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A systematic review and meta-analysis of visuospatial attentional deficits in Parkinson's patients

Madalina Bucur [a,b], Alexandria N. Holcomb [b], Maurizio Luciani [b], Costanza Papagno [b], Selene Schintu [b,c,*]

[a] Department of Biomedical and Clinical Sciences, University of Milan, Milan 20157, Italy
[b] Center for Mind/Brain Sciences - CIMeC, University of Trento, Rovereto 38068, Italy
[c] Department of Psychological and Brain Sciences, The George Washington University, Washington, DC 20006, United States

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ABSTRACT

Parkinson's disease (PD) is a neurodegenerative condition primarily characterized by motor deficits, yet cognitive impairments are increasingly recognized. While deficits in executive functioning are well documented even in the absence of cognitive decline, evidence of attentional deficits in PD remains inconsistent, and the role of motor symptom lateralization is unclear. In this systematic review and meta-analysis, we examined visual attention in right-handed, cognitively unimpaired idiopathic PD patients, focusing on the canonical attentional domains (sustained, selective, divided) and processes (alerting, endogenous and exogenous orienting, reorienting), as well as visuospatial bias.

Four databases were searched for studies comparing PD patients with healthy controls. Meta-analytic estimates were derived using Hedges' g within random-effects models, and studies that could not be quantitatively integrated were summarized narratively. In addition, studies directly comparing patients with left- and right-predominant motor symptoms (LPD vs. RPD) were reviewed qualitatively.

Across 51 studies, PD patients exhibited deficits in sustained, selective, and divided attention. Among attentional processes, only exogenous orienting was impaired, whereas alerting, endogenous orienting, and reorienting were preserved. Findings from the few studies examining visuospatial bias indicated small, context-dependent shifts in spatial attention rather than a consistent directional bias.

These findings indicate that PD patients show visual-attentional impairments, particularly under high-demand conditions, while basic alertness and voluntary orienting appear preserved. Exogenous orienting deficits and subtle rightward spatial tendencies in LPD suggest disruption of right-hemisphere attentional networks. These results have implications for early cognitive assessment, rehabilitation strategies, and understanding the neural bases of attentional dysfunction in PD.

1. Introduction

The World Health Organization estimated that, as of 2019, over 8.5 million individuals worldwide were affected by Parkinson's disease (PD), a number that is expected to rise due to population aging and growth, along with the limited progress in developing therapies and our understanding of the disease. PD is a neurodegenerative disorder characterized by progressive loss of dopaminergic neurons in the substantia nigra, and consequently in the basal ganglia, disrupting information flow through the cortico-striatal-thalamic-cortical loops that mediate both motor and cognitive functioning (Papagno and Trojano, 2018; Przedborski, 2017). Although dopamine is best known for its role in motor control, it also modulates cognitive processes (Nieoullon, 2002). In fact, while motor symptoms are PD most prominent feature playing a central role in the diagnosis, non-motor and cognitive effects of PD are also significant and warrant attention (Papagno and Trojano, 2018; Trojano and Papagno, 2018).

Even in the earliest stages of the disease, PD patients exhibit subtle cognitive problems, which mainly include executive functioning - a set of cognitive processes responsible for regulating goal-directed behavior (Dirnberger and Jahanshahi, 2013; Kudlicka et al., 2011). This complex cognitive domain has been defined and categorized in various ways, and

* Correspondence to: Center for Neurocognitive Rehabilitation, CIMeC, University of Trento, via Matteo del Ben 5/B, 38068, Rovereto (Trento), Italy.
E-mail address: selene.schintu@unitn.it (S. Schintu).

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its impairment is widely attributed to dopamine-dependent frontostriatal dysfunction. However, while executive functions core components have been clearly stated and updated over the years, allocation of attention has always been implicitly embedded (Anderson et al., 2014; Lezak, 1995; Norman and Shallice, 1986). This suggests that attentional control is a fundamental yet often underacknowledged component of executive functioning, particularly considering that attention relies on the frontoparietal attentional network (Corbetta and Shulman, 2002; Petersen and Posner, 2012), which includes the prefrontal cortex, central to executive regulation, and is therefore influenced by frontostriatal pathways that are altered in PD (Xu et al., 2016).

Evidence of attentional deficits in PD is contradictory and somewhat difficult to interpret. This is not surprising given the complexity of PD pathophysiology (Przedborski, 2017) and the fact that there is still no clear consensus on what *"attention"* actually entails. Despite decades of research, beginning with William James et al. (1890), the definition and mechanisms of attention remain actively debated among researchers (Hommel et al., 2019; Krauzlis et al., 2023; Wu, 2024). Attention can be operatively defined as the process that allows the selection of relevant information among distractors to reach awareness, and thus further processing (Desimone and Duncan, 1995). However, attention is not simply a separate cognitive domain but rather a core regulatory system that enables other cognitive functions to operate efficiently and coherently (Chun et al., 2011; Petersen and Posner, 2012). It is indeed crucial for allocating cognitive resources; for example, when referring to executive functions, the ability to plan, sequence actions, and maintain goal-directed behavior depends on sustained and selective attention. Without it, higher-order processes like working memory, reasoning, and goal management would break down due to information overload, disorganization, or distraction. Furthermore, attention is crucial for most of the neuro-rehabilitative strategies, aimed at slowing down cognitive decline and preserving residual abilities. Attentional deficits may have important consequences for everyday functioning, affecting activities that require continuous monitoring of information, rapid adaptation to environmental changes, and efficient allocation of cognitive resources (Chun et al., 2011; Petersen and Posner, 2012). Moreover, attentional dysfunction may interact with non-motor symptoms commonly observed in PD, including hallucinations, apathy, and fatigue, further impacting patients' quality of life (Pauletti et al., 2017; Shine et al., 2013). Therefore, knowing whether attention is impaired in early stages of PD is of critical importance from a clinical but also fundamental point of view. The present review and meta-analysis aimed to answer this crucial question.

When reviewing the literature on attention and PD, one is immediately struck by the large number of studies claiming to investigate attentional functions. However, a closer look reveals that many of these studies focus on other cognitive processes that merely involve or require attention, rather than on attentional performance itself. Moreover, many of the neuropsychological measures commonly used in clinical research are inherently multidimensional and engage additional processes such as processing speed, visual scanning, executive functioning, and motor performance. Consequently, attention is often not assessed in a process-pure manner, making it challenging to isolate its specific mechanisms and compare findings across studies. Additionally, the distinct domains and processes that compose the attentional domain, along with the wide variety of tasks used across studies, further complicate efforts to draw consistent or conclusive insights. To assess whether attention is impaired in idiopathic PD, we thus limited our investigation to visual attention, which is the most frequently studied, and classified the literature based on the types of tasks used and the corresponding attentional domains or processes assessed. To this end, we selected and organized studies that quantitatively assessed either one of the four canonical attentional domains commonly used in neuropsychological practice - sustained, selective, divided attention, and spatial bias (van Zomeren and Brouwer, 1994) or specific attentional processes such as alerting, orienting, and reorienting, all relying on the frontoparietal network (Petersen and Posner, 2012; Posner and Petersen, 1990).

PD motor symptoms typically have an asymmetrical onset, and although those become bilateral as the disease progresses, the onset side often remains more severely affected throughout the illness. Considering the dominant role of the right hemisphere in attention and spatial processing (Heilman and Abell, 1980; Kinsbourne, 1987; Mesulam, 1981; Sheremata and Silver, 2015; Thiebaut de Schotten et al., 2011), it is reasonable to expect that visuospatial attentional differences may be associated with the laterality of motor symptoms. Individuals whose motor symptoms begin (or are most severe) on the left side of the body (LPD), and therefore exhibit greater dopaminergic disruption in the right hemisphere, have displayed poor spatial performance on the clock drawing test (Seichepine et al., 2015), neglect-like behavior in cancellation tasks (Villardita et al., 1983), but also worse sustained attention as compared to those PD patients whose motor symptoms are worst on the right side of the body (RPD) (DeGutis et al., 2023). LPD individuals have been found to estimate the midpoint of a horizontal line as shifted to the right of the actual center (Albert et al., 2025; Lee et al., 2001) or to place the midpoint further to the right (i.e., neglect-like behavior) than both RPD and healthy controls (Laudate et al., 2013). However, not all findings support the presence of neglect-like spatial biases in LPD, as some studies reported no evidence of a rightward bias in such population (Salazar et al., 2019). Given these conflicting results we decided to include a dedicated section comparing LPD and RPD.

To summarize, this systematic review and meta-analysis investigated the possible presence of visuospatial attentional deficits in right-handed idiopathic PD without cognitive impairment, organizing and analyzing findings from the literature according to attentional domains or processes in order to identify possible attentional deficits in PD.

2. Methods

2.1. Protocol

This manuscript adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The protocol for the systematic review and meta-analysis was registered with PROSPERO (Registration ID: CRD42025644271).

2.2. Literature search and study selection

A comprehensive literature search was conducted by SS and MB on November 22, 2024, across four electronic databases: PubMed, Web of Science (via Clarivate), SCOPUS, and EMBASE. Additionally, reference lists of identified studies, systematic reviews, and meta-analyses on the same topic were manually screened for further eligible studies. No publication date restrictions were applied, and only studies published in English were included. The detailed search strategy is presented in the supplementary materials Doc S1 Search Strategy.

2.2.1. Database Search

The specific search terms used in each database were as follows:

(i) PubMed: Parkinson AND (visual attention OR spatial attention OR attention deficit OR attention bias OR attention orienting).
(ii) Web of Science (via Clarivate): (TS = (Parkinson)) AND TS = (visual attention OR spatial attention OR attention deficit OR attention bias OR attention orienting); filters applied: Limited to articles published in English.
(iii) SCOPUS: (ALL (Parkinson) AND ALL (visual AND attention OR spatial AND attention OR attention AND deficit OR attention AND bias OR attention AND orienting)); filters applied: Limited to articles published in English.
(iv) EMBASE: Parkinson AND ('visual attention'/exp OR 'visual attention' OR (visual AND ('attention'/exp OR attention)) OR 'spatial attention'/exp OR 'spatial attention' OR (spatial AND

('attention'/exp OR attention)) OR 'attention deficit'/exp OR 'attention deficit' OR (('attention'/exp OR attention) AND deficit) OR 'attention bias'/exp OR 'attention bias' OR (('attention'/exp OR attention) AND ('bias'/exp OR bias)) OR 'attention orienting' OR (('attention'/exp OR attention) AND orienting)); filters applied: Limited to articles published in English, with an age restriction set for studies including participants aged ≥ 45 years.

2.2.2. Study selection process

The RAYYAN software system (Ouzzani et al., 2016) was used for study management and data collation. Initially, MB and SS independently conducted a preliminary search, screening titles and abstracts for eligibility. Any discrepancies were resolved by discussion. In the second stage, ANH and ML screened the full text of all studies that met the inclusion criteria. Any discrepancies were discussed and resolved collaboratively between reviewers.

Inclusion / Exclusion Criteria.

