VIENNA TEST SYSTEM

MANUAL

RESPONSE INHIBITION

Test label INHIB

Version 22

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1 SUMMARY

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Application

Test to measure various aspects of response inhibition. The test uses a stop signal paradigm, a go/no-go paradigm, a cued go/no-go paradigm and a behavioral shift paradigm.

Main areas of application: neuropsychology, clinical psychology

Theoretical background

The ability to suppress unwanted reactions is a basic prerequisite for flexible and appropriate behavior; in the literature it is termed “response inhibition”. Response inhibition is regarded as a component of the executive functions. It requires the integrity of specific prefrontal areas and their subcortical connections. Impairments of response inhibition are observed in many neurological and psychiatric disorders and have a significant impact on the sufferer’s ability to function in everyday life.

Method

The present test facilitates the detailed measurement of various aspects of response inhibition; the precise assessment that results can provide a starting point for therapeutic intervention. For practical purposes it is recommended that one test form is administered as a routine test. This can then be followed by detailed assessment with further test forms tailored to the specific issue under investigation and the respondent’s ability level.

Test forms

There are eleven test forms. For each of the following paradigms there is a pair of parallel test forms: stop signal (S1/S2), go/no-go (S3/S4), cued go/no-go (S5/S6), behavioral shift (shift only, S7/S8), behavioral shift (shift and inhibition, S9/S10). There is also one short form that uses the go/no-go paradigm (S13).

Scoring

The main variables are the parameters that reflect the inhibition process (*Stop signal reaction time, Commission errors*). In addition, other error types and reaction times are measured as an aid to comprehensive interpretation of the test results.

Reliability

The test’s reliability was estimated by calculating split-half reliability coefficients for the main variables for the norm sample of each test form. For Forms S1/S2 (stop signal) the value of the resulting coefficient is 0.87; for Forms S3/S4 (go/no-go) it is 0.83; for Forms S5/S6 (cued go/no-go) it is 0.67; for Forms S7/S8 it is 0.79 and for Forms S9/10 it is 0.77 for the variable *Commission errors* and 0.67 for *Number of shift errors*. For Form S13 Cronbach’s Alpha is 0.71.

Validity

Extensive literature supports the validity of the tests used here. In particular, construct validity at the level of neuropsychological functions is confirmed by factor analytic studies in which these tests load onto a common inhibition factor. However, the intercorrelations vary between the studies, which indicates that the test forms measure different aspects of a common construct.

Norms

Norms are available for the individual test forms varying in size between 354 and 359 individuals aged between 16 and 84. For some test forms norms separated according to education, age and gender are also available.

Testing time

The time required for forms S1 – S10 is approximately 7-10 minutes (including instructions). Forms S13 requires approximately 3-4 minutes. The total testing time depends on the degree of detail with which response inhibition needs to be measured – i.e. how many test forms are used.

2 DESCRIPTION OF THE TEST

2.1 Theoretical background

2.1.1 Response inhibition as a central executive function

The ability to suppress unwanted reactions, termed “response inhibition” in the literature, is fundamental to flexible and appropriate behavior (Aron, 2007). If environmental conditions change, established reaction patters are often dysfunctional; they need to be suppressed so that they can be replaced with new situationally appropriate behaviors. Response inhibition is usually classed as one of the executive functions, these being higher cognitive functions required for the organization of complex, goal-directed behavior (Kaiser et al., 2005; Norman and Shallice, 1986). There are various models of the executive functions, many of which include functions such as planning, rule shifting and manipulation in working memory in addition to response inhibition. Studies that have used factor analysis to identify the structure of the executive functions invariably recognize inhibition as a stable independent factor (Miyake et al., 2000; Royall et al., 2002).

Executive functions require the functioning of the prefrontal cortex and its subcortical connections to be intact (Mega und Cummings, 1994). Impairments of response inhibition accordingly occur in various neuropsychiatric disorders that affect this network (Royall et al., 2002). Impaired response inhibition was first described in patients with focal lesions of these networks, especially the prefrontal cortex. There are now many studies that have found impairments of response inhibition in degenerative or inflammatory diseases such as Parkinson's disease or Alzheimer’s. The construct of response inhibition has become particularly important in psychiatry. In this field impairments of response inhibition are most clearly seen in disorders that involve poor impulse control (e.g. ADHD, emotionally unstable personality disorders, dependency disorders). They are also found, however, in disorders characterized by inflexible and inappropriate behavior, such as compulsive disorders, schizophrenia and depression.

Identifying impairments of response inhibition in neurological and psychiatric diseases is important because disorders of the executive control functions have a significant impact on the prospects for retaining or regaining everyday functions (Royall et al., 2002; Struchen et al., 2008; Velligan and Bow-Thomas, 1999). In addition, the status of the executive functions has been discussed as a predictor of the success of pharmacological interventions and cognitive rehabilitation (Dunkin et al., 2000; Wykes and Huddy, 2009). A differential assessment of the subfunctions can contribute to a differential diagnosis and provide a starting point for specific training adapted to the individual’s needs.

2.1.2 Levels of response inhibition

The tests most frequently used to investigate response inhibition utilize stop signal and go/no-go paradigms.

In a stop signal task, a motor response that has already been initiated must be suppressed. This form of inhibition is the one that most closely resembles a motor skill (Verbruggen and Logan, 2008). In each trial the respondent is presented with a stimulus to which he must respond. In some trials a cue (stop signal) also appears that indicates that the response must be terminated. The response is initiated in all trials, but only in some trials is inhibition subsequently required.

A go/no-go task, by contrast, requires the respondent to discriminate between stimuli that require a response and those that require an inhibition (Drewe, 1975). In addition, a succession of similar responses builds up a dominant response tendency. Unlike in stop signal tasks, in go/no-go tasks it is not simply the suppression of a motor response that is important; the respondent must also decide whether a given stimulus calls for a response or an inhibition. This decision is made before the response is initiated.

Flexible behavioral control requires the ability both to inhibit a dominant response and to initiate a new one (Shafritz et al., 2005). For a behavioral shift, both functions are needed. Paradigms such as the Stroop test or flanker tasks are often referred to as response inhibition tasks. In these paradigms, however, the suppression of the motor response is not the key requirement; instead they involve two information processing pathways and require the respondent to use the less automated pathway in the face of interference from the dominant processing pathway (Melcher et al., 2008). Strictly speaking, this involves not response inhibition but the control of cognitive interference. These tasks are not therefore included in the present response inhibition test battery.

2.1.3 Neuronal correlates of response inhibition

The prefrontal and subcortical areas involved in response inhibition have been well identified in recent years through the use of imaging techniques. At cortical level, consistent activation of the (right) ventrolateral prefrontal cortex (VL-PFC) and the medial supplementary motor areas (SMA) has been described in connection with both stop signal and go/no-go paradigms (Buchsbaum et al., 2005; Simmonds et al., 2008). These imaging results are consistent with impaired response inhibition when there are lesions of these areas (Picton et al., 2007). In functional terms the ventrolateral prefrontal cortex may be involved in the decision to inhibit a response on account of an existing rule; activation in this region increases as the rules become more complex (Heinen et al., 2006; Simmonds et al., 2008). Supplementary motor areas are linked to actual implementation of the inhibition in the motor system (Aron et al., 2007; Mostofsky and Simmonds, 2008). The subthalamic nucleus (STN) has been identified as the most important subcortical area involved in response inhibition (Aron and Poldrack, 2006). The interaction between these three regions has also been confirmed by connectivity studies (Aron et al., 2007).

