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REVIEW ARTICLE

In search of a neuropsychological profile for migraine: A scoping review

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Abstract

Objective: Migraine is commonly overlooked by the general population and by professionals in research and clinical practice. Moreover, it is difficult to grasp the neuropsychological profile of migraineurs due to the cyclic nature of the disorder. With this in mind, a scoping review of the literature was conducted with the goal of characterizing cognitive domains associated with deficits in migraine.

Methods: PubMed, PsychInfo, Scopus, EMBASE and OpenGrey databases were searched for studies published from 1st January 2006 to 30th November 2022. Following the review process, 52 eligible studies were included in the review.

Results: Studies included in this review show mixed and sometimes contradictory findings. Overall, both visual and auditory perception appear to be impaired. Deficits on attention, many memory processes, visuospatial function and spatial navigation and on a wide range of executive functions (set-shifting and cognitive flexibility, decision-making and reasoning, working memory and prospective memory) complete a complex cognitive profile in migraine. Lack of consistency across studies in sample selection and sizes, lack of detailed links between cognitive deficits and specific migraine phases, or length and chronicity, inconsistencies on the role of aura in cognitive function; and heterogeneity and sometimes questionable reliability and validity of some of the cognitive measures used may affect the clarity and consistency of results observed.

Conclusion: Further research properly addressing the role of gender and age, migraine stage, length and chronicity of the condition, the effect of aura and co-morbidities is needed, alongside increasing consistency across diverse neuropsychological assessment protocols.

Significance: This review provides a comprehensive, up-to-date picture of the current status of knowledge in relation to the characterization of the complex cognitive profile of migraine. It offers detailed information of the existing research gaps and challenges to improve the cognitive characterization of migraine across its different stages and leads clinicians to carefully consider the selection of relevant cognitive tasks, in order to grasp more accurately the patient's cognitive profile; an assessment that should be an integral part of any protocol developed for the clinical assessment and subsequent treatment planning for migraine.

1 | INTRODUCTION

Migraine is commonly overlooked as a novel head pain or a pain condition by both the general population and professionals rather than recognized as being a complex disorder of the nervous system. Migraine is globally frequent, being the third leading cause of disability worldwide (Meng et al., 2018; Steiner et al., 2015; Stovner et al., 2018). Albeit common among the general population with a conservative 14% reported to be suffering from the disorder worldwide, migraine is still largely unknown (Saylor & Steiner, 2018; Stovner et al., 2018).

Many of the functional and causal mechanisms for migraine are not clearly established; and migraine treatment, despite continuously developing alongside theory and technology, remains inadequate for many (Goadsby, 2015; Goadsby et al., 2017; Qubty & Patniyot, 2020). In relation to this, many inadequacies can be attributed to large proportions of literature and practice emphasizing and focusing primarily on relieving migraine pain.

However, this emphasis on pain relief has led to overlooking neurological, psychological and behavioural events that occur (1) before (which is known as the pre-ictal phase or pro-drome), (2) during (i.e. the ictal phase) and (3) after the onset (i.e. the post-ictal phase or post-drome) of the characteristic pain that individuals with migraine frequently report (Burch & Rayhill, 2021; Chen & Wang, 2018; Karsan & Goadsby, 2021). Moreover, a general overarching consensus has considered migraine as a vascular pain condition, thus overlooking approaches to migraine as a multi-systemic neurological disorder (Goadsby, 2015).

The migraine cycle begins with the pre-monitory phase (also known as pre-ictal or pro-drome) which occurs as early as 72 h before the pain onset. In this phase, migrainous individuals experience significant changes in neurological, physiological and psychological functioning (Goadsby et al., 2017; Green & Muskin, 2013; Karsan & Goadsby, 2021; Laurell et al., 2016; Qubty & Patniyot, 2020). Such dysfunction is often presented in the form of sensory aura, intense fatigue, satiety changes, deregulatory mood, gastrointestinal distress, polyuria, yawning, kinesiophobia, sub-cutaneous allodynia, phonophobia and photophobia (Karsan & Goadsby, 2018; Wang et al., 2021). These symptoms may persist throughout the ictal stages and are typically not the focus of research or intervention. Imaging studies have further demonstrated the complexity of migraine and the potential origin of some of these non-painful symptoms, such as the increased activation in regulatory areas of the brain during the ictal stages of a migraine attack, including the hypothalamus, thalamus, periaqueductal grey region, dorsal pons and the brainstem (Goadsby et al., 2017; Karsan & Goadsby, 2021; Maniyar et al., 2014).

A review by David et al. (2020) found that neuroimaging revealed increased activation and abnormal functioning of cortical areas intrinsic to memory processing and formation, the integration of sensory information and temporal cortical areas responsible for language and visuospatial functioning (see also Ravishankar & Demakis, 2007). Similarly, another review found abnormal functional connectivity in various networks including salience, sensorimotor, executive, attention, limbic and default mode networks and networks related to visual processing (Chong et al., 2019). A different review by Liu et al. (2018) further suggests abnormal functional connectivity of the hippocampus at resting state in migraineurs. While this research depicts the neurological profile of migraine, little research aims to compile a cognitive profile using standardized neuropsychological tests that are applicable in a clinical setting and can determine what cognitive processes may be impaired.

However, when trying to approach neuropsychological and cognitive literature on migraine, research is laden with contradictory findings, with alternative reviews suggesting either no significant cognitive dysfunction or long-term decline among the population (Gil-Gouveia & Martins, 2019; Rist & Kurth, 2013). De Araújo et al. (2012) reported defective performance in memory, attention and processing speed for those migraineurs attended in neurological care centres, but not for those in the community (similar to findings from Vuralli et al. (2018)). Foti et al. (2017), in a more recent review, suggested that while cognitive deficits during migraine attacks are now recognized, only few studies confirm the presence of cognitive impairment in migraine patients, and they suggest that future research should focus on determining whether some migraine features such as attack frequency may impact the association between migraine and cognitive decline.

It is possible that more distinction on whether research pertains to pre-ictal or pro-dromal (i.e. before the pain starts), ictal (i.e. during the headache), post-ictal or post-dromal (i.e. the time following the cessation of the headache) or inter-ictal (i.e. the period between two migraine attacks) functioning is needed as it is plausible that much observed dysfunction is transient and reversible (Gil-Gouveia & Martins, 2019; Gil-Gouveia et al., 2015a).

Furthermore, varied durations and temporal presentations of the migraine cycle within groups may distort findings and mask potential cyclic dysfunction relative to ictal and inter-ictal stages. For example, Vuralli et al. (2018) found that poor cognitive performance during migraine attacks is more clearly established, while inter-ictal data are more conflicting. A recent meta-analysis by Braganza et al. (2022), on the contrary, showed a moderate, negative effect on complex attention, immediate and delayed memory, spatial cognition and executive functioning during the inter-ictal period, although report that lack of performance validity tests and limited data on mood symptomatology in the reviewed studies could overestimate the magnitude of the effect.

A recent systematic review by Hakamäki and Jehkonen (2022) on neuropsychological findings in migraine is the most recent attempt to show some clarity in this topic but is also filled with contradictory results. While most studies in this review reported a worse cognitive functioning for migraineurs of distinct types (i.e. chronic, with and without aura) compared to healthy controls, those with migraine without the classification of aura symptoms performed significantly better than controls in executive, motor and language functioning and general cognitive functioning.

Separately, Pinotti et al. (2023) performed a meta-analysis restricted to search for deficits in executive functions, showing worse performance for migraine patients in executive functions when compared to healthy controls (including attention, working memory and cognitive flexibility), with no difference reported between migraine with and without aura.

In terms of tests that could be sensitive to cognitive alterations in migraine, Vallesi (2020) conducted a meta-analysis showing that trail-making test (TMT) showed adequate sensitivity for the detection of cognitive alterations in migraine. However, in order to consider the possibility of establishing a detailed assessment protocol for migraine, there is a need to synthesize the existing research to enable a more insightful narrative of the cognitive and neuropsychological functions impaired in the migraine population.

It is with this in mind that this scoping review of the literature was conducted, with the goal of identifying and trying to establish a comprehensive profile of all cognitive domains associated to deficits in individuals suffering from migraine.

2 | METHODS

2.1 | Search strategy

To ensure credibility, the search methods used in this scoping review were developed and applied with congruence to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) criteria. In addition, the recommendations by Peters et al. (2015) on how to conduct a scoping review were taken into consideration. Due to the significant variation in measurements used in the reviewed studies it was decided that meta-analysis would not be viable given the extensive methodological heterogeneity. Furthermore, as the purpose of this research is to comprehensively depict neuropsychological functioning in migraine, a scoping review was apt and broadened the scope of the research. Despite the existence of previous systematic reviews related to this topic, the laden of contradictory results, the early stage of the emerging research in this area and the need to clarify concepts, following the guidelines by Munn et al. (2018), justified the need to conduct this scoping review.

To acquire studies used in this review, PubMed, PsychInfo, Scopus and EMBASE databases, as well as OpenGrey for grey literature, were methodologically searched using the following syntax: (Migraine) AND (cognition OR neuropsychology OR neuropsychological OR neurobehavioural OR neurocognitive) AND ("decision-making" OR attention OR mood OR memory OR "spatial behaviour" OR perception OR sleep). For the purpose of this review and to capture the current scope of the literature, research published in the last 16 years (from January 1st, 2006, to November 30th, 2022) were included.

2.2 | Selection, screening and extraction

The search from the combined databases returned a total of 2271 references which were compiled and assessed for duplicates. A total of 1742 eligible studies remained following extraction of duplicate references. The 1742 references were further uploaded to Rayyan Systems Inc (www.Rayyan.ai), an online software for collaborative systematic reviews. To minimize bias, the studies were divided and screened independently by each of the authors.

Inclusion criteria for the review included adults over the age of 18 years experiencing primary migraine and use of clinically administered standardized measures of cognition and neuropsychological functioning.

A substantial number of studies were excluded with regard to the inclusion criteria of this study. Many references were excluded due to studies focusing on other primary headache disorders such as familial hemiplegic migraine, tension-type headache or secondary headache attributed to a causal or identifiable factor. Articles which clearly included migraineurs with comorbid secondary conditions were further excluded due to potential confounding effects on the findings. Similarly, many studies that were initially returned in the search did not include neuropsychological or cognitive measures. Such studies were focused on genetics, pharmacology, imaging and electroencephalography and were outside the scope of the review. Following the screening process, a total of 89 studies were inspected further to ensure relevance to the review and overall credibility. After thoroughly screening each of the remaining studies, 37 were excluded. While many of these studies claimed to investigate cognition, in 20 of them included no cognitive measures were used (instead, such studies focused on contrast discrimination, saccades or sensory thresholds), 13 included self-report measures on cognition, two had mixed samples with different conditions and the remaining two included participants under 18 years old. This quality review process led to a total number of 52 eligible studies that were included in the review.

3 | RESULTS

Figure 1 shows the PRISMA diagram describing the entire process of article search, selection, screening and extraction.

Table 1 summarizes the information of the 52 eligible studies included in the scoping review. The following subsections focus separately on those results obtained with regards to (1) global cognitive functioning screening measures, (2) perception (subdivided in visual and auditory perception), (3) attention (4) memory, (5) visuospatial functioning and (6) executive functions.

3.1 | Global cognitive functioning screening measures

Some of the studies reviewed informed on global cognitive performance based on extensively used cognitive screening tasks such as the Montreal Cognitive Assessment (MoCA) and the Mini Mental State Examination (MMSE). Results from these studies were mixed, with the majority of studies finding statistically significant differences on the MoCA between migraineurs and controls, with worse results for migraineurs with aura and chronic migraineurs.