Studies were considered eligible if they met the following criteria:

- Participants diagnosed with idiopathic PD
- A minimum sample size of five PD participants
- Case-controlled studies where participants performed a visual attention task
- Peer-reviewed journal publications

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Studies were excluded if they met any of the following criteria:

- Participants younger than 45 years old
- Review articles or meta-analyses
- Lack of a proper control group or normative reference
- Presence of cognitive impairment, as reported in the study
- Severe motor symptoms, defined by Hoehn and Yahr (H&Y) stage > 3 or motor UPDRS score > 54.7
- Studies focusing on non-visual attention modalities (e.g., auditory or tactile attention)
- Inclusion of left-handed PD participants only /absence of a distinct group of right-handed PD participants
- Participants with deep-brain stimulation (DBS)
- Presence of neurological conditions other than PD
- Unpublished Ph.D. theses
- Studies with non-extractable or inaccessible data, including those published more than five years prior, where authors did not respond to two follow-up contact attempts.

The age and disease-severity criteria were selected to reduce clinical heterogeneity and to focus on typical idiopathic PD. Restricting inclusion to participants older than 45 years minimized the influence of atypical or early-onset forms of PD, while limiting disease severity to H&Y ≤ 3 reduced the potential confounding effects of advanced motor disability on attentional performance.

2.3. Data extraction

For each study included in the analysis, four independent reviewers (SS, MB, ANH, and ML) extracted data using a standardized form. The coded information primarily encompassed details necessary to calculate effect sizes, their variances, and potential moderators for meta-regression analyses. When data extraction was not possible, missing information was requested from the corresponding author through two emails sent two weeks apart. When means and standard deviations (SDs) were unavailable, they were estimated from figures using WebPlotDigitizer, v 5.2 (Rohatgi). If only standard errors (SEs) were reported, they were converted to SDs using the formula $SD = SE \times \sqrt{n}$, where n represented the sample size. If a paper reported multiple attention tasks, each task was considered separately based on the specific attentional domain or process being assessed and included accordingly if it fell into one of the predefined categories.

When multiple tasks assessed the same attentional domain within a study, only one measure was selected for quantitative synthesis to ensure independence of observations. Preference was given to the measure most commonly used (i.e., the task most frequently represented within a given attentional domain across the included studies) and/or the measure providing the most direct assessment of the attentional domain under investigation (i.e., the task considered to best capture the attentional construct of interest). Specifically, the following data were extracted: 1) Participant recruitment methods; 2) Study location; 3) Handedness; 4) Lateralization of symptoms; 5) UPDRS motor and cognitive scale values and/or Hoehn and Yahr stage; 6) Age; 7) Education level; 8) Sample size for each group; 9) Gender; 10) PD medication status (on or off); 11) Disease duration; 12) Medication type and dosage (e.g.; L-dopa, LEDD); 13) Deep brain stimulation (DBS) status; 14) Cognitive assessments and corresponding scores; 15) Attention task details; 16) Type of attention assessed; 17) The aim of the original study; and 18) Statistical information (including means, standard deviations, and effect direction for the PD group).

2.4. Quality assessment

To assess the quality of the included papers, an adaptation of the Effective Public Health Practice Project (EPHPP) "Quality Assessment Tool for Quantitative Studies" was used (Armijo-Olivo et al., 2012; Thomas et al., 2004). Papers were evaluated at the study level, with authors ANH and ML independently assessing their quality. Any discrepancies were resolved through discussion. The following criteria were assessed: 1) Selection bias of the participants; 2) Study design; 3) Confounders; 4) Data Collection methods; 5) Withdrawals and drop-outs.

2.5. Data synthesis and analysis

For each attention type, meta-analyses were conducted when at least three studies with extractable data were available. Studies that fulfilled the inclusion criteria but did not provide extractable data were synthesized narratively, so that in some cases both a meta-analysis and a narrative synthesis were presented for the same attention type. The primary outcome measure in the meta-analysis was the standardized mean difference (SMD) in visual attention performance between individuals with idiopathic PD and healthy controls. Analyses were conducted based on the type of visual attention assessed or the hypothesized underlying mechanism. These were categorized into two main groups: (i) attention type, which included sustained, selective, divided, and spatial bias, and (ii) attention mechanism, which included alerting, orienting, and reorienting. The specific types of visual attention analyzed were determined after a comprehensive review of the included studies.

As a secondary outcome, a review was conducted to examine differences in visual attention performance based on the laterality of motor symptoms, thus comparing patients with greater motor impairment on the left versus the right side of the body (i.e., LPD versus RPD).

2.6. Effect size calculation and heterogeneity assessment

Effect sizes were calculated as SMDs for continuous variables using a random effects model. Given the small sample sizes in most studies, Hedges' g was preferred to Cohen's d. Hedges' g was defined as the mean difference in performance on the visual attention task between individuals with PD and healthy controls, divided by the pooled standard deviation. Heterogeneity was assessed using the I^2 statistic, with values ≤ 50% indicating low to moderate heterogeneity and values > 50% indicating moderate to high heterogeneity (Duval and Tweedie, 2000; Higgins and Thompson, 2002).

2.7. Assessment of publication bias

Publication bias was assessed using a funnel plot. To further adjust for potential publication bias, we applied Duval and Tweedie's trim and fill method (Duval and Tweedie, 2000) along with the rank correlation test for funnel plot asymmetry, Egger's test, and the Classic Fail-Safe N (Borenstein, 2022).

2.8. Software and analytical tools

SMDs, sample variances, and summary analyses, including figures and graphs, were generated using Comprehensive Meta-Analysis Version 4 (Borenstein, 2022).

3. Results

3.1. Study selection

The literature search identified 6862 records across four major databases: PubMed (n = 2006), Scopus (n = 2333), Web of Science (n = 1617), and Embase (n = 906). An additional two studies were located through manual reference list screening. Following automated and manual duplicate removal (n = 1635), a total of 5229 unique records were screened by title and abstract. Of these, 4757 were excluded for not meeting the inclusion criteria, leaving 472 full-text reports to be assessed for eligibility. Three of these reports could not be retrieved, either because the full text was not accessible online or because authors did not respond to repeated contact attempts, resulting in 469 articles being fully reviewed. After full-text screening, 418 articles were excluded. The most common reasons were: non-idiopathic or unclear PD diagnosis (n = 15), advanced disease severity (n = 72), absence of at least one attentional measure (n = 50), general cognitive impairment (n = 39), left-handers only (n = 12), use of deep brain stimulation (n = 8), small sample size (n = 3), irrelevant outcomes (n = 170), lack of a proper control group or normative reference (n = 44), and data that could not be extracted (n = 5).

A total of 51 studies met the inclusion criteria for meta-analysis and systematic review. Of these, 46 were suitable for meta-analysis, while 5 were included in the review only because no extractable data were available. The full screening and selection process, including detailed exclusion criteria, is summarized in the PRISMA flowchart (Fig. 1).

3.2. Participant characteristics

Overall, the 51 included studies comprised data from 1650 PD and 1544 healthy controls. In accordance with this review inclusion criteria, all studies recruited right-handed individuals with a confirmed diagnosis of idiopathic PD and no cognitive decline. The diagnostic criteria

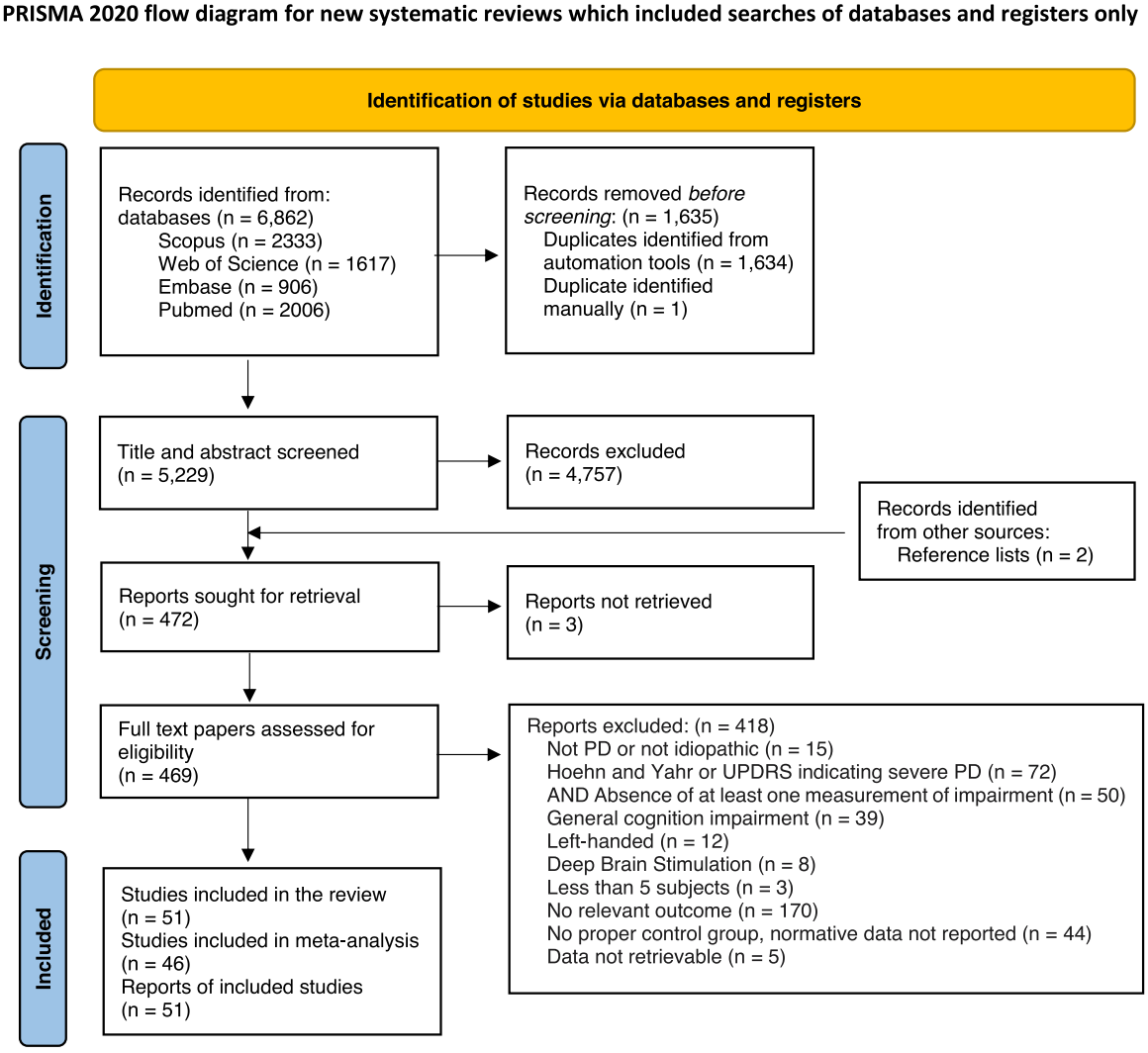

Fig. 1. PRISMA flowchart of study selection. Identification, screening, eligibility, and inclusion of studies following PRISMA 2020.

were consistent across studies, with most employing the UK PD Society Brain Bank guidelines or neurologist-confirmed clinical criteria.

Sample sizes within PD groups ranged from 10 (Mari et al., 1997; Lee et al., 2002) to 111 participants per study (Dana et al., 2021), reflecting variability in cohort scale across publications. Gender distribution was generally reported, and male participants were the majority in most samples, typically representing 55–75% of the PD group. The average years of formal education ranged from 5.73 to 20.21 years in PD groups and from 5.98 to 20.14 in healthy control groups.

All studies included matched healthy control groups, as required by the inclusion criteria. Matching was based on age and sex. However, inconsistent reporting of control group education and cognitive scores limited detailed comparative profiling in some studies.

