Temporal Integration Theory, Schizophrenia, and the Lateralised Paced Auditory Serial Addition Task

A dissertation presented in partial fulfilment of the requirements for the
degree of Doctor of Philosophy in Psychology at Massey University
(Palmerston North, New Zealand)

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2000

Acknowledgements

I am extremely grateful to Dr John Podd and Dr Julie Bunnell (both at the School of Psychology, Massey University, Palmerston North, New Zealand) for their unyielding support and supervision. They kept me on task and motivated during a very difficult decade of my life. Their technical and statistical advice has been of incalculable value.

I greatly appreciate the assistance of professional colleagues who were my additional motivators, and /or who referred themselves, friends, family, and clients to be participants in this research. Some of whom deserve special mention are: Gail Russell, Graham Beaumont, Joanna Taylor, Carol Adamson, Olivia Hamid, Andy Smith, Margaret Strom, Carol Mattinson and Doug Upfold. I am also very grateful to all those persons who volunteered as participants; particularly clinical participants, because they knew their involvement would not change their own health circumstances.

My thanks also go to Harvey Jones, Hung That Ton, Mike Hughes, and Malcolm Loudon (School of Psychology, Massey University) for their computer and audiovisual technical expertise. I received great assistance also from Ralph Pugmire (Information Systems, Massey University) in the initial programming for the computer generated paced auditory serial addition task.

During the latter stages of this research I received collegial support from Dr Robert Miller (Department of Anatomy and Structural Biology, Otago University, Dunedin, New Zealand) and the Schizophrenia Research New Zealand group. I was also assisted in 1999 by a small financial grant from the national office of Schizophrenia Fellowship (New Zealand).

My wife and three sons also deserve special mention as they have shown such great understanding and patience about the demands of my study and inspired me to persevere. The laptop computer they bought for me contributed a huge amount to the organisation and completion of written material.

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Abstract

The Paced Auditory Serial Addition Task (PASAT) was lateralised for the purpose of investigation into hemispheric specialisation for temporal integration. A right ear advantage (REA), representing a left hemisphere (LH) advantage in normal participants, was predicted due to the sequential nature of the PASAT, the previous finding of a REA by Norman (1984), and Miller's (1996) theory on the LH specialisation for delayed axonal conduction. The REA was also expected given other abundant evidence on LH superiority for the processing of temporal information (Bradshaw & Nettleton, 1981; Bryson, Mononen, & Yu, 1980; Elfgren & Risberg, 1998; Gordon, 1978; Leek & Brandt, 1983; Prior, Kinsella, & Giese, 1990; Robinson, & Solomon, 1974; Troyer, Moscovitch, Winocur, Alexander, & Stuss, 1998). However, no REA was found in the present research. Careful precision in randomising and counterbalancing arithmetic outcomes, removal of the digit seven because of its two-syllable pronunciation, and the randomisation of ear of presentation and stimulus presentation rate, possibly eliminated procedural artefacts that were present in Norman's (1984) study. Therefore, despite the sequential nature of the PASAT it now appears to lack efficacy for research into temporal integration.

Other findings from the present research instead showed support for the hypotheses of the right hemisphere's (RH) specialisation for vigilance (Coslett, Bowers, & Heilman, 1987; Dimond, 1979; Heilman & van den Abell, 1979, 1980; Howes & Boller, 1975; Ladavas, Del Pesce, Mangun, & Gazzaniga, 1994; Ladavas, Del Pesce, & Provinciali, 1989; Loring, Meador, & Lee, 1989; Pardo, Fox, & Raichle, 1991; Simos & Molfese, 1997; Whitehead, 1991; Wilkins,

Shallice, & McCarthy, 1987; Yokohama et al., 1987). For normal participants a left ear advantage (LEA) was found and more clearly demonstrated with an unpredictable task condition and with the faster presentation rates (1.2 & 2.0 s) of the lateralised PASAT. The LEA was shown with both the same ear stimulus pairings (LL) and the left then right pairings (LR). Inferior performance with the right then left (RL) stimulus pairings was found in the unpredictable task condition and another task condition in which the side of stimulus presentation was predictable.

Clinical participants (i.e., participants with a history of schizophrenia) did not demonstrate a LEA, and they showed no difference compared to normal controls in performance with the right ear (LH). However, the clinical participants did manifest a particular disadvantage when stimulus processing required a shift from left to right ear (LR), but not the reverse (RL). The clinical participants manifested the LR deficit in the unpredictable and predictable task conditions. This LR disadvantage bears some resemblance to a previous finding, using the Visual Reaction Time Task, of a lateralised deficit in disengaging attention from the left visual field. Some researchers (Bustillo et al., 1997; Posner, Early, Reiman, Pardo, & Dhawan, 1988; Posner & Raichle, 1994; Wigal, Swanson, & Potkin, 1997) interpret this LR deficit as a problem of slowness of responding by the LH (right visual field) after having attention oriented to the opposite field. However, the findings in the present research of a LEA for normal controls (i.e., LL and LR), a relative deficit with RL for normals, and no difference in right ear (RR) performance between controls and clinical participants, and notably with the unpredictable condition, suggests an alternative interpretation. The LR deficit in schizophrenia may instead be due to difficulty in disengaging from the left visual or auditory field rather than impaired performance with the right field. The LR deficit may be as a result of dysfunction of vigilance, which is normally attributed to greater proficiency of the right hemisphere.

In addition, opposing trends were observed for the clinical participants compared to the normal participants at particularly slow presentation rates, and with the predictable task condition in which stimuli were presented singularly to each hemisphere. Clinical participants showed a worsening of performance with the task. Normal participants demonstrated better performance with this task compared to another task condition, much like the standard PASAT, in which both ears received a stimulus simultaneously. These trends reflect Hellige's (1987, 1993) model of cross-hemispheric integration in which it is hypothesised that for normal participants single hemisphere processing has some advantage with lighter tasks. These trends also reflect the possibility that people with schizophrenia, in slow stimulus conditions, have difficulty whereby they unnecessarily over engage both hemispheres, which wastes attentional resource that could otherwise be utilised for various other aspects of ongoing processing.

Preface To Research

The interest for this research had two sources. Initially it came from my postgraduate training in clinical and research psychoendocrinology, which began in 1979 and continued in the 1980s, with John Money (Professor Emeritus, The Johns Hopkins University School of Medicine).

Our hormonal regulatory systems (e.g., the hypothalamic-pituitary-adrenal axis; the hypothalamic-pituitary-thyroid axis; and the hypothalamic-pituitary-gonadal axis) depend on feedback from one part of the axis to another in the form of pulsatile secretions of hormones into the blood stream. Disruptions to these systems can have notable effects on physiological development and behaviour. I found it fascinating how the fidelity of these systems depend on a well regulated and ‘ timely ’ feedback loop. I then began to consider how timing is most likely also important in the complex human functions of cognitive processing and communication, but perhaps not sufficiently analysed or accounted for in many psychometric tests.

The second source of interest in this research came from my training and post clinical qualification experience in normal and clinical psychology. Learning about and interacting with persons with thought form disorders distinguishable from content disorders, such as in schizophrenia, led me to consider that these disorders may in part be naturally occurring instances of dysfunction in the timing functions of cognitive processing.

In 1982, when I was attempting to develop a master’s thesis based on the above, Geoff White (then my supervisor at Victoria University of Wellington; currently Professor at Otago University, New Zealand) was experimenting with temporal paradigms of learning in pigeons. He had come across the Paced Auditory Serial Addition Task (PASAT) and suggested that I may somehow use it to begin examining my ideas, as above.

Since the PASAT was initially developed in the 1950s and adapted as a clinical test in the 1970s (see section on The History of the PASAT) there has been much development of theory and research into brain lateralisation and specialisation. By 1982 some of this theory and research had begun reconceptualizing the left brain versus right brain dichotomy in terms of the left hemisphere being more specialised for temporal components in 'verbal' processing rather than the right hemisphere being simply 'non-verbal' by default (see sections headed Hemispheric Specialisation, and Hemispheric Specialisation for Temporal Processing). Accordingly, in 1983 I decided to adapt the PASAT in creating a lateralised version to examine its usefulness in investigating my ideas and current theory on hemispheric specialisation. When I began reviewing the background theory to the PASAT I found that the theories on temporal integration by Lashley (1937) and Hearnshaw (1956) had already conceptualised temporal processing from both psychophysiological and language and communication perspectives respectively. MacNeilage (1999) has stated that he considers Lashley's theory to be the most significant this 20th Century for cognitive neuroscience, but that it has largely fallen on deaf ears. Hence, it has taken some years for me to feel some vindication for selecting temporal integration theory as a basis for my own research. Further support has come from Miller's (1996) book on hemispheric specialisation being based also on axonal conduction time. Miller based his theory on postulates by Hebb (1949), who was a student of Lashley's. (See section headed Temporal Integration Theory for a review of the theory.)

Accepting the notions that temporal integration theory unifies to some extent various systems of human functioning, partially bridges the Cartesian split between 'mind and body', and applies to human communication, can be easily criticised as being very simplistic. However, in my view, the theory should not be simply interpreted as meaning there is some central time mechanism (i.e., 'clock') for all individual human systems. Instead, the theory can be interpreted as indicating that there exists for probably all systems, specific to each function, some reliance on each component working in a 'timely' way. Furthermore, that for each system the governance of 'timely' functioning has an innate origin (e.g., genetic and prenatal). It is also interesting to note that recent neurophysiological research has begun to identify how brain neurons work in an integrated way by means of not only proximity but also via temporal resonance, that is, similar frequency of transmission (Freund, 1997).

Hence, in 1983, I selected the PASAT to investigate cognitive temporal processing since it originated from theory that preceded but suited my own ideas. I adapted the PASAT (i.e., lateralised version) so as to test its utility in light of developments in research and theory on brain hemispheric specialisation (e.g., left hemisphere specialisation for processing of temporal components in verbal information). My Master's thesis at that first stage of research was completed in June 1984 and is reviewed within this current thesis. Because of the typical exigencies of beginning a clinical career, furthering my speciality training in psychoendocrinology, marrying and starting a family, and moving between two countries, it took until 1990 to revisit this research at a doctoral level. Continuation of the above exigencies meant this research had at times been suspended. However, in the interim another colleague (Mark Stewart) became interested in this research and so completed a Master's thesis in 1995. His work is also reviewed within the present thesis.

Since 1984, other researchers have identified and attempted to rectify potential weaknesses in the standard PASAT (see section on The History of the PASAT). Hence, the present study was a re-examination of the utility of the PASAT for investigating temporal integration theory, and necessitated an upgrading of the test for research into hemispheric lateralisation. It also included participants with a personal history of schizophrenia in acknowledgement of Lashley's (1937) point that often we cannot directly observe temporal integration except when it is dysfunctional. There is now quite substantial evidence to show abnormal hemispheric functioning in schizophrenia. (See section headed Dysfunctional Hemispheric Processing in Schizophrenia.) The problem in hemispheric functioning, for temporal processing in particular, was therefore used as a clinical basis for examining temporal integration theory and the lateralised PASAT.

The present research programme started with a complex mixed design experiment in which the lateralised PASAT was used with both clinical and control participants. However, at the conclusion of the first experiment it became evident that the lateralised PASAT was not delivering as hypothesised on the basis of temporal integration theory and gave contrary results to those found in 1984. Instead, the results indicated that attentional processes, rather than temporal integration, were being evoked and only at the fastest parts of the test. Thus, the latter two experiments of the present research aimed to re-examine results from the first experiment which suggested the involvement of right hemisphere attentional processes rather than left hemisphere temporal integration processes. Another problem found during the first experiment was the ever increasing difficulty in recruiting volunteers who had a history of schizophrenia but not other complications, such as head injury or a history of using non-prescribed substances. Hence, the latter experiments were restricted to using non-clinical participants only.

Introduction

The History of the Paced Auditory Serial Addition Task

Experimental Origins

The Paced Auditory Serial Addition Task (PASAT) and the Visual Paced Serial Addition Task (VPSAT) were first developed by Sampson (1956, 1958), and Sampson and MacNeilage (1960) at the University of Canterbury, New Zealand. The tasks were designed for researching information processing capacity in terms of temporal parameters. That is, the tasks were designed to measure the capacity of adult participants to maintain serial responding to stimuli presented at increased rates. In developing these tasks Sampson (1956) had cited and synthesised the experimental approaches of Bills (1931, 1935a, 1935b, 1937) and Conrad (cited in Sampson, 1956). The task developed by Bills (1931) was self-paced and involved the alternate mental addition and subtraction of the number three from a list of single-digit numbers. Conrad's experiments featured experimenter rather than participant control over the pacing of stimulus display changes on a sensory-motor task.

Sampson's task (Sampson, 1956, 1958; Sampson & MacNeilage, 1960) used addition only but required that addition to be serial in nature so that the number just heard was to be added to the number that immediately preceded it: the second is added to the first, the third to the second, the fourth to the third, and so on. For example, after the numbers "2, 6" the answer is "8"; if the next number is "5", this is added to the previous "6" to give the answer "11", and so on. Participants are required to inhibit encoding of their own responses, spoken to the experimenter, by not including the response in the addition task and by having to attend to the next stimulus in a series. There was no feedback on response accuracy. The task invariably used a series of 61 randomised single digit numbers, ranging from 1 to 9, as the stimulus materials. The same series of 61 digits was used at the different levels of presentation rate. Presentation rate of the digits was predetermined by the experimenter. Sampson (1956) initially varied the "stimulus on" (stimulus exposure duration) and "stimulus off" (interstimulus interval, or ISI) stimulus presentation parameters by combinations of 0.4, 0.8, and 1.2 s (Experiment 1), and 0.3, 0.6, and 0.9 s (Experiment 2). Sampson and MacNeilage (1960) reported a further eight experiments of similar design and pointed out that they had predominantly used the VPSAT because the parameters (temporal) of interest were more amenable to manipulation in the visual form rather than the auditory form of the task. According to Sampson and MacNeilage, the utility of the task purportedly arises from its temporal nature which provides for simple observation of changes in behaviour (accuracy, measured as percentage correct) in responses to changes in presentation rate.

Clinical Application of the PASAT

The PASAT was first applied outside an experimental setting as part of an assessment battery for defence services personnel in the 1950s (D. Gronwall, personal communication, April 7, 1983). It was not until the 1970s that the PASAT was applied in the investigation of the psychological effects of head injury, by Dorothy Gronwall and her colleagues, at the Department of Neurosurgery, Auckland Hospital, New Zealand (Ewing, McCarthy, Gronwall, & Wrightson, 1980; Gronwall, 1972, 1976, 1977, 1987; Gronwall & Sampson, 1974; Gronwall & Wrightson, 1974, 1975, 1981). Because of the high incidence of photophobia as a sequela of concussion, the VPSAT was dropped in favour of the PASAT (Gronwall & Sampson, 1974). The administration procedures of the PASAT remained the same as the VPSAT, except that the series of 61 digits is repeated four times at progressively faster presentation rates of one digit every 2.4, 2.0, 1.6, and 1.2 s. The last digit of the preceding series at a particular rate becomes the first digit in the next series at a faster rate. Hence, there is no break between each rate and the participant has no warning of when the rate changes. Also, a short practise trial at the slowest rate precedes but does not overlap with the test administration. With the shift of focus to the PASAT came a consequent de-emphasis on stimulus duration, because stimulus duration is assumed to be more or less constant for the spoken numbers. Gronwall and Sampson (1974) had, however, estimated an average duration across the digits of around 400 ms. Yet, Gronwall and Sampson, and consequently many authors after them, have used the term interstimulus interval (ISI) to describe the duration of the period from the onset of one stimulus to the onset of the next stimulus. Thus, stimulus duration was included as part of ISI. Hence, with the PASAT, ISI is synonymous with presentation rate.

Gronwall & Sampson (1974) demonstrated that concussed adults had poorer performance than matched controls on the PASAT, although even seriously concussed participants were able to perform the unpaced version of the task without error. This suggested that while there may be no specific disruptions in the cognitive processing of the task requirements in cases of mild head injury, the effect of concussion seems to be a definite slowing down of processing functions. This slowing down of cognitive processing becomes more obvious as the PASAT increases processing demands by increasing the speed of stimulus input, and attention deficits are considered to be largely a result of this slowing (Gronwall, 1987). As PASAT performance approached normal levels, clients with mild head injury also reported improvements in energy levels, concentration, better tolerance to noise, and decreased irritability. Accordingly, Gronwall (1977) has described the PASAT as a "useful and objective measure of reduction in information processing rate following concussion, which can be used as a guide to rehabilitation and eventual return to work" (p. 368). Performance on the PASAT has also been shown to be worse as a result of the cumulative effect of concussion in cases of two separate concussions, compared to control cases of only one concussion (Gronwall & Wrightson, 1975).

In theoretical terms, Gronwall and Sampson (1974) had adapted Broadbent's (1971) single-channel, limited-capacity information processing model to explain the effect of head injury on PASAT performance. Gronwall and Sampson assumed that head injury reduced the channel capacity of the individual, resulting in lower scores on the PASAT at all presentation rates. Hence, they interpreted poorer PASAT performance not as an impaired ability to do the actual cognitive operations of the task, but more to do with the rate at which the nervous system can transmit information, this in turn being attributed to lowered levels of arousal associated with concussion. They argued that the lowered levels of arousal were a result of temporary brain stem dysfunction. However, van Zomeren, Brouwer, and Deelman (1984) countered this argument when they found increased levels of arousal with electroencephalographic (EEG) recordings and increased heart activity during a vigilance task with head-injured participants.

International Recognition and Adaptations of the PASAT

Since its early development, described above, the PASAT has received international recognition, and is now a widely used neuropsychological test of speed of information processing associated with concussion (Binder, 1986; Lezak, 1983, 1995; Spreen & Strauss, 1998; Szymanski & Linn, 1992; Tranel, 1992). It has also undergone minor modifications at centres in Texas, USA; London, UK; and New Hampshire, USA. In the adaptation by Harvey Levin (Levin et al., 1987), sometimes referred to as the Galveston version of the PASAT and used widely in the USA (Roman, Edwall, Buchanan, & Patton, 1991), the four presentation rates each have a different series of 50 randomised digits. The aim of this adaptation was to shorten the task and to overcome any bias possibly introduced by repetition of a single series of digits. Within each series, the digits were not balanced for frequency, repetition or for sums being less or greater than 10, as is the case in the present research. Miller and Gil (1994) and Lezak (1995) also cite Levin as having created a revised PASAT, the PASAT-R, in which the number of digits in each series is only 26, with presentation rates running 0.4 s slower for each series than those in the original PASAT. A children's version of the PASAT, known as the Children's Paced Auditory Serial Addition Task (CHIPASAT) was developed in London and only differs from the PASAT in that none of the additions required have sums greater than 10 (Dyche & Johnson, 1991a, 1991b; Johnson, Roethig - Johnson, & Middleton, 1988).

Cegalis and Birdsall (1993) in New Hampshire, USA, developed a computerised version of the PASAT which allows the examiner quick modification of presentation rate (seven rates from 4.0 to 1.2 s) and test length (60, 50, or 29 stimuli), includes the standard and the CHIPASAT versions, automatic response recording, manual and/or automatic (speech recognition) scoring, and multiple response analyses (i.e., average reaction time; frequency of correct and incorrect responses, suppression failure and no responses; number of strings; and longest string). It appears that the availability of this computerised version is not yet well known as it was not mentioned in one of the more recent compendiums of neuropsychological tests (Spreen & Strauss, 1998).

Other tests have been derived from the PASAT. Vernon and Weese (1993) developed the Digit String Addition Test (DSAT) as an attempt to shorten and simplify the PASAT. The DSAT differs in that the number sequence used is only 10 digits long, and is repeated three times at rates of 3.0, 2.0, and 1.0 s per digit. The Aural Sequential Paced Arithmetic Test (ASPAT), developed by Bateman (Mielke & Hall, 1997), and the Visual Sequential Paced Arithmetic Test (VSPAT), developed by Bateman and Hall and administered by computer (Mielke & Hall, 1997), both consist of 41 digits for four presentation rates (2.5, 2.0, 1.5 and 1.0 s per digit), with sums of digits being only 10 or less (like the CHIPASAT). The ASPAT and VSPAT are purported not to be confounded by age or education. There is still little or no evidence on the clinical utility, reliability and validity of the DSAT, ASPAT, VSPAT, and Cegalis and Birdsall's (1993) computerised version of the PASAT.

It appears that the modification of the PASAT for research into brain lateralisation has only occurred in New Zealand, firstly by Norman (1984) at Victoria University of Wellington, and again by Norman (the present research begun in 1990) and Stewart (1995), both at Massey University, Palmerston North. Norman and Stewart both used the same presentation rates as the original PASAT, but presented the task laterally (i.e., separately to either left or right ear). Norman (1984) used 61 digits per series whereas Stewart implemented the same PASAT procedure as used in this present research. That is, 32 digits for each of four ear modes (left then left again, LL; right then right again, RR; left then right, LR; and right then left, RL) each presented over four presentation rates (yielding an equivalent of 128 digit stimuli per presentation rate instead of the standard 61). Stewart also adapted these same procedures to create a visual form of the task. More information on the procedures used in the present research will be presented later. However, a review of Stewart's research is provided in the next section.

Issues of Attention with the Lateralised PASAT

One could consider that by lateralising the PASAT the requirements on participants to attend to the task would be increased. Stewart (1995) attempted to examine the issues of divided attention and hemispheric specialisation. He proposed a comparison of the opposing predictions by Friedman and Polson's (1981) independent resource theory and Kinsbourne's (1975) selective activation theory. The independent resource theory assumes that the left and right cerebral hemispheres represent independent information processing resource systems. Similar tasks are presumed to be processed by one hemisphere more than the other and so will compete for attentional resources within the same hemisphere, with detrimental effect on performance. Dissimilar tasks are presumed to each go to a different hemisphere, not to have to compete for attentional resource, and performance on them to not be negatively affected (or instead enhanced) by the combined but undivided overall increase in attention. Kinsbourne's selective activation theory views attention as being distributed across space rather than between or within the cerebral hemispheres. The direction of attention to either the left or right side of space is proposed to be dependent on which hemisphere is most activated at the time.

To test the above two theories, Stewart (1995) used the lateralised version of the PASAT which gives a divided field of stimulus presentation. The divided field presentation involved the four modes and the four standard presentation rates described above. His participants were 16 university undergraduate students, all right handed, with a mean age of 26.6 years. He only analysed the LL and RR modes and so implied that these same field stimulus pairings are analogous to either hemisphere undertaking dual tasks of the same type. However, because the modes were randomly intermixed, yet counterbalanced, one could argue that both hemispheres were activated to the same degree. Hence, this might not be a fair test of Kinsbourne's (1975) theory. Even if one were to accept Stewart's notion that both the LL and RR mode pairings are analogous to tasks of the same type, then both modes could be considered to be similarly affected in terms of competing for resource allocation within their respective hemisphere. Therefore, one might predict no discernible difference in terms of field of presentation. This could also mean that Friedman and Polson's (1981) independent resources theory cannot be fairly examined by comparing only the LL and RR modes. If one follows the logic of comparing similar with dissimilar tasks in divided attention theory, then perhaps the LL and RR modes could have been compared with the LR and RL modes. One might then predict that performance would be better with the LR and RL modes. Stewart did not report any such comparison, and in any case did not find a significant LL or RR mode advantage.

An inherent problem with Stewart's (1995) proposed examination of the PASAT, in terms of divided attention, is that the so called comparisons are in fact more at the level of sensory field orientation rather than in terms of the actual nature of the sequential arithmetic task, or sub tasks, in comparison with other similar or dissimilar tasks. To attempt to include other concurrent tasks with the lateralised PASAT would likely make the task too difficult, would disrupt its underlying sequential structure, and so would essentially change the nature of the task.

However, with regard to the level of sensory field orientation, there is some possible similarity between the lateralised PASAT and the visual cued reaction time task developed by Posner, Early, Reiman, Pardo, and Dhawan (1988). The task will be described in greater detail later. Briefly though, the task requires a participant to visually detect a stimulus target (an asterisk), which is preceded by a visual cue. The cue is categorised as being either valid (correctly indicates the side at which the target will appear), invalid (orients the participant to the opposite side), or neutral (gives no information regarding where the target will appear). Hence, with regard to the four auditory modes of the lateralised PASAT, the first stimulus in each of the LL and RR modes could be categorised as valid cues; and, the first stimulus in each of the LR and RL modes could be invalid cues. There are no stimuli which could be categorised as neutral since each successive stimulus is presented to one ear or the other, and no stimuli are presented to both ears simultaneously. Accordingly, forthcoming sections will provide interpretation of results based on the above proposed similarity of the PASAT and the visual cued reaction time task.

In summary, the PASAT has been widely accepted as a clinical tool for the assessment of the effect of concussion on speed of information processing, and has triggered the development of similar tests. The lateralised version has only been previously researched in New Zealand by Norman (1984) and Stewart (1995). The reliability and validity of the nonlateralised PASAT have been examined, and evidence for these is presented in the following section.

