Neurocognitive impairment in night and shift workers: a meta-analysis of observational studies

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ABSTRACT

Objective Shift work is an essential element of modern labour, ensuring ideal conditions of service for today's economy and society. Despite the beneficial properties, its impact on the neurobehavioural performance of exposed subjects remains controversial. This meta-analysis aimed to provide the first summarising effects regarding the association between shift work exposure and different cognitive functions.

Methods A literature search was performed using the databases PubMed, PsyINFO, PsyARTICLES, MedLine, PsycNET and Scopus including eligible studies up to April 2021 that compared shift workers with non-shift workers regarding neurobehavioural performance tests. We carried out a random-effects model using Hedges' g as a meta-analytical effect size with a restricted likelihood estimator to summarise the mean differences between the exposure group and controls. Positive effect sizes indicate higher performance for non-shift workers. The heterogeneity of effect sizes was addressed by sensitivity analysis using funnel plots, Egger's tests, p-curve analysis, meta-regressions and subgroup analysis.

Results We included 18 studies resulting in a total sample of 18 802 participants and 37 effect sizes concerning six different neurobehavioural outcomes. Our results showed significantly worse performance in shift workers compared with non-shift workers in the following cognitive functions with g (95% CI): processing speed 0.16 (0.02 to 0.30), working memory 0.28 (0.51 to 0.50), psychomotor vigilance 0.21 (0.05 to 0.37), cognitive control 0.86 (0.45 to 1.27) and visual attention 0.19 (0.11 to 0.26).

Conclusions We provide the first meta-analytical findings that associate shift work with decreased cognitive performance in processing speed, working memory, psychomotor vigilance, cognitive control and visual attention.

Key messages

What is already known about this subject?

⇒ Exposure to shift work has been linked to a variety of serious health consequences by single studies as well as meta-analyses. However, the effects on neurobehavioural functioning remain ambiguous since no meta-analytic results are provided.

What are the new findings?

⇒ We provide the first summarising meta-analytic effects regarding the association between shift work exposure and neurobehavioural impairment regarding processing speed, working memory, psychomotor vigilance, cognitive control and visual attention.

How might this impact on policy or clinical practice in the foreseeable future?

⇒ Reduced neurobehavioural performance in shift workers might play an important role regarding work-related injuries and errors. Occupational health policies should focus on promoting protective countermeasures (eg, naps, cognitive monitoring, recovery plans) to prevent adverse health outcomes for workers and negative consequences for involved third parties.

INTRODUCTION

Shift work is an essential element of modern labour which has been used increasingly in a broad variety of occupational settings in recent years.[1] From an economic point of view, shift work is fundamental to ensure cost efficiency by operating machinery continuously in numerous industries.[2] Furthermore, public, and private services (eg, healthcare and law enforcement) rely heavily on shift working models to ensure ideal conditions of service.[3] Although no general definition of shift work exists, it is most often described as unusual working hours outside the conventional time frame of 07:00 to 18:00.[4]

Despite its beneficial properties for the economy and society, some studies have linked shift work to a variety of adverse health effects. These are due to the disruption of the human circadian system caused by shift working. As a result, the endogenous timing system is imbalanced, which is linked to a variety of negative physical reactions. Shift work, as an epidemiological risk factor, is recognised to be associated with sleep disorders, cardiovascular diseases, obesity and diabetes mellitus.[5] Additionally, adverse effects presumably raised by shift work account for cancer, cognitive impairment, mood disorders, social isolation and substance abuse.[6–9] Nevertheless, the existing literature is not undisputed since some studies fail to find these negative reactions.[10 11]

Therefore, meta-analyses were carried out to try to resolve the debates regarding the association between shift work and mental health issues[12] as well as physical diseases.[13] However, no meta-analytical approach has yet addressed its impact on neurobehavioural performance in working adults. Ambiguous research results thus remain, drawing contradictory conclusions regarding the magnitude of the effects of shift work on neurobehavioural functioning. An advanced understanding of this relationship, however, is vital since cognition plays a key role in numerous work-related

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tasks. Therefore, reduced neurobehavioural performance due to shift work may ultimately lead to work-related injuries.[14]

In this study we attempted to solve this issue by conducting a meta-analysis to provide summarising effects regarding the impact of shift work on neurobehavioural performance in working adults.

METHODS

Search strategy

First, we conducted a systematic literature search using the databases PubMed, PsyINFO, PsyARTICLES, MedLine, PsycNET and Scopus, which were chosen for their vast variety of clinical studies. For the literature search MeSH terms or a combination of them was used (see online supplemental table 1). Furthermore, reference lists of selected papers were reviewed for identification of additional eligible articles.