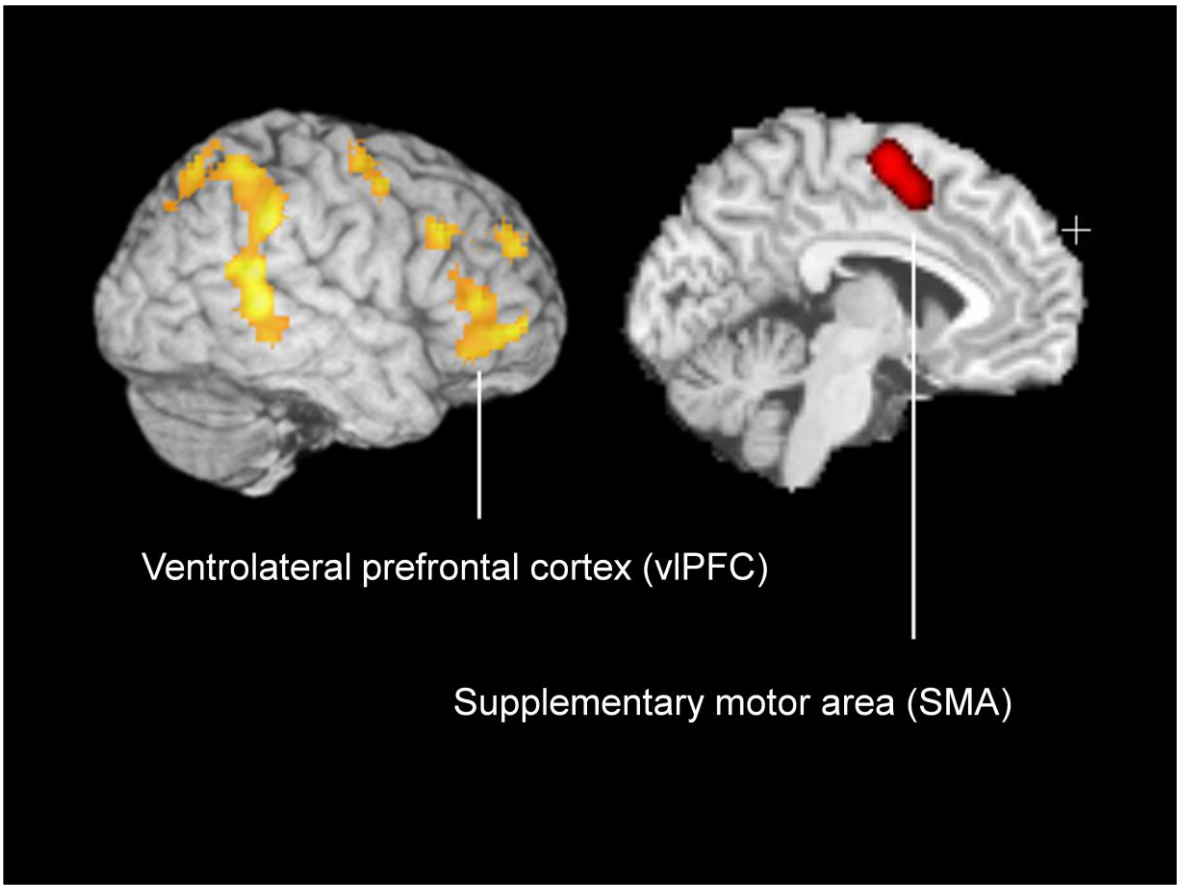

Figure 1. Areas in the right ventrolateral prefrontal cortex and the supplementary motor area activated by the go/no-go paradigm in an fMRI study conducted by the authors.

Although functional imaging techniques provide very precise spatial information, their temporal resolution is limited. Studies of event-related potentials (i.e. changes in the EEG in response to specific events) provide more accurate information about timing. In go/no-go paradigms such studies have in particular found a fronto-central negative-going wave approx. 200-300 ms after a stimulus that requires inhibition (Eimer, 1993;). This component is termed no-go N2. An increase in the frontal positive-going wave after approx. 300-400 ms, termed no-go P3, has also been found (Eimer, 1993; Fallgatter and Strik, 1999). The ventrolateral prefrontal cortex is considered to be the main neuronal generator of the no-go N2, although medial frontal areas (SMA) are also discussed in the literature (Bekker et al., 2005; Kiefer et al., 1998). The no-go P3 is associated chiefly with activation of the SMA or the anterior cingulate gyrus (Kiefer et al., 1998).

2.1.4 Disorders of response inhibition

Psychiatric illnesses

Impaired response inhibition is often observed in disorders in which poor impulse control is a feature. The impaired inhibition of inappropriate responses is discussed in the literature as a relevant mechanism for the pathogenesis of such disorders. The majority of studies have focused on attention deficit hyperactivity disorder (ADHD). Impaired response inhibition has been consistently reported when stop signal and go/no-go paradigms are used with ADHD patients; the possibility that response inhibition is an endophenotype (i.e. a measurable component of the pathway between the genes and the disease) has been discussed. In ADHD patients, response inhibition is more severely impaired than other cognitive functions (Wodushek and Neumann, 2003). Impulse control disorders are also observed in patients with personality disorders, especially emotionally unstable personality disorder of the borderline type (Nigg et al., 2005; Rentrop et al., 2008). Here, too, it is thought possible that a deficit of response inhibition is involved, although the findings are less consistent than for patients with ADHD. In addition, patients with borderline disorder seem to be less well able to adapt their processing speed to the difficulty of the task. Addictions form another group of psychiatric illnesses in which response inhibition is impaired. Some studies in this field indicate that poor response inhibition can contribute to the emergence of an addiction (Nigg et al., 2006; Perry and Carroll, 2008). On the other hand there are also indications that chronic use of substances such as alcohol or stimulants can result in impairment of these functions (Monterosso et al., 2005). Interestingly, similar mechanisms appear to be at work in behavioral addictions, such as compulsive gambling (Goudriaan et al., 2008). Impaired response inhibition is also found in manic episodes and in patients with bulimia.

Like impulsive behavior patterns, rigid, inflexible behavior is also associated with impaired response inhibition. The majority of studies in this area have looked at schizophrenia (Weisbrod et al., 2000; Wykes et al., 2000). However, it should be noted that most of the patients involved had other significantly more marked cognitive impairments. The response inhibition deficit is therefore usually regarded not as a specific impairment but as part of a broader impairment of the executive functions. However, in the context of rehabilitation this specific function is nevertheless key to the prognosis and the planning of therapy (see below). There have also been many studies of compulsive disorders (Penades et al., 2007). Here it is assumed that the impairment of response inhibition leads in particular to poor suppression of compulsive actions. Only a few studies have used executive function tests with patients with anorexia nervosa. However, some researchers have found an impairment of the behavioral shift, which could contribute to the clinical picture of cognitive and behavioral rigidity in these patients (Zastrow et al., 2009). Impaired response inhibition has also been found to be an aspect of depression (Kaiser et al., 2003); there are indications that the impairment decreases with the remission of the depressive symptoms.