Reliability and Validity of the PASAT

Spreen and Strauss (1998) provide a thorough review of the evidence for and against the reliability and construct validity of the PASAT. They report that the PASAT has a split-half reliability of about .90, that Cronbach's alpha from scores on the four rates is .90, that performance measures across the different rates are highly correlated (*r*'s between .76 and .95), and that test-retest correlations, following short re-test intervals (7 to 10 days), are high (> .90). However, Spreen and Strauss also note that significant practise effects have been reported for normal participants, adults with traumatic head injury, persons with HIV infection, and in children. Gronwall (1977) had acknowledged practise effects but had proposed that such effects tend to be minimal after the second administration. However, Feinstein, Brown, and Ron (cited in Spreen & Strauss, 1998) noted improvement over multiple sessions.

The PASAT is also reported to be moderately well correlated with other measures of attention, such as: Digit Span (Wechsler Adult Intelligence Scale - Revised, WAIS-R); the Trail Making Test; the Visual Search and Attention Test; the Stroop Test; the Freedom From Distractibility factor (WAIS-R); the Mental Control factor (Wechsler Memory Scale); and the Symbol Digit Modalities Test. However, Spreen and Strauss (1998) also note that some findings show no relation between the PASAT and measures of head injury severity, such as post-traumatic amnesia and loss of consciousness. But it can be noted that Gronwall and her colleagues argued that the PASAT is a measure of baseline and recovery from concussion not a general measure of head injury severity *per se*.

In summary, the original PASAT has good reliability and is widely accepted as a clinical test of speed of information processing as effected by concussion, although a concern remains about practise effects . However, given the cognitive operations of the PASAT, it may be vulnerable to the moderating effects of age and intelligence. These factors are considered in the next section.

The Effects of Intelligence, Arithmetic Ability, and Age on PASAT Performance

General intelligence, arithmetic ability, and age have all been identified as having possible influence on performance with the PASAT. Gronwall (Gronwall & Sampson, 1974; Gronwall & Wrightson, 1981) had claimed that the PASAT is only weakly correlated with general intelligence (.28) and arithmetic ability (.28). However, Spreen and Strauss (1998) cite more recent evidence (Egan, 1988; Deary, Langan, Hepburn, & Frier, 1991; MacLeod & Prior, 1996; Sherman, Strauss, & Spellacy, 1997) which shows the PASAT does have a modest correlation with general intelligence and numerical ability (.41 to .68). Sherman et al. (1997) found that in head-injured clients, math-related tests (WAIS-R Arithmetic, WRAT-3 Mathematics), a verbal achievement test (WRAT-3 Reading), and a test of complex motor skills (Purdue Pegs Assembly) all accurately predicted PASAT performance.

Another contraindication of the clinical use of the PASAT, not cited by Spreen and Strauss (1998), is Ward's (1997) finding of significantly better PASAT performance, using the 2.0 s presentation rate, by an older group (age range 45 to 65, mean = 52, SD = 8) versus a much younger group (age range 18 to 35, mean = 25, SD = 5). The two groups were matched on the National Adult Reading Test. There were no differences between the groups on Forwards or Backwards Digit Span (WAIS-R), but the older group were slower on a visual selective attention test (Map Search Task). The younger group, however, scored on average six items less than the older group on the PASAT. Consequently, Ward noted that this finding with the PASAT is counterintuitive; it is not what one would predict with respect to cognitive slowing with age, and for a task which claims to measure speed of information processing (Brittain, La Marche, Reeder, Roth, & Boll, 1991; Roman et al, 1991). Ward interpreted his results as indicating that younger adults these days may not be as familiar with and as well practised on basic arithmetic as were their parent's generation. Also of interest is the fact that the 2.0 s rate is considered by Gronwall (1977) to be the most sensitive to mild-head injury; yet Ward demonstrated his findings with this rate. Ward noted that of the 30 young participants, 15 would have incorrectly been classed as impaired and two as severely impaired on the PASAT by using Gronwall's assessment criteria. Johnson et al. (1988) also found age and, to lesser extent, arithmetic moderated performance levels on the CHIPASAT. They suggested that, due to arithmetic inexperience and possibly ongoing development of fluency in responding, caution needs to be taken when interpreting CHIPASAT performances of younger children, especially under 9.5 years.

The available evidence, then, suggests that age, intelligence, and arithmetic ability, may moderate PASAT performance. Therefore, it is worth considering whether other factors, such as anxiety and mood, may also have effects.

The Effect of Anxiety and Mood on PASAT Performance

Some clinicians and researchers have commented that some participants are unable to perform the PASAT at all, or find the task aversive and stressful (Stuss, Stenthem, & Poirier, 1987). Hence, there is some concern as to whether the task is appropriate for excessively anxious persons (Roman et al., 1991). Wills (1997) appears to be the first to have directly examined the issue of anxiety and PASAT performance. Her sample comprised of 42 non clinical participants (ages ranging from 16 to 54 years, mean age = 28). Thirty seven participants had passed the same level of secondary school mathematics. Participants completed the State-Trait Anxiety Inventory, form Y (STAI -Y) (Spielberger, 1983). A statistically non significant correlation

(.12) was found between STAI - Y Trait scores and total percentage correct on the PASAT, and the correlation (.43) between STAI - Y Trait scores and STAI - Y State scores was lower than the normative correlation (.65). The finding of no impact on actual PASAT performance occurred despite there being significantly higher mean anxiety ratings on the STAI - Y State inventory given during the administration of the PASAT as compared to outside of the PASAT session ($p < .001$). Hence, the study by Wills does not seem to support the impressions formed by clinicians and other researchers. However, the participant sample used was a non clinical group, and thus, it remains unknown whether different results would be found for participants with a diagnosis and history of anxiety at a clinical level.

Holdwick and Wingenfeld (1999) are the only other investigators to have directly examined the effect of subjective experience on PASAT performance. They used 80 university undergraduate students as non clinical participants (52 women and 28 men, mean age = 19.8). The participants were randomly assigned to a sad, anxious, or positive mood induction procedure, or to a neutral procedure prior to PASAT administration. The induction procedures required each participant to recollect for 10 mins the two most sad, anxious, or happy events in their life. The neutral procedure required the control participants to read two neutral magazine articles for 10 mins. Holdwick and Wingenfeld reported that the effects of these induced mood states on PASAT performance seemed to be minimal, with there being no statistically significant differences in performance between participant groups at the presentation rates of 2.4, 2.0, and 1.6 s, and this despite the positive and neutral mood groups showing significant negative mood levels. The only significant difference in performance was found between the sad and control conditions at the 1.2 rate ($p < .01$). This difference was accompanied by what appeared to be a trend of decrement in performance by the sad mood group as presentation rate increased. Holdwick and Wingenfeld suggested that either the PASAT is robust against participants' negative mood states, or that the level of induced mood in their participants was only sub clinical; thus, it required the most demanding PASAT rate (1.2 s) for an effect to be observed. Consequently, Holdwick and Wingenfeld argued that in clinical use the PASAT perhaps should not be used with participants experiencing negative emotional states, because poor performance may be attributable to a negative emotional state and not solely to attentional problems. They also suggest that clinicians using the PASAT may want to prepare participants prior to testing, or thoroughly debrief them following testing about common emotional reactions to the PASAT.

Summary

Although the PASAT was developed in the 1950s it was not until the 1970s that it was applied clinically in the assessment of the effect of concussion on speed of information processing. It has become an internationally recognised and widely used neuropsychological measure of speed of information processing, and, in turn, as an indicator of recovery from concussion . It has been shown to have good internal reliability and to correlate moderately well with other neuropsychological tests.

It was not until the late 1980s that clinicians and researchers, other than Dorothy Gronwall and her colleagues at Auckland Hospital, New Zealand, began to re-examine possible biases in the PASAT. Some of these biases have been accounted for by using different sets of randomised digits for each rate, by shortening the length of the task (i.e., using sequence lengths of 10, 26, 29, 41, and 50 digits per rate rather than the original 61), and keeping arithmetic answers under 10. These adaptations have led to the development of other tests based on the PASAT: the

‘Galveston’ version of the PASAT (1987) , the CHIPASAT (1988), the DSAT (1993), the ASPAT (1997), and the VSPAT (1997).

Contrary to Gronwall’s earlier claims (Gronwall & Sampson, 1974; Gronwall & Wrightson, 1981), general intelligence, arithmetic ability, age and practise have each been identified as having an effect on PASAT performance. There has also developed the impression that PASAT performance may be affected by emotional state. The two empirical examinations of this issue have used only non clinical participants and showed no overall effect of negative mood state on performance. However, Holdwick and Wingenfeld (1999) suggested that their findings of a significant difference in performance between a sad mood group and a neutral mood group, at the most demanding 1.2 s rate of the PASAT, indicates that clinicians still need to be cautious in interpreting performance by participants with clinical levels of negative mood. Holdwick and Wingenfeld also suggested that clinicians may want to prepare participants prior to testing by informing them about common emotional reactions to the PASAT.

Overall, the PASAT has been widely accepted as a phenomenological measure of speed of information processing, and as an indictor of recovery from concussion. As a baseline, retest, and recovery measure for the same client it serves the purpose well. However, as a diagnostic measure on single instances of testing there are some weaknesses which need to be taken into account: the clients age, general intelligence, and mathematical ability. Practise effects may also confound the outcome.

In theoretical terms, Gronwall and Sampson (1974) had adapted Broadbent’s (1971) single-channel, limited-capacity information processing model to explain the effect of head injury on PASAT performance. They assumed that head injury reduced the channel capacity of the individual, resulting in lower scores on the PASAT at all presentation rates. Hence, they viewed lowered PASAT performance not as an impaired ability to do the actual cognitive operations of the task, but as having more to do with the rate at which the nervous system can transmit information, this in turn being attributed to lowered levels of arousal associated with temporary brain stem dysfunction. However, van Zomeren et al. (1984) questioned this interpretation when they found increased arousal, via EEG recordings and heart rate, during a vigilance task. Also, Gronwall and Sampson's (1974) theoretical model does not account for the effects of general intelligence and arithmetic ability on PASAT performance which infer possible disruptions at different stages of processing, which cannot be accounted for by slowness *per se*. Thus, performance is not simply a function of the degree of concussion, and may be affected as well by the various brain functions underlying intelligence. The failure to take into account these (and other) potentially confounding factors is also a feature of Sampson and MacNeilage's (1960) earlier views on temporal integration theory, which is discussed in the following section.

Temporal Integration Theory

Hearnshaw (1956) traced the introspective origins of temporal integration theory as far back as St. Augustine in 397 AD. The present review, however, is of the development of the theory during this 20th century. Few researchers have been involved in developing this theory, but that has not translated into a lack of dichotomous argument. The PASAT itself was derived from one side of this argument (Sampson & MacNeilage, 1960). Accordingly, the first section of the following review is organised in terms of a comparison of Lashley's (1937) temporal integration theory with that proposed by Sampson and MacNeilage (1960). The review then moves into an examination of hemispheric differences in temporal processing. Christman (1990) and Miller (1996) have been the only theorists, other than Norman (1984), to relate temporal integration theory to hemispheric specialisation.

Early Temporal Integration Theory

Lashley (1937) proposed a neurophysiological view of temporal integration. He noted that accurate timing of the separate components of an organised movement is as important as the spatial pattern. In particular, most adaptive activities depend on the serial release of a succession of movements in a predetermined order, such as in the production of a musical phrase or a grammatical form in speech. It is the accurate serial release of behaviour that defines temporal integration as a fundamental organisational process in brain functioning. According to Lashley, temporal integration is not dependent on chance associative connections of external stimuli or on chained sensory excitations, as Behaviourists would propose. Rather, it is an innate process in the brain that organises widely scattered neuronal structures. Hence, Lashley also proposed that the study of temporal integration most often can only be facilitated when this process is disrupted due to brain pathology. However, Lashley also described the interval between successive movements of a musician in playing rapid scale passages, being less than the reaction time to kinaesthetic stimulation as an example of how theory on chained sensory excitations cannot account for temporal integration.

Temporal integration theory has been related to speech and comprehension of verbal information by Hearnshaw (1956). He stated that for speech to be intelligible, words must be grouped in recognisable syntactical patterns as well as in patterns of meaning. Grasping these patterns requires an integrative process and, because speech is sequential, this requires a person to be able to temporally integrate information. Hearnshaw's theory is similar to Lashley's (1937), in that he argues for pre-existing neural processes, not just neural organisation based on perceptual inputs, which enable temporal integration. To support this conclusion, he cites one of his own experiments in which a series of approximately 2,500 letters on a continuously moving tape was passed through an aperture at the rate of 100 letters per min. The aperture exposed only five letters at a time. The serial nature of the exposure was based on the repetition of three particular letters in the same order (FFR) which were separated by increasing (but randomised) long or short intervals containing other randomised but unrepeated letters. The participants were asked to comment on any feature of all the letters in the series which struck them as being unusual. Hearnshaw reported that all the participants very rapidly structured the series around the FFR letter group, but not around the familiar pairing of *A* and *B* which appeared conjointly in 73 out of 90 appearances for either letter in the series. The letters *A* and *B* were also included in counting, done spontaneously at some stage by all participants, of the letters between the FFR letter groups. Hearnshaw concluded that the grasping of the pattern (FFR) cannot be a perceptual function because the number of letters perceived in the aperture at any one time was only five. Therefore, he claimed his results to be an example of temporal integration because grasping the pattern came from processing a series of successive events spread over time. Hearnshaw's conclusions are supported by growing evidence regarding how some of the same neuroanatomical mechanisms used in imagery (construction of visual representation from long-term memory) are also involved in some aspects of pattern recognition, for which in most studies begins as a sensory event (Posner and Petersen, 1990).

Sampson and MacNeilage (1960) were the next to develop temporal integration theory, reiterating some aspects of Lashley's (1937) theory but emphasising other aspects which reflect the Behaviorist doctrine criticised by Lashley. Sampson and MacNeilage agreed with Lashley that orderly sequences of behaviour result from the successful temporal integration of all of the "elements" of a skill. They, however, went on to propose what could be classified as a stimulus-dependent model of temporal integration and attention. By doing so they implied there to be no pre-existing neural organisation with specialised functions, and that neural organisation was instead dependent upon input to the brain. They assumed that unless prevented from doing so an individual would produce a continuous, unified flow of response. However, "...in order for temporally integrated response sequences to be sustained, a variable background of stimulation is required" (p. 73). This variable background of stimulation is said to consist of the non-specific effects of the stimuli, instructions, pacing rate, and pacing change involved in a task, and the "random contribution of general environmental stimuli" (p. 73). Hence, it is assumed that temporally integrated responding is dependent on attention being sustained by a variable background of stimulation; that is, this variable background is a necessary prerequisite of attention. Otherwise, the failure of sustained attention causes the "directive" to regress towards randomness. The "directive" is defined as being "... the general neural organisation necessary to fulfill task demands as (the participant) perceives them" (p. 72). This in turn is reportedly derived from the task instructions and "multiple over-learned cues" rather than it being innate organisation. The repetitive nature of the PASAT is seen as creating a "series of stimuli (which) are homogeneous" and, without variation such as pacing rate, are thereby insufficient on their own to sustain attention. However, Sampson and MacNeilage's theory becomes rather self-fulfilling in that they state pacing rate is part of the "variable background " and that " the rate of regression (is) a function of pacing rate" (p. 72). That is, their theory proposes that regression (decrement in performance) is due to unsustained attention, whereas it seems reasonable to also infer from the theory that increased pacing creates a more variable background (i.e., less time to habituate to one stimulus before the next stimulus presents) and could therefore *increase* attention. Their theory does not include that regression could also be attributable to the fact that a fast pacing rate may overtax or not match the capability of the pre-existing neuronal system. In other words, any performance could decline if a task was presented faster than it could be processed which could then affect the sustainability of attention.

Therefore, it seems that Sampson and MacNeilage (1960) have tautologically confused the processes of attention and temporal integration by relying on a stimulus-dependent model. Consequently, they have not explained temporal integration in terms of pre-existing neural brain organisation. The fact that the PASAT has subsequently been mostly applied in the investigation and assessment of concussion, has meant that it has been used to examine the generalised effects of head injury and not more specific disruptions to information processing. This has also meant that the theoretical basis for the PASAT has to date received little or no review.

Later Temporal Integration Research and Theory

The neurophysiological theory of Lashley (1937) and the stimulus-dependent theory of Sampson and MacNeilage (1960) represent a polarisation of theoretical approaches. However, it is fair to argue that as research has progressed over recent decades some researchers are more realistic in accepting a brain and environment interactive model. This approach recognises innate and developmental brain organisation (such as hemispheric specialisation, which is discussed in subsequent sections of this thesis) and the course of information processing in the brain being also determined by stimulus characteristics. Norman (1984) has been one of few researchers to relate temporal integration theory to hemispheric specialisation, in particular to the contemporary development of evidence on hemispheric specialisation for temporal processing. The technological advances of lateralisation research and evidence of specialised temporal processing now make it possible to examine what Lashley (1937) and Hearnshaw (1956) proposed in terms of innate organisation for temporal integration.

An illustrative case of the association between temporal integration and hemispheric specialisation is the study by Christman (1990), in which he describes the procedure used as a task involving temporal integration of form. The task involves the use of a visual pattern built up out of a number of constituent elements via light-emitting diodes (LEDs). The LEDs are spatially aligned to the left and right of visual fixation. The pattern is then presented in two separate flashes that are spatially aligned but temporally displaced. The two flashes never share common elements and are complimentary in that when overlaid and integrated, a single digit is formed. The task requires only identification of the digit presented and no addition of the digits. For the two flashes to be integrated over time into the percept of the complete stimulus, there must be some adequate visible persistence of the first flash available to the visual system at the onset of the second flash. Temporal displacement is obtained by manipulating the inter-flash interval (IFI).

In Christman's (1990) first experiment, IFI was held constant at 55 ms but when luminance was systematically decreased (100, 50, 25 and 12.5% transmission of light) there was greater improvement of performance in the left visual field (LVF). Information from the LVF is initially processed in the right hemisphere (RH). In a second experiment, blurring produced greater impairment of the right visual field (RVF) where initial processing is carried out in the left hemisphere (LH). Christman concluded from these two experiments that spatial frequencies below nine cycles per degree are processed more efficiently in the RH. In a third experiment, increased blur produced greater impairment of LH performance at short IFI duration (40 ms). However, at a longer IFI (80 ms), increased blur produced equal impairment of RH and LH performance.

Christman (1990) interpreted his findings in terms of the "spatial frequency hypothesis" which emphasises that the stimulus spatial information interacts with the overall perceptual demands of the task to determine laterality results. He therefore suggested that there is no inherent hemispheric symmetry or asymmetry in the temporal integration of successive stimuli. Rather, asymmetries are determined "directly by perceptual parameters of input" (p. 372). In drawing this conclusion, Christman implies, similar to Sampson and MacNeilage (1960), a stimulus-dependent model. However, he did acknowledge that the nature of spatial frequency processing differences between the hemispheres may also involve physiological .... "cytoarchitectonic bases for high vs low resolution processes in the brain" (p. 373), referring to research by Scheibel et al. (1985). They found evidence of finer grained neuronal networks in the LH compared to the RH. Christman suggests such differences could represent a physiological advantage of the LH for processing stimuli of high resolution and of the RH for stimuli with low resolution.

Miller (1996) has expounded further on psychological evidence of lateralised differences between the LH and RH having a neurophysiological basis. In particular, he proposes that axonal conduction time differs between the two hemispheres. His "psychobiological theory" on hemispheric specialisation has as its starting point Hebb's (1949) model of learning at the level of neuronal function. Hebb was a student of Lashley's. In fact, Miller agrees that his theory can be described as an extension of Lashley's (1937) theory on innate brain organisation for temporal integration (R. Miller, personal communication, June 16, 1999).

The Hebbian learning model of synaptic modification and cell assembly assumes that repeated activation of pre- and post-synaptic membranes results in a strengthening of the synaptic connection between cells. An extension of Hebb's concept, and one which demonstrates a temporal structure in the activity of neuronal tissue, had been made by Abeles and his colleagues based on their research with cat and monkey cortex first reported in the early 1980's (e.g., see Villa & Abeles, 1990). By recording action potentials they were able to demonstrate precise temporal dependencies of the firing of one neurone upon the activity of other neurones. Abeles also noted that this temporal dependency was better demonstrated with interactions between more than two neurones (*synfire chains*) rather than only pairs, and could be at delays of a few hundred ms (e.g., a third neurone may fire at a high rate within 25 ms after a second neurone fired, but only if a first neurone had fired 375 ms earlier). However, Miller (1996) contends that the Abeles model requires the involvement of very many neuronal synfire chains, and thus infers many synaptic links, to explain the extent of temporal delay to sufficiently approximate the time scale of the *psychological moment* to be represented. Furthermore, the dispersion of activity from many synfire chains may lead to *massive divergence* of a signal and thus a temporally-structured network could be vulnerable to global changes in level of arousal, or metabolic or hormonal influences on synaptic transmission, thus being disruptive to the stability of the temporal structure in the network (p.13).

Miller (1996) also criticised the Abeles model for not sufficiently accounting for the magnitude of delay that can occur in some single axons which in turn could contribute to temporal structure. He noted that prior neurophysiological research had biases, such as recording techniques (e.g., micropipettes and microelectrodes being too large) in favour of larger neurones with fast conducting axons, of samples from brain lamina more likely to contain larger neurones, and of insufficient conduction distance between soma and synapse. These biases had given false estimation of conduction times being no slower than around 10 ms. However, the work of Swadlow (1974, 1982) with rabbit and Miller (1975) with cat cortical axons demonstrated conduction latencies ranging from 24 to 44 ms for visual and motor cortex, transcollosal responses, and somatosensory areas. Hence, Miller (1996) proposed that stability of temporal structure in a cell network is probably also facilitated by specific axons which can delay signal conduction.

Miller (1996) acknowledged that the specific evidence on axonal conduction in human cortical tissue is not yet available, partially due to the ethical considerations involved. His proposal that there are different proportions of fast-conducting myelinated and slow-conducting unmyelinated axons between the hemispheres is based on the higher proportion of white matter to grey matter in the RH compared to the LH. He further stated that given the length of some unmylienated axons in human cortex it is quite conceivable that some axons could delay conduction by many hundreds of ms. He extrapolated from Swadlow (1974, 1982) and his own work (1975), and based on degree of myelination, axonal length and proportion of white matter to grey matter in the human brain, to estimate a 100 ms criterion between the hemispheres. That is, axonal conduction in the RH is proposed to be generally no slower than 100 ms, whereas the LH is believed to have axonal conduction times slower than 100 ms and up to many hundreds of ms duration.

Miller (1996) cites longer latency of evoked potentials in the LH compared to the RH, greater EEG coherence in the RH versus greater phase delays between EEG traces in the LH, and greater left to right compared to right to left transmission time across the corpus callosum as indirect evidence in support of his axonal conduction theory. He otherwise admits a paucity of direct biological evidence. He then turned to review the indirect psychological research evidence. In so doing he covered many of the studies already reviewed by Bradshaw and Nettleton (1983), Corballis (1991), Norman (1984), and Springer and Deutsh (1993), but more closely took into account the relationship between asymmetries reported and the ms temporal parameters of the sensory tasks involved. Miller reached the same conclusion regarding the LH's specialisation for temporal processing and found many LH advantages were for tasks requiring sensory processing slower than 100 ms. (A review of research into hemispheric specialisation is discussed in subsequent sections of this thesis.)

Other research which appears to support Miller's (1996) theory, although not cited by him, is the work by Posner and colleagues (see review by Posner & Raichle, 1994). Their studies involved the recording of event-related potentials (ERPs), which are brain electrical activities measured by scalp electrodes. They compared the recorded location of ERP activity with their PET studies using the same experimental tasks (i.e., participants were required to look at words or consonant strings) and found significant consistency of brain area location. Of particular relevance to Miller's (1996) theory is their finding of a strong asymmetry about 100 ms after stimulus presentation. That is, ERPs from sites in the posterior RH were larger and preceded those in the LH. In contrast, they also found evidence for a difference in the response to words and consonant strings that started about 150 ms after a word was presented and was strongest over posterior sites in the LH. Posner and Raichle (1994) also report PET and ERP studies that indicate asymmetric and even longer temporal features for word association tasks. When participants were given 1.0 s to generate only a single word, PET showed the left frontal area alone was active. However, both Wernicke's area and the frontal area were found to be active when participants had to generate several words, or were given 1.5 s to generate a single word. ERP evidence with the 1.0 s single word generation task showed an initial peak above the left lateral frontal lobe about 200 ms after stimulus presentation. ERPs recorded over Wernicke's area, with the multiple word or 1.5 s delay single word tasks, peaked after about 700 ms. This evidence supports Miller's (1996) theory of a difference between the hemispheres for latencies in sensory processing on the scale of ms, and also demonstrates some selective and delayed activation of specific brain areas (i.e., posterior language processing areas) within the LH when the psychological task requires either the generation of many words (which would require more time) or the delay/holding of a word for longer (i.e., on the scale of seconds). These aspects of delay/holding of a word for around 1.5 s and the involvement of the language processing areas of the LH have also been specified by Baddeley in his redefinition of his phonological-loop system theory on short-term memory as involving a 1.5 s 'temporal' span rather than the earlier concept of 'digit' span capacity (Baddeley & Hitch, 1974; Baddeley, 1998, 1999). The relevance of Baddeley's theory to temporal integration theory is discussed shortly.

