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Iwan Sugiarta
PT. Prodia Occupational Health Indonesia; The Occupational and Environmental Health Research Center, Indonesian Medical Education, Research Institute (IMERI), Faculty of Medicine, Universitas Indonesia, iwan.s@prodiaohi.co.id

Dewi Yunia Fitriani
The Occupational and Environmental Health Research Center, Indonesian Medical Education, Research Institute (IMERI), Faculty of Medicine, Universitas Indonesia; Occupational Medicine Specialist Study Program, Department of Community Medicine, Faculty of Medicine, Universitas Indonesia

Muchtaruddin Mansyur
The Occupational and Environmental Health Research Center, Indonesian Medical Education, Research Institute (IMERI), Faculty of Medicine, Universitas Indonesia; Occupational Medicine Specialist Study Program, Department of Community Medicine, Faculty of Medicine, Universitas Indonesia

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Review

Vigilance Screening Tools in The Workplace: Scoping Review

Iwan Sugiarta [1,2*], Dewi Yunia Fitriani [2,3], Muchtaruddin Mansyur [2,3]
[1] PT. Prodia Occupational Health Indonesia.
[2] The Occupational and Environmental Health Research Center, Indonesian Medical Education Research Institute (IMERI), Faculty of Medicine, Universitas Indonesia.
[3] Occupational Medicine Specialist Study Program, Department of Community Medicine, Faculty of Medicine, Universitas Indonesia.
*Email: iwan.sugiarta@gmail.com

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ABSTRACT

Introduction. The vigilance performance examination is currently used widely in many disciplines, including neurophysiology, sleep medicine, and psychology to its application to workers whose daily activities require prime vigilance. A more objective inspection of vigilance has not yet become a routine screening examination for workers to detect decreased vigilance as part of a fit-to-work assessment, but only in the form of research/study using a partial sampling technique. The aim is to provide an overview of vigilance screening tools in the workplace, their terminologies, and how the process of maintaining quality such as calibration and validation.
Methods. A literature search was independently conducted from the PubMed database. We are looking for only articles that meet the following criteria: discussions on the terminology of vigilance, or research on workers that use vigilance examination tools, or research that develops its examination tools.
Results. Three articles were found that specifically discussed the term vigilance, 30 studies on workers that used vigilance performance examination tools, and 15 studies discussing the development of these tools. The definition of vigilance is still not firmly established and has been used interchangeably and leading to confusion. Workplace research has used product-based smart devices rather than dedicated hardware, as well as a number of studies that have focused on tool development.
Conclusion. Vigilance is the capability to be aware of potentially relevant or capability to be sensitive to unpredictable changes in one's environment including a quantitative and a temporal dimension. Although vigilance testing may not pinpoint the exact cause of vigilance decrement, using it as a screening tool in the workplace holds great potential. Smart device-based tools are relatively easy to obtain and inexpensive, but face enormous challenges related to calibration issues, validation issues, manufacturer's service of life, and firmware updates. It's important to consider vigilance screening tools with low-cost, portable, robust, future-proof, and easily validated with clear calibration or validation methods.

INTRODUCTION

To our knowledge, while working as an occupational medicine practitioner in Indonesia, several companies implement simple screening tests for fatigue or sleep deprivation in workers. Their purpose in carrying out those screenings is to filter out if there are workers who are not fit to work which can pose a risk of accidents while working, for example, drowsiness or lack of focus. Commercial vehicle drivers, heavy vehicle operators, machine operators, train drivers, or even emergency room doctors/nurses are an example of occupations that need prime vigilance. Those tests include checking balance, pulse, and filling out questionnaires about sleep adequacy or fatigue-related symptoms. A more objective inspection of vigilance has not yet become a routine screening examination for workers to detect decreased vigilance as part of a fit-to-work assessment, but only in the form of research/study using a partial sampling technique.

Additionally, there are several employee medical check-up providers who offer alertness screening services in Indonesia, such as the Lakassidaya examination. Informal information that we obtained suggests that this examination has a lower sales volume compared to other worker health checks such as audiometry, spirometry, neuromuscular-skeletal, psychosocial assessment, drugs/substances abuse monitoring, or biological monitoring. But we do not have detailed information about the reason for that lower sales volume. It could be due to less competitive pricing or a lack of understanding by practitioners in the industrial world about that examination or other technical problems.