Neurological diseases

In the field of neurological diseases, impairments of response inhibition have been repeatedly reported in connection with a number of different disorders, especially ones affecting the basal ganglia or structures in the ventrolateral or medial prefrontal cortex (Aron et al., 2003; Floden and Stuss, 2006; Rieger et al., 2003; Swick et al., 2008).

For example, disorders involving focal lesions of these areas of the brain can result in impaired response inhibition. Impaired response inhibition in stop signal and go/no-go paradigms has frequently been reported in patients with traumatic brain injury (Leblanc et al., 2005; Robertson et al., 1997). Children and young people with traumatic brain injury are particularly likely to be affected; in these patients response inhibition is often more severely affected than the other cognitive functions (Levin et al., 2004). There is also some evidence that even mild trauma without focal lesions can result in impaired response inhibition (Stewart and Tannock, 1999). Impaired response inhibition has consistently been reported in connection with cerebrovascular events involving lesions of the critical areas (Aron et al., 2003; Rieger et al., 2003). Response inhibition is likewise impaired in patients with focal lesions as a result of cerebral tumors; this has in particular been observed in patients with meningeomas (Aron et al., 2003).

Impaired response inhibition has also been observed in patients with other neurological diseases. In patients with Parkinson's disease, impairments of response inhibition tend to affect mainly stop signal tasks, although they can also impact on go/no-go tasks (Beste et al., 2009; Gauggel et al., 2004); this confirms the importance of fronto-subcortical loops for response inhibition. The increased stop-signal response time can be reduced by deep brain stimulation in the nucleus subthalamicus (van den Wildenberg et al., 2006). It is also interesting to note that in the early stages of Parkinson's disease altered activation of relevant brain structures is evident in fMRI before inhibition deficits become observable at behavioral level (Baglio et al., 2009). Impaired response inhibition also occurs in dementia; it is more pronounced in fronto-temporal and vascular dementia than in Alzheimer's-type dementia.

2.2 Use of INHIB

The present tool is not a single test but a test battery that enables various aspects of response inhibition, including different levels of severity, to be comprehensively assessed. Because of the limited time available in clinical practice, not every patient will be tested with every test form. For practical purposes we suggest that a test for the function area of response inhibition is first administered as a routine test. Particularly suitable tests for this purpose are Forms S3/S4 (go/no-go) or the short form S13, which is particularly economical as the time required for testing is roughly half that needed for the other forms. Forms S1/S2 (stop signal) can also be used. Additional forms for detailed assessment should then be administered; the forms used will depend on the issue under investigation and on the disease. The following diagram suggests a practical procedure that can of course be adapted to the user's specific needs.

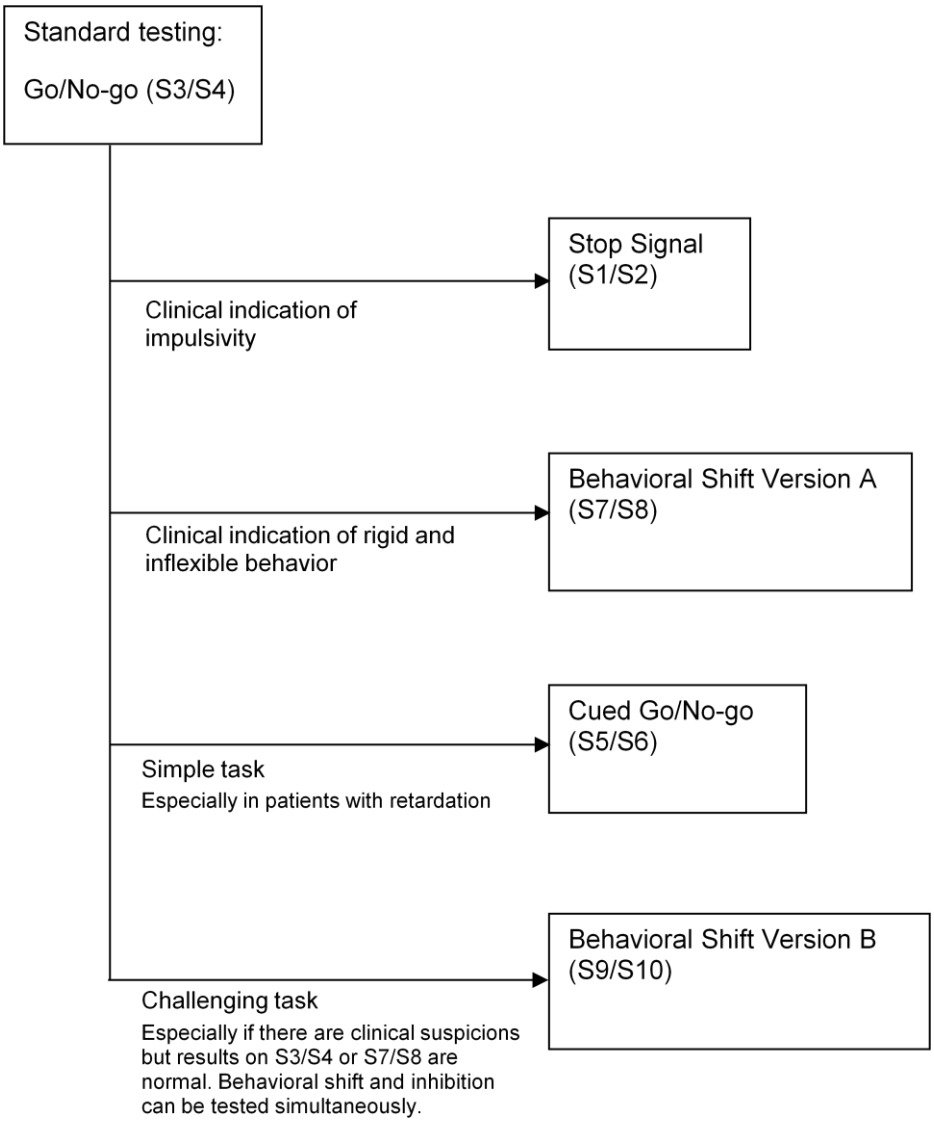

Figure 2: Flow diagram as a guide to the clinical use of INHIB. The tests listed on the right should be used in addition to the routine test.

2.3 Test structure

In Forms S1 to S10 the test consists of two parts separated by a short break. Each of the two parts is constructed on the same principles, which are described below. The short form S13 consists of only one part without a break.

2.3.1 Form S1/S2: Stop signal

In stop signal tasks a motor response that has already been initiated must be suppressed when an acoustic signal (stop signal) appears. A series of arrows are shown to the respondent one by one on the screen. The arrows point either to the left or to the right. Each half of the test consists of 100 stimuli. As soon as an arrow appears the respondent must press the “5” key if the arrow points to the left or the “6” key if it points to the right. Each arrow is displayed for one second; the time before the next arrow appears is also one second. For 76 of these stimuli the motor response is actually required (go trial). After 24 of the 100 stimuli, however, a tone at a pitch of 1000 Hz sounds for 100 milliseconds (stop signal). If the respondent hears this tone, he must not respond – in other words, the motor

response that has already been initiated must be suppressed (stop trial). The time between the presentation of the stimulus and the tone depends on the respondent's performance. The minimum interval is 50 milliseconds and the maximum is 350 milliseconds. It should be borne in mind that a longer interval between the arrow and the tone makes it more difficult to stop the response. If the testee responds correctly to a stimulus with stop signal, the interval for the next stimulus with stop signal increases by 50 milliseconds. If the response to the stimulus with stop signal is incorrect, the interval is decreased by 50 milliseconds on the next occasion. This means that correct responses to stimuli with a stop signal result in the difficulty of the task being increased, while incorrect responses result in the task being made easier. The difficulty thus adjusts adaptively to the respondent's ability.

