# MANUAL

## PERCEPTION AND ATTENTION FUNCTIONS: VIGILANCE

Test Label WAFV

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## 1 SUMMARY

#### Author

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#### Application

Assessment of sub-functions of attention, suitable for respondents from the age of 7.

Main areas of application: neuropsychology; clinical and health psychology; aviation psychology; sport psychology

#### Theoretical background

Modern views of the dimensionality of attention can be summarised by the model proposed by van Zomeren and Brouwer (1994). One of the key features of this model is the distinction between the intensity and selectivity aspects of attention; each of these aspects can in turn be broken down into more specific components. The intensity aspect of attention comprises two elements, alertness and vigilance; alertness involves the short- and longer-term arousal of attention, while vigilance relates to the sustaining of this arousal. With regard to the selectivity aspect of attention processes the model distinguishes between focused or selective attention and divided attention.

The spatial orienting of attention is a separate, additional dimension. It does not form part of the model described above (Posner et al. 1978, 1984) but is included in more recent taxonomies (Sturm 2005).

Both Posner and Raichle (1994) and Fernandez-Duque and Posner (2001) distinguish three types of attention networks: a) Orienting (corresponds to the network of spatial direction of attention), b) Vigilance (corresponds to the intensity dimension) and c) Executive Attention (corresponds roughly to the selectivity dimension).

#### Administration

The WAF test battery consists of 6 tests that can be administered independently of each other or, as a test battery, in any desired combination. In addition, WAFW can be used to make a differential assessment of sensory impairments.

- **WAFW**: Pre-tests for attention functions
- WAFA: Alertness
- **WAFV**: Vigilance / sustained attention
- WAFS: Selective attention
- **WAFF**: Focused attention
- WAFG: Divided attention
- WAFR: Spatial attention and visual field / extinction neglect

For each of the WAF tests different test forms are available, enabling dimensions of attention to be assessed under different presentation modalities. There are thus separate subtests for visual, auditory and crossmodal presentation. In some subtests of the WAF test battery automated and controlled aspects of attention are measured separately; the stimuli either become more prominent because the intensity level is increased ("popping out"), or they become less prominent because their intensity is decreased and cognitively controlled "top down" processes are then required. Both attention processes are relevant in everyday life; both can interact and both can be selectively impaired, for example as a result of brain damage, since they are based on different cerebral networks (Corbetta & Schulman 2002).

#### WAFW

In order to exclude the possibility that perceptual impairments may influence the processing of the stimuli used in WAF, thus impeding reliable diagnosis, WAFW can be used before the start of an assessment to determine whether the respondent has the perceptual ability necessary for completion of the WAF tests.

#### WAFA

WAFA measures reaction time in response to simple visual or auditory stimulus material. The stimulus is presented either with or without a warning signal in the same stimulus modality or the contrasting one (intrinsic vs. phasic alertness). A special standardisation process enables fatigue or stress parameters to be measured.

#### WAFV

In WAFV the respondent is presented with visual and auditory stimuli that occasionally diminish somewhat in intensity. The person's task is to respond to these occasional cases; when sustained attention is being measured they constitute around 25% of the stimuli while in the case of vigilance they make up some 5% of the stimuli.

#### WAFR

The spatial orienting of attention is measured using either 4 or 8 spatial positions in a task similar to a Posner paradigm. Peripheral (exogenous) and central (endogenous) spatial cues are used. In the neglect test stimuli are presented at various positions in the right or left visual field or simultaneously in equivalent positions in both halves of the field of vision (extinction condition).

#### WAFF

The respondent is presented – depending on the subtest – with relevant visual or auditory stimuli against a background of distracting stimuli. The person's task is to respond when two predefined changes in relevant stimuli occur consecutively; all other stimuli are to be ignored.

#### WAFS

The respondent receives relevant and irrelevant stimuli in one or both presentation modalities; the task is to react to changes in the relevant stimuli while ignoring irrelevant ones.

#### WAFG

The respondent receives stimuli on two visual channels or on one visual one and one auditory one. The task is to monitor both channels to determine whether one of the stimuli changes twice in succession.

#### Test forms / subtests

#### WAFW 4 test forms

Separate forms for distinguishing brightness, distinguishing shape, distinguishing tonepitch and distinguishing volume

#### WAFA 2 test forms (standard form and short form), each with 6 subtests

Subtests: intrinsic (visual), phasic (unimodal visual), phasic (crossmodal visual/auditory), intrinsic (auditory), phasic (unimodal auditory), phasic (crossmodal auditory/visual)

**WAFV: 4 test forms**, 2 short forms (sustained attention 15 minutes) for children and young people

Separate forms for vigilance (visual), vigilance (auditory), sustained attention (visual), sustained attention (auditory). Separate short forms for sustained attention (visual) and sustained attention (auditory).

#### WAFR: 5 subtests

Subtests with either 4 or 8 stimulus positions and peripheral or central cues. In addition a test for visual field / neglect under extinction conditions.

#### WAFF: 3 subtests

Unimodal (visual), unimodal (auditory), crossmodal

#### WAFS: 3 subtests

Unimodal (visual), unimodal (auditory), crossmodal

#### WAFG: 2 test forms (standard form and short form), each with 2 subtests

Subtests: unimodal (visual), crossmodal

#### Scoring

In all WAF tests the reaction times and the various error types are scored. For most of the variables a norm comparison is also carried out, yielding percentile ranks and T scores.

#### Reliability

Especially given the short testing time, the reliabilities (Cronbach's alpha) obtained for the WAF tests are very good.

• WAFA

depending on test form and subtest between r=0.86 and r=0.98 (children and young people 0.92 - 0.97)

• WAFV

depending on test form between r=0.96 and r=0.99 (children and young people 0.96 - 0.97)

WAFR

depending on test form between r=0.88 and r=0.97 (children and young people 0.92 - 0.94)

WAFF

depending on subtest between r=0.93 and r=0.97 (children and young people 0.91 - 0.96)

• WAFS

depending on subtest between r=0.94 and r=0.97 (children and young people 0.93 - 0.94)

• WAFG

depending on test form and subtest between r=0.89 and r=0.97 (children and young people 0.96)

#### Validity

A study of the tests' construct validity involving a sample of N=256 adult respondents and 270 children and young people provided empirical confirmation of the theoretical model on which the WAF test battery is based and was able to distinguish it from other models.

#### Norms

For all WAF tests norms representative of the general population are available; the norms relate to N=295 individuals in the age range 16 - 77. The norms are available both for the sample as a whole and also separated according to educational level. In addition, all WAF tests provide raw scores adjusted for age effects for the main variables; this is a particularly efficient method of standardisation for age. A norm sample of N=270 children and young people in the age range 7- 17 is also available. For the short forms of WAFG and WAFA, norms representative of the general population are available for individual subtests; the size of the norm sample is N=309 for WAFG and N=313 for WAFA.

#### Time required for the test

The time required to complete the individual WAF tests is relatively short. It is therefore possible to create batteries of tests for complex assessment purposes without requiring too much of the respondent in terms of time or motivational commitment. It is usually not necessary to administer each test in all stimulus modalities. This must be decided by the user, taking into account any information about a patient's difficulties or disabilities that has already been gathered. The test results cannot be interpreted with confidence unless the client/patient meets the sensory and motor requirements for satisfactory completion of the test.

• WAFW

approx. 2 minutes for each pre-test

• WAFA

14 – 27 minutes, depending on test form

- WAFV 15 – 30 minutes, depending on test form
- WAFR approx. 5 minutes for each test form
- WAFF approx. 10 minutes for each subtest
- WAFS
  - approx. 8 minutes for each subtest
- WAFG
  - 12 30 minutes, depending on test form

#### Note

A standard USB headset is required for administration of the auditory and crossmodal subtests of the WAF tests.

## 2 DESCRIPTION OF THE TEST

## 2.1 Theoretical basis of the Perception and Attention Functions test battery

Attention functions are important for the successful handling of the tasks that the individual encounters in daily life. In all situations other than those in which we can apply highly overlearned routine behaviours the application of attention and continuous monitoring of our actions is required. Attention functions are not independent of other skills but are a constituent of many processes of perception, memory, planning and acting as well as playing a part in speech production and reception, spatial orientation and problem-solving. Attention functions are thus basic skills that are required in almost every practical or intellectual activity.

According to psychological and neuropsychological theories, attention cannot be regarded as a single, simple function. In 1890 William James (p. 416) gave a definition of attention which describes only one of the aspects of attention that are today regarded as relevant, that of *selectivity*.

Everyone knows what attention is; it is the taking possession by the mind, in clear and vivid form, of one out of what seems several simultaneously possible objects or trains of thought. Focalization, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal better with others.

He sees attention as a sort of "spotlight" that focuses on the aspects of a situation that are currently of importance, whether they be external or mental; aspects which are irrelevant are "left in the dark" or in other words ignored. This view was also a component of the attention theories of the twentieth century. Broadbent (1958, 1971), Deutsch and Deutsch (1963) and Treisman (1969) regard attention as a "selection mechanism" that we have to employ because our information processing capacity is limited. In these theories attention-controlled selection causes particular components of the flow of information with which we are continuously bombarded to be toned down on the basis of specific physical properties. At the same time there is on the reaction side a selective modulation of reaction thresholds (e.g. through active inhibition of responses to irrelevant stimuli). More recent theories of attention distinguish between automatic and controlled methods of processing or emphasise the targeted nature and cognitive control of attention-led behaviour. Modern taxonomies take account of the "energetic" as well as the selective aspects of attention. We must be able to call on a particular level of alertness and if necessary sustain it over a lengthy period of time if we are to concentrate on a task, maintain a demanding level of involvement and separate the important from the unimportant. These "intensity aspects" of attention are thus essential to the utilisation of more complex cognitively controlled attention processes.

#### 2.1.1 Dimensions of attention

A newer model that attempts to bring together modern concepts of the dimensionality of attention was put forward by van Zomeren and Brouwer (1994).

One of the key features of this model is that it distinguishes between the *intensity* and *selectivity* aspects of attention; each of these aspects can in turn be broken down into more specific components. The intensity aspect of attention comprises two components, *alertness* and *vigilance*, which are basal processes of short- and long-term attention activation and the sustaining of this activation.

With regard to the *selectivity* aspect of attention processes the model of van Zomeren and Brouwer distinguishes between *focused* or *selective* attention and *divided* attention.

The spatial direction of attention is a separate, additional dimension that does not form part of the model described above (Posner et al. 1978, 1984).

Both Posner and Raichle (1994) and Fernandez-Duque and Posner (2001) distinguish three types of attention networks: a) *Orienting* (corresponds to the network of spatial direction of attention), b) *Vigilance* (corresponds to the intensity dimension) and c) *Executive Attention* (corresponds roughly to the selectivity dimension). Table 1 is an attempt to draw up a taxonomy of attention functions that integrates the ideas contained in the different models. Typical tasks and paradigms are assigned to the different areas and dimensions of attention and also form the basis of this attention test battery.

