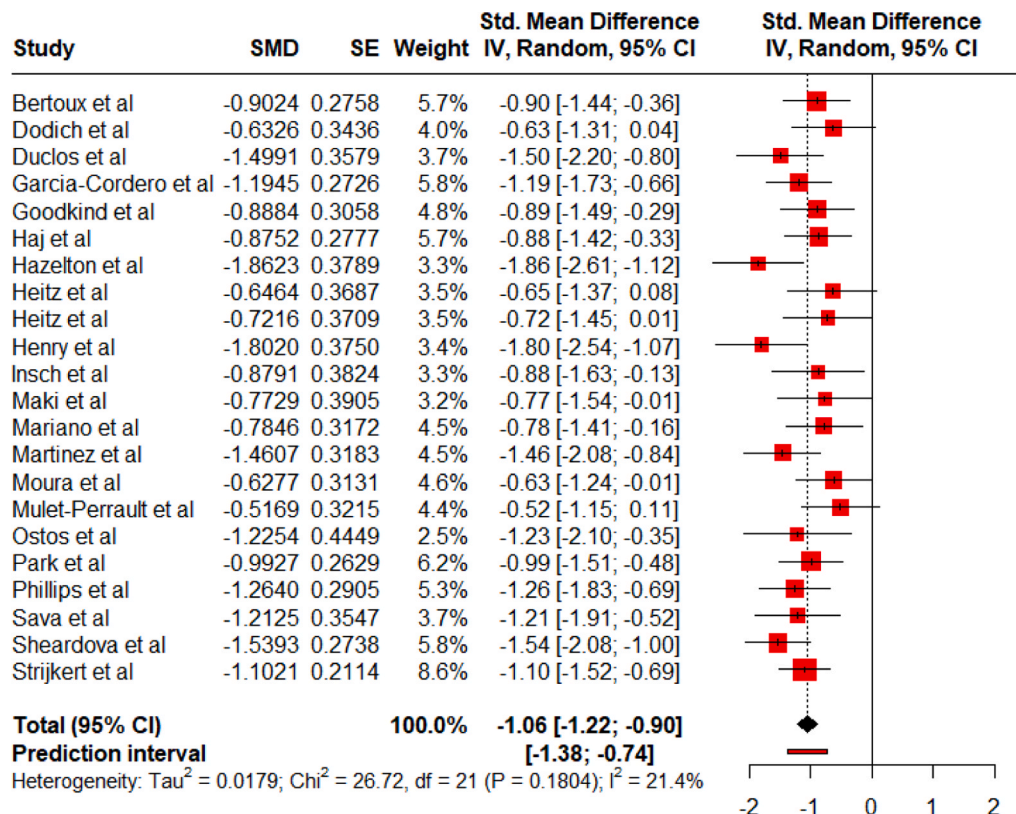


Fig. 2. Forest plot of overall emotion recognition effect sizes of the included studies. Notes: SMD: Standardised Mean Difference; SE: Standard Error; CI: confidence interval.

statistical significance of the results were unchanged. This indicates that the primary conclusions regarding impaired emotion recognition in AD are robust, while also suggesting that extreme effect sizes may contribute to observed heterogeneity.

3.4.1. Publication bias

Funnel plot and Eggers regression test were performed to analyse the presence of publication bias. Visual inspection of the funnel plot did not suggest evident asymmetry in the distribution of studies (see Fig. 3). The result of the Egger's regression test was non-significant ($p = .9410$), with a bias estimate of -0.1074 ($SE = 1.4322$), indicating no evidence of small-study effects or systematic bias due to selective publication.

4. Discussion

By integrating data from 21 studies, the present meta-analysis identified a large and statistically significant impairment in emotion recognition in individuals with Alzheimer's disease (AD) compared to healthy older adults. This finding supports the view that social cognitive dysfunction is a meaningful component of AD, extending beyond traditionally assessed domains such as memory. At the same time, the substantial heterogeneity observed across studies indicates that these deficits are not uniform and require careful interpretation.