3.1.1 | Studies focused on the MoCA

Santangelo et al. (2016) found, in a sample of 72 migraine patients (without aura, in the inter-ictal stage) versus 72 healthy controls, an overall worse performance in migraineurs both for the total MoCA score and for most subscores (except for language and orientation subscores, where no significant differences were found). Huang

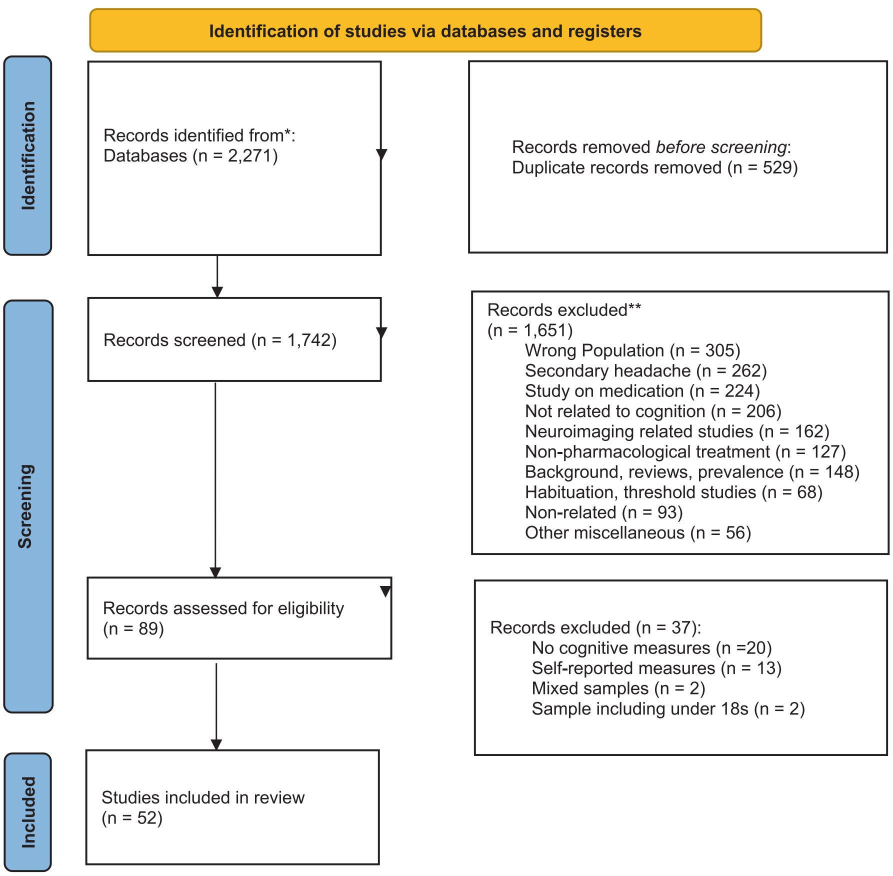

FIGURE 1 PRISMA flow diagram representing study identification, screening and inclusion process.

TABLE 1 Summary of studies included in the results.

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Agessi et al. (2014)	Case–control Cross-sectional	MwA ($n=11$) MwoA ($n=15$) HC ($n=15$)	MwA (29.5 (±5.8) years) MwoA (29.5 (±6.3) years) HC (29.1 (±5.0) years)	Gaps in Noise Test (GIN) Duration Pattern Test (DPT) Dichotic Digit Test, (DDT)	Both migraine groups performed significantly poorer on the DPT than controls ($p<0.001$) Compared to the control group, MwoA group performed significantly poorer for both right ($p<0.01$) and left ears ($p<0.01$) on the GIN test While MwA had poorer performance on the GIN test for the left ear ($p<0.05$) only compared to HCs No statistically significant difference on DDT between groups was observed Agessi et al. (2014) suggest central auditory dysfunction as a possible factor in performance differences. Performance could be a result of impaired auditory memory and attention
Baars et al. (2010)	Case–control Longitudinal	M ($n=99$) HC ($n=1724$)	M (47.1 (±12.9) years) HC (51.8 (±16.6) years)	MMSE, The Visual Verbal Learning Test, Stroop Colour Word, Test, Letter Digit Substitution Test	Migraine headaches were found to have no effect on any of the cognitive measures. Medication use also had no effect on all cognitive measures No evidence was found that migraine headaches or use of migraine-related medication are risk or protective factors for cognitive dysfunction or cognitive deterioration over time
Baschi et al. (2019)	Case–control Cross-sectional	MwoA ($n=21$) HC ($n=12$)	MwoA (27.9 (±3.16) years) HC (29 (±4.32) years)	CORSI Block Tapping Buschke Selective Reminding Test (in supraspan modality) TMTA, TMTB, BDI-SF	Participants with MwoA performed significantly better than HC in both conditions of the CORSI test exploring short ($p<0.01$) and long-term ($p<0.01$) visuospatial memory No statistically significant differences were observed between migraineurs and HC using TMTA and TMTB No statistically significant difference between groups was found in verbal memory as measured using the Buschke test
Battista et al. (2010)	Case–control Cross-sectional	M ($n=30$) MwA ($n=15$) MwoA ($n=15$) HC ($n=20$)	HC (29.45 (±6.85) years) M (30.17 (±7.21) years)	Motion direction discrimination task (MDDT) Motion after-effect task (MAET)	Results do not suggest reduced visual motion processing but rather both experiments observed an effect in the opposite direction for the migraine group ($p<0.05$) Reports of increased inhibition in migraineurs are not frequent in literature

(Continues)

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Biagianti et al. (2012)	Case–control Longitudinal	CMwMOH ($n=40$) EM ($n=40$) HC ($n=40$)	CMwMOH (42.7 (±11.0) years) EM (42.1 (±9.7) years) HC (40.7 (±10.3) years)	Clinical Interview Anxiety and Depression Hamilton Scales Severity of Dependence Scale Migraine Disability Assessment questionnaire Iowa Gambling Task (IGT)	Participants with CMwMOH and EM displayed significantly poorer decision-making as measured by IGT compared to healthy controls ($p<0.001$). Follow up results from 1 year after the detox, found no significant improvement in IGT scores No statistically significant differences in orbitofrontal cortex functioning (OFC) were found between the CMwMOH patients who relapsed into medication overuse after detox and those who did not (CM) Results suggest OFC impairment among migraineurs and MOH
Chen et al. (2021)	Case–control Cross-sectional	MwoA ($n=44$) HC ($n=20$)	MwoA (41.55 (±12.11) years) HC (38.95(±11.88) years)	TMT (Chinese Version) Digit Span (forwards and backwards) Stroop Test Attention Network Test (ANT)	In the ANT, a significant effect of group ($p<0.001$), cue condition ($p<0.001$) and flanker type ($p<0.001$) was observed on reaction times (RTs) ANT RTs were significantly longer in the MwoA group compared to HC ($p<0.001$) Statistically significant differences between groups were observed on raw scores in the efficiency of the executive network ($p<0.01$) and the overall mean RT ($p<0.05$) Multiple linear regression adjusted for age, gender, literacy and SAS, SDS showed that the efficiency of the executive network ($p<0.01$) and the overall mean RT ($p<0.05$) were associated with migraine Significant group differences were found in the raw scores of TMT-A ($p<0.001$), TMT-B ($p<0.001$), TMT-d ($p<0.005$), Digit Span Forwards ($p<0.001$), Digit Span Backwards ($p<0.001$) and Digit Span Total ($p<0.001$) Multiple regression analysis adjusted for age, gender, literacy, anxiety and depression, revealed that MwoA was correlated with the scores of TMT-d ($p<0.05$) and Digit Span Total ($p<0.005$)

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Chu et al. (2020)	Case–control Cross-sectional	M ($n = 589$) 1–4 attacks per month ($n = 231$) 5–8 attacks per month ($n = 121$) 9–14 attacks per month ($n = 109$) 15+ attacks per month ($n = 128$) HC ($n = 80$)	M (45.5 (±30.9) years) 1–4 attacks per month (39.8 (±11.9) years) 5–8 attacks per month (35.7 (±10.7) years) 9–14 attacks per month (36.7 (±12.1) years) 15 or more attacks per month (40.2 (±11.4) years) HC (41.4 (±12.8) years)	Subjective memory complaints scale Ascertain Dementia 8 (AD8) questionnaire BDI The Pittsburgh Sleep Quality Index (PSQI) Hospital Anxiety and Depression Scale Migraine Disability Assessment (MIDAS) questionnaire	Total subjective memory complaints scores tended to increase with the migraine attack frequency ($p < 0.05$) in patients with migraine with aura; similar results were obtained for AD8 scores in women with migraine with aura ($p < 0.05$) Poor sleep quality as measured by the PSQI was significantly associated with a higher total subjective memory complaint (B = 0.08, 95% confidence interval [CI] = 0.03–0.14, p < 0.01) and performance on theAD8 (B = 0.07, 95% CI = 0.02–0.11, $p < 0.01$) scores In addition, more severe depression as measured using BDI was associated with higher total subjective memory complaints and AD8 scores (B = 0.05, 95% CI = 0.02–0.09, $p < 0.01$: B = 0.08, 95% CI = 0.05–0.11, $p < 0.001$ respectively) Subjective cognitive complaints tend to increase with the frequency of migraines with aura and are mediated by depression severity and sleep disturbances
Chu et al. (2011)	Case–control Cross-sectional	MwPP ($n = 44$) MwoPP ($n = 18$) HC ($n = 35$)	MwPP (36 (±10) years) MwoP (42 (±9) years) HC (37 (±9) years)	Photophobia questionnaire Visual Discomfort Test using three patterns scored (none, mild, moderate, severe) Visual Analog Scale (VAS)	Statistically significant differences were observed in the level of discomfort between groups on each of the conditions ($p < 0.001$) Median discomfort scores were greater for migraine groups across pattern one ($p < 0.005$), pattern two ($p < 0.001$) and pattern three ($p < 0.001$) Post-hoc analysis revealed migraines with photophobia experience greater more frequent visual discomfort than controls and migraineurs without photophobia

(Continues)

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Ferreira et al. (2018)	Case–control Cross-sectional	CM ($n=30$) HC ($n=30$)	Chronic migraine (33.7 (±11.2) years) Controls (33.7 (±9.7) years)	MoCA test Verbal Fluency Task Clock-Drawing Stroop Test Colour Trails Test Wechsler Adult Intelligence Scale (WAIS-III): Digit Span (digits forward) Vocabulary and Matrix Reasoning Rey Auditory Verbal Learning Test BDI and anxiety inventories Use of Topiramate (drug)	Preliminary results from this study found that migraineurs who use topiramate performed significantly poorer than HCs on the verbal fluency task ($p<0.01$), Stroop test ($p<0.01$), Digit Span ($p<0.01$) and Matrix Reasoning ($p<0.05$) and MoCA ($p<0.01$) Regression analysis controlling for topiramate use, anxiety, depression and poor sleep found that migraine without the use of topiramate, significantly correlated with Verbal Fluency ($p<0.01$), Clock Drawing ($p<0.01$) and the second and third trials of the Stroop test ($p<0.05$) Topiramate use was significantly associated with poorer WAIS-III digit span ($p<0.05$) and vocabulary ($p<0.05$)
Gasbarri et al. (2008)	Case–control Cross-sectional	M ($n=55$) Migraine with Anti-depressant Use ($n=48$) HC ($n=48$)	Overall (30 (±3.7) years)	Memory task using two conditions: neutral and arousal Free Recall and Recognition test for each condition	Female migraineurs performed significantly better at free recall of both arousal ($p<0.05$) and neutral ($p<0.001$) conditions than male migraineurs Male HCs performed significantly better recalling the arousal condition than male untreated ($p<0.01$) and treated ($p<0.01$) migraineurs. In the neutral group, statistically significant differences between the total amount of information recalled was found between the treated migraineurs and healthy subjects ($p<0.01$) Male HCs had significantly better recognition memory in phase 2 of the arousal condition than both treated ($p<0.001$) and untreated ($p<0.001$) male migraineurs. Statistically significant differences were further observed between male migraine groups ($p<0.001$) Female HCs performed significantly better at the arousal condition than untreated ($p<0.005$) and treated migraineurs ($p<0.005$) In the neutral condition, controls performed significantly better than treated ($p<0.001$) and untreated ($p<0.001$) migraineurs Female HCs performed significantly better in phase 2 of the arousal condition than both treated ($p<0.001$) and untreated ($p<0.01$) female migraineurs. Statistically significant differences were observed between female migraine groups ($p<0.001$)