Table 1. Attempt at a taxonomy of attention dimensions and areas and their associated paradigms in accordance with the models of van Zomeren and Brouwer (1994) and Posner and Raichle (1994; dimensions shown in brackets)

Dimension	Area	Paradigms		
	Attention activation	Simple visual or auditory reaction tasks		
	(alertness)	without (tonic or intrinsic alertness) or with		
	(intrinsic, tonic and phasic)	(phasic alertness) a cue		
Intensity (alerting and vigilance)	Sustained attention	Simple signal detection tasks over a long		
	Vigilance	Monotonous signal detection tasks over a long period, low proportion of relevant stimuli		
Spatial direction of attention (orienting)	Visual/spatial attention, change of focus of attention	Tasks requiring a shift of attention from one spatial focus to another		
	Selective or focused	Choice reaction tasks (selective		
	attention	attention);		
Selectivity		tasks with distractor stimuli		
(executive attention)		(focused attention)		
		Tasks that require attention to be divided		
	Divided attention	between a number of information		
	Biviaca attention	channels (e.g. "dual tasks"); tasks for		
		measuring "cognitive flexibility"		

#### 2.1.2 Development of attention functions

A number of more recent studies have shown that visual and auditory attention improve with increasing age (Aylward et al. 2002; Lehman et al. 2006; Gomes et al. 2007). However, it remains unclear whether this development is continuous or whether it takes place in discrete stages. Klimkeit et al. (2004) studied the development of attention and executive functions in children aged between 7 and 12. They suggest that development takes place in stages with the most marked improvement occurring between the ages of 8 and 10; between 10 and 12 a plateau is reached. Similar findings were obtained in a study by Korkmann et al. (2001) in which the authors investigated the development of a large sample of 5-to-12-year-olds using a neuropsychological test battery; they found that neuropsychological functions develop particularly quickly between the ages of 5 and 8 and more slowly in the older group of 9-to-12-year-olds. By contrast, Gomez-Perez and Ostrosky-Solis (2006) found no evidence of development stages in their large-scale developmental study (n=521). They investigated the development of attention and memory over a wide age range spanning the ages of 6 to 85. They found that attention functions improve rapidly during childhood and continue to develop into adolescence. Interestingly, this study appeared to show that different cognitive functions develop in different ways: more complex functions seem to take longer to reach their final level. This accords with findings that showed that 13-year-olds have not yet achieved the same level of performance as adults in situations (such as inhibition control) that make complex demands on attention (Davidson et al. 2006). In contrast to earlier findings that postulate a decline in performance with increasing age (De Luca et al. 2003; Plude et al. 1994), they conclude that attention performance remains relatively constant between the ages of 16 and 85.

Development of the auditory system can be divided into several stages (Werner 2007). The last of these stages ("flexibility in the use of acoustic information") begins at the age of 8 - 9 years. The specific development of the auditory attention system could be a reason why 15-year-olds are less good than adults at identifying speech against a background of noise or echo (Johnson 2000). In addition, between childhood and early adulthood an improvement in auditory focused attention is found (Pearson & Lane 1991); this accords with the findings of Klimkeit et al. (2004, see above) and suggests that attention functions continue to develop into adolescence. Like the elements of visual attention, various components of auditory attention also develop in different ways depending on their complexity (Gomes et al. 2000). More complex aspects of attention (such as selective attention) develop more slowly than, for example, performance on alertness tasks.

In older people there appears to be a differential decline in aspects of attention (McDowd & Shaw 2000). Studies of the intensity of attention reveal a slight age-related decline, for example in sustained attention. With regard to selectivity the findings are considerably less clear: Hasher and Zacks (1988) suggest that with age there is an increase in distractibility and a decrease in inhibition ability. By contrast, Einstein and McDaniel (1997) found no increase in "mind wandering" in older adults. In addition, a relatively recent meta-analysis (Verhaeghen & Cerella 2002) reported no systematic age effect for Stroop and negative priming tasks. Age does, however, have a significant effect on divided attention and task switching; the effect is closely related to the level of difficulty of the task involved. In the context of an auditory attention-focusing task, Barr and Giambra (1990) showed that older adults are significantly more susceptible to interference than younger people (the "cocktail party phenomenon").

#### 2.1.3 Attention disorders

Together with memory impairments, attention problems are among the most common consequences of brain injuries of very varied aetiology and location. They also frequently accompany psychiatric illnesses (schizophrenia, depression, ADHS). Patients with severe attention difficulties are often unable to profit from rehabilitation, even if other cognitive functions are relatively unaffected. Robertson et al. (1997) showed that even the recovery of motor functions after they had been damaged can be affected by the patient's attention problems. The investigation and rehabilitation of attention skills is therefore of central importance.

#### 2.1.3.1 Manifestations

In a clinical setting the aspects of attention outlined in the preceding section are of direct practical relevance. For example, disorders of intrinsic and possibly also of phasic alertness should be assumed if a patient in an acute condition is unusually unresponsive and shows signs of being disoriented with regard to time, place and personal matters. In addition, patients with alertness problems often complain of increased tiredness and diminished ability to cope.

Patients with sustained attention problems also tire quickly and need to take frequent breaks in the course of any intellectual or practical activity. Many such patients are no longer able to engage in any prolonged form of work. Vigilance situations in the narrow sense are by contrast seldom encountered under everyday conditions. Typical activities involving vigilance include, for example, watching a radar screen, undertaking quality control on an assembly line or driving.

Increased distractibility as a symptom of an attention-focusing disorder is frequently observed after frontal lesions.

Central to the discussion of the concept of attention is the aspect of limited capacity. This is clearly relevant to the clinical issue of divided attention. Many patients complain specifically of their difficulties in situations in which a number of different things are required of them

simultaneously. A reduced attention capacity acquires additional significance from the fact that a patient may sometimes find that he needs to exercise control – i.e. to apply increased attention – to perform activities such as walking or speaking that he used to do automatically. In such circumstances a reduced attention capacity limits the extent to which the patient can compensate for a deficit.

#### 2.1.3.2 Aetiology of attention disorders

Attention disorders can occur in almost all neurological diseases that affect the central nervous system. The disorder of the attentional functions may be specific or global, depending on whether the neurological disorder leads to localised brain damage (as for example in a stroke) or to more diffuse impairment (as in craniocerebral trauma or degenerative diseases).

#### Cerebrovascular diseases

After lesions in the brainstem area of the formatio reticularis (Mesulam 1985) and after strokes, particularly those occurring in the area of the middle cerebral artery (A. cerebri media) of the right cerebral hemisphere, disorders both of alertness and of vigilance and the longer-term application of attention can occur (Howes and Boller 1975; Ladavas 1987; Posner et al. 1987).

According to Stuss and Benson (1984), attention processes make use of a network involving the reticular system of the brainstem, the diffuse thalamic projection system and the fronto-thalamic gating system. While the reticular system primes the intrinsic and tonic alertness function (see above), the fronto-thalamic gating system is involved in the selective and directed application of this alertness. Lesions of this system lead to diminished selectivity for external stimuli and to increased distractibility.

Lesions of the frontal areas of the left half of the brain also lead to impairments of the selectivity of attention, especially in situations in which rapid decisions between relevant and irrelevant aspects of a task have to be made (Dee and van Allen 1973; Sturm and Büssing 1986).

The three stages of spatial displacement of the visual focus of attention (see below) can also be selectively impaired by localised brain damage. Injuries to the posterior parietal lobe appear to lead in particular to impairments of the disengaging of attention from a stimulus when attention needs to be transferred to a target in the half of the visual field contralateral to the lesion (Posner et al. 1984). Hemineglect also tends to arise after parietal lesions. Lesions in the colliculus superior in the midbrain or in adjacent areas impair the shifting of attention to the new target, while patients with thalamic lesions (especially in the pulvinar and posterior lateral thalamus) have difficulty engaging their attention focus on the side contralateral to the lesion.

Impairments of the division of attention seem to occur particularly frequently in the wake of frontal vascular injuries (Rousseaux et al. 1996).

#### Craniocerebral trauma (CCT)

Together with memory problems, attentional impairments are the most common neuropsychological deficit resulting from craniocerebral trauma. A general, non-specific slowing down of information processing functions is consistently found after CCT. However, the cause of these functional impairments after CCT remains to a large extent unclear. "Diffuse axonal injuries" have been proposed as a pathological correlate of injury arising from rotational acceleration of the brain; these show up in CT – or even better in MR – as multiple small lesions or transient oedema.

Fontaine et al. (1999) showed that attention deficits after severe traumatic brain injury are accompanied by hypometabolism in the prefrontal and cingulate areas of the brain.

WAFV

#### Neuro-degenerative diseases

Attention disorders are often observable even in the early stages of Alzheimer's disease. In many cases they appear after memory problems have emerged but before speech and spatial skills are impaired (Perry, Watson & Hodges 2000). Other findings indicate that cognitive control of alertness and visual-spatial attention is retained for a relatively long time, but that impairments of selective attention appear at an early stage. Impairments of inhibitory control also increase as the disease progresses.

Patients with Parkinson's disease or Huntington's chorea do not normally display any deficits in phasic alertness or in vigilance tasks, in contrast to patients with progressive supranuclear palsy (PSP), whose performance in these fields is often impaired.

Impairments of the division of attention appear to be a general characteristic of dementia disorders in their advanced stages.

#### Depression and attention disorders

Impairments of memory and attention are among the principal impairments of cognitive functions that accompany depression. It is primarily conscious, cognitively controlled functions that are affected. Impairments of automatic processing occur only in very severe depression (Hartlage, Alloy, Vazques et al. 1993). In contrast to patients with craniocerebral trauma (CCT), depressive patients often gauge their performance to be worse than psychometric investigation actually reveals it to be. Farrin et al. (2003) showed that this negative self-estimate can lead to "catastrophe reactions" when errors are made in sustained attention tasks, causing longer reaction times in the immediate aftermath of the error. CCT patients do not display this reaction.

#### Schizophrenia

Although attention deficits have long been regarded as a core symptom of schizophrenia, more detailed examination of the different attention skills reveals that the findings are not uniform. Particularly well documented are impairments of sustained attention (usually assessed by means of the Continuous Performance Test – CPT – although this test requires other skills of the patient in addition to attention per se). 75% of all patients tested with the CPT showed some impairment, while on the Trail Marking Test (version B vs. A), which is more a measure of processing speed and the flexibility of attention, 66-68% displayed some impairment. This was shown by a meta-analysis carried out by Heinrichs and Zakzanis (1998). A study by Lussier and Stip (2001) found that untreated patients displayed impairments not only of sustained attention but also of (phasic) alertness, selective attention and working memory. It is rather rarer for patients without negative symptoms to have attention problems (Jones et al. 2001). Attention deficits can also often be explained by other overlying psychiatric symptoms, in particular depression.

#### ADHD patients

In children with ADHD the intensity rather than the selectivity aspects of attention appear to be impaired. It is usually alertness and the longer-term sustaining of attention that are affected; both of these attention functions are controlled primarily by the right side of the brain. Spatial attention tasks also tend to involve a deficit in the right hemisphere: Nigg et al. (1977) found that when the Posner paradigm was used with non-medicated boys with ADHD, the subjects reacted more slowly to stimuli presented on the left-hand side (without precue) than to corresponding stimuli presented on the right (see also Konrad and Herpertz-Dahlmann 2004).

The influence of drugs on attention skills

Results may be falsified by drugs, most notably by sedatives but also by stimulants or drugs (especially dopaminergic and noradrenergic ones) that affect particular neurotransmitter systems. Attention functions are particularly likely to be affected by drugs taken by the subject (Rockstroh 1993, 2000). The neuroleptic agents used in the treatment of schizophrenia are dopamine antagonists. Their effectiveness has given rise to the hypothesis that schizophrenia is caused by an excess of dopamine in the limbic system. It is assumed that at the information processing level dopamine plays a role in the filtering of stimuli and the control of the focus of attention. Many of the neuroleptic agents prescribed for psychiatric disorders have an effect on the selectivity of attention. By contrast, Rund and Borg (1999) reported positive effects with atypical neuroleptic agents such as risperidone. Antidepressants are noradrenaline or serotonin uptake inhibitors, or as monoamine oxidase (MAO) inhibitors they block the action of MAO in the nervous system. Depression is thought to involve a lack of noradrenaline or serotonin. At the information processing level noradrenaline appears to play a role in attention processes (orientation reactions, alert wakefulness). Hence antidepressants and MAO inhibitors often have a negative effect on alertness and vigilance and on orientation reactions.