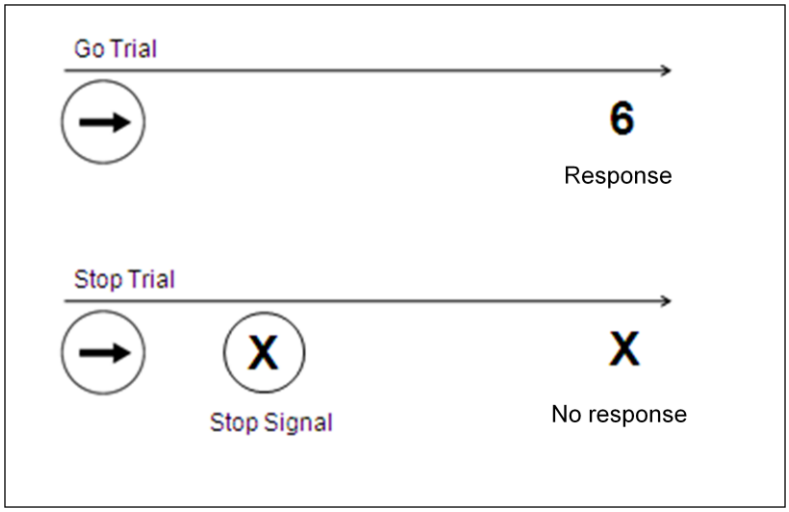

Figure 3: Schematic representation of a go trial and a stop trial.

2.3.2 Form S3/S4/S13: Go/no-go

A go/no-go task requires the respondent to discriminate between stimuli that require a response and those that require an inhibition (Drewe, 1975). In addition, a succession of similar responses builds up a dominant response tendency. The respondent is shown a series of circles and triangles that are presented one by one on the screen. Forms S3 and S4 each contain 250 of these stimuli, which are displayed for 200 milliseconds with an inter-stimulus interval of one second. Triangles occur frequently; the testee must respond to them by pressing the green button, which builds up a dominant response tendency. Circles appear rarely and require no response; this means that response inhibition is required. Each of the two test halves consists of 101 triangles and 24 circles. Form S13 is a short form of S3; it comprises the 125 stimuli from the first half of S3 and hence contains 101 triangles and 24 circles.

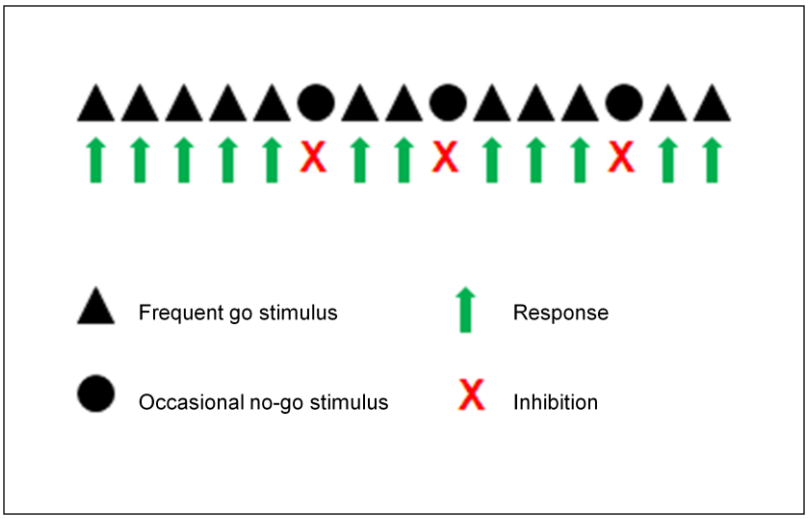

Figure 4: Schematic representation of 15 trials of the go/no-go task.

2.3.3 Form S5/S6: Cued go/no-go

In these forms response readiness is built up by presenting a cue. The respondent is shown a series of stimulus pairs that are presented one by one on the screen. Each stimulus pair consists of a plus or a minus sign, which is followed 500 milliseconds later by a square or diamond. Each sign or symbol is displayed for 200 milliseconds with an interval between the stimulus pairs of 1,500 milliseconds. Each of the two test halves consists of 50 stimulus pairs; the complete test therefore contains 200 stimuli.
In these test forms the respondent must press the green button whenever a square follows a plus sign. In each half of the test there are 12 stimulus pairs that require this response. The appearance of the plus sign signals that the second stimulus may require a response. This increases the testee's response readiness, which means that an inhibition is required if the second stimulus in the pair is a diamond.

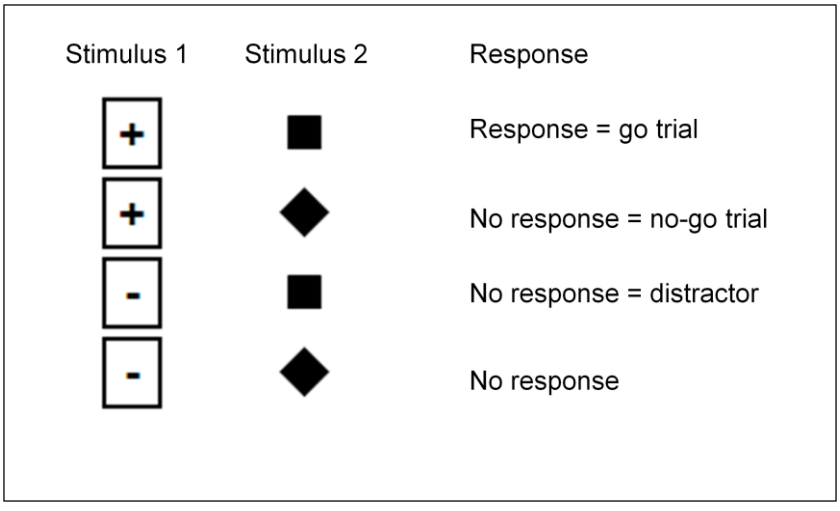

Figure 5: Schematic overview of the trial types in the cued go/no-go task.

2.3.4 Form S7/S8: Behavioral shift version A (shift only)

This form is similar to S3/S4 except that the occasional stimuli require a shift of the dominant response and not simple inhibition. A series of triangles, the tips of which point either up or

down, is shown on the screen. The majority of triangles point upwards; the “5” button must be pressed in response to these. This builds up a dominant response tendency. Occasionally the triangle points downwards. In this case the “6” button must be pressed; this therefore involves a behavioral shift. Each triangle is displayed for 200 milliseconds; the interval between triangles is always one second. In all, 250 stimuli are presented. In each test half 101 triangles point upwards and 24 downwards.