From a theoretical perspective, these findings are broadly consistent with distributed models of social cognition. Simulation-based accounts suggest that recognising others' emotions partly depends on overlapping perceptual, sensorimotor, and affective processes in the observer, whereas broader social brain frameworks highlight the role of interconnected frontotemporal and limbic systems in decoding socially relevant emotional signals and supporting inferences about others' feelings and intentions (Adolphs, 2009, Adolphs, 2001; Wood et al., 2016). The present results, showing robust but variable impairments, are compatible with a disruption of these integrated systems rather than a selective deficit in a single emotional function. In this sense, emotion recognition difficulties in AD may reflect a breakdown in the coordination of perceptual, cognitive, and affective processes required for decoding social signals.

The heterogeneity observed across studies also helps to contextualise the mixed findings reported in the literature. While some studies have described relatively preserved recognition of basic emotions, others

have reported more widespread impairments or valence-specific effects. Our results suggest that these discrepancies are unlikely to reflect a single, uniform pattern of impairment. Instead, they are likely driven by a combination of methodological and clinical factors. Differences in task design—such as the use of static versus dynamic stimuli, variation in emotional categories, and the complexity of the expressions presented—may engage distinct cognitive and neural processes (Kohler et al., 2005). In addition, variability in disease severity and sample characteristics may contribute to differences in observed effect sizes. The present meta-analysis quantifies an overall deficit but does not eliminate this heterogeneity, suggesting that variability across studies reflects both methodological differences and genuine differences within AD populations.

Global cognitive status emerged as a significant moderator, with higher MMSE scores associated with smaller deficits in emotion recognition. This suggests that performance in emotion recognition tasks is related, at least in part, to overall cognitive decline. However, this relationship should be interpreted with caution. The MMSE is a relatively coarse measure that does not isolate specific cognitive domains such as executive function, semantic processing, or visuo-perceptual abilities, all of which are likely to contribute to emotion recognition performance (Arevalo-Rodriguez et al., 2021). It therefore remains unclear which cognitive processes primarily drive this association. In addition, task demands, including attentional load and perceptual complexity, may influence performance independently of global cognitive status. Future studies using more fine-grained neuropsychological measures will be essential to clarify these relationships.

At the task level, subgroup analyses indicated that emotion recognition deficits were present across different stimulus modalities. Impairments were observed not only in studies using static facial expressions but also in those employing alternative formats such as eye-region stimuli, video clips, or drawings. Although non-facial tasks showed numerically larger effects, these differences were not statistically significant. This pattern reinforces the view that emotion recognition difficulties in AD are not restricted to a single modality. At the same time, it highlights an important limitation in the existing literature. Facial emotion recognition tasks remain the most commonly used approach, yet their ecological validity has long been questioned (Cadieux and Greve, 1997). More naturalistic paradigms, including dynamic and context-rich stimuli, may better capture the complexity of real-world social interactions and should be more systematically incorporated into future research.

From a neurobiological perspective, the present findings are consistent with the involvement of distributed networks supporting emotional and social processing. Regions such as the amygdala, anterior cingulate cortex, and temporal lobes—frequently implicated in emotion recognition—are also known to be affected in AD (Amlerova et al., 2022b; Xu et al., 2021). Rather than reflecting isolated regional dysfunction, impairments in emotion recognition are more likely to arise from disrupted connectivity within these networks, including altered interactions between limbic structures and temporoparietal and frontal regions. This network-level account aligns with broader models of AD as a disorder of large-scale brain systems (Seeley et al., 2009) and may help to explain the variability in behavioural findings across individuals.

These findings also have practical implications. Difficulties in recognising others' emotions can disrupt interpersonal communication, contribute to misunderstandings, and increase caregiver burden (Bucks and Radford, 2004; Demichelis et al., 2020). Such impairments may not be readily captured by standard cognitive assessments, yet they have clear consequences for daily functioning and quality of life. Emotion recognition tasks could therefore represent a useful complement to traditional assessments, particularly in the early stages of the disease. However, further work is needed to determine their sensitivity and specificity, as well as their potential role as targets for intervention.