Reaction time (RT) examination is widely used to assess the speed of RT in a person. This examination assesses a person's speed in responding (e.g., pressing a button) to a stimulus (e.g., audio, visual). Simple RT was first studied by Francis Galton in 1884-1893 and it was found that the speed of visual RT in respondents aged 18-60 years ranged from 181-189 milliseconds (ms). However, in 1911 Galton died and had not had time to publish details of the procedures and analysis of the data he collected.[1]

The speed of a person's RT is closely related to the vigilance mechanism or sustained vigilance mechanism in the brain. Vigilance or sustained attention is the ability to be aware of the relevance and unexpected changes in the environment, regardless of whether these changes occur or not.[2] The definition of vigilance includes being alert to avoid threats or danger, and ready to detect and respond to changes in the environment, including the quantity and possible decline over time. In other words, vigilance is the ability to be alert, to be prepared by giving ongoing attention to any changes in the environment, and to be able to quickly respond appropriately. Vigilance or sustained attention mechanisms that exist in the brain involve several underlying physiological functioning mechanisms. And its mechanism has some brain functional pathways that related one to another such as the brain-stem–thalamic–cortical, suprachiasmatic nucleus–circadian, hypothalamic-pituitary-adrenal axis, and limbic system.[3]

The various modalities of RT examination are in line with technological developments, such as simple chronoscopes, manual sticks/rulers, dedicated batteries, or software on personal computers to mobile applications based on Android®/IOS®. Crabtree and Antrim wrote a guideline on examining RT in 1988 and stated that their writing was not a definitive or complete suggestion but rather a guide and a means of a checklist to be adapted to the research to be carried out.[4] To date, several variations of the examination appeared very similar one to another, such as simple reaction time (SRT), choice reaction time (CRT), and psychomotor vigilance task (PVT) as well as variations in their respective methods. These variations may depend on how a user/researcher plans to utilize them.[5] The range of RT values has become wider in recent times, with some people now exhibiting slower RTs compared to those measured in the mid-20th century.[6,7] It is unclear what specific development or factor led to this change in RT values: changes in technology, lifestyle, or environmental factors have influenced the range of RT values over time. The decrement in RT after the year 2000 has become a concern for some researchers.

Silverman's (2010) article stated that the increase in RT is based on 4 hypotheses: (1) people have grown taller over the last 150 years, nerve impulses must travel farther as the body lengthens; (2) the sedentary lifestyle has become more common; (3) increased by the buildup of neurotoxins in the environment, such as lead, trichloroethylene, and mercury; (4) based on the idea that the adult population has changed over time, in some ways for the worse.[1] But all these hypotheses still require further study to answer them, stressed for increased levels of environmental neurotoxins and declines in infant and child mortality rates. As experimental psychologists have not shown much interest in standardizing their tests, he suggests standardizing the testing procedure for RT with respect to the size, intensity, and duration of the stimulus and the number and pacing of the test trials.[1] And this is in line with the condition that currently there is "no-definitive" gold standard examination.[8,9]

By conducting this scoping review, we hope to provide an overview of vigilance screening tools in the workplace setting, which includes the vigilance terminologies and tools used (in terms of quality control such as calibration and validation). We also aim to evaluate each tool's modality, highlighting their respective advantages and disadvantages and how these can be applied to improve workplace safety and productivity.

METHOD

Research Question

By synthesizing some of that information, we have a substantial question regarding vigilance examination tools:

1. What is vigilance?
2. How is the implementation of the use of vigilance examination tools in assessing worker vigilance, especially regarding the type of tools, its quality control procedures, and its development?

Search Strategy

This scoping review is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) extension for scoping reviews (PRISMA-ScR) checklist.[10] We conducted a literature search on PubMed databases. The predefined keywords used in the article search were: adults, workers, psychomotor performance, reaction time, neuropsychological tests, fatigue, vigilance, and alertness. The use of MeSH (Medical Subject Headings) is carried out so that the results of the tracing process become more specific, they were: "adult"[MeSH Terms], "Psychomotor Performance"[Mesh], "Reaction Time"[Mesh], "Neuropsychological Tests"[Mesh], "fatigue"[MeSH Terms], "vigilance, cortical"[MeSH Terms]. The search focused on articles in English and published between 2013-2023.

Inclusion and Exclusion Criteria

The inclusion criteria in the search used were:

1. Study the terminology of vigilance, or
2. Studies that use vigilance/reaction times examination tools in workers, or
3. Study the development of vigilance examination tools.

Exclusion criteria: research respondents were children; other than English; abstracts and manuscripts not available; and publications were not in the 2013-2023 range.

Data Selection

A literature search using predefined keywords. To ensure effective screening of articles that do not meet the inclusion criteria, we also used MeSH query and filters to apply these exclusion criteria, which are tools that help narrow down search results based on specific criteria. They were child respondents, non-English language manuscripts, availability of abstracts and manuscripts, and publications outside the 2013-2023 year. The first stage is sorting literary works based on titles and abstracts. Then proceed with the search results summarized by search flowcharts dan search results tabulation.