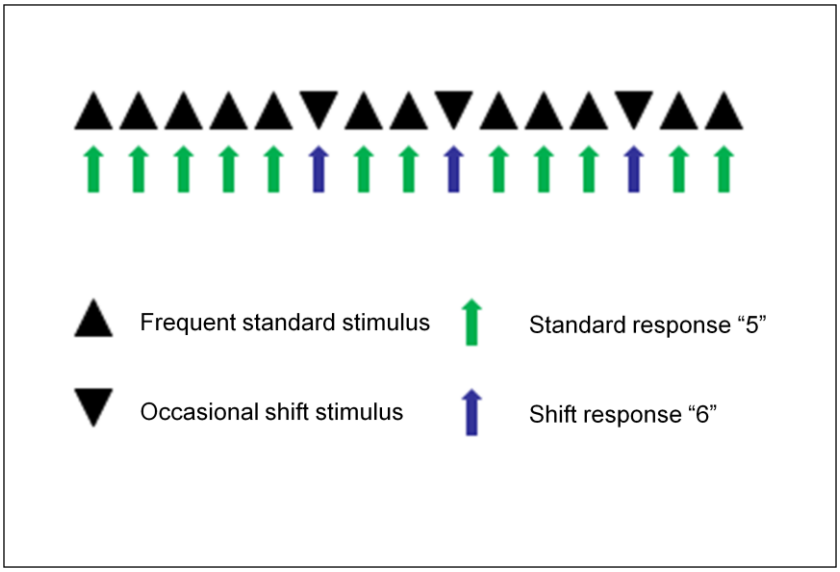

Figure 6: Schematic representation of 15 trials of behavioral shift version A.

2.3.5 Form S9/S10: Behavioral shift version B (shift and inhibition)

These test forms are a combination of Forms S3/S4 (go/no-go) and S7/S8 (behavioral shift version A). They contain in addition to the standard stimuli some stimuli that require a behavioral shift and some that require an inhibition. The standard stimulus, which occurs frequently, is an upward-pointing triangle; the “5” button must be pressed in response to this. If the triangle points downwards, the “6” button must be pressed; this therefore involves a behavioral shift. If a circle appears, no response is required; this therefore involves an inhibition. Each stimulus is displayed for 200 milliseconds with an interval of one second between stimuli. This test form again presents 250 stimuli, 125 in each half of the test. Of these 125 stimuli, 24 are circles and 24 are downward-pointing triangles. The remaining 77 stimuli are upward-pointing triangles.

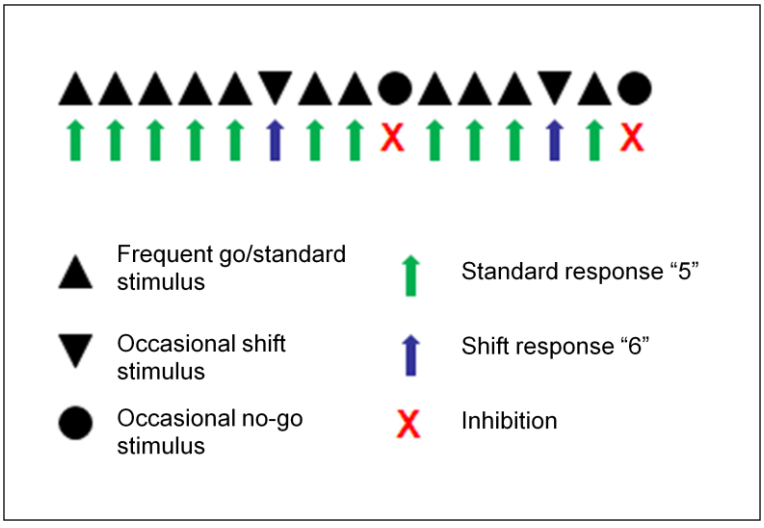

Figure 7: Schematic representation of 15 trials of behavioral shift version B.

2.4 Description of variables

2.4.1 Forms S1/S2: Stop signal

Main variable

Stop signal reaction time (SSRT)

The stop signal reaction time is calculated by deducting the mean stop signal delay from the mean reaction time.

Subsidiary variables

Mean reaction time

This is calculated as the mean of the reaction times to go stimuli; only correctly processed stimuli are included in the calculation.

Mean stop signal delay

This parameter gives the average delay of the tone.

Standard deviation of reaction time

This is calculated as the standard deviation of the reaction time; only correctly processed stimuli are included in the calculation.

Number of commission errors

This parameter reports the number of false reactions in stop trials.

Number of omission errors

This variable reports the number of omitted reactions to go stimuli.

2.4.2 Forms S3/S4/S13: Go/no-go

Main variable

Number of commission errors

This variable describes how frequently inhibition of no-go stimuli was unsuccessful.

Subsidiary variables

Number of omission errors

This variable reports the number of omitted reactions to go stimuli.

Sensitivity index d'

The sensitivity index d' is a measure of overall performance on the task; it takes account of both commission errors (pressing a button when no button should have been pressed = false alarms) and omission errors. d', which is a measure used in signal detection theory, is calculated by the formula d' = z(hits) – z(number of false alarms).

Mean reaction time

This variable is calculated as the mean reaction time for correctly processed go stimuli.

Standard deviation of reaction time

This variable is calculated as the standard deviation of the reaction times for correctly processed go stimuli.

2.4.3 Forms S5/S6: Cued go/no-go

Main variable

Number of commission errors

This variable reports the frequency of false alarms.

Subsidiary variables

Number of omission errors

This variable reports the number of omitted reactions to go stimuli.

Number of commission errors for plus/diamond combination

This variable reports the number of false reactions to plus/diamond combinations.

Number of commission errors for minus/square combination

This variable reports the number of false reactions to minus/square combinations.

Mean reaction time

This variable is calculated as the mean reaction time for correctly processed items.

Standard deviation of reaction time

This variable is calculated as the standard deviation of the reaction times for correctly processed items.

2.4.4 Forms S7/S8: Behavioral shift version A (shift only)

Main variable

Number of shift errors

This variable reports the number of standard reactions to shift stimuli.

Subsidiary variables

Number of standard errors

This gives the number of shift reactions to standard stimuli.

Omission errors – standard

This gives the number of standard trials in which no response was made.

Omission errors – shift

This gives the number of shift trials in which no response was made.

Mean reaction time – standard (frequent triangles)

This variable reports the mean of the reaction times to correctly processed standard stimuli.

Mean reaction time – shift (infrequent triangles)

This variable reports the mean of the reaction times to correctly processed shift stimuli.

Standard deviation of reaction time – standard (frequent triangles)

This variable reports the standard deviation of the reaction times to correctly processed standard stimuli.

Standard deviation of reaction time – shift (infrequent triangles)

This variable reports the standard deviation of the reaction times to correctly processed shift stimuli.

2.4.5 Form S9/S10: Behavioral shift version B (shift and inhibition)

Main variables

Number of commission errors

This variable describes the number of reactions to no-go stimuli.

Number of shift errors

This variable reports the number of standard reactions to shift stimuli.

Subsidiary variables

Number of standard errors

This gives the number of shift reactions to standard stimuli.

Omission errors – standard

This gives the number of standard trials in which no response was made.

Omission errors – shift

This gives the number of shift trials in which no response was made.

Mean reaction time – standard (frequent triangles)

This variable reports the mean of the reaction times to correctly processed standard stimuli.

Mean reaction time – shift (infrequent triangles)

This variable reports the mean of the reaction times to correctly processed shift stimuli.