#### 2.1.4 Functional neuroanatomy

#### Alertness and sustained attention/vigilance

Lesion studies in stroke patients have shown that lesions to the right hemisphere often result in a very significant increase in simple visual and auditory reaction times (Howes & Boller 1975; Posner et al. 1987; Ladavas 1987). Posner and Petersen (1990) view the noradrenergic system, located in the locus coeruleus in the brain stem, as plaving a particularly important role in the arousal of attention. Experiments on animals led researchers to hypothesise that this noradrenergic arousal must be regulated by a "top-down" - i.e. cognitively controlled - process taking place in the right frontal cortex. PET studies carried out by Sturm et al. (1999a, 2004b) demonstrated that there is a cortical and subcortical network, located almost exclusively in the right hemisphere, that serves to control and sustain alertness. When compared with a sensomotor control condition with no explicit attentional components, the performance of simple visual or auditory reaction tasks resulted in arousal in the right hemisphere in the anterior gyrus cinguli, the dorsolateral frontal cortex, the inferior parietal cortex, the dorsal fronto-mesencephalic tegmentum (possibly in the area of the locus coeruleus) and the right thalamus. The authors postulate a network in which the anterior cingulum and the dorsolateral frontal cortex, via the nucleus reticularis of the thalamus, "intrinsically" control and channel the arousal of attention that is needed for particular tasks and that is provided by the noradrenergic system in the brain stem. The central role of the anterior cingulum in the cognitive control of intrinsic alertness was demonstrated in a pathway analysis of the data of the PET study mentioned above (Sturm et al. 1999a; Mottaghy et al. 2006).

Paus et al. (1997), in a PET study involving a 60-minute vigilance task, showed that the same network is involved in the sustaining of attention in classic vigilance tasks. The authors found activity that decreased over time in the right ventrolateral and dorsolateral frontal cortex and in areas of the parietal and temporal cortex; arousal in the thalamus correlated significantly with activity in the ponto-mesencephalic tegmentum and in the anterior cingular cortex. At the same time they found that over time there was a significant increase in reaction times and in theta activity in the EEG. The finding that, in addition to the frontal and subcortical arousal, the inferior parietal cortex was also involved, both in the alertness and in the vigilance study, supported the hypothesis of Fernandez-Duque and Posner (1997), which postulates that the elements aroused by the attention arousal network include the posterior attention systems (see below) that are relevant to the orienting of attention. This would

explain why damage to the right hemisphere leads not only to general impairment of the intensity of attention but also to persistent neglect symptoms on the left.

Thus Robertson et al. (1995) observed an interesting effect of training designed to improve the sustained attention of patients with right-hemisphere lesions. After therapy, improvement was noticed not only in the patients' sustained attention but also in their neglect symptoms, even though the neglect symptoms themselves had not been treated specifically, for example by using tasks to improve the spatial directing of attention. The authors interpret the effect as an extension of the activation of attention from frontal to parietal areas of the right hemisphere. This effect of alertness training on neglect symptoms has been subsequently confirmed at both behavioural and functional level in a number of studies (Sturm & Willmes 2001; Thimm et al. 2005). Researchers demonstrated the central role played by the connection between the anterior "vigilance" and the posterior "orienting" system (fasziculus occipitofrontalis) in explaining hemineglect by stimulating the fasziculus occipitofrontalis in two patients during surgery: in a line-halving task there was a clear shift to the right (Thibaut de Schotten et al. 2005).

#### **Spatial attention**

According to Posner et al. (1984), three different structures of the brain are involved in the spatial direction of attention and in the spatial shifting of the visual focus of attention. Lesions in the posterior parietal lobe appear to lead in particular to impairments of the ability to disengage attention from a stimulus when attention needs to be shifted to a target stimulus in the half of the field contralateral to the lesion. Lesions in the colliculus superior or adjacent areas impair the shifting of attention to a new target stimulus. By contrast, patients with thalamic lesions, especially lesions in the pulvinar and posterior-lateral thalamus, have difficulty engaging the focus of attention on the side contralateral to the lesion and in ignoring distractions arising from irrelevant events in other surrounding positions. In a PET activation study, Corbetta et al. (1993) required subjects to fixate a central stimulus while allowing their visual attention to travel along a series of predictable stimulus positions in the right or left visual field so that they could react as quickly as possible to the appearance of small visual stimuli. Significant bilateral activation changes were found in the superior parietal cortex and in the frontal cortex; irrespective of the side on which the stimulus was presented, parietal activation on the right was always more marked than the corresponding activation in the left hemisphere. Similar results were obtained by Nobre et al. (1997) and Corbetta et al. (1995) using comparable visuospatial detection tasks. More recent studies have shown that there is considerable overlap between the networks involved in covert shifts of attention and those involved when eye movements occur (Corbetta, 1998). These findings indicate that the processes of attention-orienting are closely linked to oculomotor processes. On the other hand there is increasing evidence that attention-directing processes also take place crossmodally in space. This has been studied for visual, auditory and tactile modalities (see Spence & Driver 2004). In an FMRT study, Sturm et al. (2005) found a clear overlap of righthemisphere networks controlling alertness and visuospatial attention (see section on "Alertness/sustained attention"). These networks involve the posterior parietal cortex around the intraparietal sulcus, the frontal eye fields, the dorsolateral prefrontal cortex and the anterior cingulum.

#### Selective, focused and divided attention

Both Dee and van Allen (1973) and Sturm and Büssing (1986) found that patients with cortical lesions of the left hemisphere of the brain showed slowed reactions and increased error rates in choice reaction tasks. In addition, Bisiach et al. (1982) and Jansen et al. (1992), in studies involving lateralised stimulus presentation in healthy subjects, found evidence of left-hemisphere dominance for choice reactions. Some studies (Sergent 1982; Robertson & Lamb 1991) have found left-hemisphere dominance for "local" attention and a right-hemisphere preference for "global" attention; this has been confirmed in studies on patients



with lateralised brain damage as well as in more recent work using functional imaging (see below).

In a PET activation study, Corbetta et al. (1991) demonstrated the specific role of the left lateral orbito-frontal cortex, the basal ganglia (globus pallidus, nucleus caudatus) and the posterior thalamus in the performance of a selective attention task requiring attention to the shape, colour or speed of stimuli. The orbito-frontal activation in the left hemisphere may represent the inhibition process that is required to suppress reactions to irrelevant stimuli. There was also increased activation in the area of the secondary visual cortex that specialises in the processing of whichever characteristic is being selectively attended to (shape, colour, speed).

In a PET study of local and global processes involved in visual selective attention, Fink. et al (1996) identified left-hemisphere dominance for "local" attention and a right-hemisphere preference for "global" attention. The experimental stimuli were those developed by Navon (1977), which are formed of letters or numbers (global processing) that are themselves made up of a repeated letter or number (local processing). The global letter or number may be identical to the local one or different from it. The subject's task is to attend to either the global or the local aspect. When attention is directed to the global aspects, the right gyrus lingualis is activated; attention to the local aspects leads to activation of the left inferior occipital cortex. Switching between the two aspects (cognitive shifting of the focus of attention) covaried with temporo-parietal activation.

The fronto-thalamic system involved in controlling the intensity of attention also appears to be relevant for particular aspects of attention selectivity (thalamic gating). Frontal influences cause the nucleus reticularis thalami to be selective in opening for reticular activation only the thalamic gates that are required for the processing of a particular item of information. Lesions of this system lead to diminished selectivity for external stimuli and to increased distractibility.

Studies of patients who had experienced severe craniocerebral trauma (McDowell et al. 1997; van Zomeren & van den Burg 1985) or patients with ruptures caused by aneurysms of the anterior A. communicans (Rousseaux et al. 1996) show that divided attention skills are closely linked to frontal brain functions. PET activation studies of healthy subjects have found either bilateral (Madden et al. 1997) or right unilateral (Corbetta et al. 1991) prefrontal activation in divided attention tasks. However, the study by Corbetta et al. usas carried out under experimental conditions more closely resembling a sustained attention task paradigm, and these results must therefore be interpreted with reservation. Loose et al. (2003) found left prefrontal activation in the FMRI during the performance of the visual/auditory divided attention task of the TAP (Testbatterie zur Aufmerksamkeitsprüfung - Test Battery for Attentional Performance; Zimmermann & Fimm, 2002). While attention was divided, activation in the sensory processing areas decreased; this contrasts with the situation when a single task (only visual or only auditory) is performed. The authors interpret this as indicating that processing capacity is limited under divided attention conditions.

#### Automated vs. controlled attention processes

Corbetta and Shulman (2002) distinguish between a target-oriented and a stimulusindependent network of attention. In the target-oriented network ("top-down" selection of stimuli and reactions) attention is directed towards aspects of the situation that are relevant to the goal. Attention can, however, also be determined and controlled by characteristics of the stimulus ("bottom-up" control): a stimulus "automatically" attracts our attention. This type of arousal of the stimulus-dependent network is able to modulate our target-oriented attention. This illustrates the close cooperation that exists between the two systems. The "top-down" network involves the posterior dorso-parietal regions and the dorso-lateral frontal cortex. The stimulus-dependent attention network ("bottom-up") is largely lateralised on the right side; it involves temporo-parietal areas and the ventral frontal cortex.

#### 2.1.5 The theory-led assessment of attention

As has been shown, attention skills are an important requirement for coping with the demands of everyday life and attention functions are basic skills that are called on in almost every practical or intellectual task. It follows, therefore, that the differentiated assessment of attention functions is central to the process of psychological assessment both in general assessment situations and in the context of more specific investigations such as the assessment of fitness to drive. The assessment of attention has acquired particular importance in psychiatry and neuropsychology, since attention deficits are among the main symptoms of many psychiatric and neurological disorders.

A reliable assessment of attention impairments is also very important in the context of rehabilitation. Since attention disorders have many facets and attention impairments are often co-morbid with other deficits affecting perception, memory or speech, the accurate diagnosis of attention disorders is no trivial matter.

Since different psychiatric and/or neurological diseases can lead to very specific impairments of attention, any investigations where attention deficits are suspected should include at least one test for intensity of attention (e.g. alertness test, possibly administered both at the beginning and the end of the test session in order to assess fatigue effects and impairments of coping ability) and one for selectivity (e.g. test of divided attention with separate assessment of the individual components of the task). Following damage to the right hemisphere of the brain, particularly in the parietal area, the spatial direction of attention should always be assessed, even if there is no clinically significant neglect.

#### 2.1.6 Assessment of specific functions with the WAF test battery

The WAF test battery contains subtests for assessing all the attention functions listed in Table 1. Testing is normally carried out in both visual and auditory modalities in order to provide separate assessments of modality-specific attention abilities. In a study of longer-term attention (Wagensonner and Zimmermann 1991) attention was tested using stimuli in different modalities (visual/auditory). Modality-specific deficits were found in the patients. This dissociation of auditory and visual attention deficits indicates that there are probably specific mechanisms for controlling input in the different modalities. Two steps are taken to exclude the possibility that perceptual impairments may be affecting the processing of the stimuli used in the WAF during assessment, thus making a reliable assessment of attention impossible: a) throughout the test battery only very few visual and auditory stimuli are used, and they are very simple ones, and b) before testing starts the ability of the respondent/patient to perceive these stimuli should be checked using WAFW. This ensures that an important requirement of neuropsychological assessment is met – namely the need to take into account the possibility of pre-existing impairment of sensory functions (see Sturm 2000 2005).

At an early stage in attention research a distinction was made between **controlled vs. automated** attention processes (see Schneider 1985). The direction of selective attention can be controlled either by external factors such as particularly prominent or relevant stimuli, or by internal factors such as the expectation of a particular stimulus, or by the way in which a particular task is formulated. External factors tend to lead to an unconscious, automated ("bottom-up") application of attention, while internal factors result in a cognitively controlled ("top-down") approach to the task.

Triesman and Gelade (1980) also emphasise the need to distinguish between automatic ("pre-attentional") and controlled processes in information processing. At the level of perception they postulate the rapid, automatic parallel processing of visual characteristics such as shape, colour, spatial orientation etc. For example, in searching for an object with a specific property (such as green colour) among other objects, none of which have this property (for example, they are all red), the search time is independent of the number of objects. The sought object appears to jump out at the observer ("popping out" effect).