Several limitations should be acknowledged. The relatively small number of studies limited the scope of moderator analyses and restricted

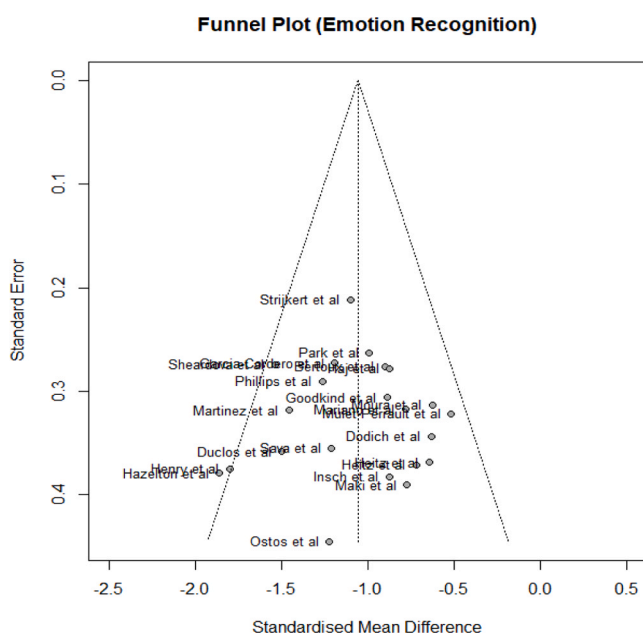


Fig. 3. Funnel plot of the analysed studies.

the examination of less commonly used task paradigms. In addition, variability in study design and reporting practices constrained the comparability of outcomes. Greater standardisation in the assessment of emotion recognition, including clearer reporting of task characteristics and participant profiles, would facilitate more precise synthesis in future work.

In conclusion, this meta-analysis demonstrates that individuals with Alzheimer's disease show substantial impairments in emotion recognition. While these deficits are associated with overall cognitive decline, they are not fully explained by it and likely reflect the combined impact of multiple cognitive and neural processes. Their presence across task modalities and their relevance to everyday social functioning underscore the importance of considering social cognition as a core feature of AD. A more detailed understanding of these processes may inform both theoretical models of the disease and more person-centred approaches to care.

Authorship contribution statement

Aitor Zamora: *Conceptualization, Methodology, Software, Investigation, Formal analysis, Writing-Original draft, Writing-Reviewing and Editing;*
Yolanda Balboa-Bandeira: *Methodology, Software, Formal analysis, Validation, Visualization, Writing-Reviewing and Editing;*
Javier Peña: *Validation, Resources, Supervision, Writing-Reviewing and Editing;*
Natalia Ojeda: *Conceptualization, Resources, Supervision, Project Administration, Writing-Reviewing and Editing.*

Ethical compliance section

Na

Funding

This research was supported by the Department of Education and Science of the Basque Government [IT1545–22].

Declaration of Competing Interest

The authors declared no potential or real conflicts of interest with respect to the research, authorship, and/or publication of this article. This includes, but is not limited to, any financial, personal, or professional relationships that could be construed to influence the work.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.neubiorev.2026.106745](https://doi.org/10.1016/j.neubiorev.2026.106745).

References

- Adolphs, R., 2001. The neurobiology of social cognition. *Curr. Opin. Neurobiol.* 11 (2), 231–239. [https://doi.org/10.1016/S0959-4388\(00\)00202-6](https://doi.org/10.1016/S0959-4388(00)00202-6). PMID: 11301245.
- Adolphs, R., 2009. The social brain: neural basis of social knowledge. *Annu Rev Psychol.* 60, 693–716. doi: 10.1146/annurev.psych.60.110707.163514. PMID: 18771388; PPMCID: PMC2588649.
- Amlerova, J., Laczó, J., Nedelska, Z., Laczó, M., Vyhánek, M., Zhang, B., Sheardova, K., Angelucci, F., Andel, R., Hort, J., 2022. Emotional prosody recognition is impaired in Alzheimer's disease. *Alzheimers Res Ther.* 14. <https://doi.org/10.1186/s13195-022-00989-7>.
- Antoine, P., Nandrino, J.L., Billiet, C., 2013. Awareness of deficits in Alzheimer's disease patients: Analysis of performance prediction discrepancies. *Psychiatry Clin. Neurosci.* 67, 237–244. <https://doi.org/10.1111/pcn.12050>.
- Arevalo-Rodriguez, I., Smailagic, N., Roqué-Figuls, M., Ciapponi, A., Sanchez-Perez, E., Giannakou, A., Pedraza, O.L., Bonfill Cosp, X., Cullum, S., 2021 Jul 27. Mini-Mental State Examination (MMSE) for the early detection of dementia in people with mild cognitive impairment (MCI). *Cochrane Database Syst. Rev.* 7 (7), CD010783. <https://doi.org/10.1002/14651858.CD010783.pub3>. PMID: 34313331; PPMCID: PMC8406467.
- Baran, Z., Cängöz, B., Ozel-Kizil, E.T., 2014. The impact of aging and Alzheimer's disease on emotional enhancement of memory. *Eur. Neurol.* 72, 30–37. <https://doi.org/10.1159/000359924>.