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Gil-Gouveia et al. (2015b)	Case–control Longitudinal during a spontaneous attack & during an inter-ictal period min 72 h after last attack 2 groups for each condition (control for practice effect) no medication or psych/ physio condition	EM ($n = 24$)	EM (38 (±11.6) years)	Zung depression scale State Trait Anxiety Inventory Symbol search Trail making A&B, Digit span backwards & forwards Verbal Fluency Visual Reproduction, Finger tapping Famous Faces Logical Memory California Verbal Learning Test Stroop reading Stroop Colour-Word Test Snodgrass Naming Test	Statistically significant differences were observed between base level performance and performance during attack in the following cognitive tests; Stroop word reading ($p < 0.05$), California Verbal Learning Test (CVLT) total learning ($p < 0.05$), CVLT short-term recall with ($p < 0.05$) and without ($p < 0.05$) semantic help and delayed recall with ($p < 0.01$) and without ($p < 0.0.05$) semantic help A significant practice effect was observed for performance on the Stroop word reading ($p < 0.01$). Similarly, pain intensity during the attack was the significantly associated with performance on CVLT short-term free recall ($p < 0.01$) Supports reversible impairment in learning and memory and language comprehension/attention however perception, motor control and executive function showed no statistically significant difference between ictal states Many other measures of language function and memory were not significant
Guo et al. (2019)	Case–control Cross-sectional	M ($n = 46$) HC ($n = 46$)	M (32.84 (±6.46) years) HC (32.65 (±6.36) years)	Modified Visual Oddball Paradigm (standard, target and novel stimuli) Self-rating Anxiety Scale, Self-rating Depression Scale, EEG, EOG	Using a modified visual oddball paradigm Guo et al. (2019) discovered emotional and inter-ictal attentive processing abnormalities in migraineurs with reduced P3 amplitudes ($p < 0.001$, partial $\eta 2 = 0.125$), P3dT amplitudes ($p < 0.00$, partial $\eta 2 = 0.1871$), P3dN amplitudes ($p < 0.001$, partial $\eta 2 = 0.230$) and lower P2dN amplitudes ($p < 0.05$, partial $\eta 2 = 0.070$). Significant effects of gender and group were observed for P3dT ($p < 0.01$, partial $\eta 2 = 0.095$), P3dN ($p < 0.01$, partial $\eta 2 = 0.111$) and P2dN ($p < 0.01$, partial $\eta 2 = 0.089$). Results suggest abnormal visual processing and attention in migraineurs. This impairment is more pronounced in female migraineurs.

(Continues)

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Han et al. (2019)	Case–control Cross-sectional	MwoA ($n = 32$) HC ($n = 32$)	MwoA (37.97 (±8.91) years) HC (39.13 (±11.38) years)	Attentional networks test (ANT) MMSE Stroop colour-word association test shape trail test (STT)	No statistically significant differences on the MMSE were observed between groups There were significant effects of group ($p < 0.00$), flanker ($p < 0.00$) and condition ($p < 0.00$) on mean ANT reaction times MwoA patients exhibited significantly longer response times of the executive control network ($p < 0.05$), whereas no statistically significant differences were observed in alerting and orienting network reaction times between groups. Migraineurs performed significantly poorer on Stroop III ($t = 2.23$, $p < 0.05$) and STT B ($p < 0.01$) between MwoA and HC groups Spearman's correlation analysis revealed positive associations between executive control network RTs and both frequency ($p < 0.05$) and duration ($p < 0.00$) of migraine attack. Stroop III reaction times were further significantly correlated with migraine duration ($p < 0.00$) and frequency ($p < 0.01$). Reaction times for Stroop I ($p < 0.05$) and II ($p < 0.05$) and STTB ($p < 0.05$) were further significantly and positively correlated with attack duration MwoA patients demonstrate impairments of the executive control network, which appear to be exacerbated by more frequent and longer migraine attacks

TABLE 1 (Continued)

Authors and publication year	Study type/methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Huang et al. (2017)	Case–control Cross-sectional	M ($n = 34$) HC ($n = 24$)	M (36.07 (±10.05) years) HC (36.05 (±12.97) years)	MoCA Rey–Osterrieth Complex Figure Test Digit Symbol Substitution Test EEG/ERP	Overall mean MoCA scores were significantly lower in the migraine group compared to controls ($p < 0.01$). Statistically significant differences were observed on language ($p < 0.01$), memory ($p < 0.01$), executive function ($p < 0.05$), calculation ($p < 0.05$) and orientation ($p < 0.05$) measures of the MoCA. No statistically significant differences on attention and visuospatial measures of the MoCA were observed between groups Migraineurs had a significantly lower score on the memory trial of Rey–Osterrieth complex figure test ($p < 0.05$) No statistically significant differences were observed on Digit Symbol Substitution and the copy trial of the Rey–Osterrieth complex figure test. No statistically significant difference in accuracy or reaction times were observed between groups The migraine group displayed significantly longer P3 latencies across parietal ($p < 0.001$), frontal ($p < 0.001$) and central ($p < 0.001$) electrode sites Migraine duration was significantly correlated with overall MoCA score (−0.478 [$p < 0.01$]), language (−0.430 [$p < 0.05$]), executive functions (−0.405 [$p < 0.05$]), calculation (−0.446 [$p < 0.01$]) and memory (−0.374 [$p < 0.05$]) Migraine frequency correlated with scores on the executive functioning (−0.458 [$p < 0.01$]) and calculation (−0.350 [$p < 0.05$]) trials of the MoCA and R-OCF recall (−0.415 [$p < 0.05$])
Kalaydjian et al. (2007)	Case–Control Longitudinal unclear what parameters were used for control group, numerous comorbidities	M ($n = 204$) HC ($n = 1244$)	M (47.5 (±12.5) years) HC (52.7 (±15.7) years)	MMSE, Immediate & delayed Recall	Migraineurs from both wave III and IV, had significantly higher mean MMSE values than healthy controls ($p < 0.05$) Wave IV migraineurs further displayed significantly higher mean immediate ($p < 0.05$) and delayed ($p < 0.05$) recall scores compared to healthy controls. Migraineurs further displayed significantly lower decline in immediate ($p < 0.05$) and delayed ($p < 0.05$) recall over the two waves compared to healthy controls

(Continues)

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Karami et al. (2019)	Case–Control Cross-sectional	OLE ($n=32$) M ($n=30$) HC ($n=31$)	Males (25.33 (±8.24) years) Females (26.08 (±7.76) years)	Bender – Gestalt II (4 components) Copy–visuomotor ability, perception, visuospatial ability Recall (visual/short-term memory) Motor (semantic memory) Perceptual	Results found statistically significant differences between groups on all components of the BGT-II; copy ($p<0.001$), recall ($p<0.001$), motor ($p<0.001$) and perceptual ($p<0.001$) Post-hoc examination indicated statistically significant differences between all groups with OLE displaying significant lower copy, recall and perceptual subscores compared to migraine and HC groups ($p<0.01$). Migraine followed OLE with lower scores on all components compared to healthy controls ($p<0.01$)
Kim et al. (2020)	Case–Control Cross-sectional	M ($n=39$) PPTH ($n=57$) HC ($n=39$)	Migraine (41.2 (±11.5) years) Persistent post-trauma headache (38.2 (±10.7) years) Healthy Controls (38.3 (9.5) years)	Migraine Disability Assessment Scale (MIDAS) Insomnia Severity index Hyperacusis questionnaire Allodynia Symptom Checklist Photosensitivity Assessment Questionnaires BDI State–Trait Anxiety Inventory PTSD checklist Rey Auditory Verbal Learning Test (RAVLT) TMT A & B	Insomnia Severity Index scores were significantly higher in the PPTH group followed by migraine and healthy controls ($p<0.001$). This trend was further observed with depression and anxiety scores ($p<0.001$) No statistically significant differences were observed between groups on the TMT A, TMT B or immediate and delayed recall of the RAVLT between all groups Significant association with insomnia severity and headache intensity ($p<0.05$), BDI ($p<0.001$) and hyperacusis scores ($p<0.05$) in PPTH group. Significant negative association between ISI scores and delayed recall in the Migraine group ($p<0.05$)
Koppen et al. (2017)	Case–Control Cross-sectional	MwA ($n=111$) MwoA ($n=89$) HC ($n=82$) FHMI ($n=13$)	MwA (57 (±8.1) years) MwoA (58 (±7.5) years) HC (55 (±7.5) years) FHMI (42 (±13.3) years)	Purdue Pegboard Test Block-Design Test Eyeblink Conditioning Task Body-Sway Test Wechsler Intelligence Scale Prism Adaptation Task	Results found no statistically significant difference between both migraine groups and controls Slight increase in ischemic lesions in the migraine group 8.5% over 4% control group. All lesions (excluding one control) in posterior lobe Differences in performance between migraineurs with and without posterior lobe lesions were observed. Migraineurs with ischemic lesions displayed significantly lower assembly scores on the Purdue-pegboard test ($p<0.01$) Participants with FHMI displayed impairment across all primary measures in the study

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Koppen et al. (2011)	Case–Control Cross-sectional	M ($n=16$) HC ($n=18$) Matched on age, gender and educational level	M (58 (±9.1) years) HC (59 (±7.4) years)	Global Local Task Attentional Network Task N-back Task	No difference in performance on the Global–Local task, Attentional Network Task, or N-back Task were observed between post-ictal migraineurs and healthy controls Migraineurs did not display statistically significant differences in perceptual organization, working memory and attention during the two-day duration following an attack
Kriegler et al. (2020)	Case–Control Cross-sectional	M ($n=36$) HC ($n=38$)	M (24.75 (±8.61) years) HC (25.39 (±8.43) years)	Landmark task (LM) Greyscale task (GRE)	Non-parametric independent samples median test showed differences in greyscale response bias between groups ($p<0.05$) No difference in landmark task bias was observed Migraineurs performed similar to that seen in unineglect patients on the greyscale task (GRE). The GRE which was significantly impaired in migraineurs requires assessment and attention of luminosity. This impairment is in line with migraineurs being sensitive to high-frequency visual stimuli Based on GRE task bias, study suggests decreased visuospatial attention in migraine related to decreased activation of temporo-parietal junction
Latysheva et al. (2020)	Cross-sectional	CM ($n=144$) EM ($n=44$)	CM (42.5 years) EM (37 years)	Perceived Deficits Questionnaire (PDQ) MoCA Digit Symbol Substitution Test (DSST) Rey Auditory Verbal Learning Test (RAVLT) Hospital Anxiety and Depression Scale (HADS)	CM reported greater levels of subjective cognitive deficits as measured by the PDQ ($p<0.05$) There was a significant positive association between perceived deficits (PDQ) and HADS anxiety ($p<0.05$) and depression ($p<0.05$) scores. No significant relationship between PDQ and the other cognitive measures was observed In the CM group, DSST ($p<0.01$) and RAVLT ($p<0.01$) scores were significantly lower compared to the EM group HADS anxiety was significantly and positively correlated with RAVLT ($p<0.05$) and MoCA scores ($p<0.05$) suggesting anxiety may enhance cognition in migraineurs

(Continues)