However, if the sought object is less easy to distinguish from the surrounding stimuli, the information processing function appears to depend on a directed (focused) application of attention; the search processes are carried out serially (one after the other), as though each stimulus in turn must be studied with the aid of a "spotlight" to identify whether it has the required characteristic. In the WAF test battery these automated and controlled aspects of attention are measured separately; the stimuli either become more prominent because the intensity level is increased ("popping out", for example by increasing the volume of a sound), or their intensity is decreased and more controlled "top down" processes are required. Both attention processes are relevant in everyday life; both can interact and both can be selectively impaired, for example as a result of brain damage. In a survey of the functional neuroanatomy of stimulus-dependent and cognitively controlled (goal-directed) attention skills, Corbetta and Shulman (2002) showed that these skills involve different cerebral networks. The method of attention control in the goal-oriented network can be described as the "top-down" selection of stimuli and reactions: attention is directed towards features that are relevant to the goals that have been set. Attention can also be determined and controlled by characteristics of the stimulus ("bottom-up" control). In this situation a stimulus attracts our attention. This type of arousal of the stimulus-dependent network is able to modulate our goal-oriented attention. This illustrates the close cooperation that exists between the two systems. The "top-down" network involves the posterior dorso-parietal regions and the dorsolateral frontal cortex. The stimulus-dependent ("bottom-up") attention network is primarily lateralised on the right; it involves the temporo-parietal areas and the ventral frontal cortex (Corbetta and Shulman 2002). The ventral and dorso-lateral areas of the frontal cortex also play a central role in executive functions and form part of the functional network of working memory (Fletcher and Henson 2001; Kopelman 2002). However, the fact that parts of the frontal cortex play a specialised "executive" role in attention and memory tells us little about the way in which attention, memory and executive functions interact. It simply highlights for the diagnostician the interactions with other neuropsychologically relevant functions that need to be taken into account in the assessment of attention processes.

## 2.2 Theoretical basis of the Vigilance test

When considering the longer-term application of attention a distinction is made between sustained attention tasks and vigilance tasks.

Long-term alertness tasks require the subject's attention "to be focused continuously for long periods of time on one or more sources of information, in order to detect and respond to small changes in the information presented" (Davies et al. 1984). Vigilance represents a special variant of long-term attention. Vigilance makes demands on attention over a long period of time – often a number of hours – and the relevant stimuli typically occur at very irregular intervals and at a very low frequency compared to the number of irrelevant stimuli. According to the definition of Mackworth (1948), a typical vigilance task is that carried out by a radar observer who has to be attentive over a long time period in order to detect a signal on the screen that stands out against irrelevant background stimuli. By definition, therefore, vigilance tasks are very monotonous. The "sustained attention" and "vigilance" subtests of WAF differ only in the frequency of the relevant stimuli (5% vs. 30%). This applies to both the visual and the auditory task. The default setting for the vigilance tasks is a test length of 30 minutes. Ideally this should not be shortened, as a reasonably long period of time is necessary before a significant decline in vigilance performance becomes noticeable (Mackworth 1948).

Relevant parameters are in particular the reaction times and the number of omissions, as well as the trend of these parameters over time. The norms take account of the normal decline in performance when attention is sustained over longer periods; this makes it possible to assess trends that may be pathological by comparing performance in the first and second halves of the test period. While a division of the test period into smaller sections

would be desirable, this is not psychometrically possible in the vigilance test because of the low stimulus density – in accordance with the underlying theory – and the consequent low number of scores.

Tests for measuring sustained attention or vigilance almost always include basic elements of selectivity, as it is always necessary to distinguish between important and unimportant components of the task. Although this aspect has been kept to a minimum in WAF, the subject is nevertheless required to take simple decisions. This means that increased error rates should not usually be interpreted as an impairment of the intensity of attention but (at least partially) as an impairment of selectivity, unless they change systematically over time.

## 2.3 Test forms

WAFV has four test forms; the forms differ both test length and in presentation modality. The two short forms S5 and S7, which have a test length of only 15 minutes each, are too short to measure inter-individual variance in sustained attention in healthy adults. These two test forms are explicitly intended for use with children and young people; norms for respondents in the age range 7 - 17 years are therefore provided for these forms.

Form	Relevant signals	Frequency	Test length
S2 Vigilance visual – long form 900 stimuli (of which 50 relevant)	Square becomes darker	5%	30 mins.
S4 Vigilance auditory – long form 900 stimuli (of which 50 relevant)	Sound becomes quieter (1000 Hz)	5%	30 mins.
S5 Sustained attention visual – short form 450 stimuli (of which 125 relevant)	Square becomes darker	30%	15 mins.
S6 Sustained attention visual – long form 900 stimuli (of which 250 relevant)	Square becomes darker	30%	30 mins.
S7 Sustained attention auditory – Short form 450 stimuli (of which 125 relevant)	Sound becomes quieter (1000 Hz)	30%	15 mins.
S8 Sustained attention auditory – Long form 900 stimuli (of which 250 relevant)	Sound becomes quieter (1000 Hz)	30%	30 mins.

Table 2. Construction and stimulus conditions of the WAFV test forms

## 2.4 Description of variables

#### Main variables

#### Mean reaction time

This variable is a logarithmic mean of the individual reaction times. The advantage of using a logarithmic mean is that it takes account of the expected skew of the distribution of the reaction times.

#### Number of missed reactions

This is the number of stimuli to which no response was made within 1500 ms.

#### Subsidiary variables

#### **Dispersion of reaction times**

This is the logarithmic standard deviation of the reaction times.

#### Number of false alarms

This variable gives the number of reactions to false or non-existent stimuli.

All the variables are reported and normed both for the test as a whole and separately for the first and last 15 minutes of the time spent working the test.

## **3 EVALUATION**

## 3.1 Objectivity

*Test administrator independence* exists when the respondent's test behaviour, and thus his test score, is independent of variations (either accidental or systematic) in the behaviour of the test administrator (see e.g. Kubinger 2003). Since the WAFV is a computerised procedure, instruction and test presentation are standardised and interaction between respondent and administrator is kept to a minimum; administration objectivity can therefore be assumed to exist.

*Scoring objectivity* exists when the test performance of each respondent leads to the same result, regardless of who scores the text (e.g. Kubinger 2003). The automatic computerised calculation of the test results ensures scoring objectivity for all the test variables of WAFV.

Interpretation objectivity exists when the same conclusion is drawn from particular test results even when they are interpreted by different people. If the test in question has been normed, it is always unambiguous in its interpretation: the norm value unequivocally determines the respondent's "position" within the reference population with regard to the measured trait (e.g. Kubinger 2003). Because it has been normed, WAFV is therefore unambiguous in its interpretation.

## 3.2 Reliability

*Reliability* aims to achieve formal exactness of the trait measurement (measurement precision) – that is, a score obtained in testing should be correct in the sense of being exact (see Kubinger 2003).

For the subtests of WAFV the norm sample yielded the following reliabilities (internal consistency as measured by Cronbach's alpha).

	Total	Education level EU 1 – EU 3	Education level EU 4 – EU 5
S2 vigilance visual – long form	0.96	0.96	0.96
S4 vigilance auditory – long form	0.98	0.98	0.98
S6 Sustained attention visual – long form	0.99	0.99	0.99
S8 Sustained attention auditory – long form	0.99	0.99	0.99

Table 3. Reliability of the main variables of the WAFV test forms (norm sample of adults).

Table 4. Reliability of the main variable "Reaction time" of the WAFV test forms (norm sample of children and young people).

	Total
Sustained attention visual (short form)	0.96
Sustained attention auditory (short form)	0.97

## 3.3 Validity

*Construct validity* exists when it can be demonstrated that a test not only meets certain pragmatic requirements but also implements a particular theory-led approach (Kubinger, 2003).

In a study of the test's construct validity the norm sample of the WAF test battery completed additional tests for determining convergent validity (Cognitrone (Wagner & Karner 2001), Discrimination Test (Schuhfried 1998) and Reaction Test (Schuhfried & Prieler 1997)) and discriminant validity (SPM Plus (J. Raven, J.C. Raven & J.H. Court, 1997)).

The structure of the tests' main variables was first explored by means of factor analysis. This yielded three factors, which between them explain 60.9% of the variance (see Table 5).

Table 5. Factor structure of the WAF test battery obtained exploratively by principal component analysis and subsequent varimax rotation. For the sake of clarity loadings of less than 0.4 have been omitted.

	Factor 1	Factor 2	Factor 3
WAFA – Mean reaction time Subtest 1		0.703	
WAFA – Mean reaction time Subtest 2		0.761	
WAFA – Mean reaction time Subtest 3		0.741	
WAFA – Mean reaction time Subtest 4		0.757	0.412
WAFA – Mean reaction time Subtest 5		0.753	
WAFA – Mean reaction time Subtest 6		0.744	
WAFF – Mean reaction time Subtest 1	0.653		
WAFF – Mean reaction time Subtest 2	0.643		
WAFF – Mean reaction time Subtest 3	0.645		
WAFS – Mean reaction time Subtest 1	0.727		
WAFS – Mean reaction time Subtest 2	0.687		
WAFS – Mean reaction time Subtest 3	0.664		
WAFG – Mean reaction time Subtest 1	0.724		
WAFG – Mean reaction time Subtest 2	0.599		0.534
WAFV – Missed reactions Test form 2			0.429
WAFV – Missed reactions Test form 4			0.740
WAFV – Missed reactions Test form 6			0.679
WAFV – Missed reactions Test form 8			0.702
WAFR – Mean reaction time Test form 1	0.648		
WAFR – Mean reaction time Test form 3	0.631		
COG – Mean time "correct rejection"	0.634		
DT – Correct responses	0.571		
RT – Mean reaction time	0.545		
RT – Mean motor time	0.580		
SPM PLUS – Correct responses			

The content of the three factors can be clearly interpreted. Factor 1 represents the selectivity aspect, while Factor 2 draws together tests that load primarily onto the short-term control of the intensity of attention (intrinsic and phasic alertness). Factor 3 comprises tests which require attention to be sustained over a lengthy period of time (sustained attention, vigilance).

All the tests that were used to check convergent validity load onto Factor 1. This means that even in single-choice reaction tests such as the RT the selectivity aspect plays a dominant role since the different signal elements (red light, yellow light) by implication induce a choice. This underlines the particular usefulness of a tool such as WAFA which makes it possible to measure the intensity aspect specifically.

For SPM Plus, which measures language-free general intelligence, there are no relevant loadings onto any of the 3 attention factors. From this it can be concluded that the aspects of attention measured by the WAF test battery can be clearly distinguished from the "G factor" of intelligence.

Since a factor-analytical approach is not entirely appropriate for the model of Zomeren and Brouwer (1994) or the expanded attention model of Sturm (2005), the same data was explored using a linear structural equation model which was drawn up on the basis of the theoretical model.

From the results of the LISREL modelling it can be seen that the empirical data fit the theoretically postulated model and therefore provide confirmation of it. This provides evidence for the construct validity of the WAF test battery and the tests contained in it. LISREL methods can also be used to test whether alternative models fit the data. An initial study investigated the hypothesis that the data could be explained by a general factor of attention that would render the postulated structure of the attention aspects unnecessary.

Table 6. Model fit for a general factor model.

Chi² / df	2.728
CFI	0.921
RMSEA	0.066
P (close fit)	0.001
AIC	561





Figure 1. Linear structural equation model for the WAF tests. The path weightings are given as standardised regression coefficients. On the first level the latent factors of Alertness (A), Vigilance (V),

Spatial Attention (R), Focused Attention (F), Selective Attention (S) and Divided Attention (G) are estimated. At the second level the latent factors of the intensity and selectivity aspects are estimated. In addition, factors are obtained which depend on the modality of the test presentation – cross-modal presentation is shown to be a combination of the visual and auditory modalities.

**Chi<sup>2</sup>/df** is the ratio of the chi<sup>2</sup> distributed test statistic to the degrees of freedom of the model. A high value indicates that the model does not fit the data. Values greater than 2 are usually taken to indicate that the model is not valid (Byrne 1989).