To recap, it is the difference in axonal conduction time in the LH versus the RH that is particularly central to Miller's (1996) theory. According to the theory, neurones cannot distinguish afferent signals that are less than 10 ms apart and any signals within this time will be integrated and processed as being simultaneous. To process signals with duration greater than 10 ms requires afferent neurones with axons which delay input. Delay is facilitated by thinner, unmyelinated axons which may have transmission times greater than 100 ms. Miller states that the RH has a higher proportion of fast-conducting myelinated axons which enables that hemisphere to rapidly process spatially complex information. More recently, Miller has referred to this rapid processing as the RH's ability to process "gestalts" of information, such as spatial information (R. Miller, personal communication, April 9, 1999). This idea of the superiority of the RH for gestalt functions, particularly visuospatial tasks, has been previously suggested by Nebes (1978).

Miller (1996) proposes that the LH has a higher proportion of slow-conducting unmyelinated axones which enables representation of smaller serial units of information. Hence, the LH is well suited to tasks of a serial nature, with units of neural processing lasting longer than 100 ms. Miller's theory predicts that a reversal in LH superiority should be observed when the same processing task takes less than 100 ms. His theory also attributes the LH's specialisation for speech production and manual praxis to slower axonal conduction time in that hemisphere. The slower conduction time allows "modelling" to occur in advance of actual movement. Modelling guides the execution of time-structured movements via the activation of motor-sensory connections within the cerebral cortex. Fuster (1995) refers to a similar concept of modelling as the formation of "temporal gestalts", and attributes responsibility to the prefrontal cortex for temporal integration of motor-sensory and higher order cognitions. This idea of modelling is also similar to Lashley's (1937) original proposition that movement is not reactively dependent on external stimuli or chained sensory excitations but can be internally generated as time-structured behaviour.

To summarise, both Christman (1990) and Miller (1996) make the point, originally made by

Lashley (1937), that temporal integration does rely on innate brain organisation. They argue that there are differences at the neuronal level between the LH and RH which account for each hemisphere's specialisation for processing stimuli in terms of spatial factors and speed. The importance of temporal factors in information processing has also been identified in other research paradigms that have a theoretical basis similar to temporal integration theory. One such paradigm is visual masking, which is briefly reviewed in the following section.

Temporal Integration And Visual Masking Research

Some investigators who use visual masking research techniques also refer to a type of temporal integration theory which does not have its origins in the theory discussed above (Di Lollo, 1980; Schwartz, Winstead, & Adinoff, 1983). In visual backward masking, an informational target stimulus is presented and then followed, after an interstimulus interval (ISI) measured in ms, by a non informational masking stimulus that interferes with or interrupts target identification. In visual forward masking, the mask precedes the target. The manipulation of ISI in this paradigm reflects the theoretical interest in the temporal gap, or lack thereof, between the target stimulus and the mask. Hence, the underlying theory is that successive stimuli will be processed as though one unless there is a sufficient temporal gap to prevent this. This theory is therefore akin to the temporal integration theory previously discussed, in that the association between ISI and assimilation is similar to Miller's (1996) distinction between rapid versus delayed temporal processing.

Visual masking research has been applied to schizophrenia (Braff, 1981; Braff & Saccuzzo, 1982; Braff, Saccuzzo, & Geyer, 1991; Saccuzzo, Cadenhead, & Braff, 1996), but has not yet included lateralised procedures to examine the issue of hemispheric processing. However, Heider and Groner (1997) did so using normal participants. Their study is discussed in more detail in a later section.

Summary

Temporal integration refers to a person's ability to process information of a serial nature, such as spoken communication, and to generate time-structured verbal responses or movements. Modern temporal integration theory, as initiated by Lashley (1937) and most recently advanced by Miller (1996), argues that the ability to temporally integrate relies heavily on innate brain organisation. Miller theorises that the LH's superiority for processing or generating spoken communication, speech production and manual praxis, is based on that hemisphere having axonal conduction times greater than 100 ms. That is, slower conduction times are better suited to the serial nature of spoken language and generation of time-structured movements. The RH has faster axonal conduction times which means it is better suited to tasks requiring rapid or simultaneous processing, such as spatial tasks or "gestalts" of information. More specifically, then, temporal integration refers to the capacity of some brain systems to delay processing of discreet units of information so that temporal associations between separate incoming and partially processed units can be maintained. Otherwise, in the case of spoken communication, for example, overall meaning from groups of units would be lost. On the other hand, the brain also has systems which can cater for when units of information that need to be processed simultaneously and not temporally, such as for spatial information or visuospatial "gestalts".

Sampson and MacNeilage's (1960) attempt at developing temporal integration theory seems to have been a rather tautological exercise brought about in part by relying on a stimulus-dependent model. Their model can not account for the subsequent evidence of hemispheric specialisation, since they dismissed the possibility of innate brain organisation. Christman (1990) similarly proposed a stimulus-dependent model for lateralised differences in the processing of spatial frequencies, but later acknowledged that psychological research can no longer ignore neurophysiological evidence of differences between the hemispheres.

The PASAT was selected for the present research because of its temporal features and not as an indication of particular support of Sampson and MacNeilage's (1960) theory. That is, the PASAT's serial aspects, its facility to manipulate presentation rate, and its verbal processing and response requirements, can be thought of as approximating the temporal aspects contained in spoken communication and verbal processing. Accordingly, the present research set out to examine the utility of the PASAT, and temporal integration theory, in helping to better understand hemispheric specialisation for temporal processing and its relationship to the verbal processing difficulties in schizophrenia. Testing the utility of the PASAT in terms of hemispheric processing in schizophrenia takes into account Lashley's (1937) point that temporal integration can often only be understood when its dysfunction is observed in the context of psychopathology. Therefore, subsequent sections of this thesis contain reviews of evidence relating to hemispheric specialisation and temporal processing in persons with and persons without schizophrenia.

However, as noted earlier, there is some similarity between temporal integration theory and working memory theory. Before proceeding with the review of research on hemispheric specialisation, then, a brief discussion of working memory in relation to temporal integration and the PASAT will be presented next.

Working Memory

This section discusses the similarity between temporal integration theory and Baddeley's theory (Baddeley & Hitch, 1974; Baddeley, 1998, 1999) of short-term working memory. The discussion begins with a brief distinction between long-term and short-term memory and then focuses on Baddeley's phonological-loop theory of working memory. This section also considers the relevance of working memory to performance on the PASAT and what predictions may then arise with regard to hemispheric specialisation.

Long-term memory refers to information stored with sufficient sustainability so as to be accessible over a period of anything more than a few seconds. Long-term memory has been variously described as episodic (remembering particular incidents), semantic (knowledge about the world), implicit (priming by prior learning without having to remember the time and context of that learning), and explicit memory (the recall of the context in which learning took place so as to remember specific aspects of that learned).

Short-term memory (STM) purportedly operates so as to temporarily hold information that is required for only brief intervals of time (no more than a few seconds) and then becomes irrelevant and unnecessary to remain in storage. An example of such information that may become unnecessary for storage could be the numbers used in a calculation task once the completed sum has been reached. The completed sum may be all that is needed for future retrieval from long-term memory. Baddeley and Hitch (1974) proposed a model of STM in which a controlling attentional system (central executive) supervises and coordinates a number of slave systems. They theorised the central executive to have limited-capacity but Baddeley (1999) still acknowledges that its actual processes are unknown. Baddeley and Hitch instead chose to delineate two slave systems, the visuo-spatial sketchpad and the articulatory or phonological loop system. The visuo-spatial sketchpad is assumed to be responsible for setting up and manipulating visual-spatial images (e.g., mental rotation) prior to the encoding of an 'outcome' image into long-term memory. The phonological loop system is theorised as being responsible for the manipulation of speech-based information. With regard to the present research the phonological loop system is the most relevant and is discussed in more detail below.

Baddeley and Hitch (1974) based their phonological-loop system theory for STM on prior findings by Peterson and Peterson (1959) and Conrad (1964). The 'Peterson effect' refers to the reliance of STM on subvocal rehearsal. It is theorised that forgetting is not only due to decay in STM but is also as a result of proactive interference by subvocal rehearsal. For instance, the initial stage of a digit sequence learned for recall shows little or no forgetting but rehearsal of digits already held in STM interferes with the later arriving digits. This led to the general belief that most persons have a STM span, for efficient remembering, of about 6 to 7 units of information (e.g., a 6 to 7 digit span). However, subsequent research by Baddeley and his colleagues (see reviews by Baddeley, 1998, 1999) found a relationship between the speed at which an individual could read out sequences of words and their STM span. Fast talkers are reportedly good at remembering. Consequently, Baddeley redefined STM span as the amount of time remaining constant (approximately 1.5 s) not the number of items. Also, longer words were noted as being harder to remember because they required longer rehearsal time. Preventing rehearsal (e.g., by requiring generation of repetitive speech) stops the advantage of shorter over longer word length.

Conrad's (1964) work had shown that STM was based on an acoustic or speech-related code regardless of whether the information arriving in memory was visual or auditory in form. For instance, despite visual presentation of letters in sequences, performance was better with similar sounding rather than dissimilar-sounding letters. Baddeley and colleagues (see reviews by Baddeley, 1998, 1999) also showed how recall was disrupted more by other sound (e.g., irrelevant spoken material but not other non-specific noise) rather than meaning. Accordingly, Baddeley and Hitch (1974) hypothesised that the subvocal rehearsal is an operation which occurs in the same areas of the brain which are themselves involved in language processing and articulation (such as Broca's and Wernicke's areas). Hence, their proposal for calling this operation the phonological (articulatory) loop system.

Baddeley (1999), though, still only briefly extrapolates from his theory, and other reports on language deficits associated with brain damage, to infer an association between STM and the LH's specialisation for language processing. He has not addressed the vast research on hemispheric specialisation as a means to examine this proposed association between STM and the LH. An example of such research, which may support his theory but is not cited by him, is the study by Hellige and Cox (1976). They found that memory load interferes selectively with LH performance. That is, with an 'easy' memory load of 2 to 4 nouns, visual recognition of complex polygon forms was improved over a non-load condition. However, if the load was 6 or more nouns LH performance decreased. Performance with the RH (left visual field) was not as affected by memory load. Hence, one could interpret these findings as indicating that the 'easy' load condition activated phonological working memory, and the involvement of rehearsal, but left sufficient capacity for a concurrent task. The greater load condition did not leave sufficient capacity within phonological working memory, and so still indicated a selective but negative influence on LH performance. Other evidence possibly supporting the proposed association between the LH and phonological working memory, comes from the series of PET and ERP studies reported by Posner and Raichle (1994). These studies, which were reviewed in an earlier section of this thesis, demonstrated asymmetric activation of LH frontal and posterior areas for tasks requiring multiple word generation or the holding of a single word for 1.5 s. This temporal factor is the same as that specified in Baddeley's redefinition of STM span (Baddeley, 1998, 1999). However, Baddeley has not cited this PET or ERP research either.

The purposes of STM for 'holding information' and temporal integration for 'delaying processing of discreet units of information', each for brief intervals of time, sound somewhat synonymous. In fact, MacNeilage (1999) cites Lashley (1951) as having anticipated the concept of working memory with his own concepts of 'priming' and 'internal speech'. Specifically, Lashley stated: " There are indications that, prior to the internal or overt enunciation of the sentence, an aggregate of word units is partially activated or readied" (p. 119). Baddeley (1999) has further defined the purpose of his articulatory loop system as being for "preserving the order of information" (p. 53). It is therefore possible to view Baddeley's concept of working memory, particularly his redefinition now including temporal and order aspects, as being a partial restatement of temporal integration theory. Despite citing Lashley's (1929) 'principle of mass action of the cortex', Baddeley (1998) is perhaps unaware of Lashley's (1937 , 1951) founding of modern temporal integration theory and so has not discussed the similarity with his own theory on working memory.

Nevertheless, there are aspects of working memory that are applicable to the PASAT. Firstly, the PASAT's requirement of a participant to 'hold' a digit for a brief interval would seemingly involve STM, which is pretty synonymous with temporal integration anyway . Secondly, the specified intervals for holding each digit at the fastest 1.2 and 1.6 s presentation rates are very close to the 1.5 s STM span defined by Baddeley (1998, 1999). Thirdly, the mental operations involved in doing the PASAT include the recall of the digit held, identification of the new digit, addition of these two digits, speech production of the sum, suppression and discarding of the sum, and 'holding' of the digit last heard before arrival of the next new digit. (Refer to page? and Figure ? for further discussion on these operations.) Therefore, optimum performance with the PASAT would presumably require efficient STM (i.e., being able to do as much of these operations as possible within the 1.5 s span). Given that Baddeley (1998, 1999) presumes the phonological loop system is a specialist function of the LH, then one might predict an advantage by the LH for doing the PASAT. Conversely, the findings by Hellige and Cox (1976), of the effects of memory load selectively on LH performance, might suggest that for some participants the PASAT's mental operations are too numerous for STM and consequently may result in poorer LH performance. However, allowing more time to do the operations (i.e., slowing presentation rate beyond 1.5 s) may alleviate poorer LH performance.

To summarise, there is a great deal of similarity between the concepts of working memory and temporal integration. The fastest presentation rates of the PASAT (i.e., 1.2 & 1.6 s) closely approximate Baddeley's (1998, 1999) redefinition of phonological loop working memory as having a 1.5 s temporal span rather than a 'digit' capacity span. Furthermore, whether based on working memory or temporal integration, predictions of LH compared to RH performance with the PASAT would conceivably be the same; particularly with regard to the LH's capacity to 'hold' or 'delay' information for processing. It is at this point that this discussion now returns to reviewing research on hemispheric specialisation.

Hemispheric Specialisation

There now exists paleontological evidence of the larger LH, and even Broca's area, along with the relative changes in size of the occipital and frontal lobes, being evolutionary markers which distinguish the earliest species of *Homo* from the former Australopithecines (Leakey, 1994). Lateralised preference for arm movement, before full development of the brain, has been observed in first trimester human foetuses (Hepper, McCartney, & Shannon, 1998). Also, different postnatal phases of growth spurt for the LH and RH have been demonstrated, using EEG, in a large (n = 577) cross-sectional study of normal children. The LH has marked growth from age 3 to 6 years, and the RH has a slightly smaller growth spurt between the ages of 8 to 10 years (Thatcher, Walker, & Giudice, 1987). Collectively, this paleontological and developmental evidence supports the view that there are phyletic bases to brain organisation and lateralised behaviour. (For an extensive theoretical review of the evolutionary aspects of hemispheric specialisation the reader could consult Corballis, 1991, 1999.)

However, argument continues over brain asymmetry at the functional level and how this translates into behaviour. The following is a brief review of the cumulative scientific evidence on hemispheric specialisation, beginning with the first clear reports in the 19th Century of the consequences of lateralised brain damage. The next substantive stage of scientific investigation into hemispheric specialisation occurred mostly in the 1960s and 1970s, assisted by the invention of lateralised research techniques and commissurotomy studies. Later scientific interest in hemispheric specialisation has included the synthesis of evolutionary, psychological, neurophysiological, clinical and non-clinical evidence.

The purpose of the present review is to provide a general history of the research into hemispheric specialisation. There is an enormous literature relating to lateralisation studies and so no attempt is made to review all of these. (There have been many reviews; for example, see Bertelson, 1982; Bradshaw & Nettleton, 1981; Corballis, 1991; Miller, 1996; Springer & Deutsh, 1993.) Information on hemispheric specialisation and temporal processing, central to the hypotheses under investigation in this thesis, is reviewed later. As a consequence, the latter subsections of the present review are mostly to do with evidence for RH specialisation. The subsequent section on temporal processing is a review related more to the LH.

Nineteenth Century Observations of Brain Damage

It was during the 19th Century that speculation about separate functions of the brain began to receive support from clinical observations of persons with LH damage and aphasia, by Dax (1836) and Broca (1861), and with difficulties in understanding speech, by Wernicke (1874) (all three references cited in Bradshaw & Nettleton , 1981, & Corballis, 1991). These early observations further inspired the theoretical basis for dichotomising the functions of the brain in terms of language functions and unilateral specialisation (Bradshaw & Nettleton, 1981). Jackson (1864; cited in Corballis, 1991) had speculated that the RH might be at least equal or superior for visuospatial functions. Luys (1881; cited in Corballis, 1991) began the speculation that the RH might be responsible for control over emotion. He had observed that persons with right-brain damage tended to be more manic and hyperemotional, whereas persons with left-brain damage tended to be passive and apathetic. His ideas were supported by preceding observations of persons with hysterical disorders who tended to manifest symptoms on the left side of the body (Corballis, 1991).

However, the greater difficulty in investigating non-linguistic functions, and perhaps the social significance of language, led to the persistent idea that the LH is "dominant" for a variety of functions. The RH was considered, by default, to have only "minor" or no specialist functions of its own. This unsubstantiated and rather strict dichotomy was to remain popular until at least the 1960s when modern technology (e.g., tachistoscopic lateralisation techniques and commissurotomy studies) began to make it possible for scientific testing of theoretical speculations on hemispheric specialisation.

Modern Lateralisation Research

Right visual field advantages for word and letter recognition tasks had been initially interpreted in terms of perceptual learning (Mishkin & Forgays, 1952) or of stronger evoked scanning habits (Heron, 1957). However, Kimura (1961) suggested that these right visual field advantages could also be attributable to the LH's dominance for linguistic processing. Kimura used Broadbent's (1954) dichotic listening test to demonstrate a right ear advantage (REA) for recall of digits in right-handed participants. Kimura also showed a left ear advantage (LEA) for participants of whom it had been ascertained, by using the sodium amytal (Wada) test (Wada & Rasmussen, 1960), that the control of speech was in their RH. Kimura (1967) also noted that dichotic competition, rather than just monaural tests where digits would instead be presented to one ear at a time, seems necessary to demonstrate the ear asymmetry. This led her to propose that a REA occurs from the combination of the LH's specialisation for language functions and the suppression of the ipsilateral auditory pathway in favour of transmission over the stronger contralateral pathway.

Haggard and Parkinson (1971) used undergraduate students in a dichotic experiment to demonstrate a REA with a task requiring the processing of the voicing of stop consonants (actually 4 synthesised speech utterances). In a second experiment, a task requiring the identification of the emotional tone of a naturally spoken sentence gave an LEA. The investigators concluded that the nature of the tasks exerted a greater influence than the acoustical attributes of the stimuli used.

Springer (1973) found a REA in terms of reaction time rather than percentage correct, the traditional measure in dichotic tasks, for the processing of speech material opposed by contralateral noise. In this study, participants listened to a dichotic tape in which 1 of 6 consonant-vowel syllables was paired with a burst of white noise on each trial. Eight blocks of 40 trials were presented, with the syllables within a block being presented to the same ear. On each trial, participants had to decide if "ba" was presented. Mean reaction time to the right ear items was 440.0 ms, and to the left ear 453.6 ms. Springer concluded that the two dichotic stimuli presented on a trial do not have to be of the same perceptual class for an ear advantage to occur.

Many other studies have also demonstrated REAs for language- related material (e.g., see Bertelson, 1982; Bradshaw & Nettleton, 1981; Corballis, 1991; Miller; 1996; Springer & Deutsh, 1993). The general consensus is that the LH is specialised for language functions (Allen, 1983). However, concurrent with the incorporation of visual field and commissurotomy studies came the gradual erosion of the "verbal versus non-verbal" dichotomy which had been a translation of the stricter "dominant versus minor" dichotomy inherited from the 19th century. Consequently, in more recent times the RH has been given more serious consideration in lateralisation research.

The Right Hemisphere and Language

Sperry (1982) points out that commissurotomy studies seemed to show that the disconnected RH was by no means either word-deaf or word-blind. Lateralised testing demonstrated the RH has the ability to comprehend spoken words, to read printed words flashed to the left visual field, to match objects or pictures with spoken or written words, and the tactual retrieval of objects described not directly by name but by moderately complex phrases. Although such demonstrations relied heavily on manual or tactual responding (LeDoux, Wilson, & Gazzaniga, 1977), it still showed the RH to have considerable capacity for cognitive understanding and the comprehension of both written and spoken language. Sperry's explanation for why previous lateralised lesion studies did not clearly demonstrate similar findings is that individual variation and background pathology obscured rather subtle and qualitative left-right differences. Under the conditions of commissurotomy, background factors are equalised, so small left-right comparisons are possible within the same participant working on the same task.

Other findings for RH involvement in language have arisen from a tachistoscopic study with normal participants by Geffen, Bradshaw, and Nettleton (1972). Their participants judged whether letters (A, E, M, & R - upper and lower cases) were the "same" or "different" on the basis of either physical or name matches. By using response time as the dependent measure the investigators demonstrated that the stimuli which had the same name, but different case, were responded to more quickly when they were presented in the right visual field, whereas, matching was faster when physically identical stimuli were presented in the left visual field.

In an auditory study, Elias, Yandell, and Kavacos (1982) examined the ability of the RH to comprehend spoken words presented monaurally to either left or right ear. Their procedure required participants to say whether a word matched an object which was presented visually but not lateralised. Differences in vocal response latencies indicated that words relating to the function of the object were responded to more quickly when presented to the left ear. Words relating to a physical characteristic of the object were responded to more quickly when presented to the right ear. Another interesting finding from this study was that asymmetry was demonstrated with a monaural presentation, rather than the typically used dichotic procedure. These results found by Elias et al. are an indication that the RH has a superiority, not only for visuospatial"gestalts", but also for processing words as being connotative of "gestalts" of meaning. Further information on the RH's superiority for processing figurative language is presented shortly.

Muller et al.(1999) have shown, via the use of positron emission tomography (PET), that during listening to sentences normal participants demonstrated the expected stronger LH frontotemporal blood flow increases. This asymmetry was reduced in participants with late LH lesion (identified after age 20 years) and *reversed* in participants with early lesion (identified before age 5 years). The investigators interpreted these results as being indicative of the plasticity of the human brain in certain developmental stages, and the RH's ability to assume specialist language functions.

There is also evidence that the RH has some advantage in the processing of figurative versus literal language, such as interpreting idioms (Van Lancker & Kempler, 1987) and metaphors (Anaki, Faust, & Kravetz, 1998; Brownell, Simpson, Bihrle, Potter, & Gardner, 1990).
St George, Kutas, Martinez, and Sereno (1999) have also demonstrated, with the use of magnetic resonance imaging (MRI), greater activation of the middle temporal sulcus of the RH

when participants read untitled paragraphs. The reverse was found for the reading of titled paragraphs. The investigators suggested that the right middle temporal regions may be important for global coherence of semantic integration. These findings concur with those reported by Alpert, Rubinstein, and Kesselman (1976). In their study, participants were tested for immediate recall of semantically well integrated and semantically poorly integrated sentences that were presented monaurally in conjunction with binaural noise. The participants were 32 people with schizophrenia and their normal controls. The controls showed a REA for both types of sentences, but a superior REA for the well integrated as opposed to the poorly integrated sentences. Among the participants with schizophrenia, those who had hallucinatory symptoms and those without showed a smaller REA and LEA, respectively.

On the whole, the LH is credited with being superior for phonemic analysis, syntax, and articulation, whereas the RH operates more at the level of connotative, associative, and imaginal processes - and may act in a supportive role in identifying inputs by their visual and auditory “gestalts”, and attending to extralinguistic contexts (Bradshaw & Nettleton, 1981).

The above evidence collectively suggests that the debunking of the “superior vs. minor” and “verbal vs. non-verbal” dichotomies of the LH and RH is indeed truly valid. The RH hemisphere can no longer be ignored as having its own specialisation with respect to language and the capability to compensate for a damaged LH at certain stages of development. There is other evidence of the RH also having its own specialisations, which is discussed next.

Right Hemisphere Specialisation for Visuospatial Functions

Other evidence has arisen to show that the RH cannot be dismissed as being “minor” in comparison to the LH, and indeed being possibly superior for visuospatial functions. This superiority for visuospatial functions was first suggested by Jackson (1876; cited in Corballis, 1991) who reported on a person with a RH tumour who manifested what Jackson called “imperception”. The person reportedly could not recognise familiar people and places and was spatially disoriented.

Evidence of right hemisphere superiority for visuospatial functions has also come from studies of participants without brain damage. A left visual field advantage has been found for the perception of line orientation (Atkinson & Egeth, 1973), dot localisation (Bryden, 1976), stereopsis (Carmon & Bechtoldt, 1969), lightness (Davidoff, 1975), colour discrimination (Davidoff, 1976), stereoscopic depth (Grabowska, 1983), curvature (Longden, Ellis, & Iversen, 1976), pattern displays (Moscovitch, 1979), face-like stimuli (Patterson & Bradshaw, 1975), and face recognition (Sergent & Bindra, 1981). A left visual field advantage has also been demonstrated when the quality of a visual stimulus is degraded, this being the basis of what is called the spatial frequency hypothesis (Hellige, 1976, 1993; Meccaci, 1993). This hypothesis states that a visual stimulus is composed of spatial frequencies which consist of sinusoidal variation of luminance across space. It has also been argued that, at some level of processing beyond the sensory cortex, the LH is biased toward proficient processing of higher, and the RH for lower, visual-spatial frequencies. (Hellige, 1993). In other words, at lower frequencies a stimulus is degraded and more difficult to discern, thereby requiring the more proficient processing of the RH.