Standard deviation of reaction time – standard (frequent triangles)

This variable reports the mean of the reaction times to correctly processed standard stimuli.

Standard deviation of reaction time – shift (infrequent triangles)

This variable reports the standard deviation of the reaction times to correctly processed shift stimuli.

3 EVALUATION

3.1 Objectivity

Administration objectivity

Test administrator independence exists when the respondent's test behavior, and thus his test score, is independent of variations (either accidental or systematic) in the behavior of the test administrator (Kubinger, 2003).
Since administration of INHIB is computerized, all respondents receive the same information, presented in the same way, about the test. These instructions are independent of the test administrator. Similarly, administration of the test itself is identical for all respondents.

Scoring objectivity

The respondent's answers are recorded automatically. The calculation of the test variables and the norm comparison also take place automatically; a scorer is not involved. Computational errors are therefore excluded.

Interpretation objectivity

Since the test has been normed, interpretation objectivity is given (Lienert & Raatz, 1994). Interpretation objectivity does, however, also depend on the care with which the guidelines on interpretation given in the chapter "Interpretation of Test Results" are followed.

3.2 Reliability

The reliability of the main variables of INHIB was estimated by the split-half method. This was done by calculating the correlation between the scores in each half of the test and then applying the Spearman-Brown formula. For Forms S1/S2 (stop signal) the value of these coefficients is 0.87; for Forms S3/S4 (go/no-go) it is 0.83; for Forms S5/S6 (cued go/no-go) it is 0.67; for Forms S7/S8 (cued go/no-go) it is 0.79 and for Forms S9/10 it is 0.77 for the variable *Commission errors* and 0.67 for *Number of shift errors.* For Form S13 Cronbach's Alpha is 0.71 and the greatest lower bound is 0.84. The greatest lower bound is a modern measure of reliability that gives the lower limit of the reliability.

3.3 Validity

Extensive literature supports the validity of the tests used here. In particular, construct validity at the level of neuropsychological functions is confirmed by factor analytic studies in which these tests load onto a common inhibition factor (literature review in Royall et al., 2002). However, the intercorrelations vary between the studies, which suggests that the test forms measure different aspects of a common construct (Friedmann & Miyake, 2004). This is also indicated by the results of functional imaging tests, where the paradigms result mainly in common activations but also in some differential activation (Nee et al., 2007).
With regard to ecological aspects of validity, consistent correlations have been found with disinhibition and impulsivity at behavioral level (Young et al., 2009). More recent studies also take greater account of the correlation with rigid and inflexible behavior patterns (Lipszyc & Schachar, in press).

3.4 Economy

Since they are computerized, 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 standardized, 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.

3.5 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 that meet all the other quality criteria to at least the same extent (Kubinger, 2003). The usefulness of using INHIB to measure response inhibition has already been described in the introduction and in connection with the description of validity. Some other tests for measuring response inhibition are sometimes mentioned in the literature, although not as frequently as INHIB. These other tests include the Hayling Sentence Completion Test, anti-saccadic tasks and various versions of the Continuous Performance Test. However, there is less data on the psychometric properties of these tests, and in some cases they are significantly more time-consuming to administer.

3.6 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 in absolute terms, but needs also to be considered in relation to the specific purpose of the assessment – i.e. in relation to the benefit derived from using the test (e.g. Kubinger, 2003). Here INHIB has the advantage of flexibility, since the duration and difficulty of testing can be adjusted to the individual respondent. Thus with a severely impaired patient it may be appropriate to use just one test form to obtain a general impression of the patient's abilities. By contrast, with a more able patient it is possible to use several test forms, enabling a more differentiated assessment of response inhibition to be made. Information on test selection can be found in Section 2.2: Use of INHIB.

3.7 Resistance to faking

A test that meets the meets the quality criterion of resistance to faking is one that can prevent a respondent answering questions in a manner deliberately intended to influence or control his test score (see Kubinger, 2003). Since INHIB is an ability test, "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 and carrying out plausibility checks during the test session. It is the case with all the tasks that patients can avoid errors by reducing their reaction speed, either deliberately or unconsciously. Testees are therefore instructed to respond quickly. In addition, the mean reaction times are always quoted; this enables the corresponding parameters to be checked.

3.8 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 (Kubinger, 2003). The fairness of INHIB is given because separated norm samples are available for subgroups for which relevant mean differences have been found.

4 NORMING

The norms 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 *XX* and *N* is the size of the sample.

4.1 Form S1/S2: Stop signal

This comparison sample consists of the data of N=356 adults, of whom 173 (48.6%) are male and 183 (51.4%) female. The mean age of the sample is 44.12 with a standard deviation of 17.51 years. The youngest respondent is 16 years old and the oldest is 84.
2 (0.6%) individuals in this sample have fewer than nine years of schooling or have attended a special school (EU educational level 1); 78 (21.9%) have completed compulsory schooling or basic secondary school but without completing vocational training (EU educational level 2); 167 (46.9%) have completed vocational training or a course at a technical college (EU educational level 3); 70 (19.7%) have a school-leaving qualification at university entrance level or a qualification from a technical university (EU educational level 4) and 39 (11.0%) have a university degree (EU educational level 5).

4.2 Form S3/S4 (go/no-go)

This comparison sample consists of the data of N=359 adults, of whom 175 (48.7%) are male and 184 (51.3%) female. The mean age of the sample is 44.07 with a standard deviation of 17.60 years. The youngest respondent is 16 years old and the oldest is 84.
2 (0.6%) individuals in this sample have fewer than nine years of schooling or have attended a special school (EU educational level 1); 79 (22.0%) have completed compulsory schooling or basic secondary school but without completing vocational training (EU educational level 2); 168 (46.8%) have completed vocational training or a course at a technical college (EU educational level 3); 71 (19.8%) have a school-leaving qualification at university entrance level or a qualification from a technical university (EU educational level 4) and 39 (10.9%) have a university degree (EU educational level 5).

4.3 Form S5/S6 (Cued go/no-go)

This comparison sample consists of the data of N=357 adults, of whom 172 (48.2%) are male and 185 (51.8%) female. The mean age of the sample is 44.03 with a standard deviation of 17.542 years. The youngest respondent is 16 years old and the oldest is 84.
2 (0.6%) individuals in this sample have fewer than nine years of schooling or have attended a special school (EU educational level 1); 78 (21.8%) have completed compulsory schooling or basic secondary school but without completing vocational training (EU educational level 2); 169 (47.3%) have completed vocational training or a course at a technical college (EU educational level 3); 70 (19.6%) have a school-leaving qualification at university entrance level or a qualification from a technical university (EU educational level 4) and 38 (10.6%) have a university degree (EU educational level 5).

4.4 Form S7/S8 (behavioral shift A)

This comparison sample consists of the data of N=355 adults, of whom 170 (47.9%) are male and 185 (52.1%) female. The mean age of the sample is 44.45 with a standard deviation of 17.504 years. The youngest respondent is 16 years old and the oldest is 84.
2 (0.6%) individuals in this sample have fewer than nine years of schooling or have attended a special school (EU educational level 1); 76 (21.4%) have completed compulsory schooling or basic secondary school but without completing vocational training (EU educational level 2); 170 (47.9%) have completed vocational training or a course at a technical college (EU educational level 3); 69 (19.4%) have a school-leaving qualification at university entrance level or a qualification from a technical university (EU educational level 4) and 38 (10.7%) have a university degree (EU educational level 5).