Motor symptom severity was consistently reported across studies using the motor subscale of the UPDRS, with values ranging from 7.60 to 37.50, indicative of mild to moderate motor impairment. In contrast, non-motor subscales—particularly the UPDRS cognitive component—were often omitted. Similarly, non-motor symptoms potentially affecting attention, such as depression, apathy, hallucinations, and fatigue, were inconsistently reported across studies and therefore could not be examined as moderators.

Disease duration was reported in 44 of the 51 studies, with estimates ranging from 15.4 months (just over one year) to 166.8 months (nearly 14 years). This range reflects a clinically relevant spectrum of disease chronicity, encompassing early- to mid-stage PD.

Levodopa equivalent daily dose (LEDD) values, when reported (32 of the 51 studies), ranged from 147.06 mg/day (Peraza et al., 2017) to more than 1126 mg/day (Gérard et al., 2022), reflecting heterogeneity in dopaminergic treatment regimens. In most cases, participants were assessed during their regular "ON" medication state, which likely reduced variability due to transient motor and cognitive fluctuations associated with dopaminergic cycling.

A minority of the included studies (seven) stratified participants by motor symptom laterality, distinguishing between left-onset (LPD) and right-onset (RPD) subgroups. These studies often focused on the impact of asymmetric nigrostriatal degeneration on lateralized attentional processes, particularly in visuospatial orienting and executive control, reflecting the influence of hemispheric specialization in Parkinson's disease.

All participant characteristics are detailed in Table 1.

3.3. Attentional domains

3.3.1. Sustained attention

3.3.1.1. Meta-analysis. The sustained attention meta-analysis included seven studies employing simple or choice reaction-time paradigms (Badenes et al., 2018; Ferrazzoli et al., 2017; Golińska et al., 2021; Norton et al., 2016; Peraza et al., 2017; Tommasi et al., 2015; Uc et al., 2005) and dynamic tracking tasks such as Multiple Object Tracking (Norton et al., 2016), in which participants continuously track several targets as they move among distractors.

The analysis yielded a statistically significant effect size (Hedges' $g = -0.419$, 95% CI [−0.704 to −0.133], $p = 0.004$), indicating reduced sustained attention in people with PD relative to healthy controls. Moderate between-study heterogeneity was observed ($I^2 = 59\%$), pointing to variability across study methodologies. Full results are reported in Table 2 and Supplementary Table S1, and the forest plot is shown in Fig. 2 (with the funnel plot in Supplementary Figure S1).

3.3.1.2. Review. Two papers, even though they met all the inclusion criteria, did not report data that could be extracted for the meta-analysis (Bledsoe et al., 2018; Riekkinen et al., 1998). Riekkinen et al. (1998) reported that mild to moderate, non-demented PD patients performed with comparable accuracy to controls on sustained attention tasks, with deficits limited to slowed responses under dopaminergic withdrawal and accuracy impairments emerging only when noradrenergic activity was reduced under high attentional load, which exceeds the sustained attention domain. Bledsoe et al. (2018) found no differences in sustained attention between cognitively unimpaired PD and controls.

3.3.2. Selective attention

Selective attention was assessed in nine studies using various visual discrimination tasks (Berry, 1999; Buhmann et al., 2015; Ferrazzoli et al., 2017; Filoteo and Maddox, 1999; Filoteo et al., 1997; Golińska et al., 2021; Hirsch and Röhrle, 2011; Rodríguez-Ferreiro et al., 2010; Tommasi et al., 2015).

The most commonly employed measure, used in five studies, was the visual search task (VST), which requires detecting a target item among distractors (Wolfe, 1994). Three studies used multiple-choice reaction time tasks, in which participants made rapid responses by selecting one alternative among several options. Finally, one study (Filoteo and Maddox, 1999) employed an experimental selective-attention paradigm that required participants to attend to one stimulus dimension while ignoring another, irrelevant one.

Meta-analytic results revealed a statistically significant difference, with PD participants typically showing lower performance than controls (Hedges' $g = -0.575$, 95% CI [−0.857, −0.292], $p < 0.001$). While the effect size was considerable, the presence of heterogeneity ($I^2 = 56\%$) suggests that methodological and sample-related differences across studies may have influenced the findings. A visual representation of the effect sizes for selective attention is available in the forest plot in Fig. 3 (and the funnel plot in Supplementary Figure S2).

We found no additional studies on selective attention that met the inclusion criteria but lacked extractable data for the meta-analysis. Therefore, all eligible studies provided the necessary data, and a separate review section on selective attention was not required.

3.3.3. Divided attention

Divided attention, examined in 20 studies, was most commonly assessed using the Trail Making Test part B (TMT-B) (Badenes et al., 2018; Broeders et al., 2013; Crescentini et al., 2012; Dana et al., 2021; Elgh et al., 2009; Guner et al., 2017; Liu et al., 2020; Liu et al., 2024; Miller et al., 2013; Pal et al., 2018; Petrova et al., 2012; Reekes et al., 2020; Salazar et al., 2019; Scally et al., 2011; Segura et al., 2014; Yang et al., 2018; Yang et al., 2021; Çakmaklı et al., 2020; Gardoni et al., 2023), except for one study employing a closely related task (color trails test; D'Elia et al., 1996), and another one (Uc et al., 2005) using an experimental dual-target task in which targets were presented at both central and peripheral locations.

The meta-analysis revealed a relatively large and statistically significant impairment in divided attention among participants with PD compared to healthy controls (Hedges' $g = -0.815$, 95% CI [−1.077, −0.554], $p < 0.001$). The observed heterogeneity was considerable ($I^2 = 85\%$), suggesting notable variation in task paradigms and sample characteristics across studies. The forest plot corresponding to divided attention outcomes is presented in Fig. 4 (and the funnel plot in Supplementary Figure S3).

3.3.3.1. Review. Two additional studies investigated divided attention in PD but could not be included in the quantitative synthesis because extractable data were not available (Bledsoe et al., 2018; Delgado-Alvarado et al., 2023). However, their findings add nuance to the meta-analytic results. Both studies included the TMT-B within their neuropsychological batteries and reported that patients with mild to moderate PD and preserved global cognition performed at the level of healthy controls, suggesting that divided attention is maintained in the absence of cognitive impairment. In Bledsoe et al. (2018) TMT-B deficits emerged only in patients with MCI or dementia. Similarly, Delgado-Alvarado et al. (2023) observed intact TMT-B performance in

Table 1
Summary of participant demographics, clinical measures, and cognitive assessments in PD and control group.

Authors	Attention Domain	Task	H&Y Score	UPDRS Motor Sub-score	N PD	N Control	Age PD	Age Control	Education PD	Education Control	Sex PD N Male	Sex Control N Male	PD Disease Duration months	L-Dopa (mg) [LEDD]	Cognitive Assessment	Cognitive Assessment PD Score	Cognitive Assessment Control Score
Badenes et al., 2018	A. Sustained B. Divided	A. Attention/ Monotony Resistance RTs B. TMT-B	[1–2.5]	13.7 (8.1)	37	33	63.2 (9.8)	64.0 (9.7)	8.2 (4.9)	10.4 (3.9)	31	22	NS	[449.3 (300.9)]	MMSE	28.3 (1.8)	28.8 (1.8)
Bennett & Castiello, 1996	Reorienting	Posner_like Validity	1.25 (0.43)	NS	16	16	50.25 (3.38)	49.5 (2.76)	NS	NS	8	8	39.72 (10.08)	NS	MMSE	29.13 (1.08)	29.56 (0.73)
Bennett et al., 1995	A. Orienting B. Reorienting	A. Posner_Benefit B. Posner_Cost	1.25 (0.43)	NS	32	32	49.9 (2.85)	50.9 (3.02)	NS	NS	18	18	27.72 (9.6)	NS	MMSE	26	29.3 (4.0)
Berry, 1999	Selective	Exp. Visual Search_Conjunction	NS	15 (8)	13	10	60 (8.7)	62.6 (5.02)	NS	NS	10	2	50.4 (16.8)	NS	NART	109.5 (9)	113.4 (9)
Bledsoe et al., 2018	Divided	TMT-B	[2-3]	26.5 (8.7)	23	24	72.9 (5.8)	71.8 (6.1)	16.2 (2.4)	16.4 (2.7)	21	14	116.4 (52.8)	757.2 (441.2)	MMSE	29.0 (1.1)	29.3 (0.9)
Broeders et al., 2013	Divided	TMT-B	1.7 (0.7)	16.0 (7.4)	59	40	62.5 (9.5)	61.4 (6.8)	11.6 (2.4)	12.6 (2.0)	32	22	17.5 (7.4)	153.9 (144.3)	MMSE	27.9 (1.8)	28.9 (1.1)
Buhmann et al., 2015	Selective	Visual Search_Target Present_Conjunction	1.9 (0.5)	16.9 (9.6)	22	22	60.6 (9.1)	55.2 (14.5)	NS	NS	12	13	67.9 (48.1)	< 500	MMSE	29.4 (0.7)	> 28
Çakmaklı et al., 2020	Divided	TMT-B	[1-2]	NS	25	18	53.4 (9.0)	46.3 (14.0)	9.0 (4.5)	15.0 (1.27)	15	5	66.2 (62.0)	NS	MMSE	26.1 (3.5)	28.3 (1.69)
Crescentini et al., 2012	Divided	TMT-B	[1–2.5]	22.9 (10.1)	16	16	63.6 (5.9)	61.6 (4)	9.7 (4.3)	11.2 (4.1)	8	6	72 (42)	386.4 (277.6)	MMSE	28.8 (1.4)	29.3 (0.6)
Dana et al., 2021	Divided	TMT-B	2.1 (0.8)	13.3 (6.3)	111	149	49.41 (6.33)	50.62 (6.07)	NS	NS	52	73	51.6 (14.4)	[321.76 (109.23)]	MMSE	25.2 (4.7)	25.1 (1.7)
Delgado-Alvarado et al., 2023	Divided	TMT-B	2.05 (2.6)	18.63 (8.5)	19	21	66.58 (7)	68.65 (3.9)	14	13	16	11	81	[947.77 (433.33)]	MMSE	29.053 (1.129)	29.3 (0.865)
Drago et al., 2008	Spatial Bias	Line Bisection Top-Down condition	NS	32 (9.08)	18	10	72.7 (10.1)	69.6 (14.8)	NS	NS	18	2	NS	NS	MMSE	> 28.00	> 28.00
Elgh et al., 2009	Divided	TMT-B	NS	23.8 (9.7)	88	30	68.1 (9.3)	68.2 (6.6)	9.9 (4.1)	11.5 (3.5)	49	16	22.71 (22.44)	NS	MMSE	28.7 (1.4)	29.1 (0.8)
Ferrazzoli, D., et al., 2017	A. Sustained B. Selective	A. Exp. Simple RT Task B. Exp. Multiple Choices RT Task	2.6 (0.5)	18.6 (4.9)	103	34	66.2 (9.2)	65.4 (7.1)	10.5 (4.3)	10.4 (4.3)	57	18	123.6 (61.2)	[661.8 (328.4)]	MMSE	27.3 (1.9)	28.7 (1.3)
Filoteo & Maddox, 1999	Selective	Exp. Selective Attention Task	2.14 (0.55) [1–3]	NS	22	22	66.0 (8.67)	68.59 (7.19)	14.13 (3.52)	14.23 (3.26)	13	10	71	NS	DRS	133.73 (6.85)	135.64 (4.52)
Filoteo et al., 1997	Selective	Exp. VSAT Conjunction_RT	2.25 (0.54)	NS	20	20	65.55 (7.11)	68.85 (6.55)	15.15 (3.54)	14.15 (2.79)	15	11	87	NS	DRS	134.10 (5.97)	136.25 (4.69)
Gardoni et al., 2023	Divided	TMT-B	[2-3]	33.71 (11.74)	21	23	64.76 (7.81)	63.75 (8.69)	11.90 (4.22)	12.14 (3.80)	14	10	93.72 (45.12)	[664.90 (409.71)]	Movement Disorder Task Force	28.3 (1.6)	29.2 (0.9)
Gèrard et al., 2022	A. Alerting B. Orienting	A. ANT_Alerting B. ANT_Orienting	2	18	14	18	61 (9)	60 (7)	NS	NS	7	10	108 (48)	[1126 (333)]	MoCA	27	28
Golinska et al., 2021	A. Sustained B. Selective	A. ROBBIA_Simple RT B. ROBBIA_Choice RT	[1-2]	NS	13	13	62.62 (5.94)	65.54 (7.37)	NS	NS	5	6	NS	[1019.62 (795.82)]	MMSE	28.38 (1.71)	28.77 (1.68)
Guner et al., 2017	Divided	TMT-B	1.52 (0.77)	7.60 (5.90)	45	39	66.58 (7.11)	65.90 (7.42)	5.73 (1.83)	6.08 (2.12)	24	20	21.72 (24)	[386.64 (132.47)]	MMSE	28.07 (1.39)	28.57 (1.00)