- Bertoux, M., De Souza Lc, L.C., O'Callaghan, C., Greve, A., Sarazin, M., Dubois, B., Hornberger, M., 2015. Social cognition deficits: The key to discriminate behavioral variant frontotemporal dementia from Alzheimer's disease regardless of amnesia? *J. Alzheimer's S. Dis.* 49, 1065–1074. <https://doi.org/10.3233/JAD-150686>.
- Boller Farid El Massioui, F., Devouche Latchezar Traykov Simone Pomati, E., Starkstein, S.E., Boller, F., 2002. Processing emotional information in Alzheimer's disease: effects on memory performance and neurophysiological correlates, original research article. *Dement Geriatr. Cogn. Disord.*
- Borenstein, M., Hedges, L.V., Higgins, J.P.T., Rothstein, H.R., 2010. A basic introduction to fixed-effect and random-effects models for meta-analysis. *Res Synth. Methods* 1, 97–111. <https://doi.org/10.1002/jsm.12>.
- Bucks, R.S., Radford, S.A., 2004. Emotion processing in Alzheimer's disease. *Aging Ment. Health* 8, 222–232. <https://doi.org/10.1080/13607860410001669750>.
- Cadioux, N.L., Greve, K.W., 1997. Emotion processing in Alzheimer's disease. *J. Int. Neuropsychol. Soc.* 3, 411–419. <https://doi.org/10.1017/S1355617797004116>.
- Chainay, H., Gaubert, F., 2020. Affective and cognitive theory of mind in Alzheimer's disease: The role of executive functions. *J. Clin. Exp. Neuropsychol.* 42, 371–386. <https://doi.org/10.1080/13803395.2020.1726293>.
- Chaudhary, S., Zhornitsky, S., Chao, H.H., van Dyck, C.H., Li, C.-S.R., 2022. Emotion Processing Dysfunction in Alzheimer's Disease: An Overview of Behavioral Findings, Systems Neural Correlates, and Underlying Neural Biology. *Am. J. Alzheimers Dis. Other Demen* 37. <https://doi.org/10.1177/15333175221082834>.
- Comon, M., Rouch, I., Edjolo, A., Padovan, C., Krolak-Salmon, P., Dorey, J.-M., 2022. Impaired facial emotion recognition and gaze direction detection in mild Alzheimer's disease: Results from the PACO study. *J. Alzheimer's S. Dis.* 89, 1427–1437.
- Cumming, G., 2012. *Understanding the New Statistics: Effect sizes, Confidence Intervals, and Meta-Analysis.* Routledge, New York.
- Demichelis, O.P., Coundouris, S.P., Grainger, S.A., Henry, J.D., 2020. Empathy and Theory of Mind in Alzheimer's Disease: A Meta-analysis. *J. Int. Neuropsychol. Soc.* 26, 963–977. <https://doi.org/10.1017/S1355617720000478>.
- Dodich, A., Crespi, C., Santi, G.C., Marcone, A., Iannaccone, S., Perani, D., Cappa, S.F., Cerami, C., 2022. Emotion Recognition Deficits in the Differential Diagnosis of Amnesic Mild Cognitive Impairment: A Cognitive Marker for the Limbic-Predominant Phenotype. *J. Int. Neuropsychol. Soc.* 28, 203–209. <https://doi.org/10.1017/S1355617721000254>.
- Duclos, H., Bejanin, A., Eustache, F., Desgranges, B., Laisney, M., 2018. Role of context in affective theory of mind in Alzheimer's disease Running title Context and affective ToM in AD. <https://doi.org/10.1016/j.neuropsychologia.2018.08.025f>
- El Haj, M., Raffard, S., Antoine, P., Gely-Nargeot, M.-C., 2015. Emotion and Destination Memory in Alzheimer's Disease. *Curr. Alzheimer Res* 12, 796–801. <https://doi.org/10.2174/1567205012666150710112802>.