4.5 Form S9/S10 (behavioral shift B)

This comparison sample consists of the data of N=354 adults, of whom 167 (47.2%) are male and 187 (52.8%) female. The mean age of the sample is 44.50 with a standard deviation of 17.574 years. The youngest respondent is 16 years old and the oldest is 84.
2 (0.6%) individuals in this sample have fewer than nine years of schooling or have attended a special school (EU educational level 1); 76 (21.5%) have completed compulsory schooling or basic secondary school but without completing vocational training (EU educational level 2); 167 (47.2%) have completed vocational training or a course at a technical college (EU educational level 3); 70 (19.8%) have a school-leaving qualification at university entrance level or a qualification from a technical university (EU educational level 4) and 39 (11.0%) have a university degree (EU educational level 5).

4.6 Form S13 (go/no-go)

The norm sample data for the short form S13 was collected in 2012 in the research laboratory of SCHUHFRIED GmbH and in the context of teaching and research at the University of Vienna. The data relates to an Austrian sample of 313 individuals from the normal population aged between 16 and 80. Individuals were not included in the sample unless they could state that they had not previously suffered from any serious neurological or psychiatric illness and that they were not currently taking any medication that affects the central nervous system. The sample consists of 171 (54.7%) women and 142 (45.3%) men. The mean age is 44.16, with a standard deviation of 17.27 years. A total of 44 people (14.1%) have completed compulsory schooling or basic secondary school but without completing vocational training (EU educational level 2); 103 people (32.9%) have completed vocational training or a course at a technical college (EU educational level 3); 112 people (35.8%) have a school-leaving qualification at university entrance level or a qualification from a technical university (EU educational level 4) and 54 people (17.3%) have a university degree (EU educational level 5). In addition to the total norm, norms separated according to age, gender and education are also available. More specific norms for the upper age range are also available upon request.

5 ADMINISTRATION OF THE TEST

INHIB consists of an instruction phase and the test phase itself.

5.1 Technical precision of measurement

Measuring reaction times to the nearest millisecond is not straightforward, Many test programs or neuropsychological experiment generators quote reaction 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 (see 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.

5.1.1 Visual stimulus material

The display of visual stimulus material in the Vienna Test System is extremely precise – on both CRT and LCD monitors. If INHIB is administered on an uncalibrated system, minor technical measurement errors of up to ± 5 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 fully accurate percentile rank measurements.

Fig. 5: 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).

5.1.2 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.

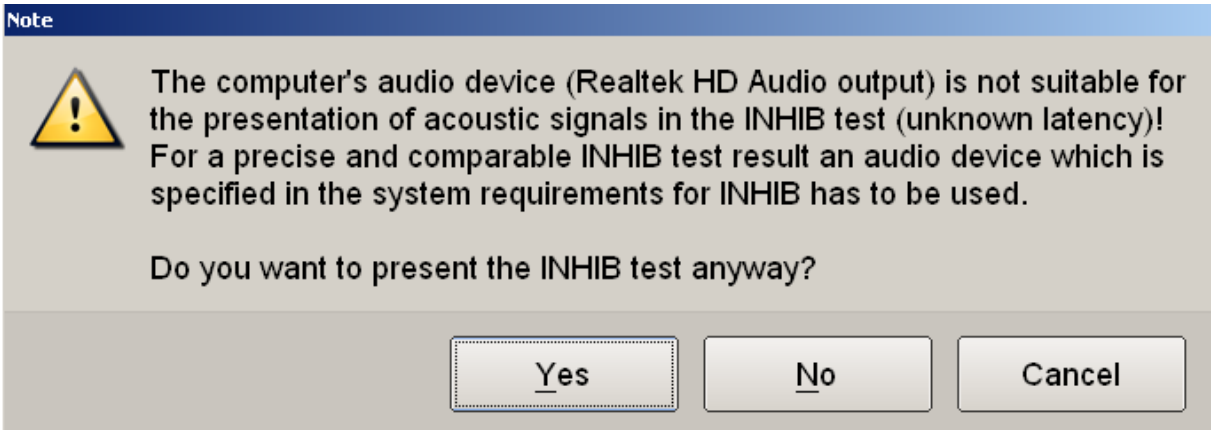

Figure 6. Warning issued when a non-standard audio output device is used.

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.

5.2 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. Each subtest is preceded by standardized instructions with practice examples. When working with patients it is nevertheless advisable for the administrator to be available to assist during the instruction phase; during testing, too, he should check at least from time to time that respondents are working in accordance with the instructions. The administrator is informed if the respondent does not comply with the instructions or if his behavior indicates that the instructions have not been understood. In this case the instruction and practice phase must be repeated.

5.3 Test phase

The practice phase is immediately followed by the test phase, the length of which varies according to the test form used. The test phase lasts around10 minutes in Forms S1 and S2, around 3-4 minutes in Form S13 and around 7 minutes for the remaining test forms. In Forms S1 – S10 there is a short break in the middle of the test; the length of this break can be controlled by the respondent. S13 consists of only one section and therefore contains no break.

6 INTERPRETATION OF TEST RESULTS

The percentile ranks of the test results for the individual variables of the INHIB test forms provide the basis for interpretation. Guidance on interpreting the main and subsidiary variables of INHIB is given below after the general notes on interpretation.

6.1 General notes on interpretation

In general a percentile rank of <16 can be interpreted as representing a below-average level of the corresponding variable.

A percentile rank between 16 and 24 can be regarded as representing a below-average to average level of the corresponding variable.

A percentile rank between 25 and 75 can be regarded as representing an average level of the corresponding variable.

Percentile ranks between 76 and 84 reflect an average to above-average level of the corresponding variable.

A percentile rank of >84 reflects a clearly above-average level of the corresponding variable.

The norm scores always relate to the particular reference population used.

6.2 Interpretation of the main and subsidiary variables of INHIB

6.2.1 Forms S1/S2: Stop signal

Main variable

Stop signal reaction time (SSRT)

The stop signal reaction time reflects the speed and hence the effectiveness of the inhibition process. As described above, this always relates to the inhibition of a motor response that has already been initiated. The stop signal reaction time is calculated by deducting the mean stop signal delay from the mean reaction time. A long stop signal reaction time should be regarded as an indication of an impaired inhibition process.

Subsidiary variables

Mean reaction time

The mean reaction time reports the speed of responses to go stimuli. Slow reaction times may be the result of psychomotor retardation in the patient. Alternatively, patients may slow their reactions to avoid errors in stop trials. In order to shift the focus towards reaction time in this speed/accuracy trade-off, the instructions emphasize speed of response.

Mean stop signal delay

This parameter gives the average delay of the tone. It is quoted here merely in order to render the calculation of the stop signal reaction time transparent to the user.

Standard deviation of reaction time

This variable reflects the variation in reaction times from trial to trial. Increased reaction time variability has been described in some disorders such as ADHD and schizophrenia and in connection with frontal brain lesions. The underlying mechanism is thought to be fluctuations in attention. Variability also increases with age. Fatigue can also result in greater variability in reaction times.