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Table 1 (*continued*)

Authors	Attention Domain	Task	H&Y Score	UPDRS Motor Sub-score	N PD	N Control	Age PD	Age Control	Education PD	Education Control	Sex PD N Male	Sex Control N Male	PD Disease Duration months	L-Dopa (mg) [LEDD]	Cognitive Assessment	Cognitive Assessment PD Score	Cognitive Assessment Control Score
Hirsch and Röhrle, 2011	Selective	TAP_Visual Search_Target Present_Feature	[1-3]	NS	54	54	57.59 (7.25)	57.69 (7.68)	NS	NS	34	34	90.6 (70.2)	304.63 (186.33)	Test for the early diagnosis of dementia	43.13 (3.42)	45.28 (2.44)
Hsieh et al., 1996	A. Orienting B. Reorienting	A. Posner-like_Benefit B. Posner-like_Cost	2 (0.39)	NS	13	13	63.5 (8.0)	64.9 (6.6)	6.7 (3.9)	8.8 (3.3)	7	4	NS	NS	CASI	> 75	> 75
Keri et al., 2013	A. Alerting B. Orienting	A. ANT_Alerting B. ANT_Orienting	1.60 (0.34)	25.1 (5.0)	26	25	49.2 (7.4)	48.6 (6.5)	14.1 (6.6)	13.9 (7.4)	17	18	15.4 (7.4)	[250]	WAIS-R	104.6 (11.0)	105.4 (10.1)
Liu et al., 2020	Divided	TMT-B	2	19.32 (7.93)	42	43	63.45 (8.15)	61.40 (8.24)	10.74 (2.60)	10.58 (2.74)	26	27	24	NS	MMSE	29	29
Liu et al., 2024	Divided	TMT-B	1.75 [1-2]	19.32 (7.93)	52	45	64.45 (8.15)	63.40 (8.17)	10.17 (2.49)	9.18 (2.14)	26	18	24 [11-60]	NS	MMSE	28.5 [27–29]	29 [28–29]
Mari et al., 1997	A. Orienting B. Reorienting	A. Posner_Benefit B. Posner_Cost	1.5 (0.5)	NS	10	10	59.4 (5.4)	57.0 (3.8)	NS	NS	4	4	26.4 (8.9)	NS	MMSE	29.1 (1.1)	29.9 (0.3)
Miller et al., 2013	A. Divided B. Visuospatial Bias	A. TMT-B B. Line Bisection	[1-3]	20.1 (9.1)	42	28	64.8 (7.7)	63.9 (8.6)	17.3 (2.1)	17.3 (1.8)	21	14	80.4 (49.2)	[356.5 (246.0)]	Modified MMSE	NS	NS
Norton et al., 2016	Sustained	Exp. Multiple Object Tracking	1.9 (0.6)	17.57 (7.3)	26	21	63.5 (6.4)	67.4 (7.6)	17.1 (1.8)	17.3 (1.8)	11	6	NS	[465.6 (286)]	MMSE	> 27	> 27
Pal et al., 2018	Divided	TMT-B	[1-3]	NS	65	26	58.87 (8.0)	55.96 (8.60)	14.38 (3.75)	14.15 (2.33)	44	15	72.18 (41.75)	NS	MMSE	28.09 (1.50)	29.35 (0.99)
Pauletti et al., 2017	A. Alerting B. Orienting	A. ANT_Alerting B. ANT_Orienting	[1-3]	15.9 (5.1)	17	37	70 (9.4)	69.5 (7.7)	10.8 (4.5)	11.6 (4.1)	11	24	63.6 (50.4)	[291.6 (188.7)]	MMSE	26.9 (1.1)	29.5 (0.9)
Peraza et al., 2017	Sustained	CDR_DV_Accuracy	NS	24.59 (10.39)	62	30	62.77 (10.83)	64.05 (7.92)	14.32 (3.9)	14.13 (3.65)	37	17	6.43 (4.76)	[147.06 (112.0)]	MMSE	29.01 (0.93)	29.36 (0.88)
Petrova et al., 2012	Divided	TMT-B	2.6 (0.4)	30.5 (12.0)	36	26	69.8 (7.9)	68.7 (5.9)	11.8 (3.1)	13.2 (2.4)	NS	NS	98	NS	MMSE	26.4 (1.4)	28.5 (1.0)
Plomhause et al., 2014	A. Orienting B. Reorienting	A. Posner_Benefit B. Posner_Cost	NS	19.8 (6.5)	15	20	61.4 (7.5)	64.8 (7.6)	10.5 (1.7)	11.4 (3.4)	11	15	49.2 (38.4)	[633.0 (342.3)]	MMSE	28.1 (1.4)	28.6 (1.4)
Pollux & Robertson, 2001	A. Reorienting Endogenous B. Orienting Endogenous C. Reorienting Exogenous D. Orienting Exogenous	A. Posner Endo_COST B. Posner Endo_BENEFIT C. Posner Exo_COST D. Posner Endo_BENEFIT	1.96 (0.71)	NS	13	20	63.3 (9.35)	62.1 (7.86)	NS	NS	6	10	115.32 (111.48)	NS	MMSE	30	29
Reekes et al., 2020	Divided	DKEFS TMT_condition 4	{1.88} (0.84)	20.08 (12.80)	46	32	67.34 (6.45)	65.63 (5.84)	15.83 (2.68)	16.53 (3.29)	46	32	NS	[591.05 (484.88)]	MMSE	28.83 (1.25)	28.94 (1.01)
Riekkinen et al., 1998	Sustained	Exp. SCRT (simple RT)	[1-2]	NS	20	27	60 (1.2)	NS	NS	NS	NS	NS	56.4 (12)	535 (49)	MMSE	28 (1.2)	NS
Rodriguez-Ferreiro et al., 2010	Selective	Exp. Visual Search_Target Present_Feature	1.96 (0.68)	NS	50	42	72.92 (8.57)	74.08 (6.91)	7.04 (3.27)	5.98 (3.16)	26	6	114 (52.92)	NS	MMSE	26.94 (2.49)	28.09 (2.06)

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Table 1 (*continued*)

Authors	Attention Domain	Task	H&Y Score	UPDRS Motor Sub-score	N PD	N Control	Age PD	Age Control	Education PD	Education Control	Sex PD N Male	Sex Control N Male	PD Disease Duration months	L-Dopa (mg) [LEDD]	Cognitive Assessment	Cognitive Assessment PD Score	Cognitive Assessment Control Score
Salazar et al., 2019	A. Divided B. Spatial Bias	A. TMT-B B. Landmark Task	2	21.0 (9.8)	79	67	65.0 (6.9)	62.9 (8.7)	17.4 (2.1)	17.1 (2.2)	44	27	75.6 (52.8)	[539.4 (335.6)]	MMSE	> 26.25	> 26.25
Scally et al., 2011	Divided	TMT-B	NS	15.37 (9.86)	19	19	68.74 (6.72)	68.05 (7.20)	14.16 (3.06)	13.63 (4.32)	15	13	78.96 (54.12)	NS	MMSE	29.21 (1.23)	29.37 (1.12)
Segura et al., 2014	Divided	TMT-B	1–3	13.16 (7.67)	43	32	60.77 (10.51)	64.69 (8.63)	12.02 (5.05)	11.00 (4.15)	21	17	74.76 (48.60)	[692.81 (452.801)]	MMSE	29.47 (0.74)	29.69 (0.47)
Tommasi et al., 2015	A. Sustained B. Selective	A. Exp. Simple RT Task B. Exp. Choice RT	NS	37.5 (2.4)	12	12	57.1 (2.3)	56.1 (2.6)	13.6 (1.1)	13.7 (1.0)	7	7	166.8 (28.8)	[804.4 (81.1)]	MDRS	140.8 (0.6)	NS
Uc et al., 2005	A. Sustained B. Divided	A. Exp. Simple RT B. Exp. Divided Attention	2.2 (0.6)	24.1 (8.4)	76	161	67.0 (8.8)	68	13	16	64	78	69.9 (60)	[567 (581)]	MMSE	28.1 (1.8)	NS
Vandenbossche et al., 2012	A. Alerting B. Orienting	A. ANT_Alerting B. ANT_Orienting	[2-3]	33.21 (2.07)	14	14	68.03 (1.37)	66.30 (1.86)	20.21 (0.99)	20.14 (0.48)	11	11	98.52 (10.92)	NS	MMSE	28.79 (0.37)	29.29 (0.30)
Yang et al., 2018	Divided	TMT-B	1.73 (0.8)	24.81 (12.04)	31	100	57.03 (10.19)	58.2 (7.57)	12.70 (3.12)	12.63 (3.24)	15	38	73.92 (76.32)	[472.74 (293.16)]	MMSE	29.13 (1.12)	29.03 (0.69)
Yang et al., 2021	Divided	TMT-B	1.50 (0.65)	15.19 (9.83)	26	22	67.54 (9.30)	64.32 (8.02)	13.12 (3.71)	14.73 (3.28)	14	12	61.8 (7.56)	[530.62 (304.51)]	MoCA	26.19 (2.19)	26.23 (2.27)
Zhou et al., 2012	A. Alerting B. Orienting	A. ANT_Alerting B. ANT_Orienting	[1-3]	NS	44	28	58.1 (10.8)	57.3 (12.7)	9.05 (4.28)	10.2 (4.2)	25	20	29.4 (18.48)	NS	MMSE	28.3 (1.5)	28.8 (1.1)

Note:

Data are presented as means, with standard deviations in parentheses, confidence intervals in square brackets, and medians in curly brackets. For the column L-Dopa (mg) [LEDD], levodopa equivalent daily dose (LEDD) values are reported in square brackets.