For screening, we included every study that has examined the effects of exposure to shift work on the neurobehavioural performance of working adults compared with non-exposed controls. We defined shift work as atypical working routines taking place outside the standard daytime working routine from approximately 07:00 to 18:00. This condition included rotated as well as fixed-shift schedules including evening work. The control group was defined as having no history of shift work or working regular day shifts. The literature search was conducted from inception until April 2021, following no restrictions regarding country, language or year of publication. No restraints regarding types of occupation were administered to avoid summarising effects which are biased towards specific professions and their conditions. Eventually we excluded experimental studies from our literature search since aggregation with observational data did not seem appropriate regarding the validity of the results.

Selection criteria

The first step in our literature search resulted in a total of 2763 articles for consideration. Publications were screened regarding titles and abstracts, excluding any work which did not correspond with our research interest. Overall, 18 studies were included in our meta-analysis that met the following inclusion criteria:

1. Treatment group (shift workers) and control group (non-shift workers) were compared regarding neurobehavioural performance using neurobehavioural tests (eg, Wechsler Adult Intelligence Scale).
2. The study reported the sample size and appropriate statistics to calculate an effect size.
3. The subjects included were considered to be healthy working adults (eg, publications concerning subjects with neurobehavioural impairments were excluded).
4. The study had been empirically reviewed.
5. The study included at least one neurobehavioural test which was used by at least two different included publications that fulfilled the criteria 1 to 4.

For a more detailed representation of the study selection process see figure 1.

In total, the 18 included studies provided adequate data to analyse the summarising effects of five different neurobehavioural tests. A concise summary of the specific neurobehavioural tests and subtests is provided below.

1. *Coding* is a core subtest of the *Wechsler Adult Intelligence Scale* (WAIS) regarding the framework of processing speed. On a page, a sequence of numbers must be quickly matched with a sequence of symbols by the subjects during the test. The response score of the participants consists of the correctly matched sequences within a given time frame. *Coding* measures not only processing speed, perceptual speed and visual speed, but also attention and motor speed.[15]
2. *Digit Span* is a core subtest of the WAIS concerning working memory and consists of three different variations. During the test, subjects are asked to repeat a sequence of numbers read by the examiner, either in order (forwards), ascending order (sequencing) or in reversed order (backwards). The correctly repeated numbers form the participant's response score, measuring attention, encoding, working memory as well as mental manipulation.[15]
3. The *Psychomotor Vigilance Task* (PVT) is a 10-min computer-based test using simple reaction time tasks. Subjects must react to either visual or auditory stimuli that are presented in random intervals by promptly pressing a button. The participant's response score is measured by the mean response time in milliseconds, measuring sustained attention.[16]
4. The *Stroop Test* measures the performance of cognitive control based on the *Stroop effect*. Participants are shown three different tables which must be read as quickly as possible naming the written colours correctly. While the first two conditions display congruent presentations, the third trial consists of incongruent stimuli (eg, the word green is printed in red). The mean response time in milliseconds forms the subject's response score, measuring not only the ability to inhibit cognitive interference but also attention, processing speed and cognitive flexibility.[17]
5. The *Trail Making Test* is used regarding visual attention and task switching, and consists of two separate subtests, A and B. During the *Trail Making Test A* subjects are asked to connect a sequence of circled numbers on a page by drawing lines as quickly as possible (eg, 1-2-3-4 etc). In the *Trail Making Test B* participants must follow identical instructions but with the additional task of alternating between letters and numbers (eg, 1-A-2-B-3-C etc). The mean completion time in milliseconds reflects the subject's response score, subtest A measuring visual attention and processing speed while subtest B assesses executive functioning.[18]

Data extraction and quality assessment

Data extraction was carried out by two of the authors (TD and AB) using a coding scheme developed for the screening process. Study abstracts were initially screened by the tool to exclude ineligible research, for example, studies without empirical data. Outcomes were reviewed by the first author (TV) and discrepancies were resolved by consensus. Using a two-way mixed-effects model, a mean rating (k=2; absolute agreement) an ICC of 0.97 was estimated for coded effect sizes regarding inter-rater reliability. The data extraction process focused on relevant characteristics of the study and fundamental outcomes of neurobehavioural test performance (for a detailed description see online supplemental table 1). For our study, neurobehavioural performance is characterised by processing speed, working memory, psychomotor vigilance, cognitive control, visual attention and task switching which resulted due to our selection criteria (see Selection criteria). When publications reported separated results (eg, for males and females), the subgroups were included as independent samples in the meta-analysis. Concerning the quality assessment of the relevant studies, the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (QATOCCSS) of the National Heart, Lung, and Blood Institute was employed.[19] The methodological quality of the studies was examined by a