Commissurotomy studies also support the idea of RH superiority for visuospatial tasks, such as better performance for completing shapes from incomplete information (e.g., whole circles from arcs) and in judging the alignment of dots (Badan & Caramazza, 1997; Nebes, 1978). Nebes proposed that the RH is responsible for forming the spatial cognitive maps ("gestalts") of our surroundings upon which behaviour is planned and organised. This idea of cognitive mapping in the spatial context supports what Lashley (1937) referred to as innate organisation for the planning and execution of behaviour in both spatial and temporal contexts. It also compliments what Miller (1996) referred to as "modelling" for speech production in motor-sensory connections within the cerebral cortex, and supports his proposal of faster axonal conduction times in the RH facilitating the processing of "gestalts".

Right Hemisphere Specialisation For Emotion and Music

The RH has also been credited with being specialised for processing the emotional content of information, such as an LEA for the perception of human emotional calls (Carmon & Nachshon, 1973), and the identification of emotional intonation in dichotic sentences, where an REA is instead demonstrated if the participant is instructed to attend to the verbal content (Haggard & Parkinson, 1971). LEAs have also been shown for the rating of emotionality in spoken passages (Safer & Leventhal, 1977), and for the identification of emotionality in tonal sequences (Bryden, Ley, & Sugarman, 1982). Left visual field advantages have been found for discerning the degree of emotional expression in faces (Ley & Bryden, 1979; Suberi & McKeever, 1977), and for spontaneous facial expressions (Moscovitch & Olds, 1982). Clinical observations via unilateral inactivation by injection of sodium amytal, of unilateral cerebral lesions, and commissurotomy, also strongly indicate the relative dominance of the RH for emotions (Gainotti, 1979; Campbell, 1982).

With regard to music, the LH is recognised as being generally superior for rhythm (Gordon, 1978; Prior, Kinsella, & Giese, 1990; Robinson & Solomon, 1974). On the other hand, LEAs are found via dichotic presentation for judgements of musical chords (Gordon, 1970; Taub, Tanguay, Doubleday, & Clarkson, 1976), timbres (Kallman & Corballis, 1975), pitch (Blumstein & Cooper, 1974), and melodies (Bartholomeus, 1974; Kimura, 1964; King & Kimura, 1972).

Summary

What the above review indicates is that the RH cannot be dismissed as being just minor or inferior to the LH. Instead, it is better to consider that the functions of the two hemispheres compliment and support each other whenever a person is engaged in the various aspects any task can contain. This appears to be true not only for cognitive functions but also essential life functions, such as sympathetic modulation of cardiac activity being mainly controlled by the RH and parasympathetic modulation by the LH (Wittling, Block, Genzel, & Schweiger, 1998). The demotion of the 'verbal versus non-verbal' dichotomy has also been a consequence of redefining the LH's superiority with respect to language, in broader terms of specialisation for temporal processing. The next section provides a review of the evidence for the role of the LH in temporal processing.

Hemispheric Specialisation For Temporal Processing

Left Hemisphere Specialisation for Temporal Processing

The research discussed in the preceding sections show that the LH can no longer be viewed as solely dominant for the processing of language, and that the RH has some specialisation for the "gestalts" of language. However, Leek and Brandt (1983) proposed that a more robust hypothesis of differential hemispheric processing could instead be based on temporal factors, language being one of the many examples of temporal processing. They noted a previous suggestion that the LH, rather than specialising in speech *per se*, instead mediates underlying temporal information in the speech signal. Schouten (1980), in his review of speech research, proposed a similar rejection of the concept of a specialist speech mode of perception in favour of proposing that speech is processed by the same mechanisms as other acoustic stimuli.

In Leek and Brandt's (1983) investigation, participants were trained to manually respond to the presence of a preassigned target order of a two-element sequence. The stimuli were made up of vowel-shaped noise and two different complex tones and were dichotically presented. Their results showed that although there were no lateral differences in accuracy of response, reaction times to rapid target sequences presented to the right ear were significantly shorter than left ear reaction times. Leek and Brandt's interpretation is that their results support the idea of the processing superiority of the right ear (LH) being for sequences provided those sequences have sufficient temporal complexity - especially when these temporal characteristics are similar to temporal values found in speech.

A tachistoscopic study by Wilkins and Stewart (1974) involved the direct manipulation of temporal parameters of stimulus presentation and showed lateralised differences. Participants had to indicate by a key press response whether or not letter names (upper and lower case B, D, G, H, N, Q, R, & T) were the same. A single letter was presented at fixation and was followed after a short (50 ms) or long (990 ms) interval by a second letter in the right or left visual field. Each letter stimulus was presented for 100 ms. Their results showed that for letter pairs with the same name and case, there were fewer errors at short intervals when the second letter in each pair was presented to the left visual field. At long intervals right visual field presentations produced greater accuracy. For letters with the same name and different case, there were no field differences at short intervals, but at long intervals there was a right visual field superiority. This Field x Interval interaction is consistent with temporal integration theory, and particularly Miller's (1996) theory based on axonal conduction time being different in the LH compared to the RH. More specifically, Wilkins and Stewart's findings of a RH advantage at the short (50 ms) interval and a LH advantage at the long (990 ms) interval are in agreement with Miller's hypothesis of a 100 ms cut-off between the two hemispheres.

The LH's ability to discriminate temporal order with non-linguistic stimuli has also been investigated. Mills and Rollman (1980) used a procedure similar to that used by Efron (1963), who had utilised visual and tactile methods to demonstrate that the temporal discrimination of simultaneity and order is performed in the hemisphere which is "dominant" for language. In Efron's study a pair of stimuli (either two light flashes or two shocks), separated by a manipulated time interval, were delivered to the right or left nasal retina or right or left index finger, respectively. They were repeated every 2 s until the participant could determine the sequence, that is, right before left. In Mills and Rollman's study their participants were asked to identify either the order or simultaneity of two clicks when each was presented to a different ear. Their results showed that the threshold for temporal order was smaller when the right ear click preceded the left ear click, compared to the opposite order of presentation.

Other evidence supportive of the above findings has been reported in a review of the literature on hemispheric specialisation by Bradshaw and Nettleton (1981). They noted that clinical studies have shown that persons with LH lesions typically need more time to process order and sequencing irrespective of spatial complexity. The authors also noted that evidence of REAs has been found for non-linguistic tasks using acoustic stimulation, such as identification of rhythmic patterns, dichotically paired rhythmic pure tones, complex tonal sequences with emphasis on temporal transitions, discrimination of duration, short time intervals, and Morse sequences. However, none of the research reviewed above refers to temporal integration theory, which, since its modern origins from Lashley (1937) postulates innate brain organisation for the processing and production of the temporal components in language (Hearnshaw, 1956; Miller, 1996; Norman, 1984).

In the first study to directly link temporal integration theory with hemispheric specialisation Norman (1984) used a lateralised modified version of the PASAT. The standard presentation rates of one digit every 1.2, 1.6, 2.0, and 2.4 s were used. The participants were undergraduate university students and other volunteers who were either persons with a history of schizophrenia or their matched controls. The non-clinical participants showed a significant REA, whereas the clinical participants showed no REA. Another group of normal controls and a group of clinical participants with a history of only depression, did not show any ear advantage either. Both of these participant groups were generally older than the participants with schizophrenia and their respective controls (mean age of 49 vs. 28 years).

Although other studies do not directly refer to temporal integration theory, their manipulation of temporal factors, or results pertaining to such factors, are still very relevant. For example, Heider and Groner (1997) used backward masking in two tachistoscopic experiments in which one involved the lateralised presentation of words, and the other involving faces. In both experiments a target stimulus was presented in one visual field for 30 ms and a mask was presented afterward in the opposite visual field at ISIs of either 15, 45, 75, 105, or 135 ms. The intertrial interval was always 1000 ms. In the first experiment, participants were required to indicate by manual key press whether they saw a word (a "yes" response) in either visual field or another key press (a "no" response) when a non-word was presented in either visual field. In the second experiment the procedures were identical except the stimuli to be discriminated were non-distorted facial images and distorted facial images.

In the first experiment a right visual field advantage was found in terms of accuracy. Heider and Groner (1997) noted that this was despite the very short stimulus duration (30 ms) and the decreased perceptibility due to masking effects. They concluded that these results counter previous claims that short exposures lead to a RH advantage in any case. Yet, the right visual field advantage only arose in one of two masking conditions. That is, it arose when the mask was a scramble of both words and non-words taken from the stimuli set but not when the mask was a uniform black and white noise image. There was no significant interaction between visual field and ISI, which the investigators argue invalidates the hypothesis that processing speed differs in the two hemispheres for the specialised processing of words. However, this could have been due to insufficient statistical power in the study, since the sample size was only n = 5. However, Heider and Groner proposed that the different interactions with mask type supports the assumption of a higher-order processing level for LH processing of lexical stimuli. But they did not consider that this could also mean that the processing times in their first experiment could not be based just on the ISIs between each stimulus and mask. Processing times could instead be a function of stimulus duration and processing, onset of the mask, and possibly even the onset of the next non-mask stimulus. Hence, one could redefine the temporal factors as being more like stimulus onset asynchronies (SOAs) as used in the study by Koivisto (1997), discussed below. In Heider and Groner's study, SOAs could conceivably be calculated as being 30 ms + ISI + 30 ms + ISI. Then temporal values would range from 105 ms to 330 ms. If this were true then the processing times for the right visual field advantages for lexical stimuli may well be above 100 ms which Miller (1996) proposes as a criterion differentiating processing times (axonal conduction time) in the LH versus RH.

Results from Heider and Groner's (1997) second experiment more clearly support the hypothesis of different processing times in each of the hemispheres. They obtained a significant interaction between Visual Field and ISI, and this did not depend on mask type. The masks used were the same noise mask from the first experiment, and a pattern mask consisting of a scramble of both faces and non-faces taken from the stimulus set. It was suggested that faces presented in the LVF escape the masking effect more rapidly than in the RVF, and that this is attributable to the delay resulting from callosal transfer from the LH to the RH. However, they did not consider that because the RH's processing of facial stimuli was less effected by masking stimuli this could simply be due to the RH's ability to process stimuli more rapidly. A visual inspection of their accuracy x ISI data (p. 1117) showed that, in fact, the LVF performance in their second experiment possibly plateaus in the noise mask condition and drops away in the pattern mask condition, with both of these occuring at the 105 ms ISI. If this is true, then again this observation, at around the 100 ms cut-off, supports Miller's (1996) argument regarding the different processing times (based on axonal conduction time) of each hemisphere.

Another study, which could also be interpreted in terms of temporal integration theory, was conducted by Koivisto (1997). In this study, which investigated the hemispheric processing of words, participants were required to press one of two keys to indicate whether a target stimulus was either a real word or a non-word following a primer stimulus which was always a real word. The duration of stimulus presentation for the target was always 180 ms and for the prime 150 ms. The target followed the prime to the LVF or RVF either after a 15, 100, 350, or 600 ms ISI. The investigator also redefined these temporal parameters in terms of stimulus onset asynchronies (SOAs). That is, a SOA represents the time period which begins from the onset of the prime stimulus to the onset of the target, and so gives temporal values that are simply the combination of the prime's stimulus duration (150 ms) and the manipulated ISI. In Koivisto's study, this gave SOAs of 165, 250, 500, and 750 ms. What Koivisto found was that for pairs of non-associated but categorically related words (e.g., *car* and *ship*), with one being presented in the same visual field as the other, a significant priming effect was observed in the RVF but not the LVF at the 165 ms SOA. There were no effects for the intermediate 250 and 500 ms SOAs. However, at the 750 ms SOA a significant priming effect was found with the LVF. Koivisto argued that these results suggest that, instead of the two hemispheres being differentiated in terms of their processing of syntactic versus connotative language, it is the time course of semantic activation that may be different in the RH and LH.

On the one hand, Koivisto's (1997) findings with regard to the right visual field advantage at the 165 ms SOA is in agreement with Miller's (1996) temporal integration theory. On the other hand, however, Koivisto's latter finding with regard to the left visual field advantage at the slower 750 ms SOA appears not to be, at least at first glance. A possible explanation is that at the slower SOAs other intermediary stages of processing (e.g., finding and associating visual imagery with the word stimuli) have greater chance of being included and involve the RH more than the LH. In turn, it is possible that the slower SOAs used by Koivisto were not sufficiently fast to exclude additional stages of processing, which means he may have prematurely dismissed the depth of activation by the RH for language processing. Also, had he been aware of temporal integration theory he may have then included SOAs faster than 100 ms, which might have then yielded an left visual field advantage due to actual faster processing.

The above reviewed studies provide substantial evidence of the LH's specialisation for the processing of temporal information. In particular, the evidence shows that the LH is more proficient for processing information presented with longer intervals and the RH for shorter intervals. The LH specialisation for delayed processing is important so that temporal associations between separate incoming and partially processed units can be maintained. Otherwise, in the case of spoken communication, for example, overall meaning from groups of units of information would be lost.

All of the studies reviewed above included only adult participants. There is also research into developmental phases which suggests that the differences between the LH and RH for temporal processing are developed through childhood. Some of this evidence is presented next.

Developmental Phases of Human Capacity For Temporal Processing

Simos and Molfese (1997) used auditory evoked responses (AERs) to investigate the discrimination of temporal order differences in four-day old infants. The AER is a portion of an EEG that is temporally synchronised to the onset of an auditory stimulus. Temporal lags of 0, 20, 40 and 60 ms were used to separate pairings of two-tone non-speech stimuli presented via a single speaker centered above the infant's head. The investigators report that there was an abrupt reduction in peak amplitude of AERs when temporal lags changed from 20 to 40 ms. The changes in AER were found via electrodes attached at the parietal regions of both hemispheres, but not at other regions. The infants showed only minimal response when temporal lags changed from 0 to 20 ms or 40 to 60 ms. It is also reported that the pattern in voltage changes shown by the infants was very similar to that found in pre-school children in previous studies they had conducted using the exact same procedures. They also note that the pattern differs from that previously found for adults. That is, for adults, abrupt reduction in peak amplitude of AERs were found when temporal lags changed from 40 to 60 ms, and were mostly located at the right parietal regions. These findings of right hemisphere superiority for temporal lag discrimination in adults may at first seem contrary to that generally hypothesised about the left hemisphere's superiority for temporal processing. However, the temporal parameters in these studies of electrophysiological responses fall below the 100 ms criterion that Miller (1996) proposes to distinguish the right and left hemisphere's axonal conduction time for processing.

Simos and Molfese (1997) state that the evidence from infant AERs suggests an innate basis to the neural operations necessary for temporal order discrimination. They also propose that the lack of hemispheric differences in infants suggests that lateralised specialisation for such discrimination is developed through childhood.

Further evidence to support the idea that lateralised specialisation for temporal processing is developed through childhood comes from an auditory dichotic study by Bryson, Mononen, and Yu (1980). They also showed how important temporal factors are in the processing of language- related stimuli. They demonstrated the lateralisation of speech processing to the LH in Taiwanese children as young as 4 years of age. A REA was found with the dichotic presentation of single, double, and triple Chinese digit pairs. The results show that the side of laterality (LH) for speech processing in children is the same regardless of cultural and linguistic background. Furthermore, they report a differential finding of a REA for 4-year old males with self-paced intertrial intervals (ITIs) (Experiment 2) but not for a standard 5 s ITI procedure (Experiment 1). Female participants at this same young age level showed the REA across both procedural conditions. The results were interpreted as demonstrating a mismatch between the development of speech processing in children and research procedural constraints (e.g., 5 s ITI as used in adult studies) which disguise evidence of laterality.

The above findings by Bryson et al. (1980) can also be understood in terms of the integration of information over time. That is, the necessity to use self-paced ITIs to demonstrate a REA for 4-year old males suggests that while these participants showed they could adequately process the information, they required less temporal constraints in order to do so. This finding suggests that the processing of more complex speech material (e.g., sequential semantic stimulus presentation) requires the development of the capacity to temporally integrate verbal information, which in turn depends on the development of the LH. The marked growth spurt that the LH has from age 3 to 6 years (Thatcher et al., 1987) supports this view.

The LH's specialisation for the processing of temporal information concurs with the idea of innate brain organisation for temporal integration, as initially proposed by Lashley (1937). The studies reviewed above (Simos and Molfese, 1997; Bryson et al., 1980), demonstrate how the lateralisation of brain functions is developed throughout childhood. Muller et al. (1999) have shown that the normal asymmetry for some language functions is reversed in cases of early childhood lesions. Other studies of persons with unilateral brain damage also indicate that the LH is more effected than the RH for processing temporal information, such as, temporal order and sequencing (Bradshaw & Nettleton, 1981). The following section presents some recent evidence on the effects of temporal lobe removal and of lesions on the processing of rhythmic patterns and semantic fluency, respectively. Both the processing of rhythm and semantic fluency are considered to be LH specialist functions.

Recent Research On Left Hemisphere Brain Injury and Temporal Processing

Penhume, Zatorre, and Feindel (1999) found evidence of poorer performance on certain tasks by persons with right as opposed to left anterior temporal lobe removal due to intractable epilepsy. These tasks required the perception and retention of rhythmic patterns. At first sight these results may seem surprising because of the general belief that the LH is superior for the processing and reproduction of the temporal patterns in rhythms (Gordon, 1978; Prior et al., 1990; Robinson & Solomon, 1974). Penhume et al.'s (1999) experiment required participants to imitate 16 different randomly presented rhythmic sequences. Each sequence contained 6-element rhythmic patterns, composed of short (250 ms) and long (750 ms) elements separated by a constant 250 ms ITI. The auditory elements were 3000 Hz tones with 5 ms rise and fall times delivered binaurally via headphones.

The poorer performance by persons with right as opposed to left anterior temporal lobe removal, however, was selectively highlighted from a background of different scoring methods which gave conflicting results. An “iterative” method derived a median cut-point between the short and long responses based on overall percentage correct across all sequences. Using this method Penhume et al. (1999) found, in fact, that participants with left anterior temporal lobe removal showed overall poorer performance for the auditory sequences. The other (“SD”) scoring method used an averaging of participant responses plus the standard deviation (SD) to determine correct short responses (< Average/short + 1.5 SD) and correct long responses (> Average/long + 1.5 SD). This second method created a greater number of “ambiguous” responses not included in the analyses; this was particularly the case for the participants with right anterior temporal lobe removal whom the investigators report as showing the overall poorer performance. Consequently, it is not clear whether these results dispute previous findings of a LH superiority for processing and reproducing the temporal patterns in rhythm.

However, a study by Troyer, Moscovitch, Winocur, Alexander, and Stuss (1998) of persons with focal frontal lobe or unilateral temporal lobe lesions, found evidence contrary to that reported by Penhume et al. (1999), but consistent with the argument of LH superiority for temporal processing. Troyer et al. (1998) used a phonemic fluency test (participants are asked to generate words beginning with a specific letter) and a semantic fluency test (participants are asked to generate words belonging to a semantic category, such as *animals*). Although these tests do not directly manipulate temporal factors, they do mimic the sequential nature of speech production. The dependent measures were number of clusters (which are groupings of successively correct words), number of switches (which are the transitions between clusters), and total number of correctly generated words. Participants with left-dorsolateral or superior-medial frontal lobe lesions switched less frequently but produced normal cluster sizes on both fluency tests. On phonemic fluency, the participants with temporal lobe lesions were unimpaired on both switching and clustering. However, on semantic fluency a lateralised effect was demonstrated in that participants with left temporal lobe lesions produced smaller clusters than participants with right temporal lobe lesions. Hence, the poorer performance by the participants with left temporal lobe lesions is again indicative of LH specialisation for language-related processing of a temporal nature.

Troyer et al.'s (1998) results are also consistent with the findings from another recent study by Elfgren and Risberg (1998). In this study the participants were 20 healthy right-handed university students. The tests used were a design fluency test (DFT) and a verbal fluency test (VFT). In the DFT participants are asked to invent as many and as different designs as possible. The designs were not allowed to represent actual objects or nameable abstract forms. The test score was the total number of novel 'correct' designs made in 8 mins. The VFT was the same phonemic test as used by Troyer et al. (1998), but of 8 mins duration to match the DFT. Regional cerebral blood flow (rCBF) was the main dependent measure. During the DFT, significant flow changes were observed in both frontal lobes compared to baseline. For the VFT, the rCBF suggested significantly more activity in the LH prefrontal cortex.

Elfgren and Risberg (1998) also argue that differences in cognitive strategy (internally driven responses) affected some of the lateralised observations of rCBF. The participants' own reports were used to obtain information about the cognitive strategy they used when doing the two fluency tasks. Participants were divided into one subgroup with a "pure" verbal memory strategy and another with a mixed verbal and visual search strategy. The participants who reported using a verbal strategy during the VFT showed statistically significant flow increases in the left dorsolateral prefrontal cortex extending into inferior parts of the left orbital areas. However, participants who reported using the mixed strategy showed no significant flow increases. Elfgren and Risberg further noted that the mixed strategy group produced significantly fewer words than the pure verbal group, indicating that the mixed strategy resulted in less efficient performance.

Overall, these results indicate that when persons with no brain pathology produce fluent verbal responses it is their LH rather than the right that appears to be the more active. Brain pathology affecting the LH more than the RH disrupts these fundamental temporal processes.

Summary

The preponderant evidence on the LH's specialisation for the processing of temporal information comes from a range of studies covering developmental, neurophysiological, and normal and abnormal psychological functioning.

The developmental evidence begins with the findings by Bryson et al. (1980) of the necessity to remove temporal constraints (5 s ITI) to demonstrate a REA for the processing of dichotically presented digits in 4-year old male children (Bryson et al., 1980). This concurs with physiological evidence that suggests specialisation for temporal processing is dependent on a marked growth spurt of the LH from age 3 to 6 years (Thatcher et al., 1987). Simos and Molfese (1997) also found evidence to show that the lateralisation of temporal lag discrimination is absent in early childhood, but demonstrable in adults. The RH advantage reported by Simos and Molfese is for temporal lag changes from 40 to 60 ms; which is consistent with Miller's (1996) hypothesis of an approximate 100 ms criterion that distinguishes the RH ability for rapid processing and the LH proficiency for delayed processing.

In adults without any brain disorder, the LH specialisation for temporal processing has been demonstrated with discrimination of temporal order (Efron, 1963; Leek & Brandt, 1983; Mills & Rollman, 1980); the processing and reproduction of rhythms (Gordon, 1978; Prior et al., 1990; Robinson & Solomon, 1974); letter or word recognition (Koivisto, 1997; Wilkins & Stewart, 1974); and with regional cerebral blood flow during a verbal fluency test (Elfgren & Risberg, 1998).

Commissurotomy studies demonstrate that the RH is capable of some verbal processing (Sperry, 1982). Penhume et al. (1999) reported that persons with right as opposed to left anterior temporal lobe removal had poorer performance on a task requiring imitation of rhythmic sequences; but the reverse was found with a different method of scoring participant performance. However, the study by Troyer et al. (1998) found that participants with left as opposed to right temporal lobe lesions had poorer performance on a test of semantic fluency; their findings are consistent with the evidence for normals reported in the review above, and prior reviews on the effects of brain damage (e.g., see Bradshaw & Nettleton, 1981).

In those studies reviewed and which directly manipulated temporal parameters, such as ISIs, ITIs or SOAs, most of the evidence is consistent with Miller's (1996) argument for there being a 100 ms criterion that distinguishes the RH ability for rapid processing and the LH proficiency for delayed processing. It is the ability to delay processing which makes the LH proficient in responding to the temporal, particularly sequential, factors that underlie linguistic communication.

It is this ability to delay processing that distinguishes temporal integration from rapid or simultaneous integration.

Miller's (1996) psychobiological theory is an extension of the temporal integration theory originated by Lashley (1937) who argued that temporal integration relies on innate brain organisation. There is now evidence from neuronal studies that inhibitory interneurons have a temporal function in the hippocampus by governing the precise timing of individual principal cell discharges in relation to an entire interconnected cell assembly (Freund, 1997). So at the neuronal level there is some evidence to support Lashley's theory. Miller bases his theory on the LH having a higher proportion of slow-conducting axones and the RH fast-conducting axones, which in turn provide the basis for the higher proportion of gray to white matter in the LH. Hence, Miller makes a direct association between the neuronal and behavioural levels of function.

As the above review shows, there is evidence from the behavioural level in lateralisation research which is consistent with temporal integration theory. The present research uses a test (the PASAT) actually developed out of temporal integration theory and modified for lateralised presentation to further examine the efficacy of the theory. The principal hypothesis is that due to the sequential nature of the PASAT, a REA (LH) will be observed for normal participants. This hypothesis is also examined with regard to dysfunctional hemispheric processing in schizophrenia.

There is now a lot of evidence of dysfunctional hemispheric processing in schizophrenia. Much of this evidence shows abnormal processing by the LH for temporal information. That is, many studies show a REA found for normal participants is in fact absent or reversed for participants with schizophrenia. Other findings have begun to indicate that the LH can not be attributed with having the full responsibility of dysfunctional hemispheric processing. Instead, some of these findings suggest involvement of a dysfunctional RH affecting attention, and so not just LH difficulties in temporal processing as the basis for cognitive difficulties. Hence, the principal hypothesis of expecting a REA for normal participants will be evaluated within the context of lateralisation research on schizophrenia, which is reviewed next.