- Fernández-Ríos, M., Redolat, R., Serra, E., González-Alcaide, G., 2021. A systematic review of facial emotion recognition in alzheimer's disease: A developmental and gender perspective. *An. De. Psicol.* <https://doi.org/10.6018/analesps.439141>.
- Fischer, A., Landeira-Fernandez, J., Sollero de Campos, F., Mograbi, D.C., 2019. Empathy in Alzheimer's Disease: Review of Findings and Proposed Model. *J. Alzheimer's S. Dis.* 69, 921–933. <https://doi.org/10.3233/JAD-180730>.
- García-Cordero, I., Migeot, J., Fittipaldi, S., Aquino, A., Campo, C.G., García, A., Ibáñez, A., 2021. Metacognition of emotion recognition across neurodegenerative diseases. *Cortex* 137, 93–107. <https://doi.org/10.1016/j.cortex.2020.12.023>.
- Goodkind, M.S., Sturm, V.E., Ascher, E.A., Shdo, S.M., Miller, B.L., Rankin, K.P., Levenson, R.W., 2015. Emotion recognition in frontotemporal dementia and alzheimer's disease: A new film-based assessment. *Emotion* 15, 416–427. <https://doi.org/10.1037/a0039261>.
- Gressie, K., Kumfor, F., Teng, H., Foxe, D., Devenney, E., Ahmed, R.M., Piguet, O., 2023. Error profiles of facial emotion recognition in frontotemporal dementia and Alzheimer's disease. *Int Psychogeriatr.* 110. <https://doi.org/10.1017/S1041610223000297>.
- Gressie, K., Kumfor, F., Teng, H., Foxe, D., Devenney, E., Ahmed, R.M., Piguet, O., 2024. Error profiles of facial emotion recognition in frontotemporal dementia and Alzheimer's disease. *Int Psychogeriatr.* 36, 455–464. <https://doi.org/10.1017/S1041610223000297>.
- Harrer, M., Cuijpers, P., Furukawa, T.A., Ebert, D., 2019. Doing Meta-Anal. *R A Hands-Guide.* <https://doi.org/10.5281/zenodo.2551803>.
- Hazleton, J.L., Fittipaldi, S., Fraile-Vazquez, M., Sourry, M., Legaz, A., Hudson, A.L., Cordero, I.G., Salamone, P.C., Yoris, A., Ibáñez, A., Piguet, O., Kumfor, F., 2023. Thinking versus feeling: How interoception and cognition influence emotion recognition in behavioural-variant frontotemporal dementia, Alzheimer's disease, and Parkinson's disease. *Cortex* 163, 66–79. <https://doi.org/10.1016/j.cortex.2023.02.009>.
- Heitz, C., Noblet, V., Philippis, C., Cretin, B., Vogt, N., Philippis, N., Kemp, J., De Petigny, X., Bilger, M., Demuynck, C., Martin-Hunyadi, C., Armspach, J.P., Blanc, F., 2016. Cognitive and affective theory of mind in dementia with Lewy bodies and Alzheimer's disease. *Alzheimers Res Ther.* 8. <https://doi.org/10.1186/s13195-016-0179-9>.
- Henry, J.D., Rendell, P.G., Scicluna, A., Jackson, M., Phillips, L.H., 2009. Emotion Experience, Expression, and Regulation in Alzheimer's Disease. *Psychol. Aging* 24, 252–257. <https://doi.org/10.1037/a0014001>.
- Higgins, J.P.T., Thompson, S.G., 2002. Quantifying heterogeneity in a meta-analysis. *Stat. Med* 21, 1539–1558. <https://doi.org/10.1002/sim.1186>.
- Insch, P.M., Slessor, G., Phillips, L.H., Atkinson, A., Warrington, J., 2015. The impact of aging and Alzheimer's disease on decoding emotion cues from bodily motion. *AIMS Neurosci.* 2, 139–152. <https://doi.org/10.3934/Neuroscience.2015.3.139>.
- Jiskoot, L.C., Poos, J.M., Vollebergh, M.E., Franzen, S., van Hemmen, J., Papma, J.M., van Swieten, J.C., Kessels, R.P.C., van den Berg, E., 2021. Emotion recognition of