Abbreviations: Exp. = experimental task; H&Y = Hoehn and Yahr scale; LEDD = levodopa equivalent daily dose; NA = not applicable; N = number; NS = not specified; UPDRS = Unified Parkinson's Disease Rating Scale.

Cognitive assessments: CASI = Cognitive Abilities Screening Instrument; Clinical Signs Scale = Clinical Signs of Dementia Scale; DRS = Dementia Rating Scale; MDRS = Mattis Dementia Rating Scale; MMSE = Mini-Mental State Examination; MoCA = Montreal Cognitive Assessment; NART = National Adult Reading Test; SMMT = Standardized Mini-Mental Test; WAIS-R = Wechsler Adult Intelligence Scale – Revised.

Tasks: ANT = Attentional Network Test; CANTAB = Cambridge Neuropsychological Test Automated Battery; CDR = Cognitive Drug Research computerized assessment battery; Color Trails Test = Divided attention task; CRT = Choice Reaction Time; DKEFS = Delis-Kaplan Executive Function System; DV = Digit Vigilance; Landmark Task = Spatial bias task; Posner Endo_COST / Endo_BENEFIT / Exo_COST / Exo_BENEFIT = Posner cueing task components, where Endo = endogenous and Exo = exogenous; RT = Reaction Time; RVP = Rapid Visual Information Processing; SCRT = Simple and Choice Reaction Time; ROBBIA = ROtman–Baycrest Battery for Investigating Attention; TAP = Test of Attentional Performance; TAP_Visual Search = Visual Search subtest of TAP; TMT-B = Trail Making Test subtest B; VSAT = Visual Search and Attention Test.

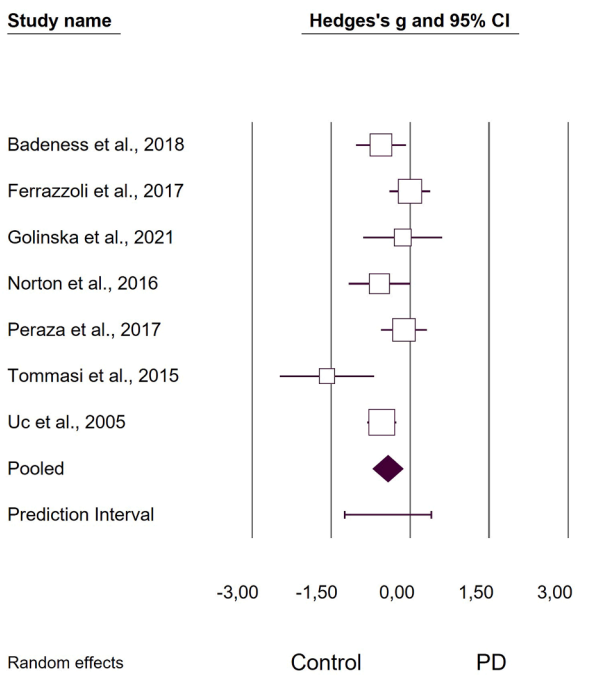

Fig. 2. Forest plot for sustained attention. Pooled standardized mean differences (Hedges' g) comparing PD and controls; negative values indicate poorer performance in PD.

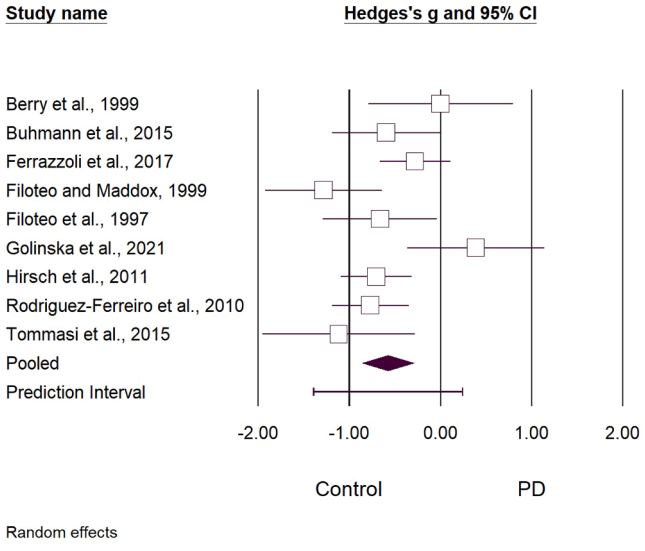

Fig. 3. Forest plot for selective attention. Pooled effect sizes showing reduced selective attention efficiency in PD.

cognitively unimpaired PD patients, whereas PD-MCI patients showed impaired performance.

3.4. Attentional processes

3.4.1. Alerting

Performance related to alerting was evaluated across four studies (Kéri et al., 2013; Pauletti et al., 2017; Vandenbossche et al., 2012; Zhou et al., 2012), all using the Attentional Network Test (ANT; Fan et al., 2002). Results showed no significant difference between individuals with PD and healthy controls (Hedges' g = −0.187, 95% CI [−0.614, 0.240], p = 0.391). The analysis revealed moderate heterogeneity (I^2 = 55.5%), suggesting some variability across studies. These findings

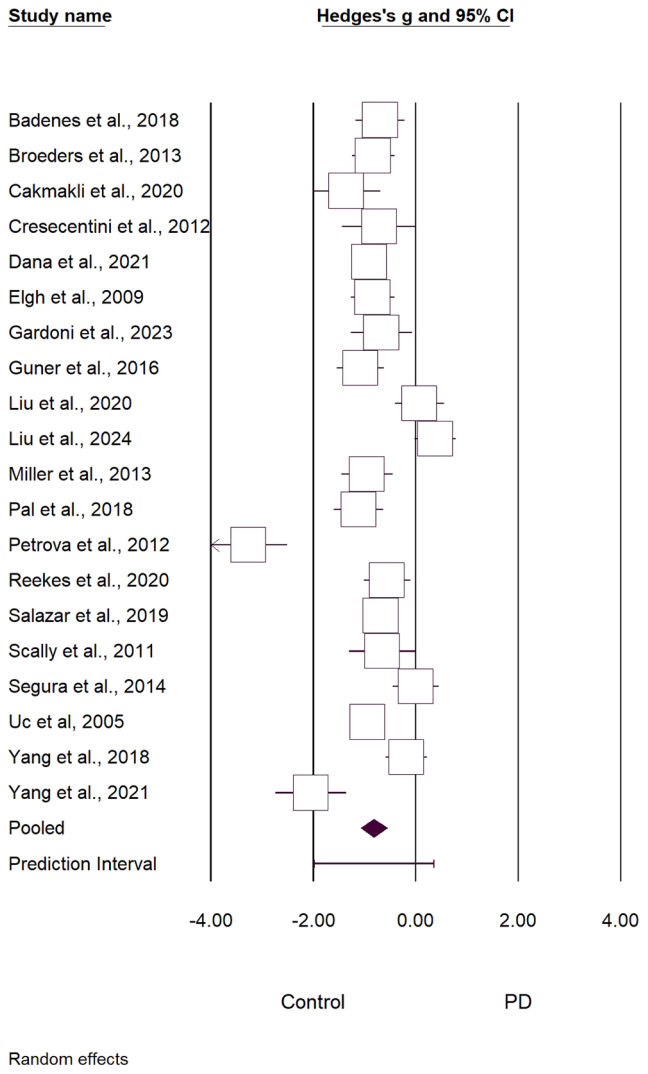

Fig. 4. Forest plot for divided attention. Standardized mean differences (Hedges' g) from divided-attention tasks showing impairment in PD.

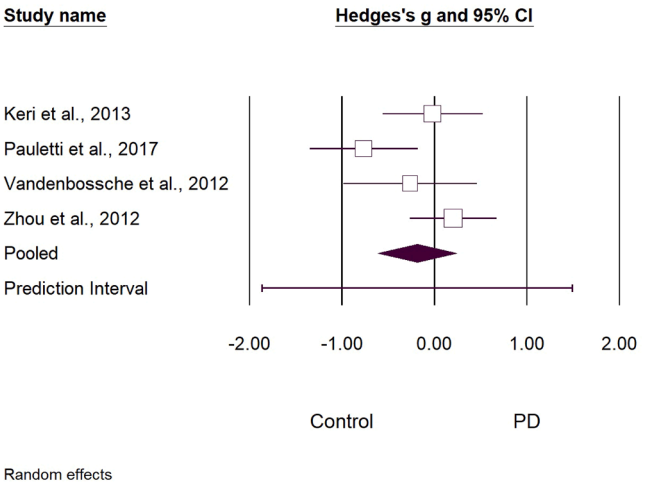

Fig. 5. Forest plot for alerting. Comparison of alerting performance between PD and controls.

indicate that the ability to achieve and maintain a state of readiness is relatively preserved in PD. The forest plot in Fig. 5 (and the funnel plot

in Supplementary Figure S4) illustrates the meta-analytic findings related to alerting performance.

3.4.1.1. Review. Gérard et al. (2022) assessed alerting using the ANT but could not be included in the meta-analysis due to the lack of extractable data. The study found no significant group differences in this attentional component; patients with PD performed similarly to healthy controls.

3.4.2. Orienting

3.4.2.1. Endogenous attention. The influence of endogenous cues on attentional allocation was examined in three studies, employing either the classic Posner cueing task (Bennett et al., 1995; Pollux and Robertson, 2001) or a Posner-like paradigm (Hsieh et al., 1996). The meta-analysis revealed a small, non-significant effect (Hedges' $g = -0.323$, 95% CI [−0.675, 0.028], $p = 0.071$), with no evidence of heterogeneity ($I^2 = 0\%$). These results suggest that, compared with controls, individuals with PD did not show a statistically reliable reduction in their ability to voluntarily orient attention. A graphical summary of the pooled effect sizes is presented in Fig. 6, while the corresponding funnel plot is shown in Supplementary Figure S5.

3.4.2.2. Review. There is little additional evidence beyond the meta-analysis of voluntary orienting changes in PD versus controls. Mari et al. (1997) found that early-stage patients performed similarly to controls, and reduced efficiency only emerged at later PD stages.

3.4.2.3. Exogenous attention. Exogenous orienting, driven by stimulus salience, was measured in five studies using either the ANT (Kéri et al., 2013; Pauletti et al., 2017; Vandenbossche et al., 2012; Zhou et al., 2012) or Posner cueing paradigm (Pollux and Robertson, 2001). Participants with PD demonstrated significantly reduced performance during these tasks compared to healthy controls (Hedges' $g = -0.726$, 95% CI [−1.092, −0.360], $p < 0.001$). Moderate heterogeneity was observed ($I^2 = 44.8\%$), suggesting some variation in the sample composition across studies. Forest plot data depicting exogenous orienting performance across studies are reported in Fig. 7 (and the funnel plot in Supplementary Figure S6).

3.4.2.4. Review. Evidence from two additional studies, which could not be included in the statistical analysis, suggests that stimulus-driven orienting remains intact in cognitively unimpaired PD. Mari et al. (1997) observed preserved cueing across groups, and Plomhause et al. (2014) found no group differences in Posner task performance.