For the comparative fit index **CFI** (Bentler 1990) values < 0.9 are generally interpreted as indicating that the model does not fit (Backhaus et al. 2004).

**RMSEA** is a test statistic for the validity of the model that takes account of the model's complexity. The associated significance test is **P(close fit)**; if the test is significant this indicates that it is very unlikely that the data would have been obtained if the postulated model were valid.

The Akaike Information Criterion (**AIC**; Akaike 1973) is an information theory measure of the economy of a model. This takes account of the fact that data can more easily be described by a more complex model. When two models are being directly compared, the one with the lower AIC should be preferred.

The data obtained deviate more than by chance from the underlying model of a general attention factor (Table 6). It can also be shown that the theoretical model explains the data by more than a chance extent more than the hypothesised modification does ( $chi^2=113$ , df=1, p<0.001).

The hypothesis was therefore rejected: a differentiated structure of attention is necessary to explain the existing data.

A second study investigated the hypothesis that the structure of the different presentation modalities might be unnecessary – that is, the distinction might not be actually reflected in the data.

Table 7. Model fit for a model that does not take account of test presentation modalities.

chi² / df	3.246
CFI	0.880
RMSEA	0.075
P(close fit)	< 0.001
AIC	663

The data obtained deviate more than by chance from the underlying model which does not take presentation modality into account. It can also be shown that the theoretical model explains the data by more than a chance extent better than does the hypothesised modification ( $chi^2=263$ , df=25, p<0.001).

The hypothesis should therefore be rejected: the presentation modalities used in the subtests have a clearly identifiable effect on the results.

#### Factor structure of WAF in children and young people

The structure of the main variables of the WAF subtests was also explored by means of factor analysis for the sample of children and young people (n=270).

This, too, yielded three factors (see Table 8). Factor 1 represents the selectivity aspect; it is noticeable that, unlike in the adult sample, the WAFV variables also load onto this factor. It is likely that this is because the sample of children and young people worked short versions of the WAFV test with a higher stimulus density (sustained attention). These short versions have a significantly lower intensity aspect and correspond to relatively long-term attention tasks with a low selectivity aspect. By contrast, Factor 2 combines tests that load primarily onto the short-term control of the intensity of attention (intrinsic and phasic alertness). It is interesting to note that aspects of the spatial orienting of attention are also represented here (although with low loadings, since spatial attention loads primarily onto Factor 3). This demonstrates the close connection between intensity and spatial aspects of attention. Factor 3 comprises the main loadings for spatial attention together with subsidiary loadings for various tests of attention in children, even more than in adults, involves both selectivity and intensity aspects of attention and occupies the ground between the two.

Table 8. Factor structure of the WAF test battery obtained exploratively by principal component analysis and subsequent varimax rotation for the sample of children and young people. For the sake of clarity loadings of less than 0.4 have been omitted.

	Factor 1	Factor 2	Factor 3
WAFA – Mean reaction time Subtest 1		0.788	
WAFA – Mean reaction time Subtest 2		0.806	
WAFA – Mean reaction time Subtest 4		0.729	
WAFA – Mean reaction time Subtest 5		0.693	
WAFF – Mean reaction time Subtest 1	0.625	0.424	0.445
WAFF – Mean reaction time Subtest 2	0.610		0.554
WAFS – Mean reaction time Subtest 1	0.551	0.408	0.501
WAFS – Mean reaction time Subtest 2	0.665		0.458
WAFG – Mean reaction time Subtest 1	0.630		0.463
WAFV – Missed reactions Test form 5 (15 mins.)	0.732		
WAFV – Missed reactions Test form 7 (15 mins.)	0.730		
WAFR - Mean reaction time unilateral left		0.468	0.794
WAFR - Mean reaction time unilateral right		0.479	0.803
WAFR - Mean reaction time bilateral			0.830

## 3.4 Scaling

The quality criterion of *scaling* is met when the empirical behavioural relationships under consideration can be represented exactly by the test scores (Kubinger 2003). To confirm the scaling of WAFA it is necessary to show that the reaction time relationships are a sufficient statistic for the latent dimension they are intended to measure. This was done for the validation sample using model tests for the Latency Model of Scheiblechner (1985). This model can be used to investigate the unidimensionality of tests in which the latency time of a behaviour is the variable of particular interest. In order to test the validity of the model empirically, Scheiblechner recommends the use of a Likelihood Quotient Test (LQT) according to Andersen (1973) on the basis of a CML estimation of the item parameter. In this LQT the likelihoods of model estimates of varying restrictiveness are related to each other, and this estimate is transformed into a  $\chi^2$  statistic for inferential statistical corroboration. According to Rost (2004) this corresponds to the testing of person homogeneity – that is, the statistical equivalence of item parameter estimates in different subgroups of individuals in relation to the total sample.

Table 9. Results of the LQT for the test variable Mean Reaction Time for different splitting criteria in the WAFV subtests. Because of the technical limitations of the LEM software (Fischer 2003) it is not possible to carry out a model test for forms S6 (sustained attention visual) and S8 (sustained attention auditory).

Vigilance visual			
Splitting criterion	Chi <sup>2</sup>	df	р
Internal splitting criterion	6	49	0.999
Gender	4	49	0.999
Age	6	49	0.999
Education	4	49	0.999
Vigilance auditory			
Splitting criterion	Chi <sup>2</sup>	df	р
Internal splitting criterion	2	49	0.999
Gender	0	49	0.999
Age	2	49	0.999
Education	4	49	0.999

The analysis shows that none of the model tests is statistically significant. Thus no deviations at more than a chance level from the probabilistic test model used can be identified.

For WAFV this means that the latency times contain all the relevant information about the latent dimension to be measured and depict this latent dimension fairly. Taking into account the validation at scale level described in Section 3.3, these results can be summarised as indicating that the construct of the WAF test battery can be confirmed at both item and scale level.

## 3.5 Economy

Since they are computerised, the tests of the Vienna Test System are very economical to administer and score. The administrator's time is saved because the instructions at the beginning of the test are computerised, relieving him of the need to provide time-consuming verbal explanations. Because the test results are calculated automatically, the time needed for manual calculation of raw and norm scores is also saved.

## 3.6 Usefulness

The quality criterion of *usefulness* is met if, firstly, a test measures a relevant trait and, secondly, this trait cannot be measured by other tests which meet all the other quality criteria to at least the same extent (Kubinger 2003).

A wide range of neuropsychological hypotheses can be investigated with WAFV either on its own or in combination with other tests of the perception and attention functions. This demonstrates the outstanding usefulness of the WAF test battery.

## 3.7 Reasonableness

In order to meet the quality criterion of *reasonableness*, tests must be so constructed that the respondent is not overstretched physically and is not put under psychological stress either emotionally or in terms of energy and motivation. This applies at all times, but needs in particular to be borne in mind in relation to the diagnostic context in which the test is being used (e.g. Kubinger 2003).

With regard to test presentation and length WAFV can be said to be entirely reasonable.





## 3.8 Resistance to falsification

A test that meets the meets the quality criterion of *resistance to falsification* is one which caprevent a respondent answering questions in a manner deliberately intended to influence or control his test score (e.g. Kubinger 2003). Since WAFV is an ability test, falsification in the sense of "faking good" is not possible. "Faking bad" can be prevented by creating a test setting in which the respondent feels at ease and by remaining observant during the testing session.

## 3.9 Fairness

If tests are to meet the quality criterion of fairness, they must not systematically discriminate against particular groups of respondents on the grounds of their sociocultural background (e.g. Kubinger 2003). WAFV is demonstrably fair because separate norms exist for the subgroups for which relevant mean differences were found.



## 4 NORMING

The norm scores were obtained by calculating the mean percentile rank PR(x) for each raw score X according to the formula (from Lienert & Raatz 1998):

$$PR_x = 100 \cdot \frac{cum \ f_x - f_x/2}{N}$$

*cum* fx corresponds to the number of respondents who have achieved the raw score X or a lower score, fx is the number of respondents with the raw score X, and N is the size of the sample.

Descriptive statistics of the normed test variables can be found in the Vienna Test System under the menu option **Extras** => **Norm Table Explorer**. The tables there show the distribution of all the normed test variables in the total sample and in the subsamples.

## 4.1 Adult norms

A norm sample is available for WAFV consisting of 295 individuals representative of the general population (46.4% men; 53.6% women) aged between 16 and 77 (Md=39; sd=15.1). The distribution of the sample in terms of educational background is as follows:

Educational level	Description	%
EU 1	No school-leaving qualification	0.0 %
EU 2	Compulsory schooling or intermediate secondary school	11.5 %
EU 3	College or vocational training	41.0 %
EU 4	Higher secondary school with university entrance qualification	39.7 %
EU 5	University	7.8 %

Table 10. Educational distribution of the norm sample. Subjects are assigned to an educational group on the basis of the highest educational qualification obtained.

Norming was carried out between December 2005 and April 2006 under standardized test conditions in the research laboratory of SCHUHFRIED GmbH.

For the main variables corrections that take account of age effects are also available. The corrections take the form of z-standardised residues of a regression with regard to the age variable.

Table 11. Degree of the polynomial used for the regression and associated explained variance for the test forms of WAFV. While linear functions describe the age effect by means of a straight line, quadratic functions depict a relationship with one bend and cubic functions a relationship with two bends.

	Regression polynomial	Explained variance
Vigilance visual: Mean reaction time Missed reactions	quadratic quadratic	12.9 % 5.5 %
Vigilance auditory: Mean reaction time Missed reactions	quadratic linear	3.7 % 1.0 %
Sustained attention visual: Mean reaction time Missed reactions	quadratic quadratic	2.2 % 1.1 %
Sustained attention auditory: Mean reaction time Missed reactions	quadratic quadratic	2.4 % 1.6 %

## 4.2 Norms for children and young people

In addition to the norm sample of adults, a norm sample of children and young people is also available for selected WAFV test forms. These norms were developed in the context of a research project funded by the SCHUHFRIED company at schools in the greater Aachen area.

For WAFV the norm sample consists of 270 children and young people (47.0% boys, 53.0% girls) in the age range 7 - 17 years (Md=11; sd=3.2).

A regression-based age correction is also available for this sample; this meshes smoothly with the age regression of the adult sample but has a noticeably more curved path.

Because – as expected – there are significantly more marked age effects for children and young people than for adults, the age correction should always be applied when interpreting the results obtained by children and young people.

Table 12. Degree of the polynomial used for the regression and associated explained variance for the test forms of WAFV (for the sample of children and young people). While linear functions describe the age effect by means of a straight line, quadratic functions depict a relationship with one bend and cubic functions a relationship with two bends.

	Regression polynomial	Explained variance
Sustained attention visual: (short form) Mean reaction time Missed reactions	quadratic quadratic	38.8 % 16.7 %
Sustained attention auditory: (short form) Mean reaction time Missed reactions	quadratic quadratic	25.9 % 17.9 %

WAFV

## 4.3 Selecting the norm sample

The norm sample to be used can be selected in the test scoring options: click the **Options** button on the scoring screen.

In the Options window the **Samples** tab enables the choice to be made between an overall norm and a norm partitioned according to educational group.

🍽 Resu	ilt options			
S	amples Sco	be Header	Data export	
WA	FV Perception a	nd Attention Functions: V	/igilance / Sustained Attention	-
S2	Vigilance vis	Jal		•
1	Norm sample (from	16 years)		
-	Norm sample (from level)	16 years, 2 comparative :	samples selected according to E	ducation
2				
	X		2	
	Close	Norm tables	Help	

Figure 2. Options window for selecting the norm sample(s)

It is also possible to select both norms; the two norm comparisons are then carried out separately.

The procedure for obtaining age-corrected results is very similar. The age-corrected test variables can be selected or de-selected on the Scope tab.