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Lo Buono et al. (2019)	Case–Control Cross-sectional	MwA ($n=50$) MwoA ($n=50$) HC ($n=100$)	MwA (41.05 (±14.05) years) MwoA (38.29 (±11.78) years) HC (38.16 (±11.32) years)	Attentive Matrices Trail Making A (visuomotor + selective attention), Trail Making B MIDAS Rey Auditory Verbal Learning Test (RAVLT) Semantic and Phonemic Verbal Fluency BDI Hamilton Rating Scale for anxiety	Results showed statistically significant differences between MwA and healthy controls on TMT B ($p<0.001$), RAVLT ($p<0.01$) Differences between MwoA and HC were observed on TMT B ($p<0.001$), RAVLT ($p<0.001$) and Semantic Verbal Fluency ($p<0.05$) In the MwoA group, significant positive correlations were found between scores on BDI and immediate ($p<0.01$), delayed memory ($p<0.05$), semantic ($p<0.05$) and phonemic verbal fluency ($p<0.01$) and TMT-B ($p<0.01$) In MwoA, scores on the Hamilton Rating Scale for anxiety were significantly and positively correlated with immediate memory ($p<0.05$) and TMT-B ($p<0.05$) In MwA, the Hamilton Rating Scale significantly and positively correlated with delayed memory ($p<0.01$) and MIDAS was significantly positively correlated with TMT-B ($p<0.01$)
Luedtke and Edlhaimb (2021)	Case–Control Longitudinal	M ($n=34$) HC ($n=4$)	migraine: (42 (±14) years) control (42 (±18) years)	Headache diary Personal Health Questionnaire (PHQ-9) Laterality Recognition Task MIDAS	Migraineurs performed significantly worse in identifying images biased to both left ($p<0.05$) and right sides ($p<0.01$) than healthy controls. These results were significantly replicated when comparing functioning from pain free days in migraineurs with controls Independent levels of time before, during and after an attack were significantly associated with response times to right biased images ($p<0.05$)

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Martins et al. (2012)	Case–Control Cross-sectional	C (n = 367) NMH (n = 50) M (n = 61)	C (66.8 (±9) years) NMH (69.3 (±7.9) years) M (61.9 (±7.6) years)	MMSE California verbal learning test (CVLT-9) Wechsler Memory Scale III version (WMS-III) Visual reproduction and faces I subtests TMT Semantic and Phonemic Verbal Fluency Stroop Test Digit Span Symbol Search Wechsler Abbreviated Scale of Intelligence (WASI) Geriatric depression scale (GDS) Subjective memory complaints (SMQ)	No group differences were found in the majority of cognitive measures. Compared with HC, migraine subjects performed worse on a Symbol Search task (p < 0.001) Non-migraine headache (NMH) participants presented more intrusions and worse discriminability in memory recognition and overall lower performance on semantic memory tests
Martins et al. (2020)	Case–Control Longitudinal	HC (n = 216) M (n = 35) NMH (n = 24)	HC: Base: (65.8 (±8.4) years) Follow: (70.8 (±8.5) years) Migraine: B: (61.1(±7.4) years) F: (66.1 (±7.3) years) NMH: B: (68.4 (±6.8) years) F: (73 (±6.6) years)	MMSE Geriatric Depression Scale Executive function mean: TMT A + TMT B + Semantic Food Fluency + Semantic Animals Fluency + Phonemic Fluency Episodic memory mean: logical memory + verbal paired associates MRI: White matter changes and regional cerebral atrophy	Migraine was not a significant predictor of cognitive impairment at the follow-up when controlled for depressive symptoms and age. Results suggest no evidence for increased cognitive impairment risk or steeper cognitive decline in migraineurs compared to HC and NMH groups Authors suggest that migraineurs may self-report more specific cognitive complaints

(Continues)

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
McKendrick et al. (2006)	Case–Control Cross-sectional	M ($n = 29$) HC ($n = 27$)	Median age of both groups was 26 years (range 19–43 for migraineurs, 19–47 for controls)	Global Motion Coherence Thresholds Repeatable Battery for the Assessment of Neuropsychological Status (RBANS)	In the migraine group, mean global motion coherence thresholds were significantly higher than those of controls ($p < 0.05$) No statistically significant differences were found between migraineurs and controls on the RBANS. Furthermore, performance on the global motion coherence task did not significantly correlate with any of the RBANS index scores Visual motion perception is impaired in people with migraine when stimuli are presented embedded in noise. No evidence was found for significant inter-ictal cognitive abnormalities in young, otherwise healthy people with migraine. Nor do the data support inattention as an explanation for motion perception abnormalities in migraine
Messina et al. (2021)	Case–Control Cross-sectional	M ($n = 17$) HC ($n = 16$)	M (27.7 (range 25–46) years) HC (25.1 (range 24–39) years)	Angle Discrimination Task Colour Discrimination Task TMT, Coding Test Wisconsin Card Sorting Line Orientation Rey Auditory Verbal Learning Test Rey–Osterrieth complex figure test MIDAS	No differences in reaction time and percentage of correct responses during the angle discrimination task were observed between groups. In the colour discrimination task, migraineurs had a significantly reduced percentage of correct scores compared to healthy controls ($p < 0.05$). No statistically significant differences in reaction times from the colour discrimination task were observed between groups The comparison of angle versus colour task revealed an increased activity of the right insula ($p < 0.05$), bilateral orbitofrontal cortex ($p < 0.05$) and medial frontal gyrus (p < 0.05) and decreased activity of the bilateral posterior cingulate cortex ($p < 0.05$) in migraine patients compared to controls In migraine patients, a better performance in the angle task was associated with higher activation of the right insula ($p < 0.001$) and orbitofrontal ($p < 0.001$) Messina et al. (2021) suggest an adaptive functional plasticity that might help migraine patients to overcome impaired visuospatial skills and preserve an adequate performance during a visuospatial task

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Mickleborough et al. (2013)	Case–Control Cross-sectional	M ($n=25$) HC ($n=25$)	M (26.1 (±8.7) years) HC (25.8 (±11.7) years)	Target Identification Task, EEG, EOG	Accuracy or reaction times did not significantly differ between groups In the migraine group, there was a significant interaction between the task block and both the 200–400 ms and 400–600 ms windows ($p<0.001$). In the 200–400 and 400–600 ms time window the increase in block significantly predicted an increase in the mean amplitude ($p<0.001$ and $p<0.05$, respectively) Migraine groups may exhibit impaired sensory-level habituation to repetitive evoked visual stimuli
Miller et al. (2015)	Case–Control Cross-sectional	Study 1: M ($n=9$) HC ($n=5$) Study 2: HC ($n=8$) M ($n=10$) Study 3: HC ($n=6$) M ($n=6$)	Study 1: M (37.4 (±16.1) years) C (33.7 (±14.7) years) Study 2: HC (25 (±6.2) years) M (31 (±9.8) years) Study 3: HC (24 (±2.5) years) M (24 (±4.9) years)	Visual Field Movement Task	In the first experiment, post-hoc examination found migraineurs showed increased perception of self-motion recorded by certainty estimations ($p<0.05$) In the second trial, using 8 s stimuli, the migraine group required significantly greater nulling velocity to cease perception of motion ($p<0.05$) The third experiment using longer visual stimuli (16 s), found that migraineurs showed significantly increased perception of self-motion than controls ($p<0.001$). In this task migraineurs further required significantly greater nulling velocity to stop motion perception ($p<0.01$)
O'Hare et al. (2018)	Case–control Cross-sectional	M ($n=15$) HC ($n=13$)	M (29.27 (±11.74) years) HC (26.77 (±7.53) years)	Pattern Glare Test using virtual reality (black skybox) and rilloid patterns	Migraineurs did not show more tendency for postural sway as no difference was observed between groups No significant effect of group on illusory motion induced by rilloid pattern was observed
Öze et al. (2017)	Case–control Cross-sectional	M ($n=22$) HC ($n=22$)	Median Age (range) M (42 (20–52) years) C (44 (21–51) years)	Rutgers Acquired Equivalence Task	The mean error ratio and duration of task were significantly greater in migraineurs ($p<0.05$, $\eta^2=0.144$). Migraineurs required significantly more trials to complete RAET ($p<0.05$, $\eta^2=0.130$). However no statistically significant differences were observed between groups when testing acquired pairs of the RAET In the transfer phase of the RAET, migraineurs performed significantly worse than controls ($p<0.001$, $\eta^2=0.288$)

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TABLE 1 (Continued)

Authors and publication year	Study type/methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Pellegrino-Baena et al. (2018)	Case–control Cross-sectional	HC ($n=1227$) NMH ($n=1742$) MwoA ($n=804$) MwA ($n=435$)	HC (55.33 (±9.4) years) NMH (50.42 (±8.66) years) MwoA (49.49 (±7.9) years) MwA (48.13 (±7.2) years)	Consortium to Establish a Registry for Alzheimer's Disease word list memory test (CERAD-WLMT) Semantic Fluency Test (SFT) TMT-B.	Both MwA and MwoA were associated with poorer cognitive performance on TMT-B $\beta=-0.083$ (95% CI, −0.160; −0.008) and poorer global z-score $\beta=-0.077$ (95% CI, −0.152; −0.002) The MwA was significantly associated with poor cognitive performance at TMT-B $\beta=-0.084$ (95% CI, −0.160, −0.008) and global z-score $\beta=-0.077$ (95% CI, −0.152; −0.002) In participants of the ELSA-study, all migraine headaches and migraine without aura were significantly and independently associated with poorer cognitive performance
Poormina et al. (2017)	Case–control Cross-sectional	M ($n=30$) HC ($n=30$)	M (28.40 (±5.29) years) HC (29.30 (±4.85) years)	TMT-A, TMT-B Stroop Test (colour word)	Compared to controls, migraineurs took more time to complete the Stroop colour word test ($p<0.001$) and TMT-B ($p<0.005$) Among the migraine subjects, obese individuals had an increased frequency of migraine attack per month ($R^2=0.797$)
Puschmann and Sommer (2011)	Case–control Cross-sectional	EM ($n=17$) FM ($n=16$) HC ($n=20$)	EM (41.35 (±11.87) years) FM (43.4 (±13.3) years) HC (39.8 (±10.5) years)	MIDAS State Trait Anxiety Inventory BDI Penn State Worry Questionnaire Emotional Stroop Index (words and faces)	No statistically significant difference in STAI was observed between groups however BDI was significantly higher in the FM group No statistically significant differences between groups were observed on the word index of the Emotional Stroop In the face index of the Emotional Stroop, FM displayed significantly less attentional bias to negative stimuli compared to controls and responded quicker to negative faces ($p<0.05$)
Quadros et al. (2020)	Cross-sectional	Inter-ictal ($n=76$) Pre-ictal ($n=28$) Ictal ($n=21$) Post-ictal ($n=18$)	Total (36.2 (±9.9) years) Inter-ictal (34.7 (±9.7) years) Pre-ictal (38.7 (±8.6) years) Ictal (37.6 (±10.2) years) Post-ictal (35.6 (±11.2) years)	Digit symbol subtest of Wechsler Adult Intelligence Scale III TMT (A, B and B-A) Stroop Colour Naming	No statistically significant difference on cognitive measures were observed between ictal states