A total of 10,374 articles were initially retrieved after conducting a literature search with the predefined keyword, MeSH term, and filter configuration. Of these, 10,198 articles were excluded from the review as they did not meet the search criteria based on keywords in the title or abstract. We use a third-party text viewer application to assess efficiently the relevance of titles and abstracts extracted from PubMed to inclusion criteria. After screening relevant titles and abstracts, a total of 176 articles were selected for further analysis into manuscripts based on inclusion and exclusion criteria. Further analysis led us to exclude 122 articles because the study did not involve workers as respondents. We identified five articles that focused on developing examination tools but primarily through data modeling, rather than evaluating the tools themselves. One article did not provide clear specifications regarding the tool being validated. Out of the 48 included articles, 3 discussed the about of vigilance, 30 utilized a tool for vigilance or reaction time examination in workers, and 15 discussed the development of a new tool.

The flowchart (**Figure 1**) provides a visual representation of the literature screening process conducted in this scoping review. The screening process involved multiple stages to assess the relevance of each article according to our inclusion-exclusion criteria. We evaluated the titles, abstracts, and full texts of the articles to determine if they met the criteria for inclusion in the review. This approach enabled us to comprehensively evaluate the articles and ensure that only relevant studies were included in the review.

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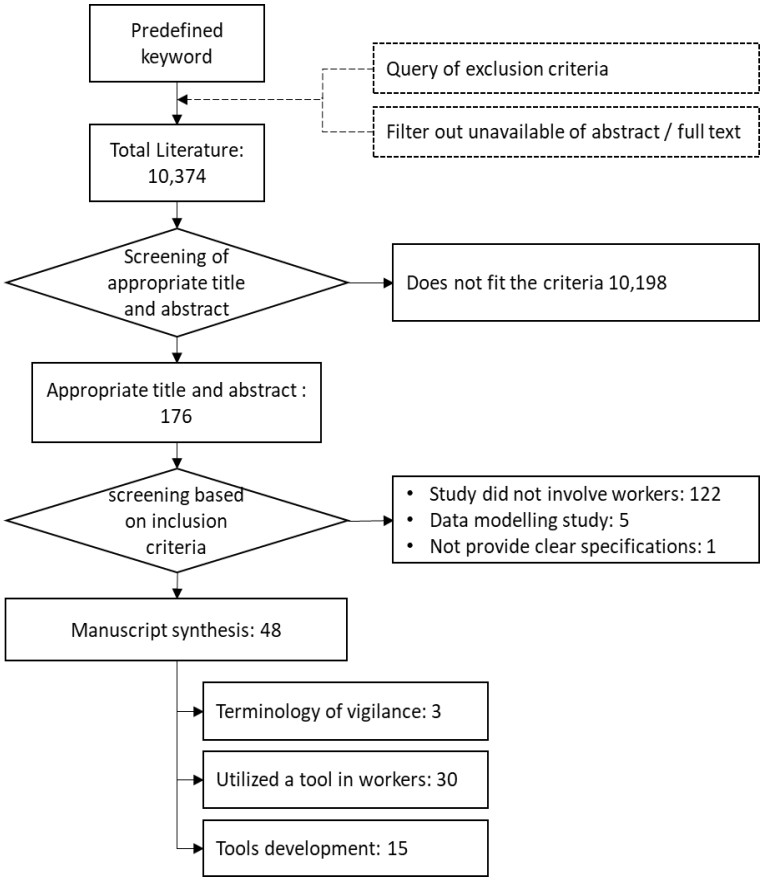

Figure 1. Screening flowchart

RESULTS AND DISCUSSION

Vigilance Terminology

We found a limited number of articles that specifically discussed the term "vigilance", but we came across one recent article by Klösch (2022) titled "*Revisiting the Concept of Vigilance*", which presented a clear and straightforward discussion. Additionally, we found an article written by van Schie, et.al. (2021) entitled "*Vigilance: discussion of related concepts and proposals for a definition"*, and another article by Hudson, et.al. (2020) that focused on sleep deprivation, vigilant attention, and brain function. Based on the titles of these three articles, it appears that the definition of vigilance is still not firmly established.

Gerhard Klösch, et.al. (2022): *Revisiting the Concept of Vigilance*

Klösch and colleagues in their article informed that the concept of vigilance has been used interchangeably with sustained attention and wakefulness, leading to confusion and unclear definitions.[11] The term of "vigilance" has been defined in various ways in psychology, physiology, and sleep research, leading to confusion and ambiguity.[11] Klösch stated that the original definition of vigilance by British neurologist Henry Head in 1923 referred to the organism's ability to reorganize itself and restore damaged functions, including the ability to differentiate between sensory stimuli. This definition emphasizes the physiological aspect of vigilance and its role in ensuring the survival of the individual. Head identified three sub-categories essential to vigilance: perception, behaviors, and reorganization, and the last sub-category that caused confusion and criticism arose over the concept of reorganization, which was unclear and inconsistently used by Head himself.