<u>s</u> WA	Samples <b>∐ Scop</b> o FV Perception an	d Attention Functions: Vigila	nce / Sustained Attention	•
	Descriptions of tests a	nd test forms		
	Comments <u>a</u> nd explan	ations		
~	Results table(s)			
~	Profile(s)			
-	Chart of reaction time	S		
~	Test variables correc	ted for age		
-	Differentiated results			
24				
Lan	guage of test result is:	sue: English (USA)		-
			ୢ	
	×.	E	8	
	C)K	Norm tables	Holp	

Figure 3. Options window for selecting scoring options. Age-corrected test scores will now be displayed.

The norm comparison can thus be carried out in a number of ways.

Table 13. Various norm options for WAFV.

Sample	Age correction	Norming
total	off	total norm
total	on	age norm
educational norm	off	educational norm
educational norm	on	age and educational norm

## **5 TEST ADMINISTRATION**

Before the start of testing it is recommended that those subtests are selected that on the basis of hypothesis are likely to be relevant to the purpose of the assessment. The relevant subtests can be combined with other tests to form a test battery.

## 5.1 Pre-testing sensority capability with WAFW

When using the tests of the WAF test battery for the purpose of psychological assessment, it is recommended that steps are first taken to clarify whether a respondent has the necessary sensory capability to be able to complete the tests. If this is not done there can be no certainty that any performance deficits identified are in fact the result of attention problems; the possibility will always remain that poor sensory capability (e.g. lack of sensitivity to contrast, residual symptoms of scotoma, inadequately compensated sharpness of vision, non-compensated hearing impairments etc.) may be the cause of the poor performance.

WAFW uses the same material as the other WAF tests but presents it without time pressure, so that the test result is as far as possible independent of the respondent's attentional performance. The WAFW results will indicate whether the respondent meets the sensory requirements for the use of WAFV.

Table 14. Recommended WAFW preliminary tests and minimum scores for the use of the WAFV test forms

	WAFW test form	Minimum % correct
S2 Vigilance visual – long form	S2 - Distinguishing brightness	90 %
S4 Vigilance auditory – long form	S6 - Distinguishing volume	90 %
S5 Sustained attention visual – short form	S2 - Distinguishing brightness	90 %
S6 Sustained attention visual – long form	S2 - Distinguishing brightness	90 %
S7 Sustained attention auditory – short form	S6 - Distinguishing volume	90 %
S8 Sustained attention auditory – long form	S6 - Distinguishing volume	90 %

## 5.2 Technical precision of measurement

Measuring reaction times to the nearest millisecond is not straightforward. Many test programs or neuropsychological experiment generators quote reactions times in milliseconds in the test results but may nevertheless be affected by measurement errors of several times this amount, depending on the hardware and software used (cf. Häusler, Sommer & Chroust 2007; Plant, Hammond & Turner 2004).

Tests for measuring aspects of attention are particularly time-critical. Even measurement errors of only a few milliseconds can cause a significant shift of the normed test score and thus result in incorrect interpretation of the test results.

WAFV

#### 5.2.1 Visual stimulus material

The display of visual stimulus material in the Vienna Test System is extremely precise – on both CRT and LCD monitors. If WAFV is administered on an uncalibrated system, minor technical measurement errors of up to  $\pm$  3 PR may occur (depending on the hardware and software used).

To achieve greater precision of measurement, the exact screen delay can be measured using the Hardware Test. This figure is then used as a correction value in all time-critical tests. Calibrated test systems are guaranteed to yield measurements that can be converted accurately into percentile ranks.



Figure 4: Calibrating a monitor with the calibration device. The VTS workstation should be calibrated every six months and whenever changes are made to the hardware (e.g. new monitor).

#### 5.2.2 Auditory stimulus material

In order to ensure the highest level of precision for auditory stimuli, we recommend the use of a standard audio output device. If external loudspeakers or a non-standard headset are used for audio output, there is a risk that the driver software of these devices will produce measurement errors of up to 100 ms. In addition, these devices may have a different sound curve, so that – for example – low sounds may be reproduced more softly in comparison to other tones than was the case in the standardisation of the WAF tests.



Figure 5. Warning issued when a non-standard audio output device is used.

If the audio output device used does not conform to the standard, you will be informed of this before the test session starts. A comment will also be included in the test results to the effect that the results were obtained under non-standard conditions.

## 5.3 Instructions

The instructions at the start of the test can be followed independently by the respondent on his screen; the test administrator is not required to provide any further explanation. Standardised instructions with practise examples are used. With patients it is recommended nevertheless that the test administrator supervises the patient during the instruction phase and also checks from time to time during testing that the instructions are being adhered to. The administrator is informed if the respondent does not comply with the instructions or if his behaviour indicates that the instructions have not been understood. In this case the instruction and practise phase must be repeated. Before the test phase begins the respondent is informed of the time that will be needed for the task.



Figure 6. Instruction page from WAFV test form S2.

## 5.4 Test phase

WAFV test forms S2 and S6 use black squares that sometimes get darker; forms S4 and S8 use sound signals that sometimes become softer. The respondent must react to these changes in intensity. In forms S2 and S4 this happens very seldom, generating a vigilance effect, while in forms S6 and S8 a significantly higher proportion of the signals are relevant (see Section 2.2).

The stimuli are presented for 1500ms; a change may take place after 500ms. There is an interstimulus interval of 500ms between stimuli.

## 6 WAFV FOR CHILDREN AND YOUNG PEOPLE

The WAF test battery can be used with children from the age of 7, provided that the norms for children and young people are used. To ensure that test presentation is as stress-free and reasonable as possible, two special test forms for children and young people have been devised.

Table 15. Recommended WAFV test forms for children and young people.

Form	Description
S5	S6 Sustained attention visual – short form
S7	S8 Sustained attention auditory – short form

The transition from the norms for children and young people to those for adults is fluid. The switch from one set of norms to the other can be made at any point in the age range 16 - 18 years without risk of error effects, provided that the age-corrected test variables are used.

## 7 INTERPRETATION OF TEST RESULTS

When interpreting the main variables the percentile rank should normally be used. A percentile rank can be understood here as the proportion of the comparison sample who obtained an equal or a lower (worse) result (Kubinger 1995). A high percentile rank can therefore be viewed as indicating that the trait being measured (here: vigilance or sustained attention) is present in strongly marked form.

Percentile rank	Proportion of reference group	Description
< 16	15 %	Below average
16 to 24	10 %	Low average to slightly below average
25 to 75	50 %	Average
76 to 84	10 %	High average to slightly above average
> 84	15 %	Above average

Table 16. Interpretation of percentile rank scores.

Additional notes on interpretation and on the planning of an assessment session can be found in Section 2.2. In particular, the possibility of repeating a task in order to assess a tendency to fatigue or diminished resilience should be borne in mind (see below).

#### Additional test variables:

There are a number of subsidiary variables that may be of relevance for more precise interpretation of the test results. These variables can be selected or de-selected via the options **Test variables corrected for age** and **Differentiated results** in the **Result options** window.

Result options		
Samples Scop	Header Data export	
WAFV Perception ar	nd Attention Functions: Vigilance / Sustained Attention	•
<ul> <li>Descriptions of tests a</li> <li>Comments and explanation</li> </ul>	and test forms nations	
Results table(s)		
✓ Profile(s)		
- Chart of reaction times		
✓ Test variables corrected for age		
✓ Differentiated results		
Language of test result issue: English (USA)		

Figure 7. Selecting the display options for the WAFA test.

The age-corrected test variables relate the respondent's test score to his age. The **Parameter** column gives the standardised residual of the test score with regard to the age regression. This indicates the extent to which the test score lies above or below the score to be expected of a person of this age on the basis of the norm sample.



This residual is quoted as a z-transformed variable; scores < -1 therefore reflect poor performance, while scores > +1 indicate good performance. Scores between -1 and +1 are in the normal range.

In addition, the **Raw Score** column gives the score of a 20-year-old person that would correspond to this particular test score. Percentile ranks are of course also given for the age-corrected test scores.

#### Qualitative interpretation of the reaction time chart

In addition to interpreting the normed test scores, it can also be informative to consider the reaction time charts. The gradient and shape of the point cluster may yield specific additional information about the respondent's ability to maintain his vigilance or sustained attention and about the pattern of such attention.

#### Main variables

#### Mean reaction time

This variable is a logarithmic mean of the individual reaction times. A high test score leads to a low percentile rank and indicates a slow processing speed in identifying the stimuli in the vigilance and sustained attention tasks.

#### Number of missed reactions

This is the number of stimuli to which no response was made within 1500 ms. A high test score leads to a low percentile rank and indicates problems in the continuous maintaining of vigilance or sustained attention. It is particularly important to note whether the omissions are evenly distributed or whether they occur in clusters (as would be expected, for example, if the subject is experiencing some form of paroxysm or micro-sleep). Alternatively, omissions may become more frequent towards the end of the test (comparison between first and second halves of the test), pointing to a possible problem in maintaining vigilance or sustained attention.

#### Subsidiary variables

#### **Dispersion of reaction time**

This is the logarithmic standard deviation of the reaction times. A high standard deviation leads to a low percentile rank and indicates a marked intra-individual variability in processing speed in vigilance / sustained attention.

#### Number of false alarms

This is the number of times a reaction key was pressed in response to irrelevant stimuli or when no stimulus had been presented. Raised error rates should normally be interpreted as an indication not of an impairment of the intensity of attention but (at least partially) of an impairment of selectivity, unless they vary systematically over time.

All variables are reported both for the test as a whole and separately for the first and second halves. This makes it possible to identify any diminishment of sustained attention or vigilance performance over the course of a relatively lengthy task.

## 8 MEASUREMENT OF CHANGE

The tests of the WAF test battery can also be used to measure change that may have occurred. This is useful if it is necessary to measure the effect of an intervention or a spontaneous change in a subject over a particular period. Table 17 gives critical T-score differences ( $d_{crit}$ ) in reaction time for each of the WAFV test forms (only for the test as a whole). If these are exceeded, a statistically provable change has occurred. A detailed introduction to the measurement of change can be found in Kubinger, Rasch & Häusler (2006).

Table 17. Critical T-score differences ( $d_{crit}$ ) for the "Reaction Time" of the WAFV test forms at a statistical certainty of 90% and 95%. If the critical T-score difference is exceeded, a significant change (at the given level of statistical certainty) has occurred.

	Critical T-score change (d <sub>crit</sub> )	
	Statistical certainty 90%	Statistical certainty 95%
Vigilance visual	5	6
Vigilance auditory	3	4
Sustained attention visual	2	3
Sustained attention auditory	2	3

## 9 COGNITIVE TRAINING WITH COGNIPLUS

## 9.1 Training specific attention functions

A meta-analysis by Robert (1990) came to the conclusion that computerised training of attention functions is on the whole effective, although some studies have yielded negative results.

Cicerone et al (2000, 2005) published meta-analyses of evidence-based cognitive rehabilitation in the field of "attention therapy". They found that the studies demonstrate the effectiveness of specific attention training in ways that go beyond the effects of non-specific cognitive stimulation, both for patients who have suffered craniocerebral trauma and for stroke patients. Training should cover different sensory modalities and a range of complexity levels.

There is, however, inadequate evidence of the effectiveness of attention therapy in the early phase of rehabilitation, since the effects of attention therapy cannot be distinguished from those of spontaneous remission.

# 9.2 Development and evaluation of the Aixtent attention training program

Sturm et al. (1993) have developed computerised training programs **(AIXTENT)** in the style of games for treating impairments of alertness, vigilance, selective attention and divided attention:

- Alertness training: A racing car or motorcycle that is travelling at speed must be brought to a halt promptly in front of an obstacle.
- **Vigilance training:** Radar observation (detection of flying objects that appear only infrequently); conveyor belt task (detection of faulty articles).
- **Training of selective attention:** While clay pigeon shooting or on a photo safari only specified objects or combinations of objects are to be attended to.
- **Training of divided attention:** In the cockpit of an airplane the client must simultaneously observe the horizon, the flight speed and untoward engine noises.