Dysfunction of Hemispheric Processing in Schizophrenia

This section begins with a general background on schizophrenia and its related language disorders. It then specifically reviews the neuropsychological, neurophysiological, and neuroanatomical knowledge to date on problematic hemispheric processing in schizophrenia, purportedly due to either left hemisphere or right hemisphere dysfunction, or failure in interhemispheric (callosal) transfer. Evidence of difficulties in temporal processing in schizophrenia is also presented, although only a few of these studies have directly examined hemispheric specialisation.

Schizophrenia and Language Disorder.

The characteristic symptoms of schizophrenia have been conceptualised as falling into two broad categories, namely, positive and negative (Andreasen & Olsen, 1982 ; Mortimer, Lund, & McKenna, 1990). Positive symptoms reflect an excess, or distortion, in normal functions, whereas negative symptoms reflect a loss of normal functions. The positive symptoms include distortions or exaggerations of inferential thinking (delusions), of perception (sensory hallucinations), of language and communication (disorganised speech), and behavioural monitoring (grossly disorganised or catatonic behaviour). Negative symptoms include restrictions in the range and intensity of emotional expression (affective flattening), in the fluency and productivity of thought and speech (alogia), and in the initiation of goal-directed behaviour (avolition) (American Psychiatric Association, 1994).

While delusions are thoughts with unusual content (e.g., paranoid suspiciousness), formal thought disorders are specific disturbances in the form rather than the content of what is expressed. Examples of thought form disorder are: giving answers that do not follow the questions asked (nonsequetive responding), going off at a tangent from that being discussed (tangentialism), the coining of new meaningless words (neologisms), making rapid nonsense statements (drivelling), habitual insertion of wrong words (paraphasias), and uncontrollable racing thoughts (flight of ideas). Although none of these thought form disorders are manifested in only one specific condition of mental illness, all but flight of ideas are still more prevalent in schizophrenic illness (Jampala, Taylor, & Abrams, 1989).

Thought form disorders are disturbances in the use of language but are not speech errors like that seen in aphasia (Jampala et al., 1989; Frith, 1992). In fact, persons with schizophrenia generally appear to use syntactic rules appropriately and their speech errors are similar to those made by persons without schizophrenia (Schwartz, 1982). In a study of linguistic performance in childhood (age 11 years) of persons who later manifested schizophrenia, Done, Leinonen, Crow, and Sacker (1998) found that these persons did not differ from normal controls on any of the measures of syntactic production, grammatical errors, or spelling. Here again, the evidence indicates that the thought form disorders in schizophrenia are problems of thought generation and organisation rather than related to a specific premorbid language deficit. This, of course, does not preclude there being other cases in which a generalised deficit in intellectual function (IQ) can predate the onset of schizophrenia. Intellectual problems in childhood may suggest a neurodevelopmental aetiology in some cases of schizophrenia. However, a longitudinal (20 years) follow-up study of IQ assessments in childhood and in adulthood after the onset of schizophrenia, showed no worsening of intellectual function (Russell, Munro, Jones, Hemsley, & Murray, 1997). The participants in this study also demonstrated no change in the relative difference between verbal and performance subtest measures. Russell et al. concluded that the stable impairment in general intellectual functioning contrasts with the effects manifested as psychosis.

The notion that the thought form disorders in schizophrenia may instead represent underlying problems in information processing has been explored by Knight and Sims-Knight (1979). Participants were presented with interrelated parts (sentences) of a complex idea and were subsequently tested for their memory of new and old (previously seen) instances of these ideas. It was found that, unlike controls, some of the participants with schizophrenia failed to integrate ideas from simple sentences into more complex sentences. This was particularly so for participants with a chronic history of schizophrenia. Knight and Sims-Knight also noted, as has Frith (1992), that previous studies have found that persons with schizophrenia have adequate recognition memory for words and intact lexical storage. Therefore, they concluded that their results indicated problems in integration rather than difficulties with memory.

Other evidence of the difficulty persons with schizophrenia have in integrating thoughts prior to speech comes from two case studies by Satel and Sledge (1989), in which they used audiotape playback as an external aid for thought organisation. Both cases were reported to have sustained language disturbance in the absence of continued active psychosis. Following audio tape playback therapy, Case A demonstrated a striking development in a sense of herself as a person perceived by other persons, whereas Case B described his thought disorder as the need for delay before he could respond to a question, or take action. He said his speech was produced at a much slower rate relative to the speed of his thoughts and he worried that he would lose information. With the help of audio tape playback, he was able to directly address discrepancies in flow and coherence and was able to make his thought productions more meaningful.

Overall, the evidence indicates that although persons with schizophrenia typically manifest disordered verbal communication, the underlying problems are more to do with deficits in the generation and integration of thoughts rather than speech or memory problems. Other evidence of information processing deficits, or failure to integrate information, in schizophrenia comes from research into hemispheric dysfunction, which is covered next.

Hemispheric Dysfunction in Schizophrenia

Asymmetric brain dysfunction in psychopathology was first noted in persons suffering from left-sided lesions who tended to have associated schizophrenic-like symptoms, whereas those persons suffering from right-sided lesions tended to have associated affective disorder symptoms. Similarly, Flor- Henry's (1969) investigation of persons with temporal lobe epilepsy found that those with schizophrenic-like psychotic disturbance compared with those without, showed a greater incidence of a LH focus for their epilepsy. Flor- Henry's investigation further showed a greater incidence of RH focus for epilepsy in persons who manifested affective bipolar-type psychotic reactions. Thus, the notion that schizophrenic symptoms might be related to asymmetric

(left) brain dysfunction was primarily derived from these clinical observations of epilepsy.

Walker and McGuire (1982), in their review of the research on hemispheric information processing in schizophrenia, proposed that the most comprehensive explanation for the disorder would presume left hemisphere overactivation. Their evidence for this explanation they argue is an exaggerated right ear advantage (REA). However, the type of tasks they cite to demonstrate the exaggerated REA actually involved word comprehension, or discrimination of which ear received stimulus input. With regard to word comprehension, this type of task would now be considered to just as likely fall within the normal RH's specialisation for connotative meaning rather than only the normal LH's specialisation for syntax and fluency. Hence, the exaggerated REA reported for participants with schizophrenia could reflect the reversal or failure of normal lateralisation rather than necessarily an over activation of a normally lateralised LH function (Crow, Done, & Sacker, 1995).

Walker and McGuire (1982) report their own study and only one other (Gruzelier & Hammond, 1980) with regard to citing discrimination tasks to support their view of exaggerated REAs. In Walker and McGuire's study, participants were presented with strings of three digits dichotically, and after each trial they were required to report either right or left ear input. There was no difference in overall accuracy between the clinical participants with schizophrenia and their normal controls. However, clinical participants showed more left ear intrusions; that is, they more frequently reported right ear input when the left ear was stimulated. Hence, the more frequent and inaccurate reports of right ear inputs were taken to represent over activation of the LH. An alternative interpretation could, however, be that the failure to discriminate many left ear inputs represents difficulty in attention to the left sensory field. In terms of hemispheric processing, this could indicate dysfunction in the RH as opposed to the LH. There is evidence from persons with unilateral brain injury to support this alternative interpretation. For example, Pardo, Fox, and Raichle (1991) report that in cases of right as opposed to left frontal lobe injury there is greater impairment in the ability to effectively use priming cues. Pardo et al. further report that studies of normal persons, which have used PET to measure regional cerebral blood flow (rCBF), have shown increased activation in the right, but not the left, frontal lobe when participants are required to sustain attention.

In the study by Gruzelier and Hammond (1980), two three-digit strings were presented simultaneously to the ears. In one part of the study, digits were presented at the same loudness to each ear. There were no differences between the clinical participants with schizophrenia and their controls in overall accuracy, and both groups showed a similar REA. In the second part of the study, the stimulus to one ear was louder and the opposite ear received a cue. In this condition ipsilateral ear performance improved for all participants, but the clinical participants performed more poorly when the right ear input was louder and the left ear was cued. These findings were again interpreted to represent overactivation of the LH; that is, the louder right ear stimulus was assumed to instigate overreaction of the LH. However, another explanation could be that the clinical participants had even greater difficulty with attending to the left sensory field when the left ear stimulus was quieter than the right ear stimulus, and had no decrement in performance when the left ear was louder, because loudness assisted attention.

Walker and McGuire's (1982) dismissal of the LH dysfunction hypothesis was therefore premature. They did not adequately account for the consistency amongst haptic, dichotic, and hemiretinal studies (Connolly, Gruzelier, Kleinman, & Hirsch, 1979; Eaton, 1979; Gruzelier &

Hammond, 1979; Hillsberg, 1979; Kugler & Henley, 1979) which show that persons with schizophrenia, in comparison to normal controls and other clinical participants without schizophrenia, are slower in processing stimuli directed to the left hemisphere.

Other studies have also found evidence that does not support Walker and McGuire's (1982) hypothesis of LH overactivation. Colbourn and Lishman (1979) used a dichotically presented consonant-vowel syllable identification task, and showed a LH advantage (REA) for participants with affective bipolar disorder, clinical participants with no history of psychosis, and normal controls. The participants who had schizophrenia did not show a REA. Colburn and Lishman found that there was no evidence of a deficiency in callosal transmission since the left ear performance did not differ between the groups. A second dichotic listening task, tone-contour identification, showed an expected LEA for all the participants.

Bruder et al.(1995) used a dichotically presented task in which participants had to distinguish between fused pairs of rhyming words; that is, word pairs in which each member of every pair differed from the other only in the initial consonant (e.g., *coat, goat*). The word pairs were presented dichotically and fused as a single auditory image. Participants indicated what they heard by marking a prepared answer sheet that had four choices: both members of the dichotic pair and two other words which again only differed by the first consonant. Bruder et al. were able to replicate the findings of Wexler, Giller, and Southwick (1991), in which participants with schizophrenia showed a smaller REA. Bruder et al. also showed that participants with depression and no psychosis had a normal REA, and that hallucinatory behaviour was the positive symptom most strongly associated with the smaller REA in the participants with schizophrenia.

Another study possibly supportive of the LH dysfunction hypothesis was conducted by

Bustillo et al. (1997). They used Posner et al.'s (1988) cued reaction time task. Participants were required to visually detect a stimulus target (an asterisk). With participants focused on a central fixation point, a cue was presented either centrally or peripherally. The cue either correctly indicated the side at which the target would appear (valid), or oriented the participant to the opposite side (invalid), or gave no information regarding where the target appeared (neutral). The interval (ISI) between cue and target for each trial was 100, 200, or 800 ms. The participants were persons with enduring negative symptoms of schizophrenia (deficit group), persons with positive but not negative symptoms of schizophrenia (non-deficit), and normal controls. The deficit group showed an overall slower reaction time compared to the other groups and no clear abnormal asymmetry. However, the non-deficit group showed a significant asymmetry in reaction time to visual targets (right visual field slower than left visual field). This finding held regardless of whether the cue was central or peripheral, or whether it provided valid, invalid, or neutral spatial information. What is notable about these results is that this asymmetry occurred only at the100 ms ISI and not the two longer intervals. Bustillo et al. interpreted these results as being due to slower processing in the left hemisphere. They dismissed an explanation based on abnormal covert attention, since performance was not affected by the invalid cues. Posner et al. (1988) had also found that participants with schizophrenia showed the same asymmetry as above for right visual field targets but when the cue was invalid, and as a result assumed slowness of the left hemisphere. Normal participants did not show this same pattern of responding.

Bustillo et al. (1997) were probably unaware of temporal integration theory and so did not refer to Miller's (1996) theory on differences between the hemispheres in axonal conduction time. However, the findings at the 100 ms ISI only, seem to conform with Miller's theory. That is, the 100 ms ISI is equal to the cut-off point in Miller's theory, and so shorter ISIs may have been necessary to demonstrate a left visual field advantage for the normal controls. By taking into account the 100 ms cut-off, the faster left (RH) as opposed to the slower right visual field (LH) processing by the non-deficit clinical group could instead be interpreted as indicating at least some RH attentional proficiency by these participants. The fact that this group was distinguished for not having negative symptoms of schizophrenia may further support this alternative interpretation.

There have been no studies, other than Norman (1984), which have specifically researched hemispheric specialisation and temporal integration in schizophrenia. In Norman's study the effect of stimulus presentation rate on performance was examined. However, some prior studies have also found interesting results based on the rate of stimulus presentation. In the study by Baribeau-Braun, Picton, and Gosselin (1983) participants (20 with schizophrenia and 20 normal controls) had to detect occasional targets among tones in one ear and ignore all tones presented to the other ear. It was found that despite slow and inaccurate detections, the participants with schizophrenia were able to attend selectively to each ear but only at fast stimulation rates (ISIs ranging from 250 to 750 ms). The investigators also reported that the participants with schizophrenia showed marked deficits at slower presentation rates (ISIs ranging from 500 to 1500 ms) and during divided attention (where participants had to attend and detect all targets in both ears at once). They interpreted these results as indicating that the problem is the control and maintenance of a processing strategy rather than of general slowness or a deficiency in selective attention.

Gruzelier and Hammond (1979) also reported evidence pertaining to presentation rate. In this study, participants with schizophrenia were required to discriminate longer target tones (300, 200 or 150 ms) from shorter tones (100 ms), both at 1000 Hz. The tones were presented monaurally and were switched from ear to ear. There were two rates of switching defined in terms of the probability of a given tone being presented to the ear opposite to the previous ear of presentation. The probability was either 0.3 or 0.7, and the switching rate occurred in separate trial blocks. Fifty target tones were presented in each block, 25 per ear, with the restriction that no target tone occurred within 3 s of another target. It was found that right ear performance improved with increasing dosage of treatment with the neuroleptic, chlorpromazine. In the absence of medication, the participants showed a worsening of right ear (LH) discriminations. However, participants did not show any problems in switching their attention from ear to ear. Gruzelier and Hammond suggested that these results show the problem of response selection or organisation in schizophrenia is due to the later stages of information processing.

Norman (1984) appears to be the first and only researcher to date to directly address the issues of hemispheric specialisation and temporal integration. The PASAT was used in this study and was essentially unmodified except for it being lateralised. On this test, participants with schizophrenia showed no asymmetry, whereas normal controls and other normal participants (undergraduate university students) manifested a REA. Another older group of clinical participants, who had depression but not schizophrenia did not show any ear advantage.

Overall, the above review of neuropsychological research is more supportive of a LH dysfunction hypothesis than for an overactivation hypothesis for schizophrenia. Further evidence for a LH dysfunction hypothesis has emerged from neurophysiological and neuroanatomical research which is reviewed in the following section.

Neurophysiological and Neuroanatomical Evidence of Hemispheric Dysfunction in Schizophrenia.

Flor Henry (1976) recorded EEGs while participants with either schizophrenia, affective bipolar disorder, or who were normal controls responded to verbal and visuospatial tasks. For the participants with schizophrenia he found greater abnormality in the left temporal region, while the activity in the right temporal region did not differ from that found for the normal controls. The participants with bipolar disorder showed more abnormality than the controls in both temporal regions, with the right side showing greater abnormality than the left.

Abrams and Taylor (1979) found similar evidence of lateralised abnormalities using EEG. Their participants with psychotic-affective disorder had EEG abnormalities in the parieto-occipital region, whereas participants with schizophrenia again showed greater abnormalities in the left but not right temporal lobe region. The investigators also noted that the major abnormality for the participants with schizophrenia was EEG activity of lower frequency. Coger, Dymond, and Serafetinides (1979) also found lateralised abnormal EEGs when they compared participants with non-paranoid chronic schizophrenia with participants with a history of alcoholism only, and with normal controls. For both clinical groups, but not the controls, they found greater abnormality in the left frontotemporal area. Abnormality in the right frontotemporal and bilateral bands was observed only for the participants with alcoholism.

Cerebral regional blood flow (rCBF) and glucose metabolism studies have also demonstrated findings that are different for persons with schizophrenia compared to persons without the illness. Mathew et al.(1981) reported that their six participants, who each had schizophrenia, showed lower mean rCBF values for gray matter compared to normal controls, for the RH only. These results suggested reduced neuronal metabolism in the RH compared to the LH.

However, a later two-part study by Gur and his colleagues (Gur, Resnick, Alavi, et al.,1987; Gur, Resnick, Gur, et al.,1987) found evidence which indicated abnormally increased metabolism in the LH. Cerebral glucose metabolism was measured using PET. In the first part of their study, 12 non-medicated participants with schizophrenia had lower metabolism, cortically and subcortically, and a steeper subcortical to cortical gradient, than did the 12 normal controls. Yet within the clinical participant group, those with symptoms of greater clinical severity had higher absolute metabolism and higher LH relative to RH metabolism compared to participants with less severe clinical symptoms. There was no evidence of hypofrontality. In the second part of the study, run 33 weeks later, a majority of the same clinical participants were receiving neuroleptic medication. Changes toward higher RH relative to LH metabolism were correlated with clinical improvement.

Initial neuroanatomical evidence of schizophrenia pertains to larger ventricular size (Katsanis & Iacono, 1989; Keefe et al.,1987; Seidman, Sokolove, McElroy, Knapp, & Sabin, 1987), which in turn suggests either loss of brain tissue or a failure of development. Until the existence of computerised tomography (CT) and magnetic resonance imaging (MRI), neuroanatomical research to determine brain structural pathology could only be done as post-mortem studies. In comparison with CT, MRI provides finer spatial resolution and a greater ability to discern subtle differences in tissue composition.

Suddath et al. (1989) used MRI to examine the relative gray and white matter volumes in 17 participants with schizophrenia compared to normal controls. There were no differences found between the clinical and control participants when they examined prefrontal regions, and nor for white matter overall. However, they found smaller mean volume for gray matter in both the right (18%) and left (21%) temporal lobe for the clinical group compared to the controls. The smaller gray matter volume was most pronounced in the central section of the temporal lobe, which contains the anterior hippocampus and the amygdala.

Maher, Manschreck, Yurgelun-Todd, and Tsuang (1998) conducted a similar MRI study of 16 persons with schizophrenia and found a lack of the normal asymmetry (larger LH than RH) for gray matter in the frontal and temporal areas of the brain, but not for the corpus striatum, ventral pallidum, lateral ventricles, or the temporal horns. These findings of a lack of the normal asymmetric enlargement in the LH are supportive of Crow's hypothesis that in schizophrenia there is a disturbance in the development of the normal processes of hemispheric lateralisation (Crow et al., 1995).

Miller (1996) argues that in the normally developed brain, gray matter has a greater proportion of thinner, unmyelinated axons which facilitate delay in axonal conduction time. It has been argued in previous sections that delay in conduction time is important for temporal integration. So deficient gray matter in the LH, as reported in the above reviewed studies, would have important implications for temporal integration in persons with schizophrenia. Deicken, Zhou, Corwin, Vinogradov, and Weiner (1997) provide further evidence which shows that the deficiency in gray matter in the left frontal lobe is primarily due to decreased neuronal and axonal density but not glial cell loss. They measured the presence of N-acetylaspartate, an amino acid and a putative marker for differentiating neurons and axons from glial cells, in 24 participants with schizophrenia and 15 healthy comparison participants. Deicken et al. report that the measurement of N-acetylaspartate by proton magnetic resonance spectroscopic imaging is more sensitive than

MRI. No abnormalities were noted on MRI images for both participant groups. However, N-acetlyaspartate was significantly lower in the left frontal region of the participants with schizophrenia compared to the healthy participants, which indicated a deficiency of important neurons and axons.

The functional relationship between language-related processing and the comparative differences in lateralised temporal cortex for persons with schizophrenia and persons without has been demonstrated in another MRI study(Woodruff et al.,1997). Fifteen clinical participants with schizophrenia and eight normal controls were involved in listening to speech during MRI examination. It was found that the controls showed greater response in the left rather than right temporal cortex, whereas this finding was reversed in the participants with schizophrenia. Woodruff et al. also found that during periods of intense auditory hallucinations, there was reduced activity in the right middle temporal gyrus of the clinical participants. They interpreted this as not only indicating the reversal of normal lateralisation but also suggestive of competition between auditory hallucinations and the processing of speech for common neurophysiological resources.

Zaidel, Esiri, and Harrison (1997) have found post-mortem evidence which further demonstrates the neuroanatomical differences in the temporal cortex in people with and without a history of schizophrenia. They found differences in neuronal size and shape predominantly in the left hippocampus of the persons who had a history of schizophrenia (n = 14) compared to those persons who had no such history (n = 17). In the persons without schizophrenia there were larger and longer neurons and greater variability of neuronal orientation in the left compared to the right hippocampus.

The above review shows that from both neurophysiological and neuroanatomical viewpoints the research evidence strongly indicates differences in lateralisation between persons with and persons without a history of schizophrenia. Quite recent evidence indicates specific differences in the left as opposed to the right fronto-temporal cortex, which has been identified as being particularly important for the processing of speech and the regulation of pre-speech thinking.

The Right Hemisphere in Schizophrenia

With regard to the RH, Cutting (1992, 1994) has proposed that this hemisphere has been underestimated in terms of its possible dysfunction and relevance to schizophrenia. However, the similarities between RH brain damage and schizophrenia, in terms of language functions, are generally to do with problems in the connotative processes of language and over inclusion of information. Crow (1998), in his bi-hemisphere theory of language, refers to these connotative aspects as being paradigmatic, each component of a sentence might be substituted by a member of the same class, as opposed to the syntagmatic structure, the organisation of the elements within the sentence. Indeed, there is some evidence from a study by Weisbrod, Maher, Harig, Himmelsbach, and Spitzer (1998) to support Cutting's (1992, 1994) and Crow's points of view. In this study, normal controls, on a task involving remote word associations (indirect semantic priming) indicated a RH advantage. In comparison, participants with schizophrenia, and particularly thought disorder, showed a LH advantage. Weisbrod et al. interpreted these results as representing a reversal of the normal organisation of functional asymmetry.

The study by St George et al. (1999) also provides evidence in support of Crow's distinction between the paradigmatic and syntagmatic structure of language being specialist functions of the normal RH and LH, respectively. In this study, MRI showed greater activation of the middle temporal sulcus of the RH when normal participants read untitled paragraphs. The reverse was found for the reading of titled paragraphs. This finding suggests that with titled paragraphs participants needed to be less concerned about deducing overall meaning and could instead get on with the syntagmatic process of semantic output.

Another specialist function that has been attributed to the RH is that of managing attention (Pardo et al., 1991). Hence, it was argued in earlier sections that some of the evidence put forth by Walker and McGuire (1982), to support the LH overactivation hypothesis of schizophrenia, could instead be interpreted to indicate problems in the RH and of attention. The findings by Bustillo et al. (1997) were also reinterpreted as possibly reflecting some level of proficient attention in persons with positive but not negative symptoms of schizophrenia. It was Posner et al. (1988) who had developed the cued reaction time task (described earlier) to assess visual field orienting. They found a lateralised abnormality in reaction time for participants with schizophrenia; that is, longer reaction times to targets in the right visual field (LH) after attention was cued in the left visual field (RH). They interpreted this finding as indicating that participants with schizophrenia have difficulty in directing their attention to the right visual field due to slowness of the LH. Wigal, Swanson, and Potkin (1997) replicated the above finding of an asymmetric deficit in reaction time with participants who had schizophrenia and were medication free. Wigal et al. similarly interpreted their findings in terms of slowness of the LH.

Summary

The evidence from neuropsychological, neurophysiological and neuroanatomical research, in relation to schizophrenia, generally indicates dysfunction rather than overactivation of the LH. Recent research, with better neuroanatomical specificity via MRI, indicates that neuronal systems in the left fronto-temporal cortex may be particularly important for the sequential organisation of communicative language. Some of this evidence also suggests that in schizophrenia there is either a reversal or lack of development of the normal lateralisation of brain organisation. It is therefore hypothesised that the LH dysfunction in schizophrenia would provide a good examination of temporal integration theory and the test used in the present research, a modified version of the PASAT.

Although the preponderance of evidence is on the LH, Cutting (1992, 1994) and Crow (1998) have proposed that the RH should not be overlooked in terms of our understanding of schizophrenia. Crow's description of the LH's syntagmatic specialist function for language is analogous to how temporal integration theory views the LH. However, Crow's hypothesis of the RH's paradigmatic specialist function also for language is beginning to receive support (e.g., St George et al., 1999; Wiesbrod et al., 1998). Furthermore, the normal RH has been identified as being specialised for managing various aspects of attention. RH dysfunction may instead be implicated in the difficulties with attention in schizophrenia. The following sections, therefore, are a discussion on the different aspects of attention, of how these may be involved with the PASAT, and the hypotheses that arise in regard to LH compared to RH performance.

Attention, Hemispheric Specialisation, and the PASAT

The following sections present discussion on the different aspects of attention. These aspects being vigilance (i.e., alertness or sustained attention), attention as selection, and attention in terms of processing resource capacity. The discussion includes how these different aspects of attention may be based on hemispheric specialisation and be involved during performance with the PASAT.