Klösch and colleagues discuss the term vigilance from several perspectives: experimental psychology, neurophysiological, and sleep-wake cycle. In experimental psychology, vigilance refers to the ability to sustain attention over a prolonged period of time, as well as to detect rare events in monotonous situations.[11] Vigilance tasks were developed in the 1940s, particularly for military defense strategies. However, there is no standardization for measuring vigilant performance and interpreting results, leading to alternative explanations and terms such as tonic alertness or vigilant attention.[11] The concept of vigilance is based on the neurophysiological findings that support the role

of the ascending reticular activation system (ARAS) in maintaining wakefulness and alertness. The EEG is considered to be the ideal representative of vigilance as it enables the time-synchronous coupling of neuronal activity with observable behavior. Attempts at classifying the waking state have existed since the late 1950s, and various vigilance indicators have been proposed, but there is still no consensus on the most suitable method for measuring vigilance.[11] And according to the sleep-wake cycle, that wake and sleep are not fundamentally opposite entities; they differ only by their vigilance profiles.[11] Vigilance tasks are important in the diagnosis of sleep disorders to point out the consequences of poor sleep on daytime sleepiness, fatigue, or tiredness. However, there is a lacking a comprehensive concept of vigilance in basic sleep research, which could be improved by approaches with attention triggered by cues, inwards or outwards oriented. The role of awareness in the context of vigilance needs further discussion.[11]

The concept of the vigilance mechanism discussed by Klösch, and colleagues involves 3 perspectives. (1) *Vigilance has a role to allocate all resources*, it means that the state of wakefulness and alertness are the biological resources that must be allocated and managed to ensure adequate responses or reactions and to adapt to changing environmental conditions.[11] Because vigilance is a very fundamental characteristic for both humans and animals in defending themselves from certain conditions or the surrounding environment, thus it requires appropriate and quick responses to all sensory information to maintain bodily functions through the autonomic nervous system. (2) *Vigilance as a trigger for subsidiary behaviors*, means that when a person's vigilance level is in declining or low level, the vigilance mechanism can trigger automatic behaviors or compensatory reactions, such as yawning, stretching, or other self-stimulating behaviors.[11] When these additional behaviors appear, we can observe and measure that decrement signals as part of vigilance monitoring. (3) *Vigilance is embedded in environmental interactions*, this shows that the vigilance mechanism does not depend on one's internal conditions alone (level of alertness, awareness, or attentiveness), but external factors such as environmental conditions can also have a big influence to its mechanism.[11] Therefore, when we observe and measure someone's vigilance levels, we must not forget to consider environmental factors as part of our unified observation and assessment.

In Klösch and colleagues' article, it is explained that among several examination modalities related to the assessment of fatigue and tiredness, it is known that the relationship between these examinations is weak.[11] Subjective assessments of fatigue or tiredness in some people may not align with objective measurements. In their article, Klösch provides an overview of the factors that might cause that misalignment between objective and subjective measurements: a person's perception of fatigue or tiredness can be varied, thus everyone has their own way of expressing their behavior, or limitations of accuracy and reliability in the measuring instruments used can also cause that misalignment.[11] These findings provide us with input that we need to conduct a thorough assessment when assessing fatigue and tiredness in a person by combining objective and subjective assessments.

Mojca K.M. van Schie, et.al. (2021): *Vigilance: discussion of related concepts and proposal for a definition*

Meanwhile, van Schie and colleagues proposed a new definition of vigilance in sleep medicine that is distinct from the concepts of alertness, arousal, and attention.[2] Alertness is defined as a quantitative measure of sensitivity to stimuli, while arousal is defined as a stimulus-induced upward change in alertness. Vigilance is defined as the capability to be sensitive to potential changes in one's environment, with quantitative and temporal dimensions. Attention adds direction toward a stimulus and requires cognitive control, while sustained attention involves purposefully maintaining attention over time. Vigilance differs from sustained attention in that it lacks a specific direction but shares some similarities in how it is measured. van Schie and colleagues propose a comprehensive definition of vigilance with three key aspects: (1) a state of being watchful for danger, (2) a quantitative aspect measuring the level of vigilance, and (3) a temporal aspect with vigilance decreasing over time in a non-stimulating environment. The proposed definition defines vigilance as the capability to be aware of relevant, unpredictable changes in the environment with two dimensions: the level of alertness required for being vigilant and the temporal aspect of vigilance.[2]