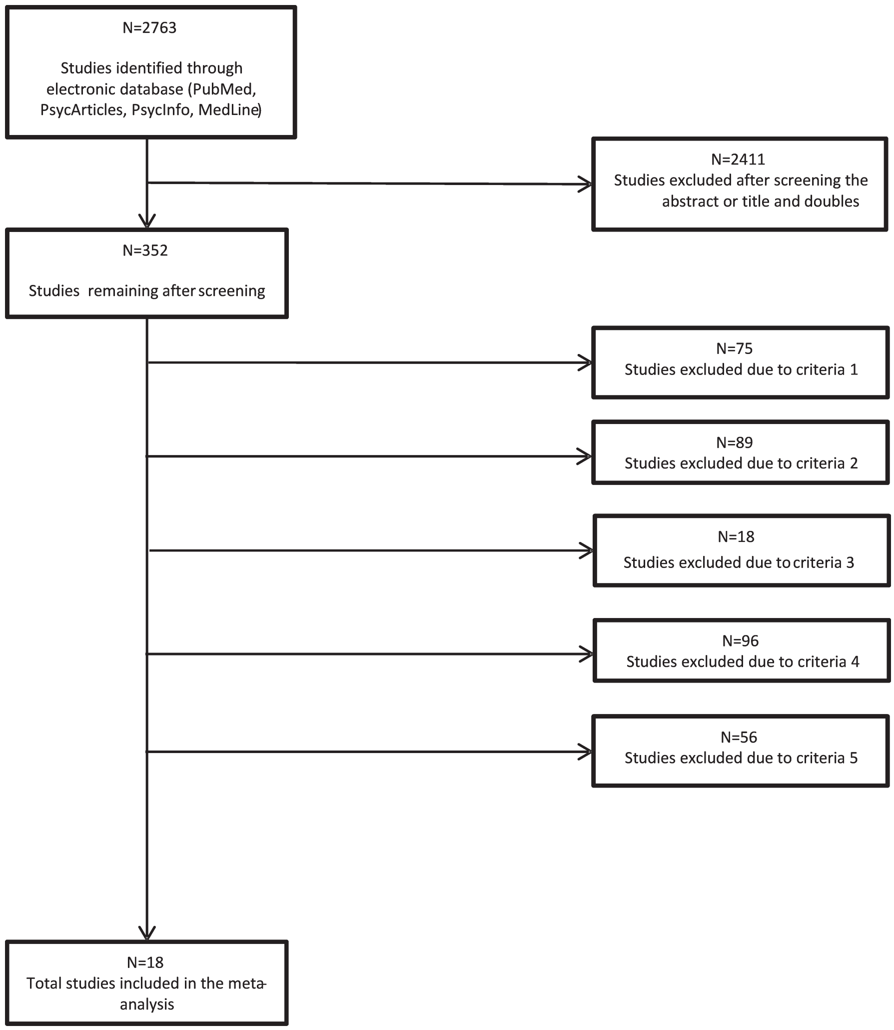

Figure 1 Flow chart for visually addressing the inclusion and exclusion of studies on account of the selection criteria.

total of 14 questions ranging from, for example, precision of the research question to the appropriateness of statistical analysis, resulting in either good, fair or poor quality. QATOCCS has been selected due to the cross-sectional design of the included studies and its use in neurobehavioural research.[20] Quality assessment was conducted independently by two researchers followed by an inter-rater reliability of 0.90. Differences were again resolved by consensus.

Data synthesis and meta-analytic procedure

For the meta-analysis, Hedges' *g* was selected as the effect size, since most of the studies reported mean differences between the exposure and control groups in the neurobehavioural tests. In comparison with Cohen's d, the estimator *g* shows less bias, especially in small samples, leading to a higher precision of estimated true effects.[21] The direction of estimates has been calculated for our meta-analysis so that positive effect sizes indicate higher values in the control group while negative effect sizes reflect higher scores in the exposure group for all neurobehavioural outcomes. Before calculating the average study effects, the identification of outliers in effect sizes was conducted using Cook's distance.[22] Pooling of effects sizes with the appropriate 95% confidence intervals was carried out separately for the different neurobehavioural tests, applying a random-effects model with a restricted maximum-likelihood estimator using Hedges' invariance weighting. Homogeneity of pooled effect sizes was quantified by τ^2 and significance examined by Q statistic.[23] When effect size heterogeneity was given, sensitivity analysis was carried out by funnel plots and Egger's tests[24] to measure the influence of possible publication bias, while p-hacking was addressed by p-curve diagrams (available from the authors on request) and analyses.[25] Potential moderating effects were examined by weighted mixed-effects meta-regressions for the different neurobehavioural effect sizes, while subgroup analyses were carried out using a random-effects model for further examination of heterogeneity in effect sizes. All statistical analyses were carried out in R using the metafor package.[26]