- morphed facial expressions in presymptomatic and symptomatic frontotemporal dementia, and Alzheimer's dementia. *J. Neurol.* 268, 102–113. <https://doi.org/10.1007/s00415-020-10096-y>.
- Klein-Koerkamp Y, Beaudoin M, Baciu M, Hot P. Emotional decoding abilities in Alzheimer's disease: a meta-analysis. *J Alzheimers Dis.* 2012;32(1):109-25. doi: 10.3233/JAD-2012-120553. PMID: 22776967.
- Kohler, C.G., Anselmo-Gallagher, G., Bilker, W., Karlawish, J., Gur, R.E., Clark, C.M., 2005. Emotion-discrimination deficits in mild Alzheimer disease. *Am. J. Geriatr. Psychiatry* 13, 926–933. <https://doi.org/10.1097/00019442-200511000-00002>.
- Latgé-Tovar, S., Bertrand, E., Cosentino, S., Dourado, M.C.N., Laks, J., Landeira-Fernandez, J., Morris, R.G., Mograbi, D.C., 2022. Self- and other-evaluation in Alzheimer's disease. *J. Alzheimer's Dis.* 90, 283–294. <https://doi.org/10.3233/JAD-220453>.
- Maki, Y., Yoshida, H., Yamaguchi, T., Yamaguchi, H., 2013. Relative preservation of the recognition of positive facial expression happiness in Alzheimer disease. *Int Psychogeriatr.* 25, 105–110. <https://doi.org/10.1017/S1041610212001482>.
- Mariano, L.L., Caramelli, P., Guimarães, H.C., Gambogi, L.B., Moura, M.V.B., Yassuda, M. S., Teixeira, A.L., de Souza, L.C., 2020. Can Social Cognition Measurements Differentiate Behavioral Variant Frontotemporal Dementia from Alzheimer's Disease Regardless of Apathy? *J. Alzheimer's Dis.* 74, 817–827. <https://doi.org/10.3233/JAD-190861>.
- Martinez, M., Multani, N., Anor, C.J., Misquitta, K., Tang-Wai, D.F., Keren, R., Fox, S., Lang, A.E., Marras, C., Tartaglia, M.C., 2018. Emotion detection deficits and decreased empathy in patients with Alzheimer's disease and Parkinson's disease affect caregiver mood and burden. *Front Aging Neurosci.* 10. <https://doi.org/10.3389/fnagi.2018.00120>.
- McLellan, T., Johnston, L., Dalrymple-Alford, J., Porter, R., 2008. The recognition of facial expressions of emotion in Alzheimer's disease: A review of findings. *Acta Neuropsychiatr.* <https://doi.org/10.1111/j.1601-5215.2008.00315.x>.
- Mograbi, D.C., Brown, R.G., Salas, C., Morris, R.G., 2012. Emotional reactivity and awareness of task performance in Alzheimer's disease. *Neuropsychologia* 50, 2075–2084. <https://doi.org/10.1016/j.neuropsychologia.2012.05.008>.
- Moura, M.V.B., Mariano, L.L., Teixeira, A.L., Caramelli, P., De Souza, L.C., 2021. Social Cognition Tests Can Discriminate Behavioral Variant Frontotemporal Dementia from Alzheimer's Disease Independently of Executive Functioning. *Arch. Clin. Neuropsychol.* 36, 831–837. <https://doi.org/10.1093/arclin/aca084>.
- Mulet-Perreault, H., Landry, M., Laforce, R.J., Macoir, J., Hudon, C., 2025. Mini-SEA: Validity and Normative Data for the French-Quebec Population Aged 50 Years and Above. *Arch. Clin. Neuropsychol.* 40, 694–707. <https://doi.org/10.1093/arclin/aca051>.
- 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.* <https://doi.org/10.1136/bmj.n71>.
- Park, S., Kim, T., Shin, S.A., Kim, Y.K., Sohn, B.K., Park, H.J., Youn, J.H., Lee, J.Y., 2017. Behavioral and neuroimaging evidence for facial emotion recognition in elderly Korean adults with mild cognitive impairment, Alzheimer's disease, and frontotemporal dementia. *Front Aging Neurosci.* 9. <https://doi.org/10.3389/fnagi.2017.00389>.