Patients with vascular, unilateral brain lesions and attention deficits in at least two areas of attention underwent 14 training sessions in one of the impaired function areas. The results showed that only the relevant specific training was effective, particularly in the attention areas of alertness and vigilance (Sturm et al. 1994, 1997). The authors were also able to show that, where elementary attention functions are impaired, the "wrong" training – which makes over-complex demands on attention – can lead to further worsening of attentional performance.

Almost identical results were obtained in a multi-centric study of the effectiveness of the same programmes for TBI patients (Sturm et al. 2003) and in use of the AIXTENT programs with patients with multiple sclerosis (Plohmann et al. 1998) or epilepsy (Engelberts et al. 2002). It seems that an improvement in elementary attention functions, in particular – in contrast to, for example, memory functions – can be brought about through stimulation therapy, without the need for the patient to acquire special strategies.

The conclusion to be drawn from these research results is that any attention therapy must be preceded by careful diagnosis of attention problems, in order to identify specific attention deficits in individual patients or clients. The Test Battery for Perception and Attention Functions (WAF) is particularly well suited to this purpose, as it enables a complete assessment of relevant attention functions to be made.



Taking advantage of the most up-to-date computer tools used in professional game development, the MS-DOS program AIXTENT has been used as the basis for a number of training programs of the cognitive training software CogniPlus. All the modules have been created from scratch, but they follow the same paradigms that were successfully used in AIXTENT. Particular importance was attached to embedding the typical attentional tasks in realistic everyday situations. Here, too, the motor demands made on the patient are extremely small, being limited to the pressing of a reaction button. Care was taken to ensure that patients with visual field restriction or hemineglect could use the training system. In accordance with the latest taxonomies of attention, two additional modules were added to the training programs:

- spatial orienting of attention (in particular for treatment of hemineglect)
- **focused attention** (for treatment of increased susceptibility to distraction and disruption)

Training program in CogniPlus
ALERT
VIG
FOCUS
SELECT
DIVID
SPACE

Table 18. WAF tests and the corresponding CogniPlus attention training programs

CogniPlus is adaptive; by analysing reaction times and errors it automatically adapts the difficulty level of the program to the patient's performance.

The progress of therapy should not be evaluated through changes in performance during the training itself; instead, external tests (such as the WAF subtests, see above) should be used. This is the only way to distinguish generalised therapy effects from trivial practice effects.

## 9.3 VIG – the CogniPlus training program for vigilance

#### Task

The client is driving along a straight highway. At irregular intervals other vehicles come towards him on the opposite carriageway or overtake him. The client's task is to react by pressing a button when an overtaking vehicle suddenly brakes in front of him. Once he has reacted the vehicle's brake lights go out and it accelerates away from him. If the client fails to react within the permitted time, the brake lights start to flash. Eventually there is a loud squealing noise, which is designed to draw the client's attention to what is happening.



Figure 8: The VIG training program

#### **Difficulty structure**

The VIG training program has 30 difficulty levels. A decreasing stimulus frequency makes it more and more difficult for the client to sustain his attention: he is overtaken by other cars increasingly rarely, the surroundings become more monotonous as darkness falls and the number of sudden braking manoeuvres from overtaking vehicles decreases. In addition, the intensity of the feedback on delayed and omitted reactions becomes weaker as the difficulty level increases. The challenge therefore changes gradually from a sustained attention task to one requiring real vigilance.

At each difficulty level the maximum permitted reaction time adapts to the speed of the client's reactions. Taking the client's first valid reactions as a starting point, an individual reaction time limit is determined and used as a basis for measuring all further reactions made in the course of the training program. This ensures that from the outset the training program is optimally adapted to the client's skill and is neither too easy nor too difficult for him.



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## **11 APPENDIX: DESCRIPTIVE STATISTICS**

The Appendix contains descriptive statistics for all the normed test variables.

m	mean
md	median
S	standard deviation

All test variables are available in normed form.

#### Test form S2 vigilance visual – total norm

Variable	range	m	md	S	skew	kurtosis
Mean reaction time	[313; 742]	492	486	87	0.41	0.28
Mean reaction time (corrected for age)	[-2.72; 2.65]	0.01	0.11	1.00	-0.48	0.37
Mean reaction time (first half of the test)	[280; 734]	478	465	82	0.53	0.35
Mean reaction time (second half of the test)	[298; 810]	609	498	98	0.54	0.16
Dispersion of reaction time	[46; 408]	125	120	47	1.26	4.10
Dispersion of reaction time (first half of the test)	[39; 281]	116	112	44	0.75	0.81
Dispersion of reaction time (second half of the test)	[37; 581]	128	121	57	1.99	12.34
Number of missed reactions	[0; 19]	2.58	2	3.63	2.27	5.48
Number of missed reactions (corrected for age)	[-4.07; 1.71]	0.19	0.48	1.00	-2.10	5.09
Number of missed reactions (first half of the test)	[0; 10]	0.93	1	1.49	2.45	6.78
Number of missed reactions (second half of the test)	[0; 23]	1.65	1	2.47	2.34	6.33
Number of false alarms	[0; 61]	2.99	2	6.47	8.74	93.36
Number of false alarms (first half of the test)	[0; 61]	1.36	1	3.90	12.51	187.09
Number of false alarms (second half of the test)	[0; 41]	1.36	1	1.90	3.15	14.69

Test form S	2 Vigilance	visual – EU	education	level 1-3
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Variable	range	m	md	S	skew	kurtosis
Mean reaction time	[314; 742]	506	500	86	0.24	-0.12
Mean reaction time (corrected for age)	[-3.14; 2.28]	-0.07	-0.05	0.99	-0.35	0.46
Mean reaction time (first half of the test)	[268; 734]	490	476	82	0.35	0.30
Mean reaction time (second half of the test)	[257; 810]	523	518	97	0.24	0.00
Dispersion of reaction time	[45; 251]	128	124	42	0.55	0.39
Dispersion of reaction time (first half of the test)	[40; 281]	122	118	44	0.80	1.34
Dispersion of reaction time (second half of the test)	[37; 270]	129	127	47	0.37	-0.22
Number of missed reactions	[0; 13]	2.72	2	3.53	2.15	5.00
Number of missed reactions (corrected for age)	[-4.06; 1.70]	0.19	0.43	0.98	-1.94	4.74
Number of missed reactions (first half of the test)	[0; 10]	1.04	1	1.52	2.20	5.57
Number of missed reactions (second half of the test)	[0; 23]	1.68	1	2.29	2.08	4.86
Number of false alarms	[0; 61]	3.26	2	5.87	6.82	62.06
Number of false alarms (first half of the test)	[0; 61]	1.79	1	5.25	9.62	106.63
Number of false alarms (second half of the test)	[0; 41]	1.46	1	2.07	2.84	10.64

## Test form S2 Vigilance visual – EU education level 4-5

Variable	range	m	md	S	skew	kurtosis
Mean reaction time	[303; 715]	479	467	85	0.70	0.25
Mean reaction time (corrected for age)	[-2.64; 2.65]	0.11	0.20	1.01	-0.64	0.45
Mean reaction time (first half of the test)	[302; 717]	465	452	81	0.77	0.70
Mean reaction time (second half of the test)	[304; 781]	494	480	97	0.92	0.85
Dispersion of reaction time	[47; 408]	122	115	52	1.73	5.92
Dispersion of reaction time (first half of the test)	[35; 242]	111	107	43	0.73	0.28
Dispersion of reaction time (second half of the test)	[37; 581]	127	114	67	2.57	14.42
Number of missed reactions	[0; 19]	2.42	1	3.74	2.43	6.23
Number of missed reactions (corrected for age)	[-4.26; 1.71]	0.19	0.54	1.03	-2.27	5.57
Number of missed reactions (first half of the test)	[0; 8]	0.81	1	1.45	2.82	8.96
Number of missed reactions (second half of the test)	[0; 14]	1.61	1	2.62	2.52	7.22
Number of false alarms	[0; 20]	2.13	2	2.46	3.29	19.35
Number of false alarms (first half of the test)	[0; 6]	0.89	1	1.11	1.60	3.09
Number of false alarms (second half of the test)	[0; 14]	1.24	1	1.67	3.63	23.39

## Test form S4 Vigilance auditory – total norm

Variable	range	m	md	S	skew	kurtosis
Mean reaction time	[331; 970]	524	511	114	0.92	1.58
Mean reaction time (corrected for age)	[-3.75; 2.56]	0.01	0.20	1.00	-0.91	1.63
Mean reaction time (first half of the test)	[305; 976]	504	495	110	0.90	1.47
Mean reaction time (second half of the test)	[322; 1000]	545	528	125	0.92	1.56
Dispersion of reaction time	[43; 263]	117	111	40	0.83	0.98
Dispersion of reaction time (first half of the test)	[40; 271]	110	102	42	0.98	1.18
Dispersion of reaction time (second half of the test)	[30; 282]	114	111	43	0.72	1.21
Number of missed reactions	[0; 43]	2.41	1	5.14	4.91	30.03
Number of missed reactions (corrected for age)	[-7.51; 0.60]	0.00	0.26	1.00	-4.87	29.72
Number of missed reactions (first half of the test)	[0; 21]	0.87	1	2.15	5.81	44.64
Number of missed reactions (second half of the test)	[0; 25]	1.54	1	3.24	4.31	22.26
Number of false alarms	[0; 39]	2.91	2	4.52	4.29	24.51
Number of false alarms (first half of the test)	[0; 36]	1.32	1	2.81	8.02	89.67
Number of false alarms (second half of the test)	[0; 21]	1.59	1	2.28	3.75	19.78

## Test form S4 Vigilance auditory – EU education level 1-3

Variable	range	m	md	S	skew	kurtosis
Mean reaction time	[231; 970]	537	530	131	0.82	1.08
Mean reaction time (corrected for age)	[-3.98; 2.56]	-0.07	0.06	1.14	-0.84	1.29
Mean reaction time (first half of the test)	[280; 976]	514	508	126	0.83	0.97
Mean reaction time (second half of the test)	[191; 1000]	561	546	142	0.82	1.15
Dispersion of reaction time	[41; 263]	120	112	43	0.83	0.69
Dispersion of reaction time (first half of the test)	[41; 271]	111	102	44	1.08	1.41
Dispersion of reaction time (second half of the test)	[40;282]	117	111	46	0.68	0.96
Number of missed reactions	[0; 43]	3.07	1	6.57	4.12	19.57
Number of missed reactions (corrected for age)	[-7.89; 0.57]	-0.12	0.26	1.28	-4.09	19.33
Number of missed reactions (first half of the test)	[0; 21]	1.11	1	2.78	4.92	29.37
Number of missed reactions (second half of the test)	[0; 25]	1.96	1	4.05	3.68	15.01
Number of false alarms	[0; 39]	3.67	2	5.71	3.60	15.92
Number of false alarms (first half of the test)	[0; 36]	1.59	1	3.69	6.83	58.82
Number of false alarms (second half of the test)	[0; 21]	2.09	1	3.10	3.28	14.10

Variable	range	m	md	S	skew	kurtosis
Mean reaction time	[339; 884]	511	497	94	0.74	0.97
Mean reaction time (corrected for age)	[-3.15; 1.68]	0.08	0.27	0.84	-0.78	0.91
Mean reaction time (first half of the test)	[319; 850]	494	484	91	0.73	1.06
Mean reaction time (second half of the test)	[323; 919]	530	506	103	0.74	0.79
Dispersion of reaction time	[44; 252]	114	111	38	0.79	1.29
Dispersion of reaction time (first half of the test)	[38; 268]	109	114	40	0.84	0.79
Dispersion of reaction time (second half of the test)	[31; 278]	111	112	39	0.70	1.43
Number of missed reactions	[0; 24]	1.74	1	3.00	4.14	24.33
Number of missed reactions (corrected for age)	[-4.17; 0.60]	0.12	0.27	0.58	-4.05	23.53
Number of missed reactions (first half of the test)	[0; 9]	0.62	1	1.19	3.60	19.15
Number of missed reactions (second half of the test)	[0; 15]	1.12	1	2.06	3.92	20.52
Number of false alarms	[0; 23]	2.16	2	2.71	3.84	25.38
Number of false alarms (first half of the test)	[0; 11]	1.06	1	1.46	2.91	15.24
Number of false alarms (second half of the test)	[0; 12]	1.10	1	1.64	3.13	15.20