RESULTS

Study characteristics

In total, 18 studies were included in our meta-analysis resulting in an overall total of 37 effect sizes for the different neurobehavioural outcomes.[27–44] Year of publication ranged from 2005 to 2020, achieving a total sample of n=18 802 participants with a mean age of 35.75 (SD 7.03) years. Approximately 31.3% (n=5) of the studies compared workers in fixed shifts with non-exposed subjects while 68.7% (n=11) compared workers in rotating shifts and non-exposed controls. However, two included studies did not specify the shift type. Concerning type

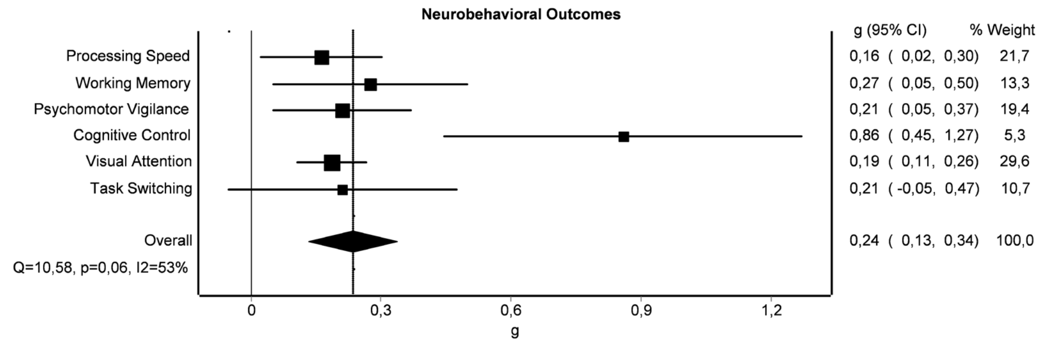

Figure 2 Forest plot for graphically displaying meta-analytic effect sizes for neurobehavioural outcomes.

of occupation, half of the studies examined nurses and/or doctors while the other half consisted of work focused on different professions (eg, police officers, IT staff, etc). For further analyses we therefore coded occupation type as 1="healthcare profession" and 2="not a healthcare profession". Furthermore, only five of 18 studies (27.80%) gave a detailed description regarding the subjects' history of shift work, which lead to a mean of 12.43 (SD 4.23) years of exposure. In contrast, seven studies (38.89%) used heterogeneous measurements of the history of shift work (eg, at least 1 month) while six studies (33.34%) did not report any information. Overall, the quality of the included publications was considered fair, primarily due to the lack of appropriate justification of samples and reported statistical information. For a more detailed description of the characteristics of the included studies see online supplemental tables 2 and 3.

Meta-analytic results

A summarising overview of the average effect sizes regarding the different neurobehavioural outcomes in given in figure 2.

Processing speed

Homogeneity could not be reached regarding the included effect sizes (Q(7)= 15.74, p=0.03) with τ^2=0.02. The random-effects model of the meta-analysis including five studies (n=5366) with eight total effect sizes showed significant mean differences in subtest coding g=0.16 (95% CI 0.02 to 0.30, p=0.02). Therefore, it can be stated that subjects exposed to shift work performed worse in the task based on processing speed than controls in the non-exposure group.

Working memory

The test of homogeneity indicated that the included effect sizes were homogenous (Q(3)= 2.97, p=0.40) with an estimated τ^2 of 0.00. The results of the random-effects model showed significant results across the three studies included (n=326) with four total effect sizes for Digit Span *g*=0.27 (95% CI 0.05 to 0.50, p=0.02). The subjects in the exposure showed significantly worse results than controls in tasks on working memory. Since the included studies for the Digit Span task exclusively examined rotating shift models, significant effects on working memory could only be detected for subjects exposed to rotating shifts.

Psychomotor vigilance

Regarding psychomotor vigilance, homogeneity of effect sizes was shown (Q(9)= 15.73, p=0.07; τ^2=0.01). Across the eight included studies (n=540) with 10 effect sizes, the random-effects model resulted in significant mean differences g=0.21 (95% CI 0.05 to 0.37, p=0.01). The results show that subjects exposed to shift work reached significantly lower scores in psychomotor vigilance than non-exposed controls.