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Raimo et al. (2022)	Case–control Cross-sectional	CM ($n=40$) HC ($n=40$)	Median (range) CM (46 (20–63) years) HC (46 (20–63) years)	The Brief Neuropsychological Examination (ENB-2): Phonemic fluency, Clock Drawing Test Abstraction, Trail Making (TMT A/B), Cognitive Estimation Ideative and Ideomotor Praxis Test, Token Test Digit Span, Immediate and Delayed Recall Prose Memory, Interference Memory at 10 and 30 s Overlapping Figures Spontaneous Drawing Copy Drawing Modified Card Sorting Test, Tower of London Test The Italian version of Reading the Mind in the Eyes Task Modified Italian version of the Emotion Attribution Task Theory of Mind Picture Sequencing Task Advanced Test of Theory of Mind (Italian version)	Differences between groups were observed on some neuropsychological measures The CM group performed significantly poorer than HCs on Overlapping Figures ($p<0.0001$), Delayed Recall ($p<0.05$), Tower of London ($p<0.005$) and the category trial of the Modified Card Sorting Test ($p<0.0001$) Statistically significant differences were further observed on Interference Memory at 30 s which the CM group performed significantly better than HCs ($p<0.01$) Chronic migraineurs performed significantly poorer than HCs on Emotion Attribution Task ($p<0.05$), Advanced Test of Theory of Mind (ATT; $p<0.005$) and Theory of Mind Picture Sequencing (TMPS; $p<0.05$). Quads rank analysis found statistically significant differences between HC and CM on ATT ($p<0.05$), and TMPS ($p<0.05$) while accounting for effects of cognitive differences Poorer performance on Emotion Attribution Task ($p<0.05$) and TMPS ($p<0.05$) were further significantly associated with the number of headache days
Ribeiro et al. (2017)	Case–control Cross-sectional	CM ($n=10$) Drug Induced Headache (DIH) ($n=10$) HC ($n=10$)	CM (35.2 (±8.4) years) DIH (39.6 (±9.7) years) HC (26.3 (±1.9) years)	Iowa Gambling Test Wisconsin Card Sorting TMT Number/Letter sequence	This shows that there is evidence of alterations in patients with migraine, in the dorsolateral circuit, based on neuropsychological tests. The association between migraine and executive disorders can cause a mild cognitive dysfunction. Still patients with migraine from overuse of analgesics showed worse results. A possible impulsivity profile can be highlighted in migraine patients from overuse of analgesics

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TABLE 1 (Continued)

Authors and publication year	Study type/methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Rist et al. (2011)	Prospective cohort study	No severe headache ($n=938$) Non-migraine headache ($n=65$) M ($n=167$)	No severe headache: (68.9 (±3.0) years) Non-migraine headache (69.3 (±3.1) years) Migraine (69.0 (±2.9) years)	MMSE Digit Symbol Substitution test from the Wechsler Adult Intelligence Scale-Revised TMT Part A and B Rey 15-word Memory Test Raven Progressive Matrices Benton Visual Retention and Facial Recognition Tests Finger Tapping Test Word Fluency Test 1 min	After adjusting for age, gender, education and smoking status, people with migraine or non-migraine headache did not experience a greater rate of cognitive decline than those without headache or migraine in any domain For the Wechsler Adult Intelligence Scale-Revised, those with migraine declined less over time ($p<0.05$) compared to those with no severe headache
Rist et al. (2012)	Prospective cohort study	Total ($n=6349$) No history of Migraine ($n=5496$) MwA ($n=195$) MwoA ($n=248$) Past history of Migraine ($n=410$)	**At study randomization** No history of Migraine (66.3 (±4.1) years) MwA (65.9 (±3.9) years) MwoA (65.3 (±3.6) years) Past history of Migraine (66.4 (±4.13) years) **At the baseline cognitive interview** No history of Migraine (71.9 (±4.1) years) MwA (71.6 (±3.9) years) MwoA (71.0 (±3.5) years) Past history of Migraine (72.1 (±4.1) years)	Baseline questionnaire about migraines Telephone interview for cognitive status Immediate and delayed recall trials of the East Boston Memory Test Delayed recall trial of the telephone interview for cognitive status 10-word list Category fluency	The global cognitive scores, verbal scores, or telephone interview for cognitive status scores did not differ significantly among the migraine categories For the category fluency test, the scores differed significantly among the migraine groups at the second and third cognitive testing ($p<0.05$)

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Santangelo et al. (2018)	Case–control Cross-sectional	MwoA ($n = 91$) HC ($n = 84$)	MwoA (33.82 (±10.53) years) HC (32.27 (±10.41) years)	MoCA BDI-II (BDI-II) Self-version of Apathy Evaluation Scale (AES-S) Italian version of the Memory for Intentions Screening Test (MIST)	Mann–Whitney *U*-test revealed that MwoA performed significantly worse than HCs on each subscale of MIST: time-based ($p < 0.001$) and event-based scales ($p < 0.05$), the multiple-choice recognition test ($p < 0.001$) and 24-h item ($p < 0.05$) Mann–Whitney *U*-test revealed that MwoA patients made significantly more Task substitution errors than HCs ($p < 0.005$) No statistically significant difference was found for other types of errors
Santangelo et al. (2016)	Case–control Cross-sectional	MwoA ($n = 72$) HC ($n = 72$)	MwoA: (34.9 (±11.2) years) HC: (33.8 (±11.9) years)	BDI-II Self-version of apathy evaluation scale State–Trait Anxiety MoCA MIDAS	Multivariate analysis of variances found statistically significant differences in MCA with migraineurs having lower total MCA ($p < 0.001$), executive functioning ($p < 0.005$), visuospatial functioning ($p < 0.001$) and memory ($p < 0.001$) compared to HC. However, impairment observed among the MwoA group on MCA was not clinically significant Correlation analysis found significant negative association between executive function scores and MIDAS ($p < 0.005$)
Santos-Lasaosa et al. (2013)	Case–control Cross-sectional	CM ($n = 30$) HC ($n = 30$)	CM: (49.33 (±10.05) years) HC (44.83 (±10.91) years)	MMSE Memory Alteration Test MoCA Working Memory Task	The CM group showed significantly lower scores when compared to controls for the MoCA ($p < 0.005$), Memory Alteration Test ($p < 0.001$) and working memory ($p < 0.001$) No difference was observed between groups on the MMSE
Schmitz et al. (2008)	Case–control Cross-sectional	M ($n = 24$) HC ($n = 24$)	M (45.50 (±9.31) years) HC (41.50 (±12.90) years)	Go-No Go Task Motor Stroop Task SWITCH Task fMRI	Compared to HC, migraineurs had reduced grey matter in the right middle frontal and left inferior parietal lobes ($p < 0.05$) Migraineurs showed significantly slower reaction times in SWITCH-effect than controls ($p < 0.05$). Reaction times to SWITCH-effect in the migraine group were significantly correlated with reduced grey matter density ($p < 0.05$) No statistically significant difference in performance on the Motor Stroop Task or Go-No Go task was observed between groups

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TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Shepherd, A.J. (2006)	Case–control Cross-sectional	M ($n = 50$) HC ($n = 50$) Storage I–Grey Screen M ($n = 25$) HC ($n = 25$) Storage II–Eyes Closed M ($n = 25$) HC ($n = 25$)	Storage I (36 years) Storage II (29 years)	Motion After Effect Task using stationary and dynamic visual stimuli Two between factors: group (M and HC) and storage (grey screen or eyes closed) and two within factor conditions: adaption speed slow or fast and storage trial (none or 15 s) Motion After Effect (MAE) measured after each trial	No statistically significant differences in motion after effect (MAE) direction was observed between groups In the migraine group, MAE duration for static stimuli (sMAE) was significantly longer than the HC group ($p < 0.001$) In the delayed condition, migraineurs displayed significantly greater reduction in sMAE than HCs ($p < 0.05$). Statistically significant differences between groups were observed with sMAE duration being greater in the migraine group ($p < 0.05$) For the dynamic visual stimuli, MAE were significantly longer across all conditions in the migraine group ($p < 0.001$)
Su et al. (2021)	Case–control Cross-sectional	M ($n = 75$) C ($n = 41$)	M (31.87 (±7.32) years) C (31.07 (±5.61) years)	Stroop Task MMSE MoCA Test Hamilton Anxiety/Depression Scale EEG	Migraineurs had significantly longer reaction times in the Stroop Task ($p < 0.001$) however no statistically significant difference in accuracy or Stroop effect was observed between groups A significant group effect was found for medial frontal negativity (MFN) amplitude with lower early negative MFN amplitude among the migraine group ($p < 0.001$). Late MFN amplitude further significantly differed between groups with migraineurs displaying lower negative late MFN amplitude in both congruent and incongruent trials of the Stroop task ($p < 0.01$). This effect was more pronounced in MwA participants than MwoA or chronic migraine
Tibber et al. (2014)	Case–control Cross-sectional	M ($n = 22$) HC ($n = 22$)	M (34.7 (±8.3) years) C (34.4 (±6.2) years)	Visual Acuity Motion Coherence Paradigm Three Equivalent Noise Paradigms: Size, Orientation and Motion	No statistically significant differences between groups in measures of internal noise (local processing) and sampling (global processing) across the three paradigms were found. The migraine group had significantly increased motion coherence thresholds compared to the HC group ($p < 0.05$, Cohen's $d = 0.78$) ultimately requiring more signal-to-noise dots to classify the direction of the motion Tibber et al. (2014) suggest potential impairment in visual noise exclusion in migraine which may be a signature of cortical hyperexcitability

TABLE 1 (Continued)

Authors and publication year	Study type/methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Tunç et al. (2018)	Case–control Cross-sectional	M ($n = 100$) MwA ($n = 47$) MwoA ($n = 53$) HC ($n = 80$)	M (36.7 (±9.4) years) HC: (34.4 (±11.02) years)	MoCA BDI and Anxiety Inventories Whole-brain MRI	No statistically significant differences in MoCA scores between the combined migraine group and healthy controls MoCA scores were significantly lower in MwA compared with MwoA and HC groups ($p < 0.05$ and $p < 0.05$, respectively). Regression analysis indicated association between the MwA and subdomains of MoCA including visuospatial/executive functions ($p < 0.005$), naming ($p < 0.05$), memory ($p < 0.05$), attention ($p < 0.005$) and abstraction ($p < 0.005$) Significant negative association with BDI and MoCA scores. BDI was not significantly associated with overall MoCA, however significant associations were found with MoCA subdomains Statistically significant differences between HC and migraine were found in frequencies of white matter hyperintensities (WMHI) with a significantly larger percentage of migraineurs having WMHI ($p < 0.05$) Significant association between attack frequency and total MoCA scores was found ($p < 0.005$)
Viticchi et al. (2017)	Cross-sectional	M ($n = 36$)	M (42.25 (±10.21) years)	Raven Colour Progressive Matrices	Linear regression underlined a progressive decrease of CPM scores with the increase of the migraine history's length ($R^2 = 0.8871$; $p < 0.001$) A similar result was obtained for the frequency of migraine attacks ($R^2 = 0.3122$; $p < 0.05$) A pathological CPM can be associated with a longer history of migraine and to a higher frequency of attacks. Accordingly, subjects with severe and disabling headaches seem to present an increased probability of developing deficits in reasoning and executive functions These findings strengthen the hypothesis of the presence of executive functions impairment in MwoA

(Continues)

TABLE 1 (Continued)

Authors and publication year	Study type/ methodology	Participants	Age: mean (SD)	Measures/techniques used	Summary of main results
Wang et al. (2014)	Case–control Cross-sectional	M ($n=30$) HC ($n=30$)	M (33.90 (±8.81) years) HC (31.63 (±8.80) years)	Discrimination task: local & global motion perception McGill Pain Questionnaire Mini Mental State exam Verbal Fluency BDI Digit Span State Trait Anxiety	No statistically significant differences between groups were observed on measures including the MMSE, BDI, Digit Span, Stait Trait Anxiety and Verbal Fluency In the local biological motion condition the mean point of subjective equality (PSE) was significantly different between groups ($p<0.05$). Unlike migraineurs, the PSE of controls in this condition was significantly negative ($p<0.005$) In the global biological motion condition, PSE's were significantly negative in the migraine and control groups ($p<0.05$, $p<0.005$ respectively)
Yannick et al. (2015)	Case–control Cross-sectional	M ($n=45$) HC ($n=45$)	M (23.29 (±2.55) years) HC (22.89 (±2.04) years)	Hospital Anxiety and Depression Questionnaire (HAD) Delis–Kaplan Executive Functions System (D-KEFS) Colour-Word Interference Test	Migraineurs performed significantly poorer on subtests 1 and 4 of the D-KEFS ($p<0.05$ and $p<0.05$, respectively). In the migraine group, interference/ selective attention scores were significantly lower compared to healthy controls ($p<0.05$) In subtests 3 and 4, migraineurs made significantly more errors than the control group ($p<0.05$ and $p<0.05$), respectively
Yetkin-Ozden et al. (2015)	Case–control Cross-sectional	M ($n=74$) MwA ($n=21$) MwoA ($n=53$) HC ($n=37$)	M (37.89 (±10.99) years) MwA (35.33 (±11.96) years) MwoA (38.91 (±10.54) years) HC (36.10 (±11.58) years)	Short version of the BFRT LOT	Migraineurs had significantly lower mean LOT ($p<0.05$) and BFRT ($p<0.05$) scores compared to controls Differences in mean BFRT were further observed between migraine groups with MwoA performing significantly worse than MwA ($p<0.05$)
Zhang et al. (2012)	Case–control Cross-sectional	M ($n=27$) HC ($n=27$)	M (33.60 (±10.41) years) HC (31.96 (±8.78) years)	Temporal Reproduction Task	In each case, migraineurs significantly overestimated the duration for the ISI for 1 s ($p<0.00$) and for the 5 s ISI ($p<0.01$). Time estimation for the 600-ms condition was impaired in migraineurs in the form of an overestimation