Vigilance is essential for sustained attention, but sustained attention is directed towards a specific task, whereas vigilance is alertness to any relevant new happening. Measuring sustained attention can be regarded as a method to assess vigilance quantitatively, but sustained attention does not always imply vigilance.[2] Tests of sustained attention require responses, but a failure to respond might be interpreted as impaired vigilance, which could increase confusion. Vigilance can be measured through sustained attention tasks, in which participants are asked to detect changes in the environment by responding to appearing or changing stimuli.[2] Performance on such tasks can be scored using measurements of accuracy, speed, or both. However, it's important to note that

sustained attention tasks will not be specific for impairments in vigilance or attention and should always be interpreted in a broader context, evaluating interference of response characteristics.[2]

Amanda N. Hudson, et.al. (2020): *Sleep deprivation, vigilant attention, and brain function: a review*

Hudson and colleagues (2020) discuss how vigilant attention is affected by sleep deprivation and restored after rest breaks and sleep. Hudson discusses the PVT, which is a high signal-load reaction-time test that is extremely sensitive to sleep deprivation.[12] According to many researchers, PVT is a neurocognitive test that assesses vigilant attention, which is thought to serve as the foundation for other higher-order cognitive processes. The authors then examine four common patterns of behavior that are observed in tests of attention, the PVT, following sleep deprivation. These patterns include increased lapses in attention, slowed reaction times, increased variability in reaction times, and changes in response speed distribution.[12] The vigilance decrement, or time-on-task effect, is characterized by increasing response variability, which is exacerbated by sleep loss.

The impairment of vigilant attention across hours and days is driven by sleep regulatory processes, including a sleep homeostatic process, a circadian process, and an allostatic process. Inter-individual differences exist in vulnerability to sleep loss.[12] The impairment of vigilant attention variability is not well explained by top-down regulatory mechanisms, and a bottom-up, neuronal pathway-dependent mechanism involving local sleep may be the main driver of response variability.[12] This mechanism may also explain the dissociation between cognitive processes regarding trait vulnerability to sleep loss.

Based on those three authors, the lack of a clear and precise definition of the term vigilance has undoubtedly hindered research efforts aimed at understanding its underlying mechanisms and the impact of sleep deficits on it. Here is a summary of terms that we can extract from articles to help us understand how they differ from one another:

- *Vigilance* is the capability to be aware of potentially relevant, the capability to be sensitive to unpredictable changes in one's environment, including a quantitative dimension (sufficient level of alertness), and a temporal dimension.[2,11]
- *Attention* is an ability to watch, listen to, concentrate, direct towards a stimulus, or focus one's mind on something/someone with interest (requires cognitive control).[2,11]
- *Sustained attention* or *vigilant attention* is an ability to maintain focus and stability across long time intervals for a task, purposefully maintaining attention over time.[2,11]
- *Vigilance decrement* is the decline in timely and correct responses.[11]
- *Alertness* is a state of being awake, prepared to act/react, a quantitative measure of sensitivity to stimuli, it is also defined as the result of the interplay between circadian processes, sleep-homeostasis, and sleep inertia that is influenced by time-awake, time-on-duty or time-on-task.[2,11]
- The two terminologies between vigilance and sustained attention / vigilant attention have overlapping scopes, hence they are often used interchangeably with one another.
- There is still no agreement on the main characteristics of a vigilance task (duration of test, stimulus type, their temporal order) and how obligatory outcome measurements are expected (performance characteristics, response definitions, etc.).[11]

In our simple perspective on how the PVT examination is carried out, there are 3 important checkpoints in the PVT examination that can influence the final measurement results: (1) external sensory input (visual or auditory stimuli), (2) stimulus processing (as per in three articles above), and (3) motor response (button pressing by fingers). The reception of sensory input is greatly influenced by the sensory organs themselves, such as the refractive ability of the eye, the condition of the eardrum and hearing bones, and the health of the retina or hair cells in the organ of Corti. Even the ratios of stimulus intensity to background conditions (signal-to-noise ratio concepts) can also influence it. Motoric movements in the muscles and joints of the fingers (pressing a button in response to a stimulus) can also influence the objective measurement outcome. As an illustration, starting from how the motor command first appears in the brain, then spreads through the nervous system to the fingers; along that route there are several potential checkpoints that can cause interference: among them are the pathways of the nervous system itself, the condition of the muscles and joints of the fingers including blood circulation which provides oxygen and nutrients to the muscles. So that we can understand that there are numerous factors involved in vigilance, that are not solely in the brain, and it would be unwise to ignore any of them when assessing worker vigilance.