Cognitive control

Heterogeneity for the included effect sizes was shown by the significant homogeneity test (Q(8)= 57.87, p<0.001) with τ^2=0.35. The random-effects model of the eight included studies (n=996) accompanied by a total of nine effect sizes showed significant results for the Stroop Test g=0.86 (95% CI 0.45 to 1.27, p<0.001). Therefore, it can be concluded that subjects exposed to shift work performed significantly worse in relation to cognitive control than non-exposed controls.

Visual attention

The included studies exhibited a homogenous picture concerning their effect sizes in the trail-making test form A (Q(2)= 0.66, p=0.72; τ^2=0.00). A significant mean difference between the compared groups could be shown by the random-effects model with a total of three studies (n=7497) including three effect sizes (g=0.19, 95% CI 0.11 to 0.26, p<0.001). It can be stated that subjects in the exposure group scored significantly lower regarding visual attention than controls.

Task switching

Again, homogeneity could be reached regarding the included effect sizes (Q(2)= 2.76, p=0.25) with a τ^2 of 0.04. In three studies (n=7497) with three effect sizes, the results of the random-effects model showed non-significant mean differences between exposed and non-exposed groups regarding task switching (p=0.12).

Sensitivity analysis

When the assumption of homogenous effect sizes was violated, sources of heterogeneity were explored by analysing the impact of outliers, publication bias, p-hacking and moderating variables. Since only two neurobehavioural domains showed heterogeneous effect sizes, the following sections focus on the sensitivity analyses of processing speed and cognitive control. However, all neurobehavioural performances were screened for outliers before being entered into the meta-analysis.

Outliers

Three outliers were detected only for the domain of cognitive control.[30 35 44] The removal of these cases from the analysis resulted in homogenous effect sizes (Q(5)= 10.16, p=0.07;

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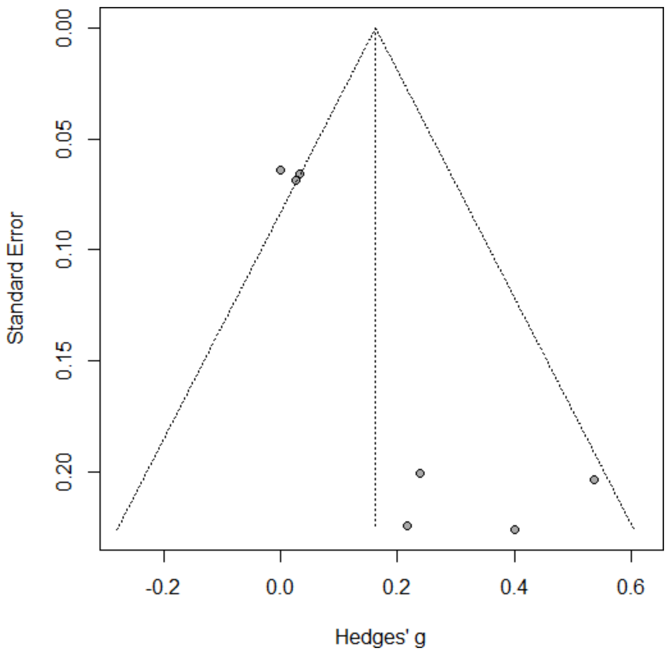

Figure 3 Funnel plot for visually detecting publication bias for processing speed.

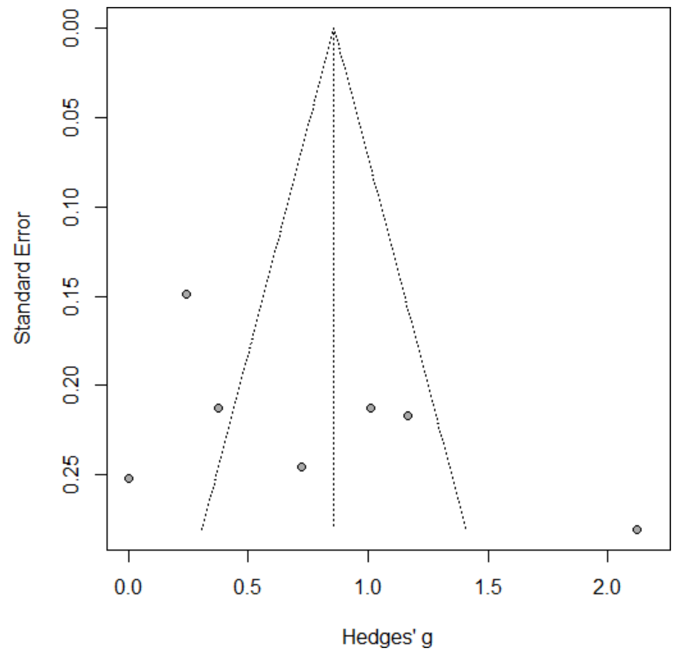

Figure 4 Funnel plot for visually detecting publication bias for cognitive control.