## Test form S4 Vigilance auditory – EU education level 4-5

## Test form S5 Sustained attention visual short form – children and young people

Variable	Range	m	md	S	skew	kurtosis
Mean reaction time	[246; 885]	454	440	110	0.79	0.64
Mean reaction time (corrected for age)	[-3.90; 3.42]	0.00	0.13	0.99	-0.48	0.96
Mean reaction time (first half of the test)	[237; 843]	435	415	104	0.83	0.69
Mean reaction time (second half of the test)	[252; 926]	474	459	120	0.73	0.43
Dispersion of reaction time	[55; 539]	155	141	71	2.03	6.58
Dispersion of reaction time (first half of the test)	[39; 731]	143	124	74	3.04	16.66
Dispersion of reaction time (second half of the test)	[48; 698]	158	143	80	3.33	18.15
Number of missed reactions	[0; 125]	8.74	5	13.49	4.11	25.62
Number of missed reactions (corrected for age)	[-8.82; 1.56]	0.03	0.21	0.97	-4.16	30.16
Number of missed reactions (first half of the test)	[0; 61]	3.19	1	5.87	5.09	39.02
Number of missed reactions (second half of the test)	[0;64]	5.56	3	8.05	3.27	15.95
Number of false alarms	[0;62]	8.00	5	9.32	2.87	10.86
Number of false alarms (first half of the test)	[0; 43]	3.26	2	4.18	4.26	31.90
Number of false alarms (second half of the test)	[0; 53]	4.75	3	6.30	3.74	20.48

Test form	<b>S6</b>	Sustained	attention	visual	– total	norm
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Variable	range	m	md	S	skew	kurtosis
Mean reaction time	[224; 797]	375	365	81	1.20	2.92
Mean reaction time (corrected for age)	[-3.13; 1.98]	0.01	0.11	1.00	-1.18	3.15
Mean reaction time (first half of the test)	[233; 639]	375	366	76	0.83	0.69
Mean reaction time (second half of the test)	[215; 995]	377	361	91	1.86	8.34
Dispersion of reaction time	[38; 362]	94	86	41	2.09	8.85
Dispersion of reaction time (first half of the test)	[39; 359]	92	85	40	2.15	9.31
Dispersion of reaction time (second half of the test)	[36; 290]	93	84	40	1.27	2.25
Number of missed reactions	[0; 193]	5.42	2	15.23	8.74	96.98
Number of missed reactions (corrected for age)	[-6.42; 0.61]	-0.06	0.16	1.00	-8.65	95.49
Number of missed reactions (first half of the test)	[0; 69]	2.26	1	5.98	7.32	70.05
Number of missed reactions (second half of the test)	[0; 124]	3.16	1	9.51	9.18	107.16
Number of false alarms	[0; 34]	3.07	2	4.41	3.06	13.87
Number of false alarms (first half of the test)	[0; 17]	1.45	1	2.32	2.73	10.53
Number of false alarms (second half of the test)	[0; 17]	1.62	1	2.49	2.85	11.72

#### Test form S6 sustained attention visual – EU education level 1-3

Variable	range	m	md	S	skew	kurtosis
Mean reaction time	[229; 625]	380	369	81	0.75	0.47
Mean reaction time (corrected for age)	[-3.12; 1.91]	-0.02	0.06	0.99	-0.72	0.55
Mean reaction time (first half of the test)	[233; 606]	379	370	76	0.66	0.27
Mean reaction time (second half of the test)	[225; 646]	382	370	88	0.80	0.52
Dispersion of reaction time	[39; 208]	97	93	38	0.94	0.38
Dispersion of reaction time (first half of the test)	[40; 197]	94	85	36	0.95	0.33
Dispersion of reaction time (second half of the test)	[37; 220]	98	87	42	0.96	0.31
Number of missed reactions	[0; 49]	5.20	2	8.86	2.85	8.50
Number of missed reactions (corrected for age)	[-3.03; 0.61]	-0.05	0.12	0.58	-2.94	9.76
Number of missed reactions (first half of the test)	[0; 20]	2.11	1	3.82	2.86	8.57
Number of missed reactions (second half of the test)	[0; 29]	3.10	1	5.50	2.68	7.41
Number of false alarms	[0; 27]	3.52	2	4.57	2.37	7.26
Number of false alarms (first half of the test)	[0; 12]	1.64	1	2.43	2.02	4.22
Number of false alarms (second half of the test)	[0; 17]	1.88	1	2.63	2.51	8.90

Variable	range	m	md	S	skew	kurtosis
Mean reaction time	[224; 797]	370	361	81	1.71	5.94
Mean reaction time (corrected for age)	[-5.34; 1.98]	0.04	0.20	1.01	-1.66	6.01
Mean reaction time (first half of the test)	[233; 639]	371	364	76	1.03	1.31
Mean reaction time (second half of the test)	[213; 995]	370	354	93	2.89	16.29
Dispersion of reaction time	[38; 362]	91	82	44	2.98	14.82
Dispersion of reaction time (first half of the test)	[33; 359]	90	85	44	2.93	14.19
Dispersion of reaction time (second half of the test)	[34; 290]	87	81	38	1.70	5.87
Number of missed reactions	[0; 193]	5.66	1	19.96	7.85	68.42
Number of missed reactions (corrected for age)	[-12.33; 0.51]	-0.08	0.18	1.31	-7.77	67.34
Number of missed reactions (first half of the test)	[0; 69]	2.43	1	7.67	6.87	53.44
Number of missed reactions (second half of the test)	[0; 124]	3.23	1	12.48	8.27	75.74
Number of false alarms	[0; 34]	2.59	1	4.20	4.11	25.69
Number of false alarms (first half of the test)	[0; 17]	1.24	1	2.20	3.80	21.73
Number of false alarms (second half of the test)	[0; 17]	1.35	1	2.30	3.40	17.49

## Test form S6 sustained attention visual – EU education level 4-5

## Test form S7 Sustained attention auditory short form – children and young people

Variable	Range	m	md	S	skew	kurtosis
Mean reaction time	[169; 942]	543	532	141	0.36	0.30
Mean reaction time (corrected for age)	[-2.79; 3.15]	0.00	0.11	0.99	-0.34	0.17
Mean reaction time (first half of the test)	[259; 941]	179	170	68	1.66	6.27
Mean reaction time (second half of the test)	[100; 974]	564	544	149	0.30	-0.05
Dispersion of reaction time	[64; 437]	189	186	61	0.85	1.65
Dispersion of reaction time (first half of the test)	[57; 595]	179	170	68	1.66	6.27
Dispersion of reaction time (second half of the test)	[60; 565]	191	189	63	1.39	5.93
Number of missed reactions	[0; 96]	17.56	10	18.50	1.81	3.73
Number of missed reactions (corrected for age)	[-3.72; 1.80]	0.03	0.26	0.93	-1.34	2.51
Number of missed reactions (first half of the test)	[0; 46]	7.03	4	8.32	1.90	4.02
Number of missed reactions (second half of the test)	[0; 58]	10.52	6	10.87	1.68	3.18
Number of false alarms	[0; 78]	12.18	9	11.67	2.20	7.04
Number of false alarms (first half of the test)	[0; 37]	5.57	4	5.70	2.06	6.23
Number of false alarms (second half of the test)	[0; 62]	6.62	5	7.04	3.13	16.72

#### Test form S8 sustained attention auditory – total norm

Variable	range	m	md	S	skew	kurtosis
Mean reaction time	[252; 867]	451	427	123	0.90	0.75
Mean reaction time (corrected for age)	[-3.50; 1.76]	-0.01	0.14	1.00	-0.89	0.89
Mean reaction time (first half of the test)	[240; 784]	434	410	115	0.80	0.41
Mean reaction time (second half of the test)	[262; 981]	480	448	137	1.10	1.47
Dispersion of reaction time	[49; 320]	129	122	47	1.02	1.26
Dispersion of reaction time (first half of the test)	[43; 273]	121	112	45	0.93	0.86
Dispersion of reaction time (second half of the test)	[52; 298]	131	123	48	0.85	0.40
Number of missed reactions	[0; 169]	13.06	5	24.07	3.71	16.44
Number of missed reactions (corrected for age)	[-5.65; 0.76]	-0.03	0.30	1.00	-3.80	17.45
Number of missed reactions (first half of the test)	[0; 54]	4.58	2	8.40	3.20	11.55
Number of missed reactions (second half of the test)	[0; 120]	8.48	3	16.45	4.02	19.33
Number of false alarms	[0; 45]	6.06	4	7.50	2.39	6.66
Number of false alarms (first half of the test)	[0; 18]	2.54	2	3.39	2.33	5.95
Number of false alarms (second half of the test)	[0; 27]	3.52	2	4.63	2.42	6.97

## Test form S8 sustained attention auditory – EU education level 1-3

Variable	range	m	md	S	skew	kurtosis
Mean reaction time	[253; 858]	469	448	135	0.70	0.00
Mean reaction time (corrected for age)	[-3.49; 1.76]	-0.13	0.03	1.08	-0.72	0.21
Mean reaction time (first half of the test)	[240; 752]	450	433	126	0.55	-0.36
Mean reaction time (second half of the test)	[266; 981]	489	465	150	0.88	0.47
Dispersion of reaction time	[58; 291]	134	124	50	0.81	0.27
Dispersion of reaction time (first half of the test)	[44; 264]	125	116	48	0.80	0.24
Dispersion of reaction time (second half of the test)	[55; 298]	135	124	51	0.80	0.13
Number of missed reactions	[0; 169]	15.83	5	27.28	3.18	12.20
Number of missed reactions (corrected for age)	[-6.69; 0.75]	-0.15	0.27	1.11	-3.33	13.54
Number of missed reactions (first half of the test)	[0; 54]	5.52	2	9.62	2.90	9.25
Number of missed reactions (second half of the test)	[0; 120]	10.31	4	18.40	3.33	13.67
Number of false alarms	[0; 45]	7.05	4	8.29	2.13	5.05
Number of false alarms (first half of the test)	[0; 19]	2.89	2	3.58	2.14	5.02
Number of false alarms (second half of the test)	[0; 27]	4.17	3	5.28	2.17	5.16

Variable	range	m	md	S	skew	kurtosis
Mean reaction time	[251; 867]	432	418	105	1.06	2.08
Mean reaction time (corrected for age)	[-3.53; 1.65]	0.13	0.25	0.89	-1.03	2.07
Mean reaction time (first half of the test)	[240; 784]	417	404	99	1.08	2.02
Mean reaction time (second half of the test)	[262; 963]	448	432	118	1.32	3.45
Dispersion of reaction time	[47; 320]	124	121	44	1.30	3.07
Dispersion of reaction time (first half of the test)	[38; 273]	116	110	41	1.08	1.90
Dispersion of reaction time (second half of the test)	[51; 264]	126	122	44	0.84	0.65
Number of missed reactions	[0; 137]	10.08	4	19.75	4.67	26.11
Number of missed reactions (corrected for age)	[-5.35; 0.76]	0.10	0.35	0.85	-4.64	26.16
Number of missed reactions (first half of the test)	[0; 39]	3.57	1	6.74	3.46	13.43
Number of missed reactions (second half of the test)	[0; 103]	6.51	3	13.86	5.39	33.88
Number of false alarms	[0; 39]	4.99	3	6.04	2.76	9.53
Number of false alarms (first half of the test)	[0; 16]	2.17	1	3.14	2.63	7.74
Number of false alarms (second half of the test)	[0;23]	2.82	2	3.71	2.58	8.85

## Test form S8 sustained attention auditory – EU education level 4-5