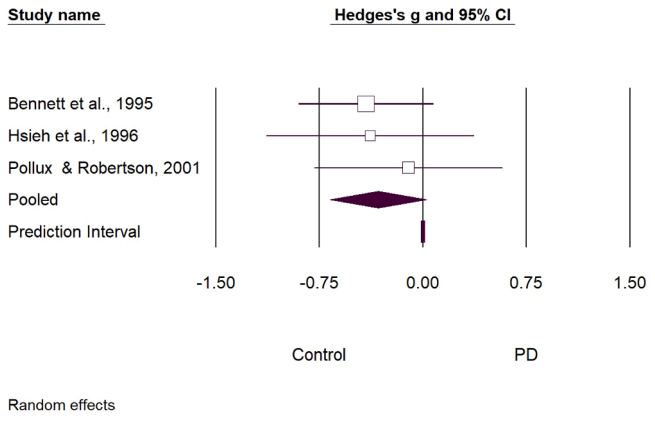

Fig. 6. Forest plot for endogenous orienting. Effect sizes comparing voluntary (goal-directed) orienting between PD and controls.

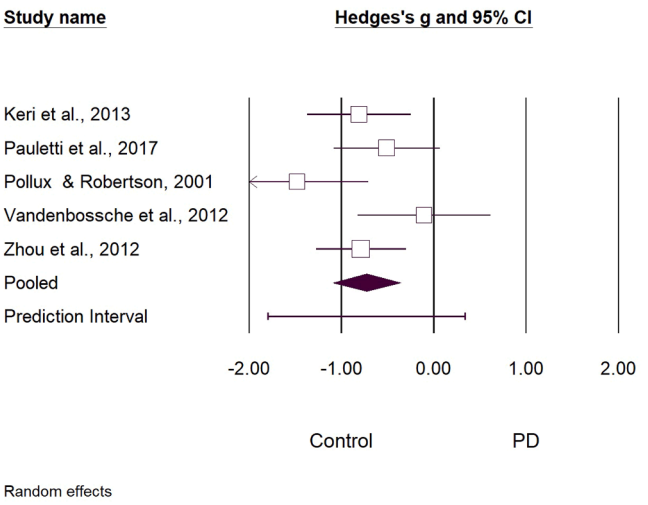

Fig. 7. Forest plot for exogenous orienting. Meta-analytic summary showing reduced stimulus-driven orienting efficiency in PD.

Fig. 8. Forest plot for reorienting. Standardized mean differences in reorienting cost between PD and controls.

3.4.3. Reorienting

The capacity to reallocate attention in response to unexpected stimuli was evaluated in three studies, using the Posner task (Bennett et al., 1995; Pollux and Robertson, 2001) or Posner-like task (Hsieh et al., 1996). A non-significant trend toward reduced reorienting performance was observed in participants with PD compared to controls (Hedges' $g = -0.316$, 95% CI [−0.667, 0.036], $p = 0.078$). The absence of heterogeneity ($I^2 = 0\%$) indicates consistent findings across studies, despite the small overall effect. The forest plot of the meta-analysis for attentional reorienting is shown in Fig. 8, with the corresponding funnel plot provided in Supplementary Figure S7.

3.4.3.1. Review. Beyond the studies included in the quantitative synthesis, additional evidence further informs the topic. Mari et al. (1997) and Plomhause et al. (2014) both reported invalid-cue costs in PD that are comparable to those of healthy individuals. This indicates that patients can disengage and shift their attention in standard Posner paradigms. However, Bennett and Castiello (1996) reported that patients exhibited disproportionately large reorienting costs when attentional demands were increased using a three-dimensional cueing task, particularly when attention had to be shifted across different spatial planes. These findings suggest that, although basic reorienting mechanisms remain intact in the early stages of PD, subtle deficits may emerge under conditions that impose greater demands on attentional disengagement.

3.5. Spatial bias

Three studies examined spatial bias in PD, including two using the line bisection task (Drago et al., 2008; Miller et al., 2013) and one employing the landmark task (Salazar et al., 2019). The landmark task (Milner et al., 1992) is a more perceptual version of the line bisection task (Schenkenberg et al., 1980) that minimizes the motor component by asking participants to judge which side of pre-bisected lines appears longer (or shorter). In both tasks, scores can be positive or negative depending on whether responses are biased to the right or left of the true center. When calculating SMDs as Control *minus* PD, the sign of the result reflects only which group has the larger mean, rather then the actual direction of spatial bias. As a result, each study was reviewed individually, as combining the data in a meta-analysis would have been misleading.

Drago et al. (2008) reported that PD showed a slight leftward deviation on the line bisection task compared to controls, which they interpreted as an exaggeration of pseudoneglect (i.e., inherent leftward bias). When attention was directed to the right side, PD participants moved their marks rightward, a pattern the authors linked to difficulty in shifting attention rather than true neglect-like behavior. Miller et al. (2013) examined only the distance of each mark from the center and found that PD participants were generally less precise, exhibiting more variability but no consistent side bias. Salazar et al. (2019) employed a landmark task in which a cursor moved horizontally from the right or left and reported a mild leftward bias in PD when the cursor started on the left side, but no difference from controls when starting from the right side, which they related to asymmetrical basal ganglia involvement affecting attention. Overall, these studies suggest that PD is characterized by small, context-dependent changes in spatial attention rather than a consistent directional bias.

Meta-analytic results and publication bias assessments for each attentional domain are summarized in Table 2 and Table S1, Supplementary.

3.6. Review left- vs right-onset PD (LPD vs RPD)

Since only a small number of studies fulfilled the inclusion criteria, we did not conduct a meta-analysis for side-of-onset comparisons. Instead, we present a narrative synthesis of the seven papers that examined attentional performance in LPD and RPD, with healthy controls included as reference groups (Adwani et al., 2016; Ebersbach et al., 1996; Lee et al., 2002; Norton et al., 2016; Ortelli et al., 2018; Salazar et al., 2019; Villardita et al., 1983; details are summarized in Table 3).

3.6.1. Sustained attention

Evidence for possible differences in sustained attention between LPD and RPD comes from three studies. Norton et al. (2016), using a multiple-object tracking task with eye-tracking, showed that both LPD and RPD patients were less accurate as compared to controls, and that the inaccuracy was more pronounced when tracking two objects simultaneously. In contrast, single-object tracking deficits disappeared once trials with unstable fixation were excluded, suggesting those impairments reflected oculomotor control rather than attentional failure. Importantly, no differences were observed between LPD and RPD, and there were no consistent hemifield-specific effects. Ortelli et al. (2018) assessed sustained visual attention using a randomized, computer-controlled reaction time paradigm. At baseline, performance did not differ between PD and controls, nor between LPD and RPD, suggesting that basic sustained attention was preserved, at least within the sensitivity of this task. Finally, Salazar et al. (2019) reported that both LPD and RPD were slower than controls, but the two subgroups performed comparably.

3.6.2. Selective attention

Adwani et al. (2016) assessed selective attention using the symbol cancellation task from the NIMHANS neuropsychological battery (Tripathi et al., 2013). Patients with PD demonstrated significantly reduced performance relative to healthy controls, whereas no statistically significant differences were reported between the left- and right PD subgroups.

3.6.3. Divided attention

Salazar et al. (2019) evaluated divided attention with the TMT-B. Both LPD and RPD performance was found to be significantly worse than controls, with no differences between the two subgroups. Within the PD group, trial-to-trial variability on the landmark task correlated with TMT-B and other executive measures, suggesting a possible link between divided-attention deficits and variability in spatial judgment.

3.6.4. Spatial bias

Spatial bias showed the most consistent laterality effects. Villardita et al. (1983) reported neglect-like omissions on a line cancellation task in LPD and in patients with bilateral motor involvement, but not in RPD or controls. Ebersbach et al. (1996), using an eye-tracking visual exploration task, found that controls and RPD tended to begin scanning on the left, whereas most LPD patients began on the right, showing a neglect-like behavior not detected by standard cancellation or bisection tests. Lee et al. (2002) examined vertical line bisection and observed that LPD patients consistently placed the midpoint below the true center, under-representing the upper visual field, while RPD patients performed similarly to controls. Finally, Salazar et al. (2019), using a dynamic landmark task, in which a vertical cursor moved slowly across a horizontal line and participants indicated when it appeared centered, found that both LPD and RPD groups showed greater leftward bias than controls when trials began on the left (i.e., when the cursor started moving from the left end of the line toward the center), but no differences when trials began on the right. Variability in spatial judgments was higher in both PD subgroups compared to controls, with LPD showing slightly greater variability than RPD on right-start trials.

Table 2
Meta-analysis results.

Attention Domain	**Number** of Studies	Sample Size		Meta-analysis							
		Control	**PD**	**SMD Hedges g**	**Lower 95% CI**	**Upper 95% CI**	**Z**	**p**	**Q**	***p***	**I^2**
Sustained	7	304	328	−0.42	−0.70	−0.13	−2.87	0.00	14.66	0.02	59
Selective	9	229	309	−0.57	−0.85	−0.29	−3.98	0.00	18.18	0.02	56.01
Divided Attention	20	947	944	−0.81	−1.07	−0.55	−6.11	0.00	128.37	0.00	85.20
Alerting	4	104	101	−0.19	−0.61	0.24	−0.86	0.39	6.74	0.08	55.47
Orienting Endogenous	3	65	58	−0.32	−0.67	0.03	−1.80	0.07	0.54	0.76	0.00
Orienting Exogenous	5	124	114	−0.73	−1.09	−0.36	−3.88	0.00	7.24	0.12	44.78
Reorienting	3	65	58	−0.32	−0.67	0.04	−1.76	0.08	1.14	0.57	0.00

Table 3
Summary of demographics, clinical measures, and cognitive assessments in left- and right- onset PD.

AUTHORS	Attention Domain	Task	H&Y Score RPD	H&Y Score LPD	UPDRS Motor Sub-score RPD	UPDRS Motor Sub-score LPD	N RPD	N LPD	N Control	Age RPD	Age LPD	Age Control	Education RPD	Education LPD	Education Control	Sex RPD N Male	Sex LPD N Male	Sex Control N Male	RPD Disease Duration (months)	LPD Disease Duration (months)	LEDD RPD	LEDD LPD	Cognitive Assessment	Cognitive Assessment RPD Score	Cognitive Assessment LPD Score	Cognitive Assessment Control Score
Adwani et al., 2016	Selective	NNB Cancellation Task	1.5 (0.3)	1.6 (0.8)	15.12 (7.10)	20.56 (12.5)	25	25	50	52.24 (7.96)	48.44 (8.07)	NS	12.32 (2.90)	12.52 (3.22)	NS	20	17	NS	27.72 (15.3)	30.96 (17.8)	483 (172.5)	463 (249.3)	MMSE	28.68 (1.40)	28.68 (1.60)	NS
Ebersbach et al., 1996	Spatial Bias	Exp. Visual Exploration	NS	NS	NS	NS	13	14	17	63.5 (6.3)	59.3 (10.3)	61.4 (9.00)	12.0 (1.9)	13.1 (2.8)	12.6 (2.6)	10	11	14	50.8 (32.9)	35.1 (29.5)	NS	NS	MMSE	NS	NS	NS
Lee et al., 2002	Spatial Bias	Line Bisection Vertical	1.87 (0.74)	2.12 (0.69)	NS	NS	8	8	8	65.8 (9.0)	64.1 (8.2)	64.9 (5.6)	NS	NS	NS	6	4	6	95	110.4 (98.4)	NS	NS	NART	9.3 (5.3)	11 (6.5)	9.1 (5.3)
Norton et al., 2016	Sustained	Exp. Multiple Object Tracking	2.1 (0.5)	1.6 (0.5)	17.4 (7.9)	17.8 (6.7)	14	12	21	63.6 (6.3)	63.5 (6.8)	67.4 (7.6)	17.1 (1.3)	17.1 (2.2)	17.3 (1.8)	5	6	6	NS	NS	524.6 (304.8)	396.8 (237.8)	MMSE	> 27	> 27	> 27
Ortelli et al., 2018	Sustained	Exp. Subtractive RTs	2.6 (0.5)	2.5 (0.5)	17.9 (5.3)	19.0 (5.3)	50	50	34	66.9 (9.2)	64.0 (9.8)	65.4 (7.1)	10.3 (4.0)	10.7 (5.0)	10.4 (4.3)	21	25	24	138 (67.2)	115.2 (57.6)	738.9 (374.7)	679.5 (222.0)	MMSE	27.2 (1.7)	27.4 (2.3)	28.7 (1.3)
Salazar et al., 2019	A. Divided B. Spatial Bias	A. TMT-B B. Landmark Task	2	2	21.1 (10.7)	20.9 (8.9)	37	42	67	65.6 (6.3)	64.4 (7.6)	62.9 (8.7)	17.4 (2.1)	17.5 (2.2)	17.1 (2.2)	21	23	27	82.8 (51.6)	68.4 (54)	540.3 (319.4)	538.3 (357.5)	MMSE	> 26.25	> 26.25	> 26.25
Villardita et al., 1983	Spatial Bias	Line Cancellation_Albert	1	1	NS	NS	7	10	15	67	65	65	6	6	5	5	4	8	NS	NS	NS	NS	WAIS-R	9	10	10