$\tau^2=0.04$) for the neurobehavioural outcome with a total of five studies and six effect sizes. Not only did the quantified heterogeneity of τ^2 drop from 0.35 to 0.04; the pooled effect size of the random-effects model also remained significant and increased slightly from g=0.86 to 0.91 (95% CI 0.67 to 1.16, $p<0.001$). Further examination revealed that one study[45] reported an effect size nearly twice as high as the next comparable one, while the other study reported an effect size almost twice as low.[46] The remaining study[47] had a sample size almost three times larger than the second largest sample. Thus, the heterogeneity of effect sizes regarding cognitive control might be explained by these outliers.

Publication bias and p-hacking

Regarding publication bias, processing speed and cognitive control showed indications of asymmetry in relation to the funnel plots (figures 3 and 4). However, only the former exhibited a significant Egger's test ($p<0.001$) while the latter was non-significant (p=0.12). When testing against p-hacking by conducting p-curve analysis, effect sizes for cognitive control showed significant right-skewness ($p<0.001$) and non-significant flatness (p=0.99), indicating robustness against p-hacking. A p-curve analysis for processing speed could not be carried out since the sample was too limited. Conclusively, only the effect size of processing speed might be influenced by publication bias as well as p-hacking. Due to this, the heterogeneity of effect sizes for processing speed might be driven by publication bias.

Moderation and subgroup analysis

Concerning processing speed, no significant moderating effects could be found for publication year ($X^2(1)=3.35$, p=0.07; $r^2=0.37$, b=0.04) or study quality ($X^2(1)=0.66$, p=0.42; $r^2=0.00$, b=0.12). Additionally, no significant subgroup differences were shown for type of shift (Q(1)= 0.20, p=0.66) or type of profession (Q(1)= 1.81, p=0.18). For cognitive control, no moderating effects could be found regarding publication year ($X^2(1)=1.88$, p=0.17; $r^2=0.11$, b=−0.08) or study quality ($X^2(1)=0.19$, p=0.66; $r^2=0.00$, b=0.10). Regarding subgroup analyses, no significant differences were found for either type of shift (Q(1)= 0.20, p=0.65) or for type of profession (Q(1)= 1.81, p=0.18). Therefore, heterogeneity of effect sizes does not seem to be caused by moderation or subgroup differences.

DISCUSSION

The results of our meta-analysis show significantly worse performance in adults exposed to shift working in comparison to non-exposed controls regarding working memory, processing speed, psychomotor vigilance, cognitive control as well as visual attention. Our findings are in line with the neurological perspective that explains these negative effects via the disruption of the circadian system due to shift working.[48] The circadian system is a key element in the regulation of the sleep–wake cycle, hormonal rhythm as well as various neurobehavioural functions. Almost all peripheral tissues have circadian rhythms which are regulated and synchronised by the suprachiasmatic nucleus located in the hypothalamus. The suprachiasmatic nucleus regulates itself by environmental time cues related to the 24-hour light–dark cycle received through retinal ganglion cells.[49] Reduced neurobehavioural functioning in shift workers can be ascribed to three possible pathomechanisms revolving around a misaligned circadian system.

First, the core function of the biological clock is to regulate the endogenous circadian rhythm according to the exogenous environmental time cues given, eventually leading to the expression of cortisol during daytime, while secretion of melatonin takes place during nighttime.[50] Studies have shown that neurobehavioural functioning is linked to circadian regulation showing peak performance during the day. However, shift workers must operate outside the typical day structure where brain activity is naturally reduced, resulting in decreased neurobehavioural performance.[51]

Second, working atypical schedules dysregulates the circadian system on a hormonal basis. Due to the exposure to shift work, the expression of various hormones is dysregulated, for example, clock genes, vasopressin and melatonin. This leads to a misaligned circadian system that is linked to disturbance of the sleep–wake cycle. Numerous studies have shown that misaligned circadian rhythms associated with disrupted sleep behaviour could be found in shift workers. Reduced quality of sleep and disturbed sleeping phases are then linked to higher fatigue in exposed subjects resulting in decreased neurobehavioural performance.[46]