Vigilance or Sustained Attention

Vigilance or sustained attention refers to a person's general readiness to respond, and ability to maintain responding, to a wide range of stimulus information, despite the special category to which the information belongs. Under conditions of psychometric testing most investigators concur that omission errors are indicative of defects in vigilance (Spreen & Strauss, 1998). The continuous performance test (CPT) is an example of a test for assessing vigilance and was initially designed to detect lapses of attention in persons with petit mal epilepsy. The CPT typically requires a participant to press a key when a target letter appears, or when the target letter is preceded by another letter. Other versions of the test instead use numbers, colours, or geometric figures as stimuli rather than letters, and can require either responses to a single stimulus or a sequence of stimuli. There is no requirement to carry out any mental operation which might include the stimulus beyond that of just indicating recognition of the stimulus presentation. The test takes approximately 14 minutes. Omissions throughout the test are taken to indicate a defect in overall vigilance, whereas slowness in responding near the end of testing is assumed to indicate an inability to sustain attention. Essentially then, vigilance is to do with a consistent ability to recognise the presence of stimuli, but does not refer to the subsequent possible range of mental operations within which any stimulus may be incorporated.

The brain injury syndromes of *neglect* are examples in which affected persons show consistent failure of vigilance. Such failure is most often multimodal (i.e., visual, tactile, auditory, etc.) and hemispatial (i.e., to one field of space, including the person's own body). Neglect as a result of RH damage is more severe and intractable than that associated with LH damage (Albert, 1973), and is frequently associated with lesions of the right parietal lobe (Posner & Raichle, 1994). Other evidence from brain injury studies also shows the greater importance of the RH over the LH for the regulation of vigilance. For example, Pardo et al. (1991) report that in cases of RH as opposed to LH frontal lobe injury there is greater impairment in the ability to effectively use priming cues. Simple reaction time (RT), with the hand ipsilateral to the brain lesion, has also been shown to be significantly slower for persons with RH injury compared to persons with LH damage (Howes & Boller, 1975; Ladavas, Del Pesce, & Provinciali, 1989; Yokoyama et al., 1987). Yokohama et al. (1987), in using the same RT task, also demonstrated that normal participants had increased heart rate in response to a warning signal. Participants with LH injury showed further increased heart rate, but those with RH injury showed no effect on heart rate. Other evidence of asymmetry in vigilance comes from a study by Coslett, Bowers, and Heilman (1987). They tested the maintenance of vigilance with a task involving RT to an irregular repeated auditory tone and another which required the sorting of two types of coins. The tasks were done separately or concurrently. Participants with RH injury had greater impaired performance on the RT task as compared to normal controls and participants with LH damage, which is consistent with the above reported studies. Coslett et al. also showed that RH injured participants, compared to the other groups, had the worse performance when both tasks were performed concurrently. In other words, the RH injured participants had greater difficulty with vigilance if their attention was already occupied. Wilkins, Shallice, and McCarthy (1987) also demonstrated impairment in vigilance for persons with frontal lobe removal from the RH as compared to LH or of temporal lobe from either hemisphere, due to intractable epilepsy, and as compared to normal controls. Their vigilance tests involved the counting of auditory or tactile stimuli delivered at 1 stimulus or 7 stimuli per second. The RH frontal lobectomy participants performed comparatively worse at both rates of presentation and in both sensory modalities. Overall, these studies indicate that the RH is more specialised than the LH for vigilance and that its injury results in impaired vigilance.

Similar evidence of a RH specialisation for vigilance has been found by RT or continuous performance tasks with participants who have undergone callosotomy (Dimond, 1979; Ladavas, Del Pesce, Mangun, & Gazzaniga, 1994; Loring, Meador, & Lee, 1989). It has been demonstrated with the same stimuli that the disconnected LH will omit responding for gaps of several seconds, whereas the RH will consistently respond to the stimuli.

Studies with normal participants also show RH specialisation for vigilance. For example, Heilman and van den Abell (1979) demonstrated how the RH gains advantage from a warning signal (i.e., a red light) 1 to 2 s before the RT stimulus (i.e., a green light). Reaction time was significantly less when the warning signal was presented to the left visual field compared to the right field. Heilman and van den Abell (1980) replicated this finding and also showed how desynchronisation of the EEG alpha rhythm was greater in the RH for stimuli presented to both ipsilateral and contralateral visual fields. Desynchronisation of similar magnitude in the LH was in response to stimuli in the contralateral field only. Pardo et al. (1991) report on PET measurement of regional cerebral blood flow (rCBF) in normal participants required to sustain vigilance. In their study participants responded to a somatosensory task (i.e., detection of 1 to 3 s pauses in a sequence of touches to the right or left large toe). The right frontal lobe and superior parietal lobe, but not their counterparts in the LH, showed the increased rCBF for both ipsilateral and contralateral tactile stimulation. Normal participants also show better RT performance with the RH when they are required to sustain vigilance for longer than 10 s in tasks involving detection of stimuli in the left versus the right visual field (Whitehead, 1991). Here again, these studies with normal participants provide evidence consistent with brain injury or callosotomy studies which show RH specialisation for maintenance of vigilance.

With regard to the unmodified PASAT, Gronwall and Sampson (1974) proposed that impaired performance is an outcome of lowered levels of arousal consequent to concussion, and so a generalised slowing of vigilance. Lowered arousal was thought to be a result of diffuse neuronal damage to the reticular system in the brain stem. However, their theory does not account for the possible asymmetric effects for vigilance, and implication for performance on the PASAT, as strongly suggested by the above reviewed studies. For example, a prior digit in a sequence might act as a cue or warning signal for the next digit, and so on, which aids the maintenance of vigilance. The studies showing RH specialisation for cue vigilance (Heilman & van den Abell, 1979, 1980) and impaired cue vigilance in RH injury (Pardo et al., 1991) suggest that on the PASAT performance might be asymmetrically affected if the RH is injured or dysfunctional. This would not be easily demonstrable with the non-lateralised PASAT. However, performance on the lateralised PASAT might show superior RH performance for participants without brain injury and relatively poorer RH performance for participants with suspected attentional deficits, such as in schizophrenia.

The time course of stimulus presentation (i.e., ISI and total trial sequence duration) has also been shown to be relevant to asymmetric performance of vigilance and again has possible relevance to the PASAT. For instance, the study by Wilkins et al. (1987) showed that persons with RH frontal lobectomy performed comparatively worse than participants with LH frontal lobectomy and normal controls with a stimulus presentation rate of 1 per second, which is close to the fastest 1.2 s rate of the PASAT. Pardo et al. (1991) demonstrated asymmetric increased rCBF of the RH in normal participants for tasks which required sustaining vigilance over the trial sequence duration of 40 s. The study by Whitehead (1991) showed RH specialisation in normal participants when tasks require the maintenance of vigilance for periods greater than 10 s, which again has possible relevance for the PASAT. On the PASAT, which has continuous stimulus sequences of 61 digits for the unmodified version and 32 for the lateralised version, this translates to be a minimum of 73.2 s or 37.2 s of continuously required performance per sequence, respectively. This far exceeds the 10 s marker found by Whitehead (1991). The 37.2 s duration of the lateralised PASAT, at the 1.2 s presentation rate, also closely approximates the 40 s duration in the Pardo et al. (1991) study. Hence, one might predict that with the long and continuous requirement to maintain vigilance on the PASAT the RH would show better performance in normal participants and poorer performance with persons with suspected RH injury or dysfunction.

The above reviewed evidence of RH specialisation for vigilance therefore suggests that with the PASAT there could conceivably be asymmetric effects in favour of the RH instead of the LH as alternatively predicted via temporal integration theory. The next section examines this proposal of asymmetric hemispheric processing with regard to selective attention.

Selective Attention

In general, the theory of selective attention assumes that more than one stimulus, or stimulus characteristic, can be identified in parallel and that the neural machinery that recognises stimuli as belonging to familiar categories computes all incoming stimuli, but with some capacity limitation (Pashler, 1998). The stimulus characteristics of sound, word, number, location, duration, etc. could simultaneously be identified as belonging to particular categories. With sufficient capacity the neural machinery of selective attention could then facilitate the various components of stimuli reaching the relevant systems of the brain for higher cognitive functioning.

Treisman (1960) proposed that in selective attention 'unattended' stimuli are not necessarily all rejected but instead 'attenuated' (i.e., only partially filtered out). Recognition of stimuli, if not immediate, can therefore take place through accumulation of information and then activation of detector units. However, attenuation is less likely to occur if the stimulus represents a concept that is related to concepts that have been already activated, which Treisman called *priming*. Kinsbourne (1970, 1973) extended this idea of priming in developing his selective activation theory in relation to hemispheric processing. In this theory attention is distributed across space rather than between or within the cerebral hemispheres. For instance, the direction of attention to either left or right side of space is proposed to be dependent on which hemisphere is most activated at the time. To test this theory Kinsbourne developed dual-task paradigms to assess the effect of concurrent verbal memory (presumed to selectively activate the LH) on the identification of nonverbal stimuli from either left or right visual field. Kinsbourne found that the subvocalisation of words improved right field performance but worsened left field performance. An initial interpretation is that attentional biases could be the complete explanation for hemispheric lateralisation, with there being no need to presume inherent differences between the hemispheres. However, other evidence requires the modification of this interpretation. For instance, studies by Haggard and Parkinson (1971) and Ley and Bryden (1979, 1982) have shown the lateralisation to both hemispheres for different aspects of the same stimuli (i.e., verbal content vs. emotional tone). A right ear advantage is found for identifying verbal content, while a left ear advantage is found for emotional tone.

Other evidence contradictory to that of assuming no inherent differences between the hemispheres also comes from studies reviewed in earlier sections of this thesis which show a LH advantage for phonemic analysis, syntax, and articulation, whereas the RH operates more at the level of connotative, associative, and imaginal processes (e.g., Anaki et al., 1998; Brownell et al., 1990; St George et al., 1999). Furthermore, selective activation theory does not sufficiently account for the RH specialisation for vigilance, which presumably may lead to earlier or greater maintained activation of the RH, and yet the LH still demonstrates advantages for many tasks within which vigilance would always be a factor from the outset of responding.

One might still consider, though, what predictions could arise from selective attention theory with regard to the PASAT. Figure 1 depicts the various sub-tasks of the PASAT and shows how a single paced serial addition response is dependent on an underlying complex range of different forms and stages of perceptual, cognitive and motor performance. After the presentation and encoding of stimulus *n* + 1, the participant must then retrieve stimulus *n* from working memory, perform the cognitive operations necessary to derive their sum, and then generate and articulate the spoken response (i.e., the speaking out of the derived sum). The derived sum is then suppressed while the participant has to simultaneously perform the operations necessary to

Stimulus	Processing	Response
n	Perception of stimulus n	
	Encoding of stimulus n	
	Maintenance of stimulus n in memory	
$n + 1$	Perception of stimulus $n + 1$	
	Encoding of stimulus $n + 1$	
	Retrieval of stimulus n from memory	
	Mental addition of stimuli n and $n + 1$	
	Generation and articulation of response n	n
	Maintenance of stimulus $n + 1$ in memory	[Inhibition of response n]
$n + 2$	Perception of stimulus $n + 2$	
	Encoding of stimulus $n + 2$	
	Retrieval of stimulus $n + 1$ from memory	
	Mental addition of stimuli $n + 1$ and $n + 2$	
	Generation and articulation of response $n + 1$	$n + 1$
	Maintenance of stimulus $n + 2$ in memory	[Inhibition of response $n + 1$]

Figure 1. A hypothetical representation of the sub task processing elements relating to stimuli, memory, cognitive operations, and responding for paced serial addition (as adapted from Stewart, 1995, p. 88).

maintain the identity of stimulus $n + 1$ in working memory, so that it can be retrieved when stimulus $n + 2$ has been presented and encoded. Most of these sub-tasks, particularly the encoding and recognition of the auditory stimulus as a digit, the generation and articulation of a response, and the 'holding' of a stimulus in working memory, could be considered the province of the LH (e.g., Broca's and Wernicke's areas). This would also include the arithmetic processing, which has also generally been accepted as a LH specialist function (McCarthy &

Warrington, 1991). Accordingly, a LH advantage might occur not only based on the sub-tasks themselves but also due to attentional bias as a result of this disproportionate activation. However, with most of the sub-tasks reflecting LH specialisation this renders the PASAT as possibly being an unfair test of the selective activation theory, as there would be minimal opportunity to demonstrate a shift from a RH to a LH advantage based on activational bias of the LH. On the other hand, the theory would not predict a RH advantage for normal participants, given the expected activational bias by the LH sub-tasks.

A limitation on testing the selective activation theory also exists with the measurement of accuracy on the lateralised PASAT being based on the LL, RR, LR, or RL ear mode presentations. In other words, the first stimulus in either the LL or RR modes would similarly activate their contralateral hemisphere to the same degree before arrival of the second stimulus of the pair. Hence, there may be no discernible difference in performance between the hemispheres. The same argument could apply to the LR and RL modes as they are essentially counterbalanced. However, selective activation theory might predict a RL advantage over the LR mode, for normal participants, given the sub-tasks again potentially favour activation of the LH and it being potentially more prepared than the RH for receiving the second digit from the opposite hemisphere.

Since the various sub-tasks of the PASAT potentially involve the LH more than the RH, this gives rise to the issue whether LH performance might instead be negatively affected by an overload on processing capacity. It is this issue of processing resource capacity which is addressed in the following discussion.

Resource Capacity

The notion of attenuation has been extended to include the possibility of limited resources or capacity. This is often referred to as *graded capacity* sharing, which means that with capacity shared among different perceptual processes this reduces the amount available to any individual stimulus and causes its recognition to take longer. The idea of different processes, rather than just singular stimuli, competing for attentional capacity has also been applied to higher levels of cognitive functioning. This is referred to as *divided attention* and involves the various categories or associations among stimuli as related to whatever task is at hand. Divided attention was first proposed to account for the difficulties people have in doing more than one task at the same time (Pashler, 1998). Furthermore, it has been proposed that dissimilar tasks might each be performed just as well together as in isolation, but similar tasks might compete for more limited capacity and so not be performed as well together as in isolation (Allport, 1980).

Kinsbourne (e.g., Kinsbourne & Cook, 1971) also theorised the problem of resource capacity in hemispheric processing, whereby overload on capacity purportedly nullifies any advantage from priming.. He further proposed that if concurrent activity demands processing primarily from one hemisphere then this would interfere with the ability of that hemisphere to engage in other activity. The study by Hellige and Cox (1976), which was reviewed in an earlier section on working memory, exemplifies this principle of limited resource capacity. In their study with normal participants, memory load was found to have a selective effect on LH but not RH performance for a concurrent task which required visual recognition of polygon forms. An 'easy' memory load (i.e., 2 to 4 nouns) improved LH performance on the concurrent task, which is consistent with selective activation theory. A 'hard' memory load (i.e., 6 or more nouns) decreased LH performance, which concurs with the limited resource capacity theory.

In reference again to Figure 1 (p. 85), it will be recalled that the various sub-tasks of the PASAT quite conceivably load more on the LH than the RH. It seems reasonable to also conjecture that with faster presentation rates the limit of capacity in attentional resource might be more easily reached. Hence, with the lateralised PASAT normal participant LH capacity might be exhausted at the faster presentations and therefore no LH advantage will be demonstrated. If this is so then one might expect participants with schizophrenia (presumed LH dysfunction) to show LH performance relatively inferior to normal participants.

Summary

Studies of participants with brain injury, or who have undergone frontal lobectomy or callosotomy, and of normal participants, all provide consistent evidence of RH specialisation for vigilance. At least three aspects of the lateralised PASAT involve vigilance. Each serial digit stimulus acting as a cue for the next stimulus, the changing ear of presentation, and the long and continuous serial performance would all require maintenance of vigilance and, hence, normal RH functioning.

The PASAT also has various sub-tasks that include the encoding and recognition of the auditory stimulus as a digit, the arithmetic operations, the generation and articulation of a response, and the ‘holding’ of a stimulus in working memory, all of which are more the province of the LH than the RH. According to the selective activation theory, this disproportionate activation of the LH would result in an attentional bias of the LH, which in itself would give a LH advantage over the RH for normal participants.

Alternatively, the processing resource capacity of the LH may not be able to accommodate the loading of the PASAT sub-tasks, particularly at the fastest 1.2 s rate, and thereby LH performance could be negatively effected. With regard to participants with schizophrenia, and presumed LH dysfunction, an overload on the LH should result in their LH performance being inferior relative to normal control participants.

Accordingly, given the above reviewed evidence, interpretation of results in the present research will not only address temporal integration theory but will also take into account the different aspects of attention for hemispheric processing. The next section provides a detailed description of the present research programme.

The Present Research

Temporal integration theory (Hearnshaw, 1956; Lashley, 1937; Miller, 1996; Norman, 1984) underpins the present research. Temporal integration refers to a person's ability to process information of a serial nature, such as spoken communication, and to generate time-structured verbal responses or movements. More specifically, temporal integration refers to the capacity of some brain systems to delay processing of discrete units of information so that temporal associations between separate incoming and partially processed units can be maintained. Otherwise, in the case of spoken communication, for example, overall meaning from groups of units would be lost. The core of Miller's (1996) theory is that the ability to delay the processing of information depends upon differences between the cerebral hemispheres in terms of axonal conduction time. The LH's specialisation for the temporal processing of language is due to its ability to delay axonal conduction, whereas the RH has the ability to rapidly conduct axonal transmissions, which enables rapid processing of 'gestalts' of information.

From a neuropsychological perspective, a good test of temporal integration theory would be if a lateralised task, using temporal parameters, yielded a particular left or right hemispheric asymmetry. The PASAT was selected for this purpose. It was selected because it arose out of temporal integration theory (Sampson & MacNeilage, 1960) and particularly for its sequential aspects, its facility to allow manipulation of presentation rate, and its verbal processing and response requirements. The standard PASAT is typically administered to both ears simultaneously. In the present research the standard PASAT was modified for lateralised presentation. Other modifications were also undertaken to upgrade the PASAT for purposes of research into hemispheric specialisation. These modifications are explained later; the next subsection provides a description of the principal hypotheses proposed in the present research.

Hypotheses

Firstly, a right ear advantage (REA) was predicted to occur for normal participants. A REA, representing a LH advantage, was expected due to the sequential nature of the PASAT, the previous findings by Norman (1984), and Miller's (1996) theory on the LH's specialisation for delayed axonal conduction. The prediction of a REA was also based on the neuropsychological evidence of LH specialisation for temporal processing, such as the apparent necessity to remove temporal constraints on stimulus presentation for young children (Bryson et al., 1980); the discrimination of temporal order (Efron, 1963; Leek & Brandt, 1983; Mills & Rollman, 1980); the processing and reproduction of rhythms (Gordon, 1978; Prior et al., 1990; Robinson & Solomon, 1974); letter or word recognition (Koivisto, 1997; Wilkins & Stewart, 1974); and with rCBF during a verbal fluency test (Elfgren & Risberg, 1998).

It was therefore predicted that on the lateralised PASAT the RR mode would show an advantage over the LL mode for the normal controls. In the RR mode condition each of two successive stimuli are presented to the right ear; and, in the LL mode condition they are presented to the left ear. In normal hearing each ear sends information to both hemispheres. However, the pathway from each ear to the contralateral hemisphere contains more fibres than does the pathway from each ear to the ipsilateral hemisphere. Hence, the contralateral hemisphere receives the transposed auditory signal quicker and with better perceptual clarity than the ipsilateral hemisphere (Hellige, 1993). Kimura (1967) noted that dichotic competition (when two items are presented simultaneously to both ears), rather than monaural tests (where digits would instead be presented to one ear at a time), seems to more effectively inhibit the ipsilateral pathway and, hence, assist with demonstrating an ear asymmetry. On the lateralised PASAT, only one stimulus at a time is presented to each ear and nothing to the other ear. This monaural arrangement was preferred because of the already increased attentional difficulty added to the test by intermixing and randomising the modes. For example, with the LR and RL modes embedded in the intermixed presentation there was already a demand on participants to frequently switch attention. Another stimulus, intended to suppress the ipsilateral pathway, could have added in an attentional confound. Furthermore, as presentation rate increases, an extra stimulus could unintentionally act as a mask over the next informational stimulus (a stimulus directly related to the actual arithmetic task) presented to the same ear. This could change the nature of the task between the different levels of presentation rate and therefore add another unnecessary confound.

The inclusion of persons with schizophrenia in the present research was in recognition of Lashley's (1937) suggestion that actual observation of temporal integration may only be possible when it is dysfunctional as a consequence of brain pathology. Hence, the second principal hypothesis of the present research was that participants with a history of schizophrenia would demonstrate either an absence or reversal of the REA as predicted for the normal controls. The prediction of contrasting results between the participants with schizophrenia and the controls was based on the neuropsychological evidence of LH dysfunction in schizophrenia, such as slower processing of stimuli directed to the LH (Connolly et al., 1979; Eaton, 1979; Gruzelier & Hammond, 1979; Hillsberg, 1979; Kugler & Henley, 1979), problems in consonant-vowel syllable identification (Colbourn & Lishman, 1979), and a smaller REA for distinguishing fused pairs of rhyming words (Bruder et al., 1995; Wexler et al., 1991). The neuropsychological evidence also includes the effects of presentation rate on performance (Baribeau-Braun et al., 1983; Gruzelier & Hammond,1979). Neurophysiological and neuroanatomical evidence of abnormal differences in fronto-temporal cortex in persons with schizophrenia also implicates the LH. The evidence comes from EEG studies (Abrams & Taylor, 1979; Coger et al., 1979; Flor Henry, 1976), measurement of cerebral glucose metabolism (Gur, Resnick, Alavi, et al., 1987; Gur, Resnick,Gur, et al., 1987), differences in mean volume for gray matter (Maher et al., 1998; Suddath et al., 1989), deficiencies in quantity, size and shape of neurones and axons (Zaidel et al., 1997; Zhou et al., 1997), and abnormal low response to speech during MRI examination (Woodruff et al., 1997).

The evidence thus far supports the argument that temporal integration is predominantly a LH specialist function. Furthermore, it is also argued above that disruption in the ability to temporally integrate information would be demonstrable in persons with schizophrenia; this argument is based on the evidence accrued to show neuropsychological dysfunction and neuroanatomical deficiencies of the LH in schizophrenia. However, some of the studies reviewed earlier (e.g., Bustillo et al., 1997; Gruzelier & Hammond, 1980; Walker & McGuire, 1982) had findings that could instead be interpreted to represent difficulties in attentional processes and, therefore, RH dysfunction. Evidence of the RH being specialised for attentional processes comes from persons with right as opposed to left frontal lobe injury having greater impairment in the ability to use primary visual cues. The RH specialist function for attention has also been demonstrated with PET studies, which show increased activity in the right but not left frontal areas when normal participants are required to sustain attention (Pardo et al., 1991).

Furthermore, Posner et al. (1988) found evidence of slower performance, by participants with schizophrenia, in responding to stimuli from the right visual field after having their orientation directed to the opposite field. Wigal et al. (1997) replicated this finding with participants medication-free at the time of being tested. Both groups of researchers interpreted this finding as indicating abnormal slowness of the LH to attentively engage.

Hence, it is possible that any lateralised effects demonstrated with the PASAT by participants with schizophrenia, may instead be due to problems in attention and not problems in temporal integration. Therefore, another hypothesis of the present research was that the participants with schizophrenia would show greater difficulty with the switching of mode (back and forth stimulation of the left and right ear). The LR and RL mixed mode pairings in the lateralised PASAT are embedded in the randomisation of all four modes, which presents a participant with the task of a high degree of unpredictable switching of attention. Therefore, it was expected that performance on the LR and RL modes would equally be inferior to the LL and RR modes. However, it was discussed in an earlier section how the LR and RL mixed mode pairings bear similarity to Posner et al.'s (1988) model of valid and invalid cues of attention. One might therefore expect that the LR mode would be inferior to the RL mode, which would support Posner et al.'s idea of a lateralised problem in disengagement rather than just with switching of attention *per se*. Accordingly, two versions of the lateralised PASAT were used to examine these additional hypotheses. The randomised, unpredictable version, as also previously used by Norman (1984) and Stewart (1995), has already been discussed in earlier sections. The second version presents all four modes as blocks of trials (i.e., LLLLLL etc., or RRRRRR etc., or LRLRLR etc., or RLRLRL), which therefore removes the unpredictability of presentation mode. It reduces the overall degree of switching but retains the requirement to switch attention with the mixed modes. However, the required degree of switching is clearly counterbalanced.

The necessary modifications to the standard PASAT for the present research are explained in the following section. Hereafter, the participants with a history of schizophrenia will be referred to as the clinical participants, and those without a mental health history will be referred to as the non clinical controls or normal participants.

General Method

For clinical practice, the standard PASAT is typically recorded monaurally on an audio tape and played back to a participant via an external speaker of a tape recorder, rather than through headphones. The participant's responses are not recorded on tape but are spoken to the examiner. The examiner records the responses manually on a prepared answer sheet. These typical procedures are not sufficient for experimental work, particularly in the research of hemispheric specialisation. Furthermore, as previously noted, there are potential weaknesses in the construction of the original PASAT; for example, its repetition of a sequence of digits (Levin et al., 1987), and it requiring additions with summations greater than 10 (Dyche & Johnson, 1991a, 1991b; Johnson et al., 1988). Therefore, a number of modifications were employed to refine the procedures of the standard PASAT for the present research.