Note:
Some studies overlap with those included in the PD versus control meta-analysis.
Data are presented as means, with standard deviations in parentheses and confidence intervals in square brackets.
Abbreviations: Exp. = experimental task; H&Y = Hoehn and Yahr scale; LEDD = levodopa equivalent daily dose; LPD = left-onset Parkinson's disease; NA = not applicable; N = number; NS = not specified; RPD = right-onset Parkinson's disease; UPDRS = Unified Parkinson's Disease Rating Scale.
Cognitive assessments: MMSE = Mini-Mental State Examination; NART = National Adult Reading Test; WAIS-R = Wechsler Adult Intelligence Scale – Revised.
Tasks: Landmark Task= Spatial bias test; Line Bisection = Spatial judgment task; Line Cancellation = Albert's test of neglect; NNB = NIMHANS Neuropsychological Battery; Posner Task (Cost/Benefit) = Orienting/reorienting measure; RT = Reaction Time; TMT-B = Trail Making Test subtest B; Visual Exploration = Exploratory eye movement task.

3.7. Quality assessment

3.7.1. PD versus controls

A total of 46 studies were evaluated. All were rated "strong" for *study design* and *data collection*, reflecting the consistent use of appropriate methodologies and validated/adequate measurement tools. With respect to *selection bias*, 42 studies were rated "moderate", three were rated "strong" (Broeders et al., 2013; Çakmaklı et al., 2020; Golińska et al., 2021), and one was rated "weak" (Reekes et al., 2020), mainly due to reliance on convenience sampling, group allocation based on specific research hypotheses, or incomplete reporting of withdrawals. For *confounder control*, more than half of the studies (n = 28) were rated "strong", 17 were "moderate", and one was considered "weak" (Drago et al., 2008). Overall, 30 studies (65.2%) achieved a "strong" global rating, and 16 (34.8%) were rated "moderate"; none were classified as "weak" (Table 4a).

3.7.2. LPD versus RPD

As in the PD versus controls set, all seven studies were rated "strong" for *study design* and *data collection*, confirming methodological rigor and reliability of the measures used. However, all were judged "moderate" for *selection bias* and *withdrawal reporting*. *Confounder control* was rated "strong" in six studies and "moderate" in one. In terms of *global ratings*, six studies were considered "strong" and one "moderate" (Table 4b).

4. Discussion

This systematic review and meta-analysis investigated whether idiopathic PD is characterized by visual attentional deficits. We included studies comparing the performance of cognitively unimpaired PD patients with healthy matched controls, provided that the visual attentional domain under investigation could be clearly mapped onto one of the canonical attentional domains or processes, as well as potential visuospatial biases. Namely, we investigated possible alterations in sustained, selective, and divided attention, along with alerting, orienting, reorienting processes and the presence of visuospatial biases. Overall meta-analytic findings indicated that individuals with PD, compared to controls, exhibit poorer performance across all three attentional domains, while among the three investigated processes, only exogenous orienting appears to be affected. These attentional deficits do not seem to be related to the side of predominant motor symptoms, whereas visuospatial biases seem to show a lateralization, with PD patients who

Table 4a
Quality assessment of papers included in the PD vs. control meta-analysis and/or review.

AUTHORS	SELECTION BIAS	STUDY DESIGN	CONFOUNDERS	DATA COLLECTION METHOD	WITHDRAWALS AND DROPOUTS	GLOBAL RATING
Badenes et al., 2018	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Bennett & Castiello, 1996	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Bennett et al., 1995	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Berry et al., 1999	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Bledsoe et al., 2018	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Broeders et al., 2013	STRONG	STRONG	MODERATE	STRONG	STRONG	STRONG
Buhmann et al., 2015	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Çakmaklı et al., 2020	STRONG	STRONG	MODERATE	STRONG	MODERATE	STRONG
Crescentini et al., 2012	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Dana et al., 2021	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Delgado-Alvarado et al., 2023	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Drago et al., 2008	MODERATE	STRONG	WEAK	STRONG	MODERATE	MODERATE
Elgh et al., 2009	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Ferrazzoli et al., 2017	MODERATE	STRONG	STRONG	STRONG	STRONG	STRONG
Filoteo & Maddox, 1999	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Filoteo et al., 1997	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Gardoni et al., 2023	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Scally et al., 2011	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Gèrard et al., 2022	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Golinska et al., 2021	STRONG	STRONG	STRONG	STRONG	STRONG	STRONG
Guner et al., 2017	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Hirsch and Röhrle, 2011	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Hsieh et al., 1996	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Keri et al., 2013	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Liu et al., 2020	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Liu et al., 2024	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Mari et al., 1997	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Miller et al., 2013	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Norton et al., 2016	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Pal et al., 2018	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Pauletti et al., 2017	MODERATE	STRONG	MODERATE	STRONG	STRONG	STRONG
Peraza et al., 2017	MODERATE	STRONG	STRONG	STRONG	STRONG	STRONG
Petrova et al., 2012	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Plomhause et al., 2014	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Pollux & Robertson, 2001	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Reekes et al., 2020	WEAK	STRONG	STRONG	STRONG	MODERATE	MODERATE
Riekkinen et al., 1998	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Rodriguez-Ferreiro et al., 2010	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Salazar et al., 2019	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Segura et al., 2014	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Tommasi et al., 2015	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Uc et al., 2005	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Vandenbossche et al., 2012	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Yang et al., 2018	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Yang et al., 2021	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Zhou et al., 2012	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG

Table 4b
Quality assessment of papers included in left- versus right- onset PD review.

AUTHORS	SELECTION BIAS	STUDY DESIGN	CONFOUNDERS	DATA COLLECTION METHOD	WITHDRAWALS AND DROPOUTS	GLOBAL RATING
Adwani et al., 2016	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Ebersbach et al., 1996	MODERATE	STRONG	MODERATE	STRONG	MODERATE	MODERATE
Lee et al., 2002	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Norton et al., 2016	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Ortelli et al., 2018	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Salazar et al., 2019	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG
Villardita et al., 1983	MODERATE	STRONG	STRONG	STRONG	MODERATE	STRONG

have more severe left-side motor symptoms (i.e., LPD) exhibiting neglect-like biases.

4.1. Attentional domains

Sustained attention, defined as the ability to maintain focus over a period of time (Fortenbaugh et al., 2017), represents the fundamental building block of attention - without it, no further selection of relevant information can take place (Sarter et al., 2001). The meta-analysis indicated that, compared with healthy controls, individuals with PD might show a reduced capacity to sustain attention. However, this impairment was not consistently supported by the two studies that could not be included in the quantitative synthesis - Bledsoe et al. (2018) reported no group differences, and Riekkinen et al. (1998) observed comparable performance between PD and controls on a simple reaction-time task, with deficits emerging only under higher attentional load in the more demanding choice condition. Once attentional focus can be maintained, selective attention, the ability to identify and prioritize relevant information for further processing while suppressing distractors, can operate effectively. The present findings indicate that this form of attention is moderately compromised in PD, consistent with reduced efficiency in prioritizing task-relevant information and suppressing interference. At a higher level of the attentional hierarchy, divided attention refers to the ability to distribute attentional resources across multiple sources of information or tasks simultaneously. Although divided attention is often assessed using dual-task paradigms, the present review focused exclusively on visual attention and therefore did not include cross-modal paradigms. Within the visual attention literature identified, TMT-B was the most frequently adopted measure of divided attention. According to our analysis, divided attention showed the largest and most consistent deficit, aligning with the notion that resource-sharing and set-maintenance are particularly vulnerable in PD. However, studies employing the TMT-B that could not be meta-analyzed reported intact performance in cognitively unimpaired PD, suggesting that divided-attention deficits might be preserved in early stages of the disease.

Despite the strict inclusion of idiopathic, non-demented PD samples, substantial heterogeneity was evident across all three domains: sustained, selective, and divided. This variability likely reflects demographic, clinical, and methodological factors, including age, education, disease duration, medication status (ON/OFF), dopaminergic dosage (i.e., LEDD), and differences in task design and scoring procedures. Such factors may account for the dispersion of effect sizes across studies despite the consistent overall trend toward attentional impairment. While the meta-analytic results revealed a progressive pattern of attentional impairment in PD across the attentional hierarchy, the results of the few papers not included in the meta-analysis do not align with this pattern. This apparent discrepancy likely reflects the nature of meta-analytic integration, which combines standardized effect sizes rather than p-values, thereby increasing statistical power and capturing the overall trend.

Overall, the statistical findings indicate that individuals with PD showed difficulties in maintaining focus over time (i.e., sustained attention) along with impairment in the ability to prioritize relevant information among distractors (i.e., selective attention) and in allocating attentional resources across multiple sources (i.e., divided attention). A likely explanation for these findings is that dopaminergic degeneration affecting the cortico-striatal-thalamic-cortical pathway disrupts the interaction between frontostriatal and frontoparietal network, which normally supports the maintenance of sustained attention and the top-down suppression of irrelevant information (Tommasi et al., 2015). This disruption likely weakens the brain's ability to sustain attentional focus and resist interference, particularly when cognitive load increases.

4.2. Attentional processes

The attentional hierarchical system has been described to range from basic alertness to higher-order executive control (Petersen and Posner, 2012; Posner and Petersen, 1990). At the lowest level, there is the alerting process that reflects the ability to prepare for and maintain sensitivity to incoming stimuli (Posner, 2008), followed by the orienting mechanism, which refers to the ability of directing attention in space to select relevant stimuli, along with the re-orienting one, which entails the ability to disengage attention from a previously attended location and shift it to a new one (Petersen and Posner, 2012; Posner and Petersen, 1990). The highest level accounted for in the model proposed by Posner and collaborators (Petersen and Posner, 2012; Posner and Petersen, 1990) is the executive control, which depends on the successful integration of alerting, orienting, and reorienting processes. We decided not to include this component in the present review because it is more closely related to executive functioning. Indeed, the tasks most commonly used to measure it, such as the Stroop and Flanker paradigms, require overriding automatic responses and resolving conflict (Fan et al., 2003) and do not allow for the isolation of specific attentional processes.