Third, studies suggest that the expression of clock genes leads to free oscillation in different brain regions, proposing the existence of multiple circadian clocks. Rhythmicity between those clock genes outside the suprachiasmatic nucleus seems fundamental for neurobehavioural functioning. Studies propose that the activity between clock genes is desynchronised due to shift work, resulting in impaired neurobehavioural performance.[52]

Recent experimental studies came to the same conclusions as we do with observational data by examining the effect of simulated shift work on human neurobehavioural performance. In the laboratory study of McHill and Wright,[53] healthy working adults with no history of regular shift work were enrolled to participate in simulated day and night shifts. The results showed significantly reduced performance in the neurobehavioural domains of psychomotor vigilance and cognitive control due to night shift work compared with day shift work.[53] Furthermore, the experimental study of Chellappa *et al*[54] showed additional negative consequences for different neurobehavioural outcomes. Similarly, healthy participants were separated into day and night working schedules, artificially generating circadian alignment (day workers) and circadian misalignment (night workers) in the subjects. In comparison, participants with circadian misalignment working atypical schedules again showed worse performance in psychomotor vigilance, but also in memory-based tasks as well as processing speed and attention.[54] In summary, the results of experimental studies support our meta-analytical findings.

Strengths and limitations

This is the first meta-analysis to examine the effects of shift working on different neurobehavioural performance results of working adults. We were able to provide the first summarising effects for a total of six specific neurobehavioural domains regarding processing speed, working memory, psychomotor vigilance, cognitive control, visual attention and task switching. The meta-analytical approach is a very useful technique when an aggregation of effect sizes in a certain discipline of research is required. Especially in scientific fields where small sample sizes are a well-known source of error in estimating effect sizes, meta-analytical procedures are frequently used. Due to the aggregation of multiple results of single studies, meta-analysis overcomes the problem of reduced statistical power by enhanced sample pools leading to estimations of effect sizes with higher precision. Nevertheless, some limitations must be considered when interpreting our results.

We encountered a very heterogeneous body of measurements used for the assessment of outcome variables. Due to the great variety of tests used to assess neurobehavioural functions, estimated summarising results are restricted to six neurobehavioural performances including 18 studies with 37 effect sizes. Therefore, only a limited number of effect sizes could be included for the different neurobehavioural domains. Especially regarding the results of task switching, with a minimum of three effects sizes, limited data might inevitably impact our analysis. Although summarising effects show higher performances in non-exposed controls, they fail to indicate statistical significance in task switching. Yet, its direction of effect coincides with the results of the remaining neurobehavioural functions, showing higher performance for non-shift workers. Moreover, an inconsistent definition of shift work is used in the current literature. Consequently, some degree of misclassification might impact our meta-analytic results. In addition, since most of the studies included shift types with some degree of night work, our findings might be biased by its effects. Thus, a homogenous utilisation of neurobehavioural assessment and specific classification of shift work is highly recommended, leading to a more consistent body of literature and further replication of analysis.

The effect size found for working memory might be restricted to rotating shift work due to a lack of variation in the included studies. For every other neurobehavioural domain, however, the results could be summarised without limitations to shift type.

Results of significant differences in psychomotor vigilance, which can be used as an indicator for fatigue in workers, may be biased by underlying recovery processes. Due to the limited data of the included studies, examinations of potential recovering effects were restricted. For a deeper understanding of the impact of shift work, we recommend that future meta-analysis focus on the recovery process of fatigue in the context of neurobehavioural performance.

Heterogeneity was detected for two neurobehavioural outcomes. Effect sizes for processing speed seem to be influenced by publication bias, therefore our results might overestimate the true effect size. Effect sizes regarding cognitive control were also found to be heterogeneous, which was not caused by publication bias, but rather by outliers. The removal of these outliers resulted in effect size homogeneity. However, neither the level of significance, its direction of effect nor its magnitude changed notably. Therefore, overestimation of the true effect seems highly unlikely in relation to the domain of cognitive control. In contrast, the remaining results on neurobehavioural performance were found to be homogenous.

Since we did not restrict the type of occupations considered, our meta-analytical findings reflect the overall effects of shift work on neurobehavioural functioning. Because occupations differ in terms of job demands and workloads, the results might over- or underestimate the impact of shift work in specific types of profession. The study characteristics revealed that the majority of the included studies focused on healthcare professions, while the remaining publications examined a wide range of occupations. Equally important professions using shift work (eg, law enforcement) seem to be underrepresented in the existing literature, therefore our results might be biased towards healthcare professions. However, our sensitivity analyses showed no indication of differences in effect sizes between the types of occupation.