Abbreviations: C, Controls; CM, Chronic Migraine; CMwMOH, Chronic Migraine with Medication Overuse Headache; EM, Episodic Migraine; HC, Healthy Controls; M, Migraine; MwA, Migraine with Aura; MwoA, Migraine without Aura; MwoPP, Migraine without Photophobia; MwPP, Migraine with Photophobia; PSE, Point of Subjective Equality.

et al. (2017) showed similar results but with slight differences, with a worse performance for migraineurs in both language and orientation, but not in visuospatial and attention components of the MoCA. Correlation analysis in this study found that migraine duration was significantly and negatively associated with overall MoCA scores (−0.446 [$p<0.01$]), as well as subdomains of language, executive functions, calculation and memory. In addition to this, Ferreira et al. (2018) found significantly lower MoCA scores for the chronic migraine group ($M=24.4$) in comparison to controls ($M=26.7$, $p<0.001$). Moreover, chronic migraine was further independently associated with a lower MoCA performance before and after controlling for medication use, anxiety, sleep and depression. Tunç et al. (2018) reported similarly that MoCA scores were positively associated with migraine frequency ($p<0.01$), reinforcing the idea that those with chronic migraine may be more likely to experience impaired cognitive performance.

Focusing on studies with distinct types of migraineurs, Latysheva et al. (2020) found no statistically significant differences on MoCA scores between episodic ($n=44$) and chronic migraineurs ($n=144$) or between migraineurs with and without medication overuse headache. However, they found that 18% of chronic migraineurs in the sample met the criteria for mild cognitive impairment compared to 6% of episodic migraineurs. Moreover, anxiety levels in the sample correlated positively with the MoCA, suggesting that anxiety enhanced the performance. Separately, comparing migraineurs with, without aura and healthy controls, Tunç et al. (2018) reported that significantly worst performance on total MoCA scores was observed only in migraineurs with aura ($M=21.7$, $SD=5$), with no differences between migraineurs without aura ($M=24.9$, $SD=3.5$) and healthy controls ($M=24.4$, $SD=3.8$).

3.1.2 | Studies focused on the MMSE

Another range of studies using the MMSE as the core assessment did not show differences in global cognition between migraineurs and healthy controls (Rist et al., 2011; Wang et al., 2014) or between groups of migraineurs with or without medication use over time and healthy controls (Baars et al., 2010). Performance on the MMSE within groups, based on migraine frequency, was also similar, with no significant differences observed between individuals with episodic and chronic migraine (Latysheva et al., 2020).

Contrary to these findings, Kalaydjian et al. (2007), using a longitudinal design, found that mean MMSE values were significantly greater for the migraine group compared to healthy controls ($p<0.05$). However, the sample sizes in this study were uneven (with 204 participants with migraine and 1244 healthy controls), and the control group was older ($M=52.7$, $SD=15.7$ years) than the migraine group ($M=47.5$, $SD=12.5$ years), which may suggest some age-related cognitive decline in the control group.

3.1.3 | Studies using both the MMSE and MoCA

General findings above, with statistically significant differences for the MoCA but not for the MMSE were also supported by Santos-Lasaosa et al. (2013), who found significantly lower scores on the MoCA in the chronic migraine group compared to controls ($p<0.001$), but not for the MMSE (see also, Martins et al., 2012, 2020).

3.2 | Perception

Up to 13 studies included in this review included measures and outcomes for perceptual functions in migraineurs. Due to the strong interconnection between perceptual performance and cognitive processes, it was deemed necessary to take the outcomes of these studies into consideration. In the following sub-sections, we divide them between those focused on visual and auditory perception.

3.2.1 | Studies focused on visual perception

Here we present studies focused on diverse visual phenomena linked to migraine (i.e. photophobia, perceived illusory motion, etc.) and their links with some cognitive processes such as attention.

Using a cross-sectional mixed design Koppen et al. (2011) examined perceptual organization and attention using a sample of clinical outpatient non-frequent and frequent migraineurs ($n=16$) and healthy controls ($n=18$) using a Global–Local task (participants were presented with hierarchically organized visual figures, in which a larger-global-letter was composed of smaller-local-letters). No statistically significant differences were observed between migraineurs and controls, or between baseline and post-drome functioning in the migraine group. However, the control group showed significantly faster reaction times to global stimuli compared to local ($p<0.05$), a performance that was not replicated in the migraine group. Koppen et al. (2011) suggest that visual channels tuned to low spatial frequency ranges of migraineurs may be less sensitive between attacks and as such processing through these channels may be impaired. Similarly, Kriegler et al. (2020), using a greyscale task, found that migraineurs performed significantly worse than controls and performed similar to that observed in unilateral neglect patients. These authors attributed this defective performance in migraineurs to an impaired attention to luminosity as a result of sensitivity to high frequencies of visual stimuli rather than size perception.

Separately, Guo et al. (2019) examined between and within group differences in visual attention among migraineurs using a three-stimulus visual oddball paradigm and found female migraineurs to have greater perceptual impairment in attentive visual processing in comparison to male migraineurs and to female controls.

In a longitudinal, repeated measures study, Luedtke and Edlhaimb (2021) found statistically significant differences between migraineurs and healthy controls on a Laterality Recognition Task. Migraineurs performed significantly worse in identifying images with both and leftward ($p < 0.05$) and rightward bias ($p < 0.01$) compared to healthy controls. No statistically significant differences in mean response time were found. Due to the longitudinal design, these researchers were able to examine differences in response times across migraine phases; and highlighted the cyclic nature of the condition in which perceptual impairment seems to be the greatest from the 24-h period before to the 24 h after a migraine attack.

When a motor or movement component is introduced, the results go in a similar direction. According to findings by McKendrick et al. (2006), visual motion perception is impaired inter-ictally in people with migraine when stimuli are embedded in noise using a Global Motion paradigm. Results from this study found that the mean global motion coherence threshold was significantly higher in the migraine group in comparison to controls ($t\,(54) = 2.1$, $p < 0.05$), suggesting inter-ictally impaired visual motion perception when stimuli are embedded in noise in migraineurs, an impairment that is irrespective of cognition (based on the results using the Repeatable Battery for the Assessment of Neuropsychological Status-RBANS) and medication.

Another study by Tibber et al. (2014) supports the findings of impaired visual motion perception in migraineurs using the Motion Discrimination Task with embedded noise. In comparison to controls ($n = 22$), migraineurs ($n = 22$) displayed significantly higher mean motion coherence thresholds (controls: $M = 24\%$, $SD = 1.8\%$; migraineurs: $M = 32\%$, $SD = 3.3\%$; $t\,(37) = -2.37$, $p < 0.05$, Cohen's $d = 0.78$). Contrary to the above, one study by Battista et al. (2010) found that migraineurs performed significantly better than controls on motion discrimination tasks with increased inhibition and ability to suppress competing visual stimuli.

An additional number of studies examined the differences between migraineurs and healthy controls in relation to perceived illusory motion. In a study by Shepherd (2006), induced motion after effects lasted significantly longer in the migraine group compared to controls ($p < 0.001$). No statistically significant differences were observed between migraineurs with and without aura. A study by Miller et al. (2015) further examined vection perception using a motion platform and a forced choice task. This study used inertial nulling (IN), which is a technique wherein visual and inertial motions are presented simultaneously, with the modalities presented in opposition in order to determine the visual stimulus that produces perceived vection that is nulled by the inertial movement. Results from this study found that migraineurs required significantly greater nulling velocity ($M = 1.18$, $SD = 0.51$ cm/s) to eliminate the perception of motion in comparison to healthy controls ($M = -0.008$, $SD = 0.56$ cm/s, $p < 0.05$). Such results of increased vection or perceived illusory motion in migraineurs are suggested as an explanatory mechanism for the increased frequency of vertigo, nausea, dizziness and motion sickness in this population (Miller et al., 2015; Shepherd, 2006). A more recent study by O'Hare et al. (2018) found no difference in postural sway or head movements between healthy controls ($n = 13$) and migraineurs ($n = 15$) in response to an illusory motion condition using a Pattern Glare Test. However, this study required participants to verbally answer the Pattern Glare test and cognitive tasks like that have been shown to counteract the effects of illusory motion (Swan et al., 2007, as cited in O'Hare et al., 2018).

Based on the findings of the studies included in this review, perceptual functions are impaired in migraine. Furthermore, in Chu et al. (2011), both migraineurs with and without photophobia experienced significantly more visual discomfort than controls on a Visual Discomfort Test, highlighting an increased sensitivity to visual stimuli. Moreover, post-hoc analysis revealed greater discomfort in migraineurs with photophobia than in those without. The adversity to perceptual stimuli and the perceptual impairments highlighted in this review encourage further exploration of perceptual processing in migraine as an important implication in migraine neuropsychology and therapy.

3.2.2 | Studies focused on auditory perception

A few studies assessed auditory perception in migraineurs. In Agessi et al. (2014), with a cross-sectional between group design, migraineurs performed significantly worse on the gaps in noise test ($p < 0.01$) and the Duration Pattern Test

($p<0.001$) compared to non-migraine controls. These results suggest impaired auditory and temporal processing in migraineurs, an impairment whose mechanism needs to be explored further to examine the role of memory and attention on performance. Zhang et al. (2012) also suggest inter-ictally impaired temporal perception in migraineurs. Using a Temporal Reduction Task, migraineurs ($n=27$) significantly overestimated stimulus presentation time when compared to healthy non-migraine controls ($n=27$) for the of 1 second ($p<0.001$) and 5 s ($p<0.01$) inter-stimulus level in the 600 ms condition. However, no impairment of time discrimination in the longer conditions of 3 and 5 s was found. Nevertheless, further correlation analysis found no significant relationship between time discrimination performance (time estimations) and cognitive performance or mood in migraineurs or controls.

3.3 | Attention

The studies in this review that measured attention showed a trend towards established attention deficits in migraine populations compared to healthy controls.

A number of studies in this review found significant impairment in migraineurs using the Stroop test. Ferreira et al. (2018) found that mean scores on the Stroop test were significantly lower in the migraine group compared to controls ($p<0.001$). In a regression analysis Stroop scores were significantly associated with migraine status ($p<0.05$). In this study, Stroop scores were not associated with topiramate use, anxiety, depression, or poor sleep. Poormina et al. (2017) also found that mean time needed to complete the Stroop test was significantly higher for migraineurs ($M=132.17$, $SD=7.027$ s) compared to controls ($M=106.40$, $SD=15.87$ s, $p<0.001$), thus suggesting inter-ictal attention and processing speed impairments in the migraine population. This attentional deficit may further worsen as a migraine cycle progresses. In a sample of episodic migraineurs without aura, Gil-Gouveia et al. (2015b) found that migraineurs performed significantly poorer on tests of attention during a migraine attack compared to baseline, inter-ictal functioning. During an attack, scores on the Stroop Words (reading) ($M=77.6$, $SD=21.0$) were significantly lower than that observed at baseline ($M=90.6$, $SD=17.1$, $p<0.05$) following adjustment for multiple comparisons, suggesting a mild selective attention deficit during an attack.