- Phillips, L.H., Scott, C., Henry, J.D., Mowat, D., Bell, J.S., 2010. Emotion Perception in Alzheimer's Disease and Mood Disorder in Old Age. *Psychol. Aging* 25, 38–47. <https://doi.org/10.1037/a0017369>.
- RefWorks Citation Manager, 2024.
- Sava, A.A., Delphin-Combe, F., Krolak-Salmon, P., Michael, G.A., Chainay, H., 2019. First-order Affective Theory of Mind in Persons with Alzheimer's Disease and in Healthy Older Adults. *Can. J. Aging* 38, 100–110. <https://doi.org/10.1017/S0714980818000363>.
- Seeley WW, Crawford RK, Zhou J, Miller BL, Greicius MD. Neurodegenerative diseases target large-scale human brain networks. *Neuron.* 2009 Apr 16;62(1):42-52. doi: 10.1016/j.neuron.2009.03.024. PMID: 19376066; PMCID: PMC2691647.
- Sheardova, K., Laczó, J., Vyhnaček, M., Anđel, R., Mokrisova, I., Vlček, K., Amlerová, J., Hort, J., 2014. Famous landmark identification in amnesic mild cognitive impairment and Alzheimer's disease. *PLoS One* 9. <https://doi.org/10.1371/journal.pone.0105623>.
- Shi, P., Chapman, H., Liu, L., Rodgers, F., Shaw, J., Livingston, G., Rankin, K.P., Warren, J.D., Sommerlad, A., 2025. Social cognition in mild cognitive impairment and dementia: A systematic review and meta-analysis (Mar). *Alzheimers Dement* 21 (3), e70076. <https://doi.org/10.1002/alz.70076>. PMID: 40145360; PMCID: PMC11947743.
- Strijkert, F., Huitema, R.B., Spikman, J.M., 2022. Measuring emotion recognition: Added value in diagnosing dementia of the Alzheimer's disease type. *J. Neuropsychol.* 16, 263–282. <https://doi.org/10.1111/jnp.12263>.
- Strijkert, F., Huitema, R.B., van Munster, B.C., Spikman, J.M., 2023. Impaired Emotion Recognition: A Potential Marker for Social Behavioral Problems in Patients With Amnesic Mild Cognitive Impairment and Early Alzheimer Disease? *Alzheimer Dis. Assoc. Disord.* 37, 189–194. <https://doi.org/10.1097/WAD.0000000000000567>.
- Torres, B., Santos, R.L., Sousa, M.F.B., de, Simões Neto, J.P., Nogueira, M.M.L., Belfort, T. T., Dias, R., Dourado, M.C.N., 2015. Facial expression recognition in Alzheimer's disease: a longitudinal study. *Arq. Neuropsiquiatr.* 73, 383–389. <https://doi.org/10.1590/0004-282X20150009>.
- Viechtbauer, W., 2010. Conducting Meta-Analyses in R with the metafor Package. *J. Stat. Softw.* 36. <https://doi.org/10.18637/jss.v036.i03>.
- Wells, G., Shea, B., O'Connell, D., Peterson, J., Welch, V., Losos, M., Tugwell, P., Ga, S. W., Zello, G., Petersen, J., 2000. The Newcastle-Ottawa Scale (NOS) for Assessing the Quality of Nonrandomised Studies in Meta-Analyses.
- Wiecheteck Ostos, M., Schenk, F., Baenziger, T., Von Gunten, A., 2011. An exploratory study on facial emotion recognition capacity in beginning Alzheimer's disease. *Eur. Neurol.* 65, 361–367. <https://doi.org/10.1159/000327979>.
- Wood A, Rychlowska M, Korb S, Niedenthal P. Fashioning the Face: Sensorimotor Simulation Contributes to Facial Expression Recognition. *Trends Cogn Sci.* 2016 Mar; 20(3):227-240. doi: 10.1016/j.tics.2015.12.010. Epub 2016 Feb 11. PMID: 26876363.
- World Health Organization: WHO, 2023. Dementia [WWW Document]. (www.who.int).
- Xu, F., Ono, M., Ito, T., Uchiyama, O., Wang, F., Zhang, Y., Sun, P., Zhang, Q., Yamaki, S., Yamamoto, R., Kato, N., 2021. Remodeling of projections from ventral hippocampus to prefrontal cortex in Alzheimer's mice. *J. Comp. Neurol.* 529, 1486–1498. <https://doi.org/10.1002/cne.25032>.