Only a marginal portion of studies reported exact time frames of shift work experience (eg, former shift work in years), while the majority used various unspecific indicators (eg, at least 1 month) or none. In more detail, almost none of the included studies reported any history of shift work separated according to exposure and control group. Due to this limitation, no distinctive long- or short-term effect could be examined in this analysis. As a result, the interpretation of the meta-analytical results must be considered under the assumption of possible effects of reversibility. A detailed description of the history of shift work of all participants is recommended for further studies.

Since the included studies of our meta-analysis followed a cross-sectional design, our results do not allow a causal interpretation between shift work and reduced neurobehavioural performance. Heterogenous measurements and missing important information regarding shift work resulted in a restricted inclusion of high-quality studies. Therefore, our findings of observational studies need to be interpreted with caution when compared with the results of laboratory studies. Although laboratory- and field-based studies still differ in measuring the impact of shift work, a combination of research designs and utilisation of advanced technology seem promising in narrowing the gap.[47 55] In general, we might underestimate our pooled effects due to the healthy worker effect, since the remaining employees tend to be healthier than their counterparts leaving shift work.[56] We encountered similar methodological challenges for neurobehavioural performance (eg, heterogeneous definitions and measurements, unprecise exposure assessments) as do other meta-analyses regarding shift work and health outcomes, which ultimately limit quantification of epidemiological risk assessment.[57]

Consequently, we highly recommend replication of analysis when an appropriate body of high-quality literature is given to further specify the impact of shift work on neurobehavioural performance.

Practical implications

Taking all the limitations into consideration, reduced performance in the examined neurobehavioural domains might contribute as a meaningful factor in explaining work-related errors or injuries. Specifically tasks of high-risk and safety-sensitive shift work professions heavily rely on consistent levels of neurobehavioural functioning to secure occupational health.

For example, Westbrook *et al*[58] investigated associations between working memory and task errors of emergency department physicians in a real-life clinical environment. The results showed that physicians with lower scores in working memory significantly increased the risk of clinical and procedural prescribing errors (eg, wrong drug, incomplete order). Additionally, decreased psychomotor vigilance, which can be used as a an assessment for fatigue due to sleep loss, has been connected to impaired attention in nurses, which is commonly reported as a contributing factor to self-injuries or errors in patient treatment.[59 60]

Furthemore Hasanzadeh *et al*[47] examined the relationship between visual attention and work-related injuries of construction workers in a real-life environment. The results showed that subjects with decreased visual attention were less likely to identify tripping hazards, which would lead to injuries.[47]

Finally, occupations involving life-threatening situations need to be addressed. For example, decision making during stressful training in police officers is associated with processing speed and cognitive control.[61] Studies with reality-based training scenarios showed that lower scores in inhibitory control were associated with negative health and safety outcomes. Therefore, police officers with higher inhibitory control are less likely to engage in risky behaviours.[61] Similar results could be found in a study that included firefighters and paramedics, with both showing reduced performance in cognitive inhibition leading to higher risk of error occurrence.[62]

According to our results, processing speed (g=0.16), working memory (g=0.28), psychomotor vigilance (g=0.21) and visual attention (g=0.19) notably differ in magnitude of effect size in comparison to cognitive control (g=0.91). Cognitive control is an executive function including cognitive processing and flexibility as well as the ability to focus on one stimulus when a second stimulus is simultaneously given. Therefore, this neurobehavioural domain is particularly important for occupational performance since it ensures adequate and accurate decision making. Workers with high performances in cognitive control show more effective adaptions to altering environments, high monitoring of important stimuli leading to a general higher quality of work, productivity and fewer errors.[45 63]

Specifically for shift work professions that are high-risk and safety-sensitive (eg, healthcare providers, security personnel, industrial/constructional workers, etc) high levels of cognitive control seem promising to prevent adverse outcomes for workers and possible third parties.

CONCLUSIONS

This meta-analysis provides the first summarising results regarding significant association between shift work and decreased performances in processing speed, working memory, psychomotor vigilance, cognitive control and visual attention. We highlight the potential impact of impairment in these neurobehavioural domains on occupational health and safety. Due to the discussed limitations of data, however, exact quantification of shift working as an epidemiological risk factor remains challenging. Therefore, we present multiple methodological recommendations for future studies to improve quality of research leading to a deeper understanding and more precise estimation of the association between shift work and neurobehavioural performance. As a conclusion, protective countermeasures (eg, naps, recovery plans, regular monitoring) for reduction in neurobehavioural performance of shift workers should be promoted to minimise the risk of adverse health and work-related outcomes. When a more consistent body of high-quality literature is available, we highly recommend replication of analysis to develop practical interventions to overcome neurobehavioural impairment.

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