Similarly, Su et al. (2021) found significant differences in response time, with migraineurs displaying longer reaction times, but reported no significant differences in Stroop accuracy between migraineurs and controls. However, Quadros et al. (2020) found no significant differences between any phases of migraine (inter-ictal, pre-ictal, ictal or post-ictal) using the Stroop test.

Impaired attention was further observed in samples with high levels of formal education. In a case–control study, Yannick et al. (2015) found that migraineurs performed worse on the Delis-Kaplan Executive-Functions System (D-KEFS) Colour-word Interference test. In this study, migraineurs displayed significantly lower mean interference scores ($M=-4.04$, $SD=7.08$) than controls ($M=-1.31$, $SD=7.73$, $p<0.05$). Levels of anxiety and depression did not significantly correlate with interference in either groups (Yannick et al., 2015).

In a case–control study, using the Attentional Networks Test, Chen et al. (2021) observed statistically significant differences between groups on reaction times ($F=84.085$, $p<0.001$), but not on levels of accuracy. Contrary to previous studies, no statistically significant differences were observed between groups on any of the Stroop Test tasks. However, the sample in Chen et al. (2021) was smaller than in other studies discussed above.

One single study seemed to point, at least partially, to a better attentional performance in migraineurs, but only to negatively biased images. Puschmann and Sommer (2011) found that healthy controls demonstrated significantly greater attentional bias for negative stimuli using the emotional Stroop test whereby performance was directly impaired by negative affective images. This attentional bias was not present in the migraine group who performed better on the negative condition of the task compared to neutral or positive conditions. While more research is needed to further understand this mechanism and establish the reliability of these findings, Puschmann and Sommer (2011) suggest that the results of the study may relate to the frequent reliance of avoidance behaviours within the disorder.

3.4 | Memory

Memory appears to be one of the most affected cognitive domains found across 15 of the studies included in this review. Studies reviewed consistently showed a worse performance in individuals with migraine, regardless of the presence of aura in some cases and even in inter-ictal, pain-free periods. Interestingly, this is the most studied cognitive domain, with studies showing differences not only based on migraine phase or type but also how gender, mood or sleep may be associated with memory performance. Similar to other cognitive domains, a series of studies showed no significant migraine specific memory performance. As with other cognitive domains, there was significant variation between the measures used among the studies, so the limitations of these neuropsychological measurements are an additional factor that needs to be considered.

First, starting with studies focused on differences between migraineurs and healthy controls, Santos-Lasaosa et al. (2013) found significant worse performance on chronic migraineurs ($n=30$) compared to healthy controls ($n=30$) on the Memory Alteration Test ($M=43.76$, $SD=3.21$ versus $M=48.83$, $SD=1.89$, $p<0.001$). Further statistically significant differences were observed between subdomains of the test including short-term memory ($p<0.001$), semantic memory ($p<0.05$), free recall ($p<0.001$) and cued recall ($p<0.001$). Similarly, Raimo et al. (2022) showed that chronic migraineurs displayed significantly poorer delayed prose memory (i.e. the delayed recall of a story read aloud twice by the examiner to the participant, which they have to repeat after a 4-min-long distracting task) and worse interference memory at 30 s compared to controls.

Another cross-sectional study by Öze et al. (2017) examined differences of performance on the Rutgers Acquired Equivalence task between groups of migraineurs ($n=22$) and healthy controls ($n=22$). Results from this study found that migraineurs made significantly more errors and needed more trials to complete the acquisition phase compared to controls. Similarly, migraineurs performed significantly poorer than controls, suggesting basal ganglia and hippocampal impairment. Using the Rey–Osterrieth Complex Figure Test, Huang et al. (2017) found that migraineurs performed significantly poorer on the recall condition of the task compared to non-migraine healthy controls ($M=20.688$, $SD=6.129$ versus $M=25.316$, $SD=5.218$, $p<0.05$). Finally, Lo Buono et al. (2019) found significant worse performance on the Rey Auditory Verbal Learning Test (RAVLT) for both migraineurs with and without aura, compared to healthy controls.

Second, focusing on different migraine phases, Gil-Gouveia et al. (2015b) found significantly decreased performance on the California Verbal Learning Test during migraine attacks compared to inter-ictal functioning between attacks. Overall total learning ($p<0.05$), CVLT short-term recall with ($p<0.05$) and without ($p<0.05$) semantic cues and delayed recall with ($p<0.01$) and without ($p<0.0.05$) semantic cues were significantly lower during a migraine attack. These findings suggest reversible impairment across various cognitive modalities including memory, learning and processing speed (Gil-Gouveia et al., 2015b).

Third, there is only one study with a focus on memory differences between types of migraineurs. Latysheva et al. (2020) found that performance on RAVLT was significantly poorer in chronic migraineurs when compared to low frequency episodic migraine during inter-ictal, pain free periods of functioning ($p<0.01$).

Fourth, in relation to potential gender differences for memory in migraine, a cross-sectional study by Gasbarri et al. (2008) examined differences in recall of arousal and neutral narratives between gender and migraine status (migraineurs and healthy controls). In this study, male and female migraineurs displayed poorer recall of both neutral and arousal conditions than male and female controls. However, this impairment was significantly greater in male migraineurs compared to female migraineurs in both the arousal ($p<0.05$) and neutral ($p<0.001$) conditions. Separately, Chu et al. (2020) found a significant association with increasing migraine attack frequency and decreasing performance on the Ascertain Dementia Questionnaire in female migraineurs with aura group, compared to male migraineurs with and without aura and female migraineurs without aura.

Fifth, regarding associations of memory performance with sleep and mood disorders, Lo Buono et al. (2019) found RAVLT scores were significantly associated with Beck's Depression Inventory (BDI) and Hamilton Anxiety Rating Scale. Separately, Kim et al. (2020) observed a significant negative association between the Insomnia Severity Index and the RAVLT delayed recall task for the migraine group, suggesting the potential of sleep as a mediating factor of memory impairment in migraine.

Finally, opposing the previously discussed articles, seven studies included in this review did not observe significant memory impairment in migraineurs. Baars et al. (2010), Baschi et al. (2019) and Martins et al. (2020) found no statistically significant differences between migraineurs and healthy controls on memory performance, although the latter observed increased self-reported cognitive complaints in the migraine group compared to controls. Martins et al. (2012) suggested that participants with non-migraine headaches experience greater impairment of semantic and recognition memory than migraineurs, although the inclusion criteria in this study for the non-migraine headache groups remain unclear. Longitudinally, Rist et al. (2011, 2012) also found no statistically significant differences in the rate of memory decline between migraineurs, non-migraine headache and healthy controls over time, using the RAVLT and The East Boston Memory Test. Finally, Kim et al. (2020) found no statistically significant difference between groups of healthy controls, migraineurs or persistent post-traumatic headache (PTH) on measures of immediate and delayed recall from the RAVLT.

3.5 | Visuospatial functioning

Only three of the studies included in this review focus on visuospatial abilities in migraine, so results, although promising, are still limited. First, Yetkin-Ozden et al. (2015) examined facial recognition and visuospatial perception in a group of 74 migraine patients with or without aura and 37 healthy controls by means of the Benton Face Recognition Test (BFRT) and Line Orientation Test (LOT). Results showed significantly poorer performance by the migraine group on both tests when compared to controls. Within groups analysis found migraineurs without aura displayed significantly lower mean scores on BFRT when compared to migraineurs with aura ($p < 0.05$). No difference within groups was found on LOT scores. Further correlation analysis found a significant negative association ($p < 0.05$) between LOT scores and duration of the condition with those who had migraine for over 10 years, showing lower mean scores ($M = 14.84$, $SD = 7.47$) in comparison to those with less than 10 years with migraine ($M = 17.86$, $SD = 5.57$).

Using a motion platform and a forced choice task, Messina et al. (2021) found that migraineurs performed significantly poorer than healthy controls on spatial navigation tasks requiring colour discrimination when compared to angle discrimination (in which no impairment was observed). Using functional magnetic resonance imaging capturing task performance, they found increased activation of brain areas involved in the perception of potentially harmful stimuli (nociception) in the migraine group. Messina et al. (2021) suggest that imaging may highlight adaptive functional plasticity in nociception brain areas that work to maintain otherwise impaired spatial performance.

Finally, in a between-groups study by Karami et al. (2019) using the Bender-Gestalt II with a sample of 32 participants with occipital lobe epilepsy (OLE), 30 with migraine and 31 healthy controls, statistically significant differences were observed on all four components of the BGT-II: copy ($p < 0.001$), recall ($p < 0.001$), motor ($p < 0.001$) and perceptual ($p < 0.001$). Post-hoc analysis revealed that OLE participants displayed significantly lower scores on all four components when compared to migraine participants. Migraineurs in this study further displayed significantly lower scores on all components compared to healthy controls ($p < 0.01$).

3.6 | Executive functions

In order to present results for executive functions in migraine in a way as clear as possible, we have subdivided the section into results pertaining (1) set shifting and cognitive flexibility, (2) decision-making and reasoning, (3) working memory, (4) prospective memory and (5) studies with non-significant or contradictory results.

3.6.1 | Set shifting and cognitive flexibility

Schmitz et al. (2008) reported that migraineurs had significantly slower reaction times to set shifting using a Visuospatial SWITCH Task compared to controls ($p < 0.05$). They further found that reaction times to SWITCH-effect in the migraine group were significantly correlated with reduced grey matter density ($p < 0.05$). Separately, no statistically significant differences however were observed in this study on both the Go-No-Go and Motor Stroop tasks. Similarly, a study by Yannick et al. (2015) found that migraineurs performed significantly poorer in cognitive flexibility compared to controls. Additionally, a study by Raimo et al. (2022) found that patients with chronic migraine achieved significantly lower scores on tests assessing executive functions including cognitive flexibility, planning and abstract reasoning with respect to healthy controls.

A subgroup of studies on cognitive flexibility relies on the TMTor similar tasks. Poormina et al. (2017) found a statistically significant difference in time needed to complete the TMT-B for migraineurs ($M = 54.77$, $SD = 8.169$ s) compared to healthy controls ($M = 56.23$, $SD = 23.457$ s; $p < 0.001$). Similarly, Pellegrino Baena et al. (2018) found significantly poorer performance for migraineurs on TMT-B ($\beta = -0.083$ [95% CI, −0.160; −0.008]) and poorer global z-score ($\beta = -0.077$ [95% CI, −0.152; −0.002]). Lo Buono et al. (2019) reported comparable results but indicated that scores on TMT-B were significantly associated with BDI and Hamilton Anxiety Rating Scale in the migraine groups ($p < 0.05$ and $p < 0.01$ respectively, both with medium effect sizes). These authors suggest that increased levels of depression and anxiety, frequently observed in migraine populations, may exacerbate the risk of executive dysfunction in migraine. Finally, Han et al. (2019) reported that migraine without aura participants performed significantly worse than healthy controls on the shape trail test (STT).

3.6.2 | Decision-making and reasoning

Some evidence for impaired decision-making among migraineurs was found by Biagianti et al. (2012), with both individuals with chronic and episodic migraine displaying significantly poorer performance on the Iowa Gambling Task compared to healthy controls

($p < 0.001$), regardless of medication use, suggesting orbito-frontal impairment in migraineurs. Viticchi et al. (2017) revealed a significant association between migraine frequency and performance on the Raven colour progressive matrices ($R^2 = 0.3122$; $p < 0.05$) suggesting poorer performance as attack frequency increased. A similar relationship was observed with length of migraine history with performance on RCPM decreasing over time ($R^2 = 0.8871$; $p < 0.001$).