As mentioned in the results section, attentional processes are typically measured using cueing tasks, like the Attention Network Test (ANT; Fan et al., 2002) and spatial orienting (Posner-like) cueing paradigms (Chica et al., 2014). In the ANT, participants indicate whether a central arrow points left or right. The target appears above or below fixation and may be flanked by distractors. The efficiency of the three attentional networks is assessed by examining how response times vary in relation to alerting cues, spatial cues, and flankers, using specific cognitive subtractions. Posner-like tasks require participants to respond to a target appearing on either side of a fixation point. A preceding cue may correctly (valid), incorrectly (invalid), or not at all (neutral) indicate the target's location. Spatial attention efficiency is measured by comparing response times across these cueing conditions. In these types of tasks, the motor contribution is minimized because orienting and reorienting effects are derived from the difference in reaction times between conditions, thereby controlling for individual response speed and isolating the attention shifting component.

The meta-analysis, based on only four studies using the ANT, revealed no reliable difference in alerting efficiency between PD and controls. The moderate heterogeneity observed likely reflects methodological and sample-related variability rather than true inconsistency in the direction of the effect.

While the ANT assesses exogenous, externally driven attention, the Posner paradigm can measure both exogenous and endogenous attention orienting depending on the cues employed - flanker stimuli are used

to elicit exogenous stimulus-driven shifts, whereas directional arrows guide endogenous, goal-directed shifts of attention. The four studies using the ANT and the one using the Posner paradigm showed that PD had a significantly reduced ability to orient exogenous spatial attention as compared to controls. Moderate heterogeneity was observed, suggesting some variation in the sample composition across studies. The two studies not included in the statistical analysis reported no differences across groups (Mari et al., 1997; Plomhause et al., 2014), suggesting that stimulus-driven orienting might be intact in cognitively unimpaired PD. On the other hand, the three studies that quantified endogenous orienting revealed a non-significant between-group difference, along with no evidence of heterogeneity, suggesting that voluntarily orienting of attention is preserved in PD. Beyond the meta-analysis results, support for an absence of alterations of voluntary orienting of attention comes from the study of Mari et al. (1997) in which patients were found to perform similarly to controls, while reduced efficiency only emerged at later PD stages.

To effectively select relevant targets in space, it is necessary not only to orient attention toward a location but also to disengage from a previously attended one and shift to a new position, thus re-orienting attentional resources. The statistical analysis of three studies revealed a non-significant trend toward reduced reorienting performance in PD as compared to controls. The absence of heterogeneity indicates consistent findings across studies, despite the small overall effect. In addition to the studies included in the quantitative synthesis, further evidence comes from Mari et al. (1997) and Plomhause et al. (2014) studies, which found that reorienting cost in PD did not differ from that of healthy controls, suggesting a preserved ability to disengage and shift attention. By contrast, Bennett and Castiello (1996) reported disproportionately large re-orienting costs when attentional demands were heightened using a three-dimensional cueing paradigm, especially when shifts across spatial planes were required. Taken together, these findings indicate that while basic reorienting mechanisms appear intact in PD, more challenging conditions may reveal subtle impairments in attentional disengagement.

To summarize, among the orienting mechanisms, solely exogenous orienting appears to be affected, as PD patients show reduced efficiency in shifting attention toward externally driven cues, while endogenous, goal-directed orienting appears intact. Both statistical and individual studies suggest that the ability to disengage attention from one location and shift it to another is generally preserved, although subtle alterations may emerge under increased task demands. This pattern of reduced exogenous but preserved endogenous orienting could indicate an alteration of the ventral frontoparietal network functioning, which is mostly lateralized to the right hemisphere, and its activation is independent of whether the stimulus initiates a shift in spatial attention (Corbetta and Shulman, 2002).

4.3. Visuospatial bias

Based on our research and inclusion/exclusion criteria, it seems that spatial bias in PD has been rarely and inconsistently explored, given that only a few studies were identified. These limited literature data indicate subtle, context-dependent changes in attention rather than a true left-right lateralization deficit. In line-bisection tasks, deviations are small and often influenced by task demands, suggesting reduced flexibility in shifting or maintaining spatial attention. Occasional leftward shifts may exaggerate normal pseudoneglect, possibly due to altered basal ganglia or interhemispheric modulation. Overall, the current data seem to point toward attentional instability rather than a consistent spatial bias in PD.

4.4. Left PD versus right PD

Given the typically unilateral onset of motor symptoms in PD and the dominant role of the right hemisphere in attention, it was expected that cognitively unimpaired patients with idiopathic PD with more severe motor symptoms on the left side of the body (LPD) would exhibit poorer attentional performance compared to those with predominant motor symptoms on the right side (RPD). Unfortunately, the number of studies that met the inclusion criteria was too small to allow a meta-analysis, and therefore only a qualitative review was conducted.

Across studies, sustained, selective, and divided attention appear similarly affected in LPD and RPD. For sustained attention, LPD and RPD patients both showed reduced accuracy compared to controls in multiple-object tracking (Norton et al., 2016), although deficits in single-object tracking were linked to oculomotor control rather than attention, and no subgroup or hemifield differences emerged. Other tasks, including a reaction time paradigm (Ortelli et al., 2018), likewise found comparable results between LPD and RPD. For selective attention, patients performed worse than controls on a symbol cancellation task (Adwani et al., 2016), but no differences were observed between onset subgroups. Finally, in the divided attention domain, both groups were impaired relative to controls on the TMT-B (Salazar et al., 2019), with no LPD–RPD differences, although variability in spatial judgment was associated with divided attention and executive performance within PD.

Spatial bias, in contrast, consistently showed laterality effects in PD, with LPD patients often exhibiting neglect-like behaviors, such as rightward initiation of visual scanning (Ebersbach et al., 1996; Villardita et al., 1983) and under-representation of the upper visual field in vertical line bisection (Lee et al., 2002). RPD patients generally performed similarly to controls, although subtle biases were observed under certain task conditions (Salazar et al., 2019). Both PD subgroups displayed greater variability in spatial judgments than controls, with LPD patients showing slightly greater variability than RPD patients.

Overall, general attentional deficits in PD appear largely independent of motor symptom lateralization, with sustained, selective, and divided attention similarly affected in LPD and RPD patients. In contrast, visuospatial attention/cognition shows consistent lateralized effects, as LPD patients often exhibit neglect-like behaviors, whereas RPD patients perform closer to controls. This could, at least partially, explain the inconsistent findings on attentional bias when comparing PD and controls in line bisection tasks, since the PD samples likely included both LPD and RPD patients, possibly canceling each other's effects at the group level.

These findings suggest that spatial attention may be differentially shaped by the side of symptom onset, with greater dopaminergic depletion in the right dominant hemisphere (i.e., LPD) potentially contributing to a rightward attentional bias. This pattern appears consistent with a possible alteration of the right ventral frontoparietal network, the dysfunction of which has been linked to neglect-like phenomena characterized by rightward spatial bias. From a neurobiological perspective, such effects could be related to dopaminergic asymmetry within the nigrostriatal system, which may influence frontostriatal and parietal network activity and shift the interhemispheric balance underlying spatial attention (Ferrazzoli et al., 2018; Ortelli et al., 2018; Seichepine et al., 2011).

A few limitations should be considered when interpreting these findings. First, most included studies assessed participants while they were in the "ON" medication state, which may differ from performance in "OFF" conditions. Because attentional performance may fluctuate across ON and OFF states, medication-related variability may have contributed to part of the heterogeneity observed across studies. Furthermore, the cognitive effects of dopaminergic treatment are known to vary according to task demands and baseline DA levels within distinct frontostriatal circuits, such that L-DOPA may have either beneficial or detrimental effects on performance depending on the cognitive process being assessed (Cools, 2006). Moreover, very few studies explicitly modeled medication effects, for example by including LEDD as a covariate, limiting the ability to disentangle pharmacological effects from disease-related attentional deficits. Second, our review included only studies on idiopathic PD and excluded participants with dementia, with the aim to characterize attentional functioning in PD in the absence of

significant cognitive decline. As a result, the magnitude of deficits reported here likely underestimates that observed in the broader and more heterogeneous PD population. Third, the number of studies available for several meta-analyses was limited, constraining the robustness of the meta-analysis results. Specifically, the analyses for alerting ($k = 4$), endogenous orienting ($k = 3$), exogenous orienting ($k = 5$), and reorienting ($k = 3$) fell below the threshold generally considered adequate for assessing heterogeneity and publication bias. Although there is no formal consensus on a minimum number of studies for adequate meta-analytic power, results based on small samples yield unstable results and should be considered as preliminary and hypothesis-generating. A further limitation concerns the assessment of attention itself. Most neuropsychological measures used in the literature are not process-pure. Although designed to assess specific attentional domains, they also engage other cognitive processes, including processing speed, visual scanning, executive functioning, and motor performance. This reflects the way attention is commonly evaluated in clinical settings and should be considered when interpreting the findings. In addition, many tasks involve a motor component, such as reaction-time or paper-and-pencil measures, raising the possibility that some observed differences reflect motor slowing rather than attentional impairment. Nevertheless, since most participants were tested under dopaminergic treatment, which alleviates primary motor symptoms, the pattern observed here is likely to reflect attentional alterations. Furthermore, the motor demands are unlikely to substantially influence performance on Posner and Posner-like tasks, as the subtraction between conditions largely cancels it out, as previously detailed. Another methodological limitation is the imbalance in the available literature. Tasks assessing attentional domains (e.g., TMT, visual search, line bisection) were far more common than paradigms targeting specific attentional processes (e.g., Posner cueing or ANT paradigms), which require computerized setups. Finally, many studies were excluded due to missing cognitive screening data or small sample sizes, potentially introducing selection bias and limiting the generalizability of the conclusions.

From a clinical perspective, these negative changes in the attention capacity are detectable already in the early stages of PD (H&Y I–II) and can affect daily functioning, therapy participation, and safety. Simplifying instructions, minimizing dual task demands, and reducing visual clutter or distractors are pragmatic strategies that align with the observed pattern of reduced sustained/selective capacity and vulnerability under higher attentional loads. Future interventions targeting attentional deficits may improve not only cognitive functioning but also everyday functioning and other non-motor symptoms that interact with attentional processes.

In conclusion, this is the first comprehensive meta-analysis and systematic review to evaluate attentional performance in PD. The findings indicate impaired sustained, selective, and divided attention, along with exogenous attentional orienting. By resolving previous inconsistencies in the literature, our data underscore the influence of dopamine on attention, albeit mainly independent of motor symptoms onset laterality, and provide a foundation for future research and potential clinical interventions targeting cognitive deficits.

CRediT authorship contribution statement

MB, CP, SS: Conceptualization; **MB, SS:** Methodology, Software; **MB, ANH, ML, SS** Investigation, Data curation; **MB:** Formal analysis; **MB, ANH, ML:** Visualization; **CP, SS:** Supervision; **MB, CP, SS:** Writing – original draft, Writing – review & editing.

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Declaration of Competing Interest

The authors declare no competing interests.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.neubiorev.2026.106884.

Data availability

Data presented in this paper will be available upon request to the corresponding author (selene.schintu@unitn.it).

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