Stimuli

The first modification required precision in randomising and counterbalancing of low and high, and even and odd number outcomes. Under normal circumstances, little thought is given to the distribution of numbers used in a typical sequence. For present purposes, it was deemed necessary to create digit sequences that had an equal number of low and high summations, and an equal number of even and odd summations. Since several different digit sequences were used, these counterbalancing procedures controlled for any confounds that may have been created. For example, participants may find summations requiring the addition of two low and even numbers (e.g., 2 + 4 = 6) easier than two higher and odd numbers (e.g., 5 + 9 = 14). Accordingly, 100 sequences of 32 digits each (the reason for 32 digits, as opposed to the unmodified PASAT's conventional 61 digits, is explained below) were randomly generated via a computer with the following constraints: (a) digits had to be from 1 to 9 inclusive (but excluding the digit 7; see below); (b) each of the eight digits had to appear exactly four times in a sequence (to produce a series of 32); and (c) no digit was allowed to repeat consecutively more than twice. The digit generator was programmed to also calculate the number of even/high, even/low, odd/high, and odd/low summations for each of the 100 sequences. Those sequences (n = 45) with even distribution of summations (i.e., even/high, odd/low, etc.) were retained for random assignment to two lots of 16 series constructed from 4 presentation modes (see below) and 4 presentation rates (see below). So, in both lots, each of the 16 series had a different set of 32 randomly selected and counterbalanced digit stimuli. One lot of the 16 series was assigned to one task condition and the other to a different task condition (see below for Unpredictable Compared to Predictable Mode Conditions).

A second modification, also not previously used, was the removal of the digit 7 from the stimuli range (digits 1 to 9 inclusive). In the present research the digit 7 was dropped out because of it having a two syllable (sev-en) pronunciation compared with one syllable for other digits from 1 through 9 inclusive. Stewart (1995) measured the enunciation of the digit 7 as taking about 450 ms as compared to a range of 250 to 350 ms for the other digits. Hence, the dropping out of the digit 7 was done to counter any possible influence of the time taken to enunciate the digit on performance on the modified PASAT.

Presentation Modes

The third modification to the standard PASAT is the same as that used by Norman (1984) and Stewart (1995). Instead of dichotic presentation, stimuli are presented laterally, one digit at a time, to one ear only. There are four possible modes of presentation, arranged as LL (left ear then left ear again), RR (right then right again), LR (left followed by right) and RL (right followed by left). The repeated ear arrangements (LL and RR) were devised because the PASAT requires the participant to sum successive and overlapping pairs of digits. Each pair of digits and the participant's response to this pair constitutes one trial. So as to have clear separation between modes (i.e., ear of presentation) and to know which mode the participant was responding to, both digits in each trial needed to be presented to the same ear. An equal number of left and right, same-ear digit pairs were devised. The LR and RL arrangements arose automatically because of the overlapping LL and RR modes (e.g., LLRRRLLL), but also gave the opportunity to observe what happens with mixed mode trials. The same number of these LR and RL modes were run for each experiment. It was discussed in an earlier section how these mixed modes are analogous to the valid and invalid cues in the cued reaction time task, which was developed by Posner et al. (1988) and used to assess problems of attention in schizophrenia. There are differences between experiments in how the 4 modes (LL, RR, LR, and RL) are distributed through each of the 16 series of 32 digits. How they are distributed is described next as differences between task conditions.

Unpredictable Compared to Predictable Mode Conditions

Norman (1984) and Stewart (1995), using a modified version of the PASAT as described above, presented the 4 modes in an unpredictable, randomised combination (e.g., LLRLRRRLRLLRR). In the present research this same unpredictable condition was employed for each of the 16 sequences of 32 digits, and is hereafter called Task UP. However, an additional task condition was also included: all 4 modes were presented as predictable blocks of trials (i.e., LLLLLL etc., or RRRRRR etc., or LRLRLR etc., or RLRLRL), but still as 16 sequences of 32 digits. (This task condition will hereafter be called Task P). The purpose for including Task P was explained earlier. Briefly, though, the two tasks were included to examine issues of attention. The two tasks each had a different set of 16 sequences.

Presentation Rates

The fourth modification to the standard PASAT was the expansion of the presentation rates. A review of Norman's (1984) data on participant responses on the PASAT with standard presentation rates (1.2, 1.6, 2.0, 2.4 s) showed that accuracy reached a level of only 75% for the slowest rate (2.4s). With accuracy levels being no greater than 75%, the question arises as to whether a low ceiling of performance masks the detection of mode differences. Accordingly, for the present research a rate of presentation was derived so as to bring performance levels up to near 100% accuracy. To derive such a rate, the incremental differences between the standard rates and their accuracy levels were simply extrapolated to the 100% level. To reach this level it was found that the presentation rate needed to be at one digit every 3.6 s. A spread of 0.8 s from one rate to the next was needed to have four rates of equal spread from 1.2, 2.0, 2.8, to 3.6 s. No faster rate was derived as it was considered that any rate faster than 1.2 s would be unmanageable for participants, especially clinical participants.

Number of Digits

A fifth modification was the extension of the number of digits for each of the 16 sequences (i.e., 16 combinations of presentation mode by presentation rate). The standard, nonlateralised PASAT has only 61 digits per presentation rate, which equates with 60 digit pairs (i.e., 60 trials). Norman (1984) also only used 61 digits. However, when divided over the four modes, there are only 15 trials per mode. Accordingly, in the present research the number of digits for each mode was set at 32 (i.e., 31 trials), which meant 128 digits for each presentation rate (slightly more than double that for the standard PASAT). The number of trials chosen was considered to give a reasonable balance between participant fatigue and the need to run enough trials to get a reliable estimate of participant accuracy at each rate.

Audio Tapes

The randomised digits assigned to each of the 16 sequences were individually entered into a computer with a high quality synthesised voice chip. The computer voice was used to lay down all 16 stimulus sequences on tape. The use of a computer voice gave 100% reproduction for the way each digit was spoken, along with equal timing between the presentation of each digit (accurate to +/- 0.1 s). Each sequence was first recorded onto the sound track of a master video tape and then recorded from the master tape onto separate audio tapes, which enabled randomisation of sequence and tape order for each new participant. This randomisation was done to counter any practice effect that could have arisen, such as participant responses improving by the latter presented tapes. A practise effect could also give a false impression of lateralised differences. One restriction to this randomisation process was that, if one of the fastest (1.2 s) tapes was at the beginning of the randomised tapes it was removed and randomly reinserted further along in the tape series. Participants were also advised when a fast tape was next in the series, and reminded to avoid getting stuck by worrying about mistakes. These steps were undertaken to help alleviate the effects of test anxiety on performance. Another restriction was that tapes having the same mode or rate were not used consecutively, which was also done to counter any practise effects.

During actual experimental sessions, participants were presented with the 16 randomised tapes played back on a stereophonic cassette tape recorder and via stereophonic headphones. All participants heard and responded to all 16 tapes in one individual session, typically for 45 mins but no longer than 1 hr. Very few participants, all clinical participants, required any break during their individual session. If a break of 5 to 10 mins was taken it was after or near the eighth tape at a point where it was possible to avoid resuming the test with one of the tapes containing the fastest (1.2 s) series.

Recording and Scoring Participant Responses

Figure 2 is an illustration of the audio equipment set-up used for playback of auditory stimuli and the recording of participant responses. The 16 tapes of the auditory numerical stimuli were played back on a stereophonic cassette tape recorder via stereophonic headphones. During data collection each participant was instructed to speak out their answer which was recorded on one channel of an audio tape via an audio mixer to another stereophonic cassette tape recorder. Simultaneously, the digit stimuli that the participant was hearing and responding to were recorded via the same audio mixer onto the remaining channel on the same audio tape. This enabled scoring of participant responses after the session, and for random checking of scoring by an independent second scorer.

Appendices A 1 and A 2 contain examples of the scoring sheets used for each task condition. In general, participant responses were judged as correct if the summations were correct and the response was clearly given for the respective pair of stimuli heard before or contiguous with presentation of the next stimulus, categorised as being within the response interval. On the faster presentation rates (1.2 and 2.0 s) particularly, some participants gave correct summations fractionally outside of the response interval but clearly were responding consistently to successive stimuli (i.e., maintained the successive task). Thus, their responses were judged as correct. The dependent measure, therefore, was the number of correct responses for each digit pair to be added in a sequence. The maximum number correct for each sequence was 31.

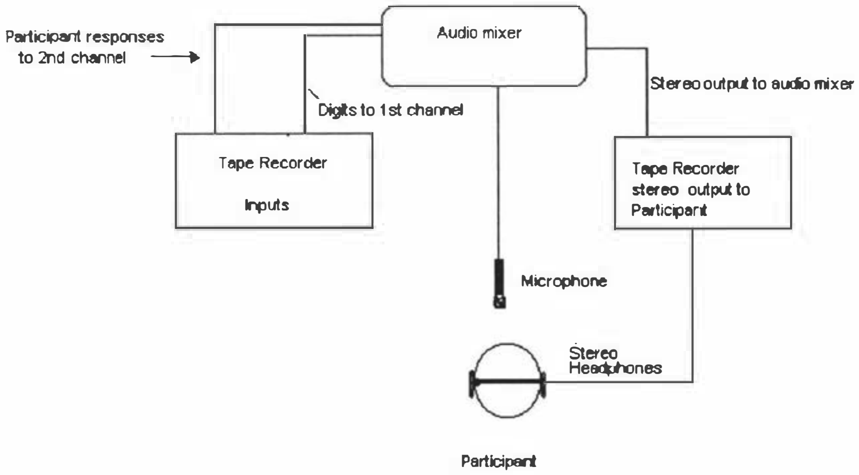

Figure 2. Audio equipment used for the lateralised PASAT playback and recording of participant responses.

In Task UP all 4 modes were randomised and so each was scored within the same sequence. The score for each mode was then summated across the 4 sequences for each rate. In Task P the LL and RR modes were presented as separate trial blocks of the same mode type at one rate and on one tape, as explained above (e.g., LLLLLL etc., or RRRRRR etc.). Accordingly, the LL and RR modes in Task P were each scored as separate blocks. However, the presentation of the LR and RL modes as separate trial blocks essentially meant the blocks were the same except for the starting stimulus (e.g., LRLRLRL etc., or RLRLRLR etc.). In other words, because the LR and

RL modes are a mirror image of each other, any repetition of either mode meant the other would also be represented at every second, fourth, sixth, etc., overlapping trial (e.g., LRLRLRL etc., and LRLRLRL etc., or RLRLRLR etc., and RLRLRLR etc.). Two trial blocks, one beginning with the LR mode and the other with the RL mode, were still used so as to have the same number of trials for these modes as for the LL and RR modes at each level of rate. Hence, each of the LR and RL modes were scored within, and then summated together across, both trial blocks for each rate.

Test Instructions

At the time of obtaining written consent from participants, they were informed about the general purpose of the PASAT and the procedure used in administering it (see Appendices B1 and B2 for the Information Sheet and Consent Form). The anticipated length of the test session was discussed, as was the need to gauge performance at different speeds and in different modes.

All participants received the same set of instructions and were given a practise of 10 digits spoken by the investigator (see Appendix C). If any participant had difficulty with the oral practise it was repeated allowing the participant to view the stimuli read out and the correct summations. The practise was repeated until, without viewing, the participant could give correct answers and follow the successive nature of the test. Each participant then listened, via headphones, to a practise audio tape with a full sequence of digits at the 3.6 s rate. This practise set was not used in the test session.

Participant Selection

Non clinical participants, including controls for clinical experiments, were all volunteers obtained from the staff of a large (approximately 400 employees) mental health service in the central region of New Zealand, or were friends or family of other volunteers or nonparticipating staff.

Participants were selected on the basis of having no history of head injury, no drug or alcohol abuse, no neurodevelopmental problems, no hearing problems (as reported verbally by the participant), and no psychiatric problems, other than the diagnosis of schizophrenia for clinical participants. Clinical participants were also volunteers from among persons who had schizophrenia as diagnosed by more than one mental health professional, according to the diagnostic criteria of the Diagnostic and Statistical Manual IV (American Psychiatric Association, 1994). Each clinical participant had been referred and was accompanied by their mental health case worker, who had previously been made aware of the present research by the investigator. All clinical participants had at least a three year history, some a much longer history, of receiving mental health treatment. All had been receiving neuroleptic treatment prior to and at the time of participation. Only two of the clinical participants had positive and no negative symptoms of schizophrenia.

All non-clinical and clinical participants were right-handed as rated by Briggs and Nebes' (1975) adaptation of Annett's (1967) questionnaire on handedness (see Appendix D). The usual neuropsychology research standard of using only right-handed participants meant that six other potential clinical participants could not be included in the present research because they were each predominantly left-handed.

Analyses

The principal means of analysis was by Analysis of Variance (ANOVA). All ANOVAs were conducted using the statistical package SAS (SAS Institute, 1996). Where estimated, effect sizes (ESs) and statistical power (SP) for the F statistic were calculated in accordance with Cohen's (1988) recommendations, and by using the Power and Precision statistical programme (Borenstein, Rothstein, & Cohen, 1997). The family-wise Type I error probability was set at the conventional level of 0.05. Results are reported according to the central hypotheses under examination in each respective experiment.

Experiment 1

Method

Design and Procedure

The overall design was a 2 x 2 x 4 x 4 factorial design : 2 tasks (Task UP and Task P); 2 samples of participants (clinicals, controls); 4 rates (1.2, 2.0, 2.8, and 3.6 s); and 4 modes (LL, RR, LR, and RL). Eighteen clinical participants and 18 control participants were recruited as previously described. Each control participant was of the same gender and approximate age as the respective clinical participant. The 18 clinical participants were randomly assigned so that half were tested with Task UP and half with Task P. The 18 control participants were similarly assigned to the two tasks. In Task UP, the age range for clinical participants was 21 to 68 years (M = 41.5, SD = 15.3), and for the control participants it was also 21 to 68 years (M = 42.5, SD = 15.4). In Task P, the age range for clinical participants was 20 to 48 years (M = 34, SD = 8.1), and for control participants it was 20 to 47 years (M = 34.3, SD = 8.3). In Task UP, there were only 2 female clinical participants and 2 female controls. In Task P, there was only 1 female clinical participant and 1 female control. The larger number of males was not due to experimental selection but instead due to the predominance of males among the clinical participants who were referred as volunteers. All participants had received information and instructions before testing, as described earlier. All participants were tested individually and completed the test in one session.

Hypotheses

The hypotheses that were under examination in Experiment 1 were discussed in the previous section on the present research. To summarise: the first hypothesis was that a REA was predicted for the control participants; the second was that an absence or reversal of the REA was expected for the clinical participants; the third hypothesis was that clinical participants were also predicted to demonstrate poorer performance with the LR and RL mixed modes; and the fourth hypothesis was that the clinical participants would show a particular deficit in performance with the LR mode.

Results

The percentage of correct responses (PC) for each combination of Rate and Mode was calculated for each participant. Table 1 shows mean PC as a function of Task, Rate, and Mode for the control participants, and Table 2 shows the same data for clinical participants. The data in Tables 1 and 2 were entered into a four-way mixed ANOVA (Sample and Task as between-subject factors, and Rate and Mode were within-subject factors). The summary ANOVA table can be found in Appendix E1.

Table 1.

Mean Percentage Correct as a Function of Rate, Task, and Mode for Control Participants

		Rate							
		1.2 s		2.0 s		2.8 s		3.6 s	
Task	Mode	M	SD	M	SD	M	SD	M	SD
UP	LL	52.7	23.1	66.3	19.7	74.2	22.7	88.2	14.8
UP	RR	40.6	18.3	63.9	19.6	80.2	16.2	90.3	15.9
UP	LR	37.7	17.9	65.9	16.9	77.8	16.9	87.8	16.2
UP	RL	44.1	12.8	66.7	21.4	82.8	10.1	88.9	17.1
P	LL	40.8	9.8	70.9	8.8	81.4	13.5	85.7	11.7
P	RR	34.0	9.4	72.7	13.8	81.0	13.7	89.2	9.3
P	LR	37.6	10.6	68.4	10.4	81.4	15.8	90.3	5.8
P	RL	36.9	15.6	66.3	16.4	78.8	17.7	93.2	4.1

Note. UP denotes the unpredictable task, and P the predictable task. LL represents the presentation mode of left ear then left ear again; RR, right then right again; LR, left then right; and RL, right then left.

Table 2.

Mean Percentage Correct as a Function of Rate, Task, and Mode for Clinical Participants

		Rate							
		1.2 s		2.0 s		2.8 s		3.6 s	
		M	SD	M	SD	M	SD	M	SD
Task	Mode								
UP	LL	32.9	23.8	46.6	24.2	57.3	25.9	64.1	24.7
UP	RR	35.1	18.0	46.2	23.7	59.7	26.2	66.7	23.7
UP	LR	25.2	17.2	48.9	25.6	57.8	28.6	63.3	22.2
UP	RL	35.1	17.5	46.9	27.9	60.2	22.7	70.6	18.9
P	LL	30.4	8.5	43.7	10.6	45.1	15.5	50.2	18.6
P	RR	31.2	10.6	40.8	18.2	46.2	21.4	48.7	25.4
P	LR	20.8	13.0	40.1	17.3	44.8	26.1	53.4	20.1
P	RL	30.5	16.1	40.1	10.5	52.3	21.3	53.0	20.1

Rate and Performance

It was expected that PC would simply increase as presentation rate (Rate) decreased, to produce a consistent and significant main effect of Rate. Indeed a significant main effect was found for Rate, F (3, 96) = 191.46, p < .0001, ES = 2.48, SP 1.00. There was no significant interaction found for Task x Rate, F (3, 96) = 1.09, p = .36, ES = .18, SP = .19, indicating that the main effect for Rate was consistent for both Task UP and Task P. The small ES of .18 supports the view that there was little or no interaction between Rate and Task.

Sample and Performance

It was also expected that clinical participants would show poorer performance compared to the control participants. Across all factors, mean PC for the clinical participants was 46.5, and significantly lower than the mean PC of 69.3 for the control participants. This was confirmed by a main effect of Sample, F (1, 32) = 19.40, p < .0001, ES = .78, SP 1.00. There was also a sizeable interaction between Rate and Sample, F (3, 96) = 12.94, p < .0001, ES = .64, SP = .96, which is illustrated in Figure 3.

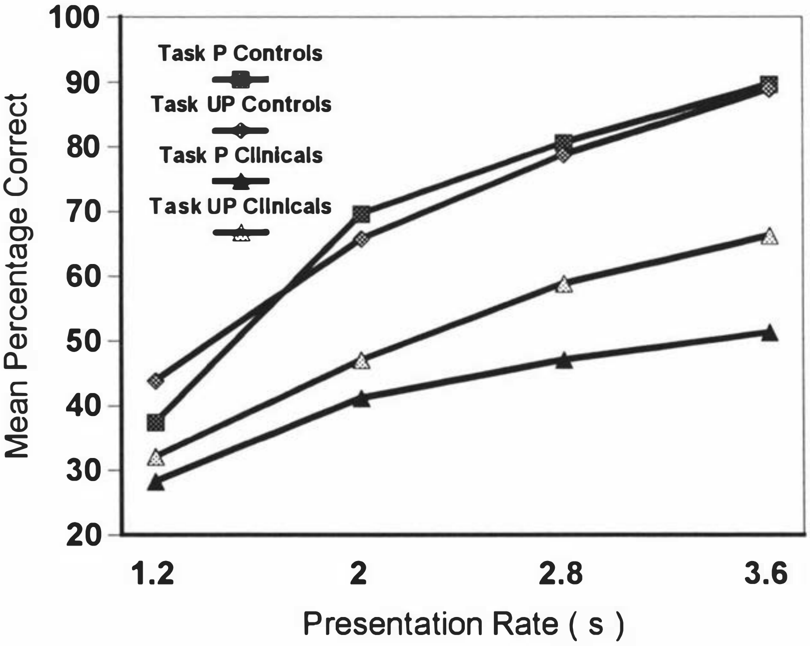

Figure 3. Performance by clinical participants compared to control participants in Task UP and Task P of Experiment 1.

A Least Squares Means (LSM) analysis of this interaction showed that the performance by clinical participants was significantly lower than that by the control participants at all four levels of Rate (all ps < .0001).

Effects of Mode

It was hypothesised that the control participants would show a RR mode superiority in accordance with the prior findings by Norman (1984) and the preponderance of evidence of LH specialisation for temporal processing. It was also expected that the clinical participants would demonstrate either an absence or reversal of the RR mode superiority predicted for the controls. This prediction for the clinical participants was based on other studies which indicate dysfunction of the LH in schizophrenia. In the present experiment, a significant Rate x Mode interaction was found, F (9, 288) = 2.69, p = .005, ES = .29, SP = .39, which is illustrated in Figure 4.

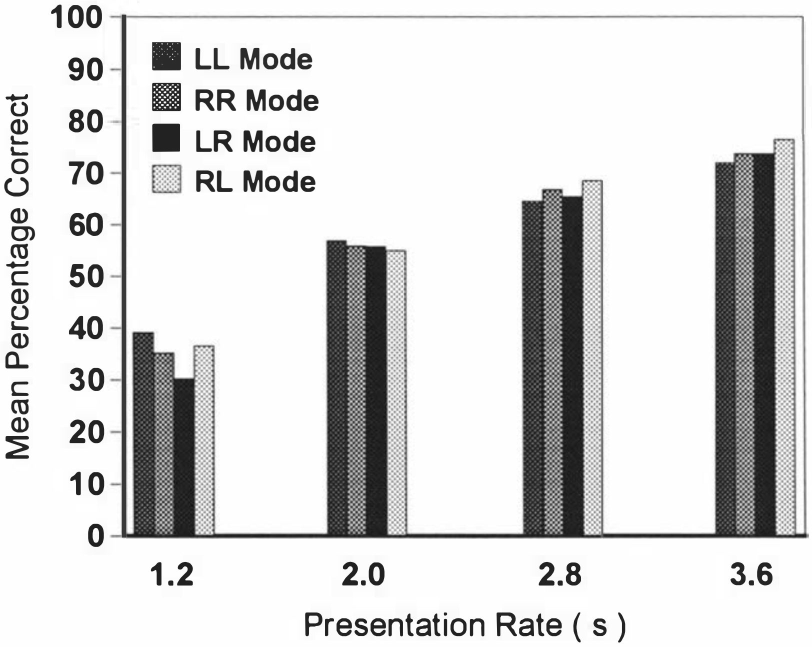

Figure 4. Mean percentage correct over all participants for each combination of Rate and Mode.

A LSM analysis of the Rate x Mode interaction showed, however, that the RR mode was not superior to LL at any levels of Rate. In fact, the reverse was found : LL was superior to RR, but only at the fastest (1.2 s) rate (p = .04). The LSM analysis also indicated that the LR mode was significantly inferior to the RL mode (p = .001), again only at the 1.2 s rate. It is evident in Tables 1 and 2 that the LL superiority over RR at the 1.2 s rate was manifested by the control participants only, and the LR inferiority to RL, at this same rate, was demonstrated only by the clinical participants, suggesting caution in interpreting these results. Furthermore, there was no significant interactions found for Sample x Mode or Sample x Rate x Mode.

Further analyses were undertaken separately for the different levels of Rate. Another four-way mixed ANOVA (Sample, Task, Rate, and Mode) was conducted for the three slower rates together and a three-way mixed ANOVA (Sample, Task, and Mode) for the 1.2 s rate. (The summary tables for these ANOVAs are shown in Appendices E 2 and E 3, respectively.) No significant effects were found at all for the three slower rates. However, at the 1.2 s rate a significant interaction was found for Sample x Mode, F (3, 96) = 2.64, p = .05, ES = .29, SP = .79. A LSM analysis of this interaction confirmed that the LL superiority over RR was indeed attributable to the control participants (p = .005). It also confirmed that the LR inferiority to RL was attributable to the clinical participants (p = .004). These differences between the samples are illustrated in Figures 5 and 6. The LSM analysis also indicated that there was no significant difference between the control and clinical participants for the RR mode (p = .20), but there was a difference between the samples for the LL mode (p < .0001), the LR mode (p < .0001), and for the RL mode (p = .02). There were no significant effects involving Task from the three-way ANOVA.

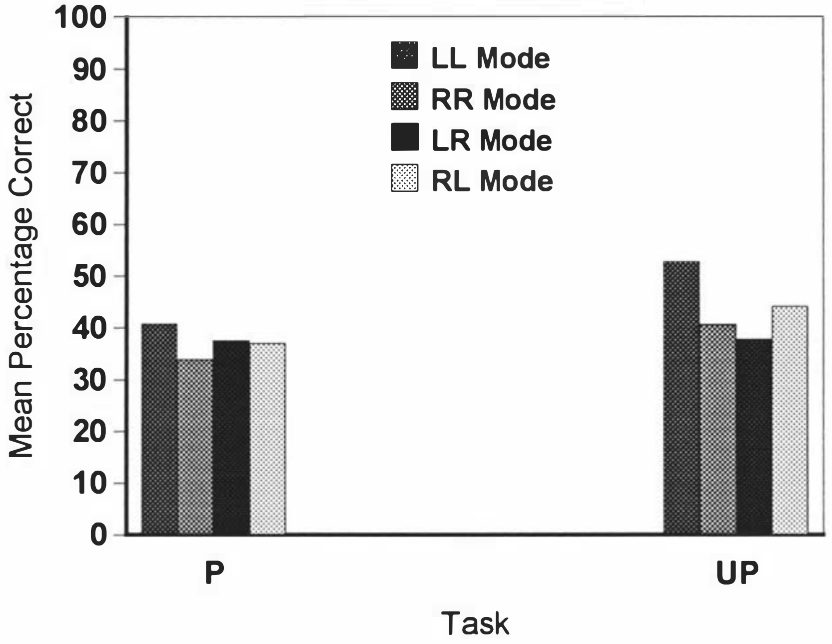

Figure 5. Superiority of the LL mode for Task P (predictable) and Task UP (unpredictable) control participants at the 1.2 s rate in Experiment 1.