3.6.3 | Working memory

In relation to the working memory performance in migraine, Santos-Lasaosa et al. (2013) found that chronic migraineurs ($M = 17.5$, $SD = 4.28$) performed significantly worse than healthy controls ($M = 24.26$, $SD = 4.12$ [$p < 0.001$]) in a working memory task. Ferreira et al. (2018) found statistically significant differences in executive functioning on tasks such as Digit Span Forwards and Verbal Fluency Task, with migraineurs performing worse than healthy controls. Regression analysis further found migraine diagnosis to be a significant predictor of poorer performance on these tasks suggesting overall impairment in key domains of executive processes, including working memory.

3.6.4 | Prospective memory

For prospective memory, only one study reported results for migraine patients. Santangelo et al. (2018) found a statistically significant difference on measures of the Memory for Intentions Test between groups with migraine without aura performing worse than healthy controls and making significantly more errors. Migraineurs further made significantly more task substitution errors than controls. However, non-parametric methods used in this study do not allow for generalization of findings to the general population.

3.6.5 | Studies with non-significant or contradictory results

This review showed five studies with neutral or non-significant findings for migraineurs in the executive functions domain, and the one that even had better results for migraineurs.

Schmitz et al. (2008), using a Go-No go task and the Stroop test, found no statistically significant differences in inhibitory processing between the migraine groups and healthy controls. Separately, Koppen et al. (2011) found no statistically significant differences in working memory using the N-back task. More recently, Martins et al. (2020) found no statistically significant differences between mean executive functioning scores in older adults with migraine and healthy age-matched controls. Equivalent results were further observed in Kim et al. (2020), who found no statistically significant differences between healthy controls, migraineurs or post-traumatic headache on TMT A & B, similar to Quadros et al. (2020). Finally, in a different trend, Baschi et al. (2019) found that participants with migraine performed significantly better on the TMT A and B and the Corsi Block Tapping Test.

4 | DISCUSSION

The goal of the current study was to establish the existence of a domain-specific cognitive profile associated with deficits in individuals suffering from migraine. The domains reviewed include global cognitive functioning, perception (visual and auditory), attention, memory, visuospatial functioning and executive functioning.

First, for global cognitive functioning, mixed outcomes were observed, depending on measures used. A range of studies using the MoCA showed worse performance in migraineurs compared to controls (Ferreira et al., 2018; Huang et al., 2017; Santangelo et al., 2016; Santos-Lasaosa et al., 2013), one reported an additional mediation of headache frequency (Latysheva et al., 2020) and one pointed to a worse performance for the subgroup of patients with aura (Tunç et al., 2018). Other series of studies using the MMSE showed no differences between migraine patients and healthy controls (Baars et al., 2010; Martins et al., 2012, 2020; Rist et al., 2011; Santos-Lasaosa et al., 2013; Wang et al., 2014), or between episodic and chronic migraineurs (Latysheva et al., 2020), with only a study finding better MMSE scores for migraineurs (Kalaydjian et al., 2007). These contradictory studies point to a problem of accuracy and sensitivity of these cognitive screening tools (Blanco-Campal et al., 2021) and question their relevance in the goal of clarifying the detailed features of cognitive performance in migraine.

In relation to visual perception, some studies showed an impaired visual perception in migraineurs (Koppen et al., 2011), with more visual discomfort and stress (Chu et al., 2011) and worse left–right discrimination (Luedtke & Edlhaimb, 2021). When movement is added to what needs to be perceived, performance worsens further (McKendrick et al., 2006; Shepherd, 2006; Tibber et al., 2014), with an increase in interference (Karami et al., 2019) and illusory motion (Miller et al., 2015), although the latter has been disputed by O'Hare et al. (2018). Further research is needed to establish to what extent this evidenced general sensitivity between migraine attacks may influence performance on a wide array of tasks that require visual processing (including neuropsychological assessment tools for attention, memory, visuospatial or executive functions that may rely on visually presented materials).

In terms of auditory perception, two studies (Agessi et al., 2014; Zhang et al., 2012) reported impaired auditory and temporal processing in migraineurs, an impairment whose mechanism needs to be explored further to examine the role of memory and attention on performance.

With regards to attention, studies show quite a consistent pattern of attention and information processing speed deficits in migraineurs (Agessi et al., 2014; Ferreira et al., 2018; Gil-Gouveia et al., 2015b; Martins et al., 2012; Mickleborough et al., 2013; Poormina et al., 2017), with some reporting a specific poorer performance in female patients (Guo et al., 2019). Yannick et al. (2015) remark a reduction of selective attention during the inter-ictal period and Chen et al. (2021) found worse attentional control in migraineurs without aura when compared to health controls. With only one study showing better attention in migraineurs (due to a bias towards faces with negative emotions) (Puschmann & Sommer, 2011) and five studies showing no significant impairment specific to migraineurs (Baschi et al., 2019; Öze et al., 2017; Quadros et al., 2020; Su et al., 2021), overall results point to the need of more research with more accurate measures that take into consideration gender differences, distinction between patient with and without aura and a focus in determining the specific periods (pre-, ictal, post- and inter-) in which these attention deficits may take place.

In relation to memory, a generalized pattern of decreased memory performance in migraineurs is the main finding across different memory processes (Agessi et al., 2014; Gil-Gouveia et al., 2015b; Santangelo et al., 2016; Santos-Lasaosa et al., 2013; Tunç et al., 2018) including general free recall and recognition (Gasbarri et al., 2008), long-term memory (Raimo et al., 2022), visuospatial memory (Baschi et al., 2019; Huang et al., 2017) and verbal memory tasks (Kim et al., 2020; Latysheva et al., 2020; Lo Buono et al., 2019), independent of aura presence. One study linked migraine to decreased memory performance in a dementia related self-reporting questionnaire (Chu et al., 2020). Separately, a range of studies did not report any significant memory differences between migraineurs and controls (Baars et al., 2010; Kim et al., 2020; Martins et al., 2020; Rist et al., 2011, 2012), with just one of the reported studies finding partial results in favour of migraineurs (Baschi et al., 2019). As with other cognitive domains, measures used to assess memory were very diverse, so the limitations of these neuropsychological measurements need to be considered, as well as the need for a clearly defined protocol of neuropsychological assessment tools. To summarize, further research is needed to better understand memory functioning in migraineurs and clarify opposing findings between migraineurs and controls and within migraine sub-groups, as well as the potential effects of other variables such as gender, mood, sleep and medication intake. This may be achievable using more homogenous measures across future research that aims to examine memory functioning in migraineurs. Finally, the use of appropriate, reliable and valid neuropsychological measures needs to be ensured, in order to accurately identify memory performance features in migraine across the lifespan.

For visuospatial functioning, results reporting deficits in visuospatial and spatial navigation abilities are scarce and contend with mixed results. Findings from studies, although limited, support the evidence on impaired visuospatial functioning in migraineurs (Karami et al., 2019), with potential implications for high-risk tasks such as, but not limited to, driving, as suggested by Yetkin-Ozden et al. (2015). Messina et al. (2021) showed a significantly decreased performance in migraineurs when compared to controls in relation to spatial navigation tasks requiring colour discrimination (compared to angle discrimination), which seems to indicate the route for further research in this particular domain.

For the domain of executive functions, a general pattern of impaired functions was found across several studies (Huang et al., 2017; Ribeiro et al., 2017; Santangelo et al., 2016; Tunç et al., 2018). In more specific terms, deficits have been reported in migraineurs in terms of slower set shifting and cognitive flexibility (Han et al., 2019; Lo Buono et al., 2019; Pellegrino Baena et al., 2018; Poormina et al., 2017; Schmitz et al., 2008; Yannick et al., 2015), impaired decision-making (Biagianti et al., 2012; Viticchi et al., 2017), worse performance in working memory tasks (Ferreira et al., 2018; Santos-Lasaosa et al., 2013) and impaired prospective memory (Santangelo et al., 2018). Against this trend, five studies reported non-significant differences between migraineurs and controls (Kim et al., 2020; Koppen et al., 2011; Martins et al., 2020; Quadros et al., 2020; Schmitz et al., 2008), despite some of them showing some trend of a worse performance in pre-ictal stages that requires further research and only one study (Baschi et al., 2019) reported better significant results for migraineurs. Additional research is required to specifically identify executive function deficits linked to the distinct phases of the migraine cycle. Unfortunately, among all the studies eligible for inclusion in this review, few investigated executive functioning between phases of the migraine cycle and there are limitations with the design seen in these studies alongside others, such as unequal observations and sample sizes per group. Further research is required to clarify whether executive functioning fluctuates throughout the migraine phases and, as some studies seem to point (although with non-significant results, such as Quadros et al., 2020), to clarify whether migraineurs exhibit (or not) overall poorer executive performance in pre-ictal phases when compared to other migraine phases.

In conclusion, studies included in this review show mixed and sometimes contradictory findings when it comes to accurately characterizing a cognitive profile for individuals with migraine. Overall, visual perception appears to be impaired (and adding movement to perceived stimuli creates further interference and illusory motion) and there is evidence of impairment in auditory and temporal processing, although the precise way in which perceptual deficits affect cognitive performance requires further investigation. Attention is also impaired, as well as memory across different processes (free recall and recognition), stages (specifically, long-term memory) and modalities (visual and verbal). Despite the limited number of studies, visuospatial function and spatial navigation are also affected and deficits on a wide range of executive functions (set shifting and cognitive flexibility, decision-making and reasoning, working memory and prospective memory) complete a complex cognitive profile in migraine.

The development of the current review has faced obvious limitations derived from the limitations of the existing research.

First, in terms of sample selection, many of the reviewed studies included either small sample sizes or non-equivalent group sizes, or both, which may limit the reliability and validity of the results. Moreover, gender or age distribution among the participants was unclear as many studies did not acquire a representative gender or age balance in the migraine groups. In addition, lack of characterization of healthy controls (i.e. absence of clear information about recruitment) was an additional problem.

Second, as a major limitation of the migraine literature, many studies did not specifically acknowledge whether symptomatology described was linked to a particular migraine stage, although most studies focused mainly on inter-ictal functioning, due to the complexity and sporadic nature of the condition.

Third, the length and chronicity of the condition was not properly addressed in many instances and studies that examined this found a significant effect of frequency and duration of migraine (i.e. episodic versus chronic migraineurs), making some individuals more vulnerable to cognitive impairment.

Fourth, the effect of aura versus non-aura was inconsistently reported across the studies reviewed and further research is needed to consistently clarify the role of the aura (if any) on the dysfunction across different cognitive domains.

Finally, cognitive assessment protocols were very heterogeneous across studies and some have relied on very general measures. For example, the use of the MoCA or the MMSE may not be appropriate to evaluate global cognitive dysfunction in migraine. In addition, the validity and reliability of cognitive tests used to specifically assess patients with migraine is another major limitation of the results that has not been carefully considered across the studies.

In summary, further research on the cognitive characterization of migraine needs to properly address (1) domain-specific cognitive deficits across different migraine phases (pro-dromal, headache, post-dromal and inter-ictal); (2) the effects on the length and chronicity of migraine history; (3) the effect of aura versus non-aura (inconsistent across reviewed studies) and (4) the interaction of mood and sleep disorders; as well as other considerations out of the scope of this review, such as gender-specific considerations, effects of different types of medications, potential comorbidities, or differences between primary migraine and migraine due to other underlying medical conditions.

But, above all, for a proper characterization of migraine from the neuropsychological point of view, the validity and reliability of the neuropsychological tests used to assess patients with migraine needs to be revisited and the establishment of a clear, consistent and a cross-culturally applicable cognitive assessment protocol across migraine studies needs to be agreed among the international research and clinical community.

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CONFLICT OF INTEREST STATEMENT

None.

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