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Implementation of the use of vigilance examination tools in assessing worker vigilance and its development

The scoping review discovered a total of 30 articles that utilized vigilance examination tools to study workers across various professions and conditions. Among the occupational categories, health services had the highest number of related articles (11 articles or 36.6%), followed by transportation (6 articles or 20%). The review also found that most studies were observational (80%), while only one was a systematic review that specifically analyzed experimental research on emergency medical services personnel. Please refer to the supplementary material **Table S1** for study details.

The tool modalities used to conduct the examination in studies involving workers were found to be quite diverse as displayed in **Table 1**. The most used tool for this purpose was the PVT examination tool based on Palm® PDA, which was used in 4 studies (13.8%). Three studies (10.3%) used PVT-192, while another three studies (10.3%) used tablet-based PVT. Additionally, two studies each (6.9%) used laptop-based PVT and smartphone-based PVT. However, there were 11 studies (37.9%) that did not provide any information about the hardware or software specifications of the PVT used. There were 2 studies each using the simple reaction time and 5-choice reaction time methods.

Table 1. Tabulation of the vigilance examination tool

Category	Total	%	Calibrated#	Validated#	Duration			
					3-Min	5-Min	10-Min	Unknown
Unknown PVT*	11	37.9%		1	2	1	6	2
PVT Palm PDA Based	4	13.8%		2	2	2		
PVT-192	3	10.3%		2		1	2	
PVT Tablet Based	3	10.3%		3	2	1		
PVT Laptop Based	2	6.9%	1	2	2			
PVT Smartphone Based	2	6.9%		2	1	1		
PVT PC Based	1	3.4%		1		1		
PVT Wrist-worn Based	1	3.4%			1			
SRT Web Online Application	1	3.4%			number of trials: 5			
CANTAB Battery (SRT & 5-CRT)	1	3.4%			number of trials / duration: unknown			
Total	29	100%	1 (3.4%)	13 (44.8%)	10 (37.1%)	7 (25.9%)	8 (29.6%)	2 (7.4%)

*the use of examination tools in systematic review study is excluded from this tabulation
#based on the information contained in the manuscript (stated or not stated)

When classified to the type of hardware they use, we try to divide it into three categories: dedicated hardware (4 or 22.2% studies), computers/laptops (4 or 22.2% studies), and smart devices (10 or 55.5% studies). The unknown category has been excluded from the count. The prevalence of smart devices as the most utilized technology aligns with our literature research, which did not yield any studies that focused on the design and implementation of hardware-specific tools. And we found 3 studies that two authors have different opinions regarding the acceptable levels of measurement bias and variability in PVT outcomes.[13–15] Please refer to the supplementary material **Table S2** for details.

Out of all the examination tools used, only one study stated clearly in its manuscript that the tool used had undergone calibration.[16] However, that study did not provide detailed information on the calibration mechanism or its results. The lack of established guidelines or widely accepted procedures for calibrating these systems, which would ensure accurate and reliable measurements, may be related to the issue at this time, thus very few studies inform about calibration.[13] The limited information about the calibration mechanism or its results had almost the same effect as studies that did not provide any information at all. This limited information raises doubts when attempting to combine the data with the results of other studies for further analysis.

There are 13 (44.8%) of 29 studies mentioned that the tools used had undergone a validation process with varying degrees of clarity in their reporting formats. It should be noted that some studies made vague claims about the validity of their tool, such as stating that the PVT was a validated tool without providing further context. On the other hand, some studies may have used validated tools but did not explicitly state this in their manuscripts. To illustrate, an example of explicit reporting is, *"…To monitor performance on duty days, participants were asked to undertake a validated 5-min version of the psychomotor vigilance task (PVT) on a Palm Centro®…"* [17]; whereas an example of vague reporting is, *"…The brief 3-min version of the Psychomotor Vigilance Test (PVT), similar to*

the one reported by Basner et al. (2011), evaluated sustained attention and response time... " [18], without providing any related further explanation. This ambiguity can pose a challenge in determining the validity of the instrument used in a study. And the effect will be even greater if added points about calibration as previously described.

Regarding calibration and validity issues, there is one study that uses an SRT test based on an online application that caught our attention, which has relatively high RT results in general. Agustiningsih and colleagues (2021) examined the effect of lead exposure on neurocognitive performance among batik workers in Yogyakarta – Indonesia, aged 40 (18-59) years (median (min-max). As a result of RT, the group of batik workers who were exposed to lead was 0.970 ± 0.206 seconds, while the group of workers who were not exposed to lead was 0.772 ± 0.052 seconds (mean±SD) and had a significant difference mean between the groups ($p < 0.001$).[19] If that measurement result is converted to milliseconds, then the result is 970 ms and 772 ms. Meanwhile, when the reaction time is greater than 500 ms, it's generally defined as "lapses".[5,20] Since the author did not provide any information in detail about the computer specifications or the calibration or validation or the measurement procedure, we are left with questions about these factors, as well as internet speed and related procedures, which could explain the comparatively high mean reaction time for both the exposed and non-exposed groups. Or is it possible that socioeconomic factors also affect a person's reaction speed in general? All these still require further research.