Number of commission errors

This parameter reports the number of false reactions in stop trials. Because the difficulty level adjusts adaptively, this variable is not an appropriate measure of inhibition performance. If the number of commission errors is very high, interpretation of the stop signal reaction time may be misleading. In this case it is recommended that an additional test form is administered.

Number of omission errors

This variable reports the number of omitted reactions to go stimuli. There are in the main two mechanisms that give rise to omission errors. Most commonly, omission errors are the result of a lapse of attention. Occasionally, though, there are respondents who avoid responses in order to make fewer commission errors.

6.2.2 Forms S3/S4/S13: Go/no-go

Main variable

Number of commission errors

This variable describes how frequently inhibition of no-go stimuli was unsuccessful; it thus reflects the effectiveness of the inhibition process.

Subsidiary variables

Number of omission errors

This variable reports the number of omitted reactions to go stimuli. There are in the main two mechanisms that give rise to omission errors. Most commonly, omission errors are the result of a lapse of attention. Occasionally, though, there are respondents who avoid responses in order to make fewer commission errors.

Sensitivity index d'

The sensitivity index d' is a measure of overall performance on the task; it takes account of both commission errors (pressing a button when no button should have been pressed = false alarms) and omission errors. d', which is a measure used in signal detection theory, is calculated by the formula d' = z(hits) – z(number of false alarms).

Mean reaction time

The mean reaction time reports the speed of responses to go stimuli. Slow reaction times may be the result of psychomotor retardation in the patient. Alternatively, patients may slow their responses in order to avoid commission errors (speed/accuracy trade-off). By contrast, fast reaction times that are accompanied by a large number of commission errors indicate that the patient has failed to adjust his processing speed to the task.

Standard deviation of reaction time

This variable reflects the variation in reaction times from trial to trial. Increased reaction time variability has been described in some disorders such as ADHD and schizophrenia and in connection with frontal brain lesions. The underlying mechanism is thought to be fluctuations in attention. Variability also increases with age. Fatigue can also result in greater variability in reaction times.

6.2.3 Forms S5/S6: Cued go/no-go

Main variable

Number of commission errors

This variable depicts the frequency of false alarms and thus the effectiveness of the inhibition process.

Subsidiary variables

Number of omission errors

This variable reports the number of omitted reactions to go stimuli. There are in the main two mechanisms that give rise to omission errors. Most commonly, omission errors are the result of a lapse of attention. Avoidance of reactions to reduce the number of errors occurs less frequently with these test forms than with S3/S4.

Number of commission errors for plus/diamond combination

This type of commission error reflects an unsuccessful inhibition after the cue has triggered a readiness to respond.

Number of commission errors for minus/square combination

This type of commission error reflects a failure to take account of the cue in making the decision. It is interpreted in the literature as a deficit in taking account of context.

Mean reaction time

The reaction time reflects the speed of correct responses when a response to the second stimulus is required. As in Forms S3/S4, retardation may be genuine or may be the result of a deliberate strategy.

Standard deviation of reaction time

This variable reflects the variation in reaction times from trial to trial. Increased reaction time variability has been described in some disorders such as ADHD and schizophrenia and in connection with frontal brain lesions. The underlying mechanism is thought to be fluctuations in attention. Variability also increases with age. Fatigue can also result in greater variability in reaction times.

6.2.4 Forms S7/S8: Behavioral shift version A (shift only)

Main variable

Number of shift errors

This variable describes how often a behavioral shift did not occur when it was required. The processes underlying the behavioral shift are inhibition of the dominant response tendency and the initiation of a new response. In cases in which it is important to identify which of

these two processes is impaired, it is recommended that Forms S3/S4 or S9/S10 are also administered.

Subsidiary variables

Number of standard errors

This type of error involves shift responses to the standard stimulus. A large number of erroneous shifts indicates poor comprehension of the task.

Omission errors – standard

This gives the number of standard trials in which no response was made. Since this test form requires a response to all stimuli, a large number of omission errors indicates a general impairment of task processing. This is frequently the result of impaired attention or poor comprehension of the task.

Omission errors – shift

This gives the number of shift trials in which no response was made. Since this test form requires a response to all stimuli, a large number of omission errors indicates a general impairment of task processing. This is frequently the result of impaired attention or poor comprehension of the task.

Mean reaction time – standard (frequent triangles)

This variable reports the mean of the reaction times to standard stimuli. Slow reaction times may be the result of psychomotor retardation in the patient. Alternatively, patients may deliberately slow their reactions to avoid errors in response to shift stimuli. By contrast, fast reaction times that are accompanied by a large number of shift errors may indicate that the patient has not succeeded in adjusting his processing speed to the task.

Mean reaction time – shift (infrequent triangles)

This variable reports the speed of correct responses to shift stimuli.

Standard deviation of reaction time – standard (frequent triangles)

This variable reflects the variation in reaction times from trial to trial. Increased reaction time variability has been described in some disorders such as ADHD and schizophrenia and in connection with frontal brain lesions. The underlying mechanism is thought to be fluctuations in attention. Variability also increases with age. Fatigue can also result in greater variability in reaction times.

Standard deviation of reaction time – shift (frequent triangles)

See the notes on the standard deviation of standard reaction times.

6.2.5 Forms S9/S10: Behavioral shift version B (shift and inhibition)

Main variables

Commission errors

This variable describes how frequently inhibition of no-go stimuli was unsuccessful; it thus reflects the effectiveness of the inhibition process.

Number of shift errors

This variable describes how often a behavioral shift did not occur when it was required. The processes underlying the behavioral shift are inhibition of the dominant response tendency and the initiation of a new response. A large number of shift errors combined with a small number of commission errors indicates dysfunctional initiation of a new response, while a large number of shift errors combined with a large number of commission errors indicates that an inhibition deficit is more likely.

Subsidiary variables

Number of standard errors

This type of error involves shift responses to the standard stimulus. A large number of erroneous shifts frequently indicates poor comprehension of the task.

Omission errors – standard

This gives the number of standard trials in which no response was made. A large number of omission errors may indicate a general impairment of task processing. This is frequently the result of impaired attention or poor comprehension of the task. Occasionally, though, there are respondents who avoid responses in order to make fewer commission errors.

Omission errors – shift

This gives the number of shift trials in which no response was made. A large number of omission errors may indicate a general impairment of task processing. This is frequently the result of impaired attention or poor comprehension of the task. Occasionally, though, there are respondents who avoid responses in order to make fewer commission errors.

Mean reaction time – standard (frequent triangles)

This variable reports the mean of the reaction times to standard stimuli. Slow reaction times may be the result of psychomotor retardation in the patient. Alternatively, patients may deliberately slow their responses in order to avoid shift or commission errors. By contrast, fast reaction times that are accompanied by a large number of shift or commission errors may indicate that the patient has not succeeded in adjusting his processing speed to the task.

Mean reaction time – shift (infrequent triangles)

This variable reports the speed of correct responses to shift stimuli.

Standard deviation of reaction time – standard (frequent triangles)

This variable reflects the variation in reaction times from trial to trial. Increased reaction time variability has been described in some disorders such as ADHD and schizophrenia and in connection with frontal brain lesions. The underlying mechanism is thought to be fluctuations in attention. Variability also increases with age. Fatigue can also result in greater variability in reaction times.

Standard deviation of reaction time – shift (infrequent triangles)

See the notes on the standard deviation of standard reaction times.

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