The second study that caught our attention was a systematic review study conducted by Martin-Gill (2017) that found the effect of naps on RT measured at the end of the shift was small, and the difference between the nap and no – nap condition was non-significant.[21] In addition to the authors acknowledging the limited sample size as a potential limitation, we suspect that another contributing factor could be the adequacy of the calibration and validation procedures for the utilized tools. We also suspect that the findings about the small effect of naps on reaction time measured at the end of shift and the difference between the nap and no – nap condition was non-significant, most likely because the analytical calculations are based on 3 examinations that differ in methods and procedures of each examination (Mackworth Clock Vigilance Task, 10-min PVP, and 2-choice visual RT). Further investigation is necessary to confirm. We really appreciate the author's hard work that makes the knowledge about vigilance performance become more extensive and richer in the midst of the difficulty of getting the ideal data as expected.

Related to the lack of established guidelines or widely accepted procedures, we found 1 original article that proposed acceptable levels of measurement bias and variability in PVT outcomes and then got responses from other authors. The two authors have different opinions regarding the acceptable levels of measurement bias and variability in PVT outcomes. Basner et al. (2021) recommend a bias of less than 5 ms and a standard deviation of bias of less than 10 ms to minimize the risk of biases in PVT systems.[13] While the other authors believe that the proposed thresholds may be unnecessarily strict and suggest that the maximally allowable margins for PVT recording systems should depend on the application and expected effect sizes.[14] However, both authors agree on the importance of accurate system calibration and reporting system latency bias and variability in PVT studies.[13–15] They both emphasize that using PVT systems with inadequate calibration can lead to increasingly biased results and decreased effect sizes, which may be unacceptable for certain applications such as research or fitness-for-duty assessments. Therefore, researchers should strive to achieve the least amount of system latency bias and variability possible, but until such standards can be easily achieved, sleep research can still benefit from the PVT performed on a variety of equipment and calibration standards.[14]

When examining each of the hardware categories utilized by these tools, it becomes necessary to evaluate the respective advantages and disadvantages of each, as these may have influenced the study's choice and use of these technologies. Dedicated hardware-based examination tools are certainly believed to have gone through a long process, including calibration, validation, and other quality control/assurance-related mechanisms. It is undeniable that these various control processes affect production costs and selling prices. One of the dedicated hardware-based is PVT-192, both bulkiness and the high price are likely prohibitive for their use in large-scale studies.[20] In many cases, the most practical and, at times, the only viable solution is to conduct testing on commercially available computers or mobile devices.[14]

The widespread availability of mobile devices and advancements in technology seem to be the primary reason why these studies have gravitated towards utilizing them, particularly those studies focusing on workers. The accessibility and mobility of examination tools on smartphones, tablets and laptops is undeniably convenient, and the cost is relatively lower compared to dedicated hardware. The drawback of PC-Desktop based when compared to smart devices or laptops is that their mobility is very limited. In addition, several studies included in this scoping review have undergone validation

tests to ensure that their "alternative tools" can function as well as reference tools even though the reference tools used also vary.

Despite the numerous benefits of consumer hardware, each device has unique features that may impact the performance of examination for vigilance, which typically operates at high speeds, measured in milliseconds. Research has demonstrated that personal computers (PCs) are inherently limited when it comes to measuring processing time accurately, as their capacity for precise time measurements is heavily reliant on various factors such as the type of computer, processing speed, hardware specifications, and software.[22]

The classic problem that can significantly slow down the performance of the smartphone itself is latency (the time delay between someone touching the screen until the system registers it as a response).[23] A study conducted by Schatz in 2015 found that there were significant differences in timing accuracy when the same test procedure was applied to several types of smartphones with different operating systems.[22] This suggests that even if the same test is conducted on different devices, the results may not be consistent due to differences in device specifications and operating systems. This highlights the importance of considering these factors when selecting and using examination tools to ensure accurate and reliable results. According to a study by Arsintescu (2017), the position of a smartphone, either in landscape or portrait mode, can also affect the performance of the PVT examination tool.[23] This indicates that the orientation of the device during testing can have an impact on the accuracy and reliability of the results. By being aware of this potential factor, researchers and practitioners can take appropriate steps to minimize variability in their findings and ensure more reliable outcomes.

As technology evolves, it is inevitable that consumer devices will need to be updated or replaced over time. This can happen due to changes in hardware specifications or software updates to the operating system that the device runs on, such as Windows®, MacOS®, Android® or iOS®. Manufacturers typically produce consumer products for a limited period, after which they may discontinue support for older models and focus on newer ones. In fact, research has shown that a PVT application, which was calibrated and validated using a 4th generation iPad®, experienced “issues” when the app was transferred to an iPad Air®.[20] Even though the manufacturer of Palm® personal digital assistants (PDA) is believed to have retired between 2010-2011, we still found 4 (13.8%) studies that still use PDA-based as a basis for the tool.[24] That's the challenge, while we attempted to utilize the most modern devices, running the most current operating systems, technological advances often occur faster than scholarly empirical research.[22] It can be a never-ending challenge to continuously validate and re-validate examination tools or apps on new devices or new updates of the operating system. This process can become more challenging if there are no established guidelines or widely accepted procedures to calibrate or validate these systems as discussed above. We assess that this condition will be the biggest challenge if we use smart-device-based tools besides calibration and validation issues.

Bilder (2019) in his article stated that clinical neuropsychological assessment today does not reflect advances in neuroscience, modern psychometrics, or technology.[25] We concluded his article as the new technologies, such as computerized adaptive testing, Web-based assessment, healthcare- and bio-informatics strategies, mobile platforms, wearables, and the Internet-of-Things, present opportunities to revolutionize neuropsychological assessment practices worldwide. To overcome resistance to change, new methods should be back-compatible with legacy instrumentation, allowing for the leveraging of validity data already accumulated for classic procedures.[25] To achieve this, a global network can be created to aggregate item-level data into a shared repository, enabling modern psychometric analyses to refine existing methods and serve as a platform to develop novel assessment strategies.[25]

Of the several examination tools used in each study on workers, we only find one author who clearly explained that the tool can connect to an internet connection, but not clearly stated that had implemented integrated data management for easy data collection and analysis.[26] Reifman (2018) in his development study has applied a unified model of performance to predict how alert a person is based on their sleep schedule, caffeine intake, and time of day.[27] Those are significant steps forward that we really appreciate. Internet-of-Things (IoT) in Industry 4.0 and Artificial Intelligence (AI) in Industry 5.0 are believed to be great opportunities that need to be empowered for the development of science, especially the ease of researchers in carrying out their research. In terms of a large-scale study, the ease and speed of collecting data from several remote locations simultaneously via the internet from low-cost tools can certainly save time and research costs. Then with the help of big data technology will deal with large arrays of data, enabling the derivation of information relevant to rapid decision-making.[28]

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CONCLUSION

Vigilance is the capability to be aware of potentially relevant or capability to be sensitive to unpredictable changes in one's environment including a quantitative and a temporal dimension. It's important to understand that vigilance is a complex mechanism influenced by multiple factors, rather than a simple process controlled solely by the brain or sleep deprivation, but also various internal and external sensory organs, and any other factors that affect this mechanism. Although vigilance testing may not pinpoint the exact cause of vigilance decrement, using it as a screening tool in occupational settings holds great potential. In determining the root cause of vigilance decrement, the role of an occupational doctor is crucial.

Based on this scoping review, smart devices were the most widely used as vigilance examination tools among researchers (55.5% of studies). However, the lack of significant information on quality control procedures, particularly calibration, and validation, raises concerns about the reliability of the results obtained. It is essential to carefully select examination tools based on the specific terminology and objectives of the research being conducted. Vigilance assessment requires a tool capable of quantitatively measuring a person's alertness and temporal awareness. The PVT-192 has been identified as a suitable option for vigilance examination, but expensive and bulky are the main barriers to their use on a large scale or in workplaces.

Finally, we agree that smart-device-based tools are relatively easy to obtain and inexpensive, but face enormous challenges related to calibration issues, validation issues, manufacturer's service of life, firmware updates, and other things. To ensure the effectiveness and reliability of vigilance screening tools for workers, it is advisable to explore more cost-efficient, portable, robust, and future-proof tools that can be easily validated with clear calibration and validation methods. Such an approach will ensure that the chosen tool remains efficient over time, even with updates or new specifications.

LIMITATION

The primary limitation of this scoping review was attributable to the broad definition and contexts of psychomotor performance or vigilance or reaction time, which could have resulted in the exclusion of some relevant articles from our search strategy. Although this scoping review may not be able to provide in-depth qualitative/quantitative analytical data, we believe it can open our awareness to the importance of maintaining quality control and quality assurance processes so that research data becomes more reliable.

DECLARATION

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SUPPLEMENTARY MATERIALS

Table S1. Studies on workers using vigilance examination tools
Table S2. Development Study

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