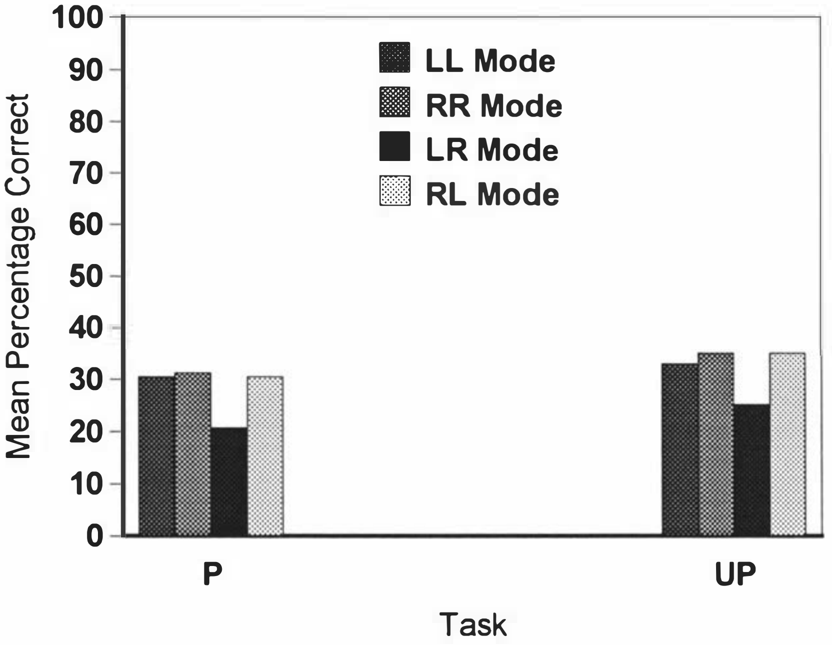

Figure 6. Inferiority of the LR mode for Task P (predictable)and Task UP (unpredictable) clinical participants at the 1.2 s rate in Experiment 1.

To summarise the findings thus far, the predicted RR mode superiority for the control participants did not eventuate. No mode effects were found at the three slower rates (2.0, 2.8, and 3.6 s). Mode effects were only found at the 1.2 s rate. The control participants demonstrated a significant LL mode superiority. Also of note is the finding that performance by the control and clinical participants did not differ for the RR mode. Clinical participants manifested neither a RR or LL mode advantage. Their performance with the RL mode did not differ from the RR or LL modes. However, they showed a significant LR inferiority to the RL mode which is illustrated in Figure 6. Whether these effects of mode at the 1.2 s rate were demonstrated generally or only by a few participants is examined next.

Standard Deviations and Individual Performance

It can be seen in Tables 1 and 2 that the SDs at rate 1.2 s tend to differ between Task UP and Task P in a similar fashion for both the control and clinical participants. For control participants, Task UP mean SD = 18.0 compared to Task P mean SD = 11.3. For clinical participants, Task UP mean SD = 19.0 compared to Task P mean SD = 12.0. This suggested that Task UP at the 1.2 s rate was experienced as being more difficult than Task P by some control and clinical participants. The larger mean SDs for Task UP also suggested that the observed differences between modes may have been attributable to large differences in performance by only a few participants. Table 3 presents the data for PC by individual control and clinical participants at the 1.2 s rate for both Task UP and Task P, and as a function of the mode effects reported above.

Table 3.

Percentage Correct by Individual Participants at the 1.2 s Rate as a Function of Task and the Specific Mode Effects Found for Control and Clinical Participants Respectively

			Percentage Correct by Individual Participant								
Sample	Task	Mode	1	2	3	4	5	6	7	8	9
CN	UP	LL	22.6	74.2	70.9	54.8	64.5	83.9	51.6	29.0	22.6
CN	UP	RR	21.9	46.9	59.4	34.4	46.9	75.0	34.4	18.7	28.1
CN	P	LL	48.4	48.4	48.4	35.5	51.6	32.2	45.2	35.5	22.6
CN	P	RR	32.2	32.2	41.9	19.3	45.2	29.0	25.8	48.4	32.2
CL	UP	RL	6.4	64.5	41.9	25.8	35.5	25.8	22.6	54.8	38.7
CL	UP	LR	10.0	60.0	30.0	13.3	20.0	13.3	16.7	46.7	16.7
CL	P	RL	41.9	32.2	22.6	12.9	19.3	32.2	25.8	19.3	12.9
CL	P	LR	35.5	22.6	25.8	48.4	19.3	29.0	29.0	12.9	16.1

Note 1. CN denotes the control participants, and CL the clinical participants; UP denotes the unpredictable task, and P the predictable task; LL represents the presentation mode of left ear then left ear again; RR, right ear then right ear again; RL, right then left; LR, left then right.

Note 2. PC data are reported for significant effects of Mode as found for controls (LL advantage over RR), and for clinical participants (LR inferiority to RL).

A visual examination of Table 3 shows that 7 out of 9 Task UP control participants performed better with LL compared to RR. The two remaining control participants (#s 1 and 9) showed little or no difference and had the worst performance with both modes. A similar pattern can be seen for Task P control participants. Seven out of 9 participants also showed better performance with LL compared to RR. The performance by the other two Task P controls (#s 8 and 9) did not differ overall from the rest of the group, but they were the only participants to show relatively better performance of RR over LL.

A similar examination was also undertaken of the individual performances by Task UP clinical participants, for the RL and LR modes at the 1.2 s rate. Eight of the participants showed better performance with the RL mode compared to the LR mode. Only one participant showed slightly better performance with LR over RL, but the difference was minimal. Task P clinical participants did not show such a clear distinction between the RL and LR modes. One participant (# 5) showed no difference at all. Of the 8 participants who did show a difference in performance, half did so in favour of RL over LR (#s 1, 2, 6, and 8), and the other half in favour of LR over RL (#s 3, 4, 7, and 9). Participant # 4 had a remarkably high score for LR and one of the lowest scores for RL. Otherwise, those participants whose performance favoured LR over RL showed only slight differences in PC. Therefore, the differences in SD, evident in Tables 1 and 2, for Task UP compared to Task P do not represent atypical levels of performance, by one or few control or clinical participants, creating false impressions of mode effects.

Discussion

A REA (i.e., RR mode advantage) for controls on the PASAT was hypothesised given the sequential and verbal processing requirements of the task, the prior finding of a REA by Norman (1984), Miller's (1996) theory of slower axonal conduction time in the LH, and the abundant evidence which indicates the superiority of the left hemisphere for the processing of sequential information (Bradshaw & Nettleton, 1981; Bryson et al., 1980; Elfgren & Risberg, 1998; Gordon, 1978; Leek & Brandt, 1983; Prior et al., 1990; Robinson & Solomon, 1974; Troyer et al., 1998). However, no REA was found with the controls in the present experiment. Instead, a LEA (i.e., LL mode advantage) was found, but only at the 1.2 s rate.

Stewart (1995), in using both an auditory and visual form of the methodology developed within the present programme, found no significant difference between the LL and RR modes analysed over all four presentation rates (i.e., rates the same as those of the standard PASAT: 1.2, 1.6, 2.0, & 2.4 s) for normal participants (i.e., undergraduate university students of mean age = 26.6 years). However, Stewart did note a trend for greater accuracy in performance for the LL mode compared to the RR mode at the faster rates (1.2 & 1.6 s) in the visual form of the test, but did not do separate analyses at each level of rate to confirm or discount any significance. His data have been reproduced in Appendix F. The trend he refers to is possibly more evident at the 1.6 s rate (LL mean = 73.3 compared to RR mean = 63.3). This trend at least does not contradict the finding of an LEA for normal participants at the 1.2 s rate in the present experiment. There are a number of possible explanations for this LEA.

Firstly, the LEA at only the fastest rate could indicate that the RH takes over all or the majority of the processing of the sequential task because of its ability to rapidly conduct information. However, the fastest rate on the PASAT is 1.2 s, which is far slower than the 25 ms hypothesised for interhemispheric transmission of information via the corpus callosum (Crow, 1998). Furthermore, Miller's (1996) theory on the cut-off between the hemispheres in terms of axonal conduction time is also on the scale of ms (i.e., RH advantage for processing information at under 100 ms). Hence, it seems unlikely that the PASAT, even at the fastest rate, was being processed in full by one hemisphere.

An alternative interpretation to that based on temporal integration theory comes from the results observed for the clinical participants. These results instead indicate problems in selective attention, rather than with the sequential task *per se*. That is, their performance on the PASAT with the RL mode did not differ from that with the LL or RR modes, and did not differ from the controls with the RR mode. Taken together, these findings suggest that the clinical participants did not have a generalised bilateral problem in switching their attention, nor LH dysfunction at the fast 1.2 s rate. However, they did show a significantly inferior performance with the LR mode at the 1.2 s rate. The findings by Posner et al. (1988), and replicated by Wigal et al. (1997) with the cued reaction time task, provide a basis for interpreting these results for the clinical participants in the present experiment.

It was discussed earlier how the first stimulus in each of the LR and RL mixed modes on the PASAT are theoretically analogous to the invalid cues used in the cued reaction time task. Posner et al. (1988) found evidence that showed that participants with schizophrenia had a particular problem with disengaging their attention from the left visual field (RH) and instead orienting to the right visual field (LH). They interpreted this finding as indicating slowness of the LH to engage in visual spatial attention.

Bustillo et al. (1997) also reported that they found slower performance in the right visual field (LH) as compared to the left visual field (RH) for participants with schizophrenia tested with the cued reaction time task. However, this slowness was independent of any valid or invalid cues, and again occurred only with the 100 ms ISI. They also argued that this indicated slowness in the LH rather than a problem in disengagement of attention from the left field (RH). However, they found these results with only a non-deficit group (i.e., no negative symptoms of schizophrenia), but not with a deficit symptom group. The deficit group had poorer performance overall but did not show any asymmetry. Both clinical groups were on medication at the time of testing. The researchers were probably unaware of Miller's (1996) theory on axonal conduction, so better performance by the non-deficit group with the left visual field at the 100 ms ISI could suggest that they had a relatively intact RH, possibly assisted by medication, compared to the deficit group. It may have taken ISIs faster than 100 ms to demonstrate a similar RH advantage in normal controls.

Nestor et al. (1992) reported results with the cued reaction time task that differ from both Posner et al. (1988) and Bustillo et al. (1997). Most of their clinical participants also had positive symptoms of schizophrenia, and were on medication. Nestor et al. found that their clinical participants, compared to controls, had an abnormally fast reaction time to invalid cues presented to the right visual field (LH). They interpreted these results as representing an abnormal rapid, rather than slowed, disengagement of attention by the LH. Clearly, these results differ from those found by Bustillo et al. even though the clinical participant groups used were similar. One explanation for the difference may be to do with medication, although types and dosages were not specified by the two sets of investigators.

Wigal et al. (1997) looked at the issue of medication. They replicated the findings by Posner et al. with clinical participants who, at the time of testing, had been medication-free, had a recent acute relapse, and were described as predominantly having chronic illness histories (which implies a higher chance of including negative symptoms).

The findings for clinical participants in the present experiment support the hypothesis of RH dysfunction for the disengagement of attention in schizophrenia. They do not agree with the findings by Bustillo et al. (1998) and Nestor et al. (1992) because, in the present experiment, the performance by clinical participants with the RL mode did not differ from that with the RR mode (LH). Also, their performance did not differ from that by controls with the RR mode. In other words, there was no evidence of poorer or enhanced performance by the LH for the clinical participants compared with the controls. A possible explanation for the lack of agreement with the findings by Bustillo et al. and Nestor et al., is that only 2 of 18 clinical participants in the present experiment were diagnosed as having only positive (non-deficit) symptoms of schizophrenia. The other clinical participants all had negative symptoms.

The other interesting finding in the present experiment is that the LR mode inferiority for clinical participants occurred in both the predictable (Task P) and unpredictable (Task UP) conditions. Nestor et al. (1992) had interpreted their results also in terms of stimulus predictability. They reported that while target stimuli were presented with equal probability, valid cues were presented in 64% of trials, invalid cues only 16%, and no cues for 20% of trials. Hence, they considered invalid cues to be less predictable. However, they further reported that the performance by clinical participants, compared to the controls, was less disrupted by the less predictable invalid cues. They concluded that this was consistent with Shakow's (1962) idea that reaction time performance of participants with schizophrenia is less disrupted by less predictable sequences of stimulus events. That is, it is presumed that people with schizophrenia have difficulties with maintaining a mental set, which would allow them to benefit from regular, predictable sequences, but some irregularity can be of assistance to evoke their attention.

However, in the present experiment great care was taken to counterbalance all four modes of presentation, and the issue of predictability was examined by blocked (Task P) as opposed to intermixed (Task UP) trials. At the 1.2 s rate, no effect of Task was found. This suggests that the LR mode inferiority found with clinical participants in both tasks is more a higher level problem of disengaging attention, rather than an effect of having to switch attention at the sensory level or a bilateral difficulty in focusing attention due to unpredictability. Furthermore, the relatively intact performance with the RL and RR modes also supports this argument.

The finding of a lateralised attention deficit with the clinical participants, in the present experiment, suggests that the LL mode superiority found for the controls represents a RH specialised function for selective or sustained attention in normals. However, the LL mode superiority might need to be viewed with some caution. This is due to the fact that the finding of a LL mode superiority at the 1.2 s rate differs from the hypothesised RR superiority at any of the rates. It obviously differs from Norman's (1984) finding of a RR superiority for control participants, and, therefore, indicates some possible instability of the PASAT to deliver reliable lateralised effects. This would have implications in terms of the PASAT's efficacy for use in the research of schizophrenia. Furthermore, the above comparisons have been with the cued reaction time task in which the scale of ISI (100 ms or 800 ms) differs from the fastest 1.2 s rate on the

PASAT. Accordingly, another experiment using non-clinical participants was undertaken to examine whether the findings for the controls in the present experiment were in fact replicable.

Experiment 2

Method

Design and Procedure

The present experiment employed a three-way factorial design : 2 Tasks (Task P and Task UP); 4 rates (1.2, 2.0, 2.8, and 3.6 s); and 4 modes (LL, RR, LR, and RL). Participants were recruited as described in the general method section. All 20 participants were non-clinical volunteers. Half of the participants were randomly assigned to Task P, and the other half to Task UP. Each task had 5 males and 5 females. The participants in Task P had an age range of 21 to 42 years (M = 33.2 years, SD = 7.4), and those in Task UP had an age range of 22 to 47 years (M = 33.4 years, SD = 9.8). As for Experiment 1, all participants were tested individually in one session.

Hypotheses

The present experiment examined the same principal hypotheses on temporal integration as in Experiment 1. However, a LEA (LL mode advantage) was found instead of the hypothesised REA (RR mode advantage) for the normal controls in Experiment 1. This finding contrasts with the REA found by Norman (1984), and so suggested some possible instability in performance on the lateralised PASAT. However, a number of careful modifications to the lateralised PASAT were undertaken in the present research to counter possible artefacts in Norman's (1984) procedures. The changes made to the PASAT in the present investigation included greater precision in randomising and counterbalancing of even and odd, and low and high arithmetic outcomes, the removal of the digit seven because of its two-syllable pronunciation, and the randomisation of presenting the different combinations of Rate and Mode to counter any practise effect. These changes may have been responsible for the disparity seen in the present results compared to those of Norman (1984). Furthermore, the finding of a LR mode inferiority to the RL mode for the clinical participants indicated a lateralised attentional deficit, as hypothesised by Posner et al. (1988), and suggested the LEA (LL mode advantage) over the right ear (RR mode) for the normal controls represents a RH specialised function for sustained attention. Accordingly, the present experiment also examined whether the finding of a LEA, instead of a REA, for the controls in Experiment 1 could be replicated.

Results

The dependent measure was again the percentage correct responses (PC) for each combination of Rate and Mode, calculated for each participant. Table 4 shows the mean PC as a function of Task, Rate, and Mode. A three-way mixed ANOVA (Task as a between-subject factor, and Rate and Mode as within-subject factors) was conducted with the data from Table 4. The summary ANOVA table is presented in Appendix E 4.

Rate and Performance

The expected increase in PC as presentation rate (Rate) decreased was found, producing a significant main effect for Rate, F (3, 54) = 174.18, p < .0001, ES = 3.10, SP 1.00. There was no significant interaction of Task x Rate, F (3, 54) = 0.20, p = .89, ES = .10, SP = .26 , which shows that overall performance did not differ between the participants of Task UP (M = 75.9) and Task P (M = 77.2). This finding concurs with there being no interaction found for Task x Rate in Experiment 1.

Effects of Mode

The principal hypothesis of the present experiment was the same as that for Experiment 1, that is, that normal participants would demonstrate a REA with the lateralised PASAT. However, once again, no REA was found with the participants of this present experiment. A main effect of Mode was found, F (3, 54) = 3.41, p = .02, ES = .44, SP 1.00. A Tukey test indicated that the LL mode was superior to the RR mode; that is, there seemed to be a LEA, as for Experiment 1. However, there was also a significant Task x Rate x Mode interaction, F (9, 162) = 2.82, p = .004, ES = .39, SP 1.00, qualifying the main effect of Mode. A LSM analysis of this interaction showed that the LL mode superiority over the RR mode occurred only at the 1.2 s rate and only for the Task UP participants (p < .0001). This finding is illustrated in Figure 7.

Table 4.

Mean Percentage Correct as a Function of Rate, Task, and Mode in Experiment 2

		Rate							
		1.2 s		2.0 s		2.8 s		3.6 s	
		M	SD	M	SD	M	SD	M	SD
Task	Mode								
UP	LL	57.4	10.4	78.1	14.2	87.4	14.4	92.9	9.6
UP	RR	44.7	8.2	71.9	14.3	87.2	12.8	89.7	9.1
UP	LR	44.7	11.2	80.3	12.2	92.0	8.8	89.0	16.5
UP	RL	42.2	9.3	74.5	15.8	89.0	9.9	93.2	9.8
P	LL	48.4	12.6	76.8	15.5	89.3	12.2	97.1	2.8
P	RR	47.1	18.9	79.3	18.5	88.7	9.3	92.2	9.0
P	LR	52.2	14.6	73.2	15.4	88.7	7.5	92.9	5.2
P	RL	43.9	16.9	76.8	11.7	92.9	5.6	96.1	3.7

The Task x Rate x Mode interaction also indicated some effects that were not found with the control participants of Experiment 1. First, as already mentioned, the Task P participants in this present experiment did not show a LEA or REA. In Experiment 1 there were no interactions with Task. This suggested that the Task P participants of that experiment did manifest a significant

LEA, as illustrated in Figure 5, albeit smaller than the LEA shown by the Task UP participants. Secondly, the LSM analysis of the above Task x Rate x Mode interaction indicated that the Task P participants of Experiment 2 manifested a LR mode superiority over the RL mode at the 1.2 s rate (p = .007), as illustrated in Figure 7. This finding also differs from the observation of no apparent difference in performance between the LR and RL modes for the Task P participants of Experiment 1, and the Task UP participants of both experiments.

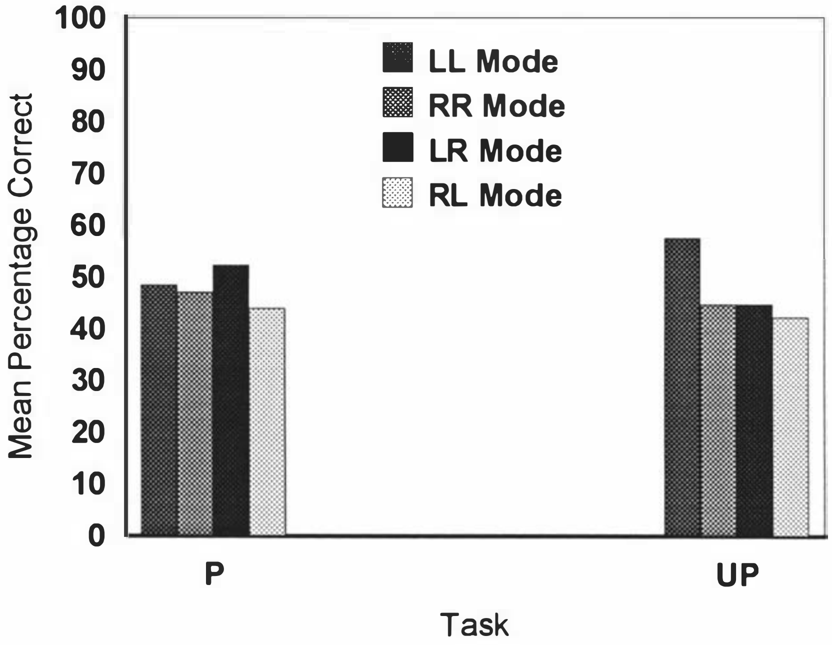

Figure 7. Superiority of the LL mode for normal participants in Task UP compared to Task P at the 1.2 s rate in Experiment 2.

Standard Deviations and Individual Performance

It can be seen in Table 4 that at the 1.2 s rate the SDs are larger for Task P than for Task UP. The mean SD for Task P is 15.7, compared to the mean SD of 9.8 for Task UP. This again raised the question of whether there were atypical levels of performance by only a few participants creating false impressions of mode effects. Table 5 displays the data for PC by individual participants at the 1.2 s rate for both Task UP and Task P, and as a function of the mode effects reported above.

Table 5.

Percentage Correct by Individual Participants at the 1.2 s Rate as a Function of Task and the Specific Mode Effects Found in Experiment 2

		Percentage Correct by Individual Participant									
Task	Mode	1	2	3	4	5	6	7	8	9	10
UP	LL	61.3	61.3	71.0	74.2	45.2	45.2	54.8	45.2	54.8	61.3
UP	RR	40.6	40.6	50.0	53.1	34.4	40.6	43.8	40.6	40.6	62.5
P	LL	51.6	41.9	51.6	54.8	41.9	45.2	22.6	45.2	58.1	70.9
P	RR	45.2	22.6	54.8	35.5	51.6	45.2	25.8	45.2	54.8	90.3
P	LR	41.9	41.9	67.7	51.6	70.9	38.7	35.5	48.4	48.4	77.2
P	RL	48.4	25.8	67.7	29.0	29.0	41.9	29.0	41.9	51.6	74.2

Note. In Task UP, Experiment 2, the only mode effect found was a LEA (LL superiority). The LL and RR mode data are also shown for Task P, as the absence of a LEA with this task is notable. The data for the LR and RL modes in Task P are shown because the LR mode superiority was found in Task P.

It can be seen in Table 5 that for Task UP, 9 out of 10 participants showed the LEA. Participant # 10 was the only one to show no difference between the LL and RR modes. In Task P, two participants (#s 6 and 9) showed no difference in performance with the LL and the RR modes. Of the remaining 8 Task P participants, half showed performance in favour of LL over RR and the other half showed the reverse. With regard to the LR and RL modes with Task P, 6 participants demonstrated better performance with LR compared to RL. The remaining 4 participants (#s 1, 3, 6, and 9) showed either no or only slightly better performance with the RL mode. Hence, the LEA clearly demonstrated in Task UP but not Task P, and the LR superiority in Task P, were not due to atypical performance by only a few participants.

Combined Analyses

The results from Experiments 1 and 2 were disappointing in that none of the main hypotheses of temporal integration were supported. Because Experiment 2 was an exact replication of the Task P and Task UP conditions of Experiment 1, it was possible to increase the power of the statistical tests by combining the results. Further analyses of the combined data for all non-clinical normal participants from both experiments were conducted, which increased sample size from 9 (Experiment 1) or 10 (Experiment 2) to 19 for each task condition.

A three-way mixed (2 tasks x 4 rates x 4 modes) ANOVA indicated a significant Mode x Rate interaction, F (9, 324) = 3.79, p < .0001, ES = .31, SP 1.00, and a significant Task x Mode x Rate interaction, F (9, 324) = 3.38, p = .0006, ES = .30, SP 1.00. The summary ANOVA table is shown in Appendix E 5. A LSM analysis of the Mode x Rate interaction, illustrated in Figure 8, showed again that this interaction is attributable to the LL mode being superior to the other three modes but only at the 1.2 s rate (all ps <.0001). A LSM analysis of the Task x Mode x Rate interaction showed that the LL superiority clearly occurred within the unpredictable but not the predictable condition at the 1.2 s rate. The interaction also indicated that for Task P there was no significant difference between the LL and RR modes, but performance was significantly better with the LR mode compared to the RL mode at the 1.2 s rate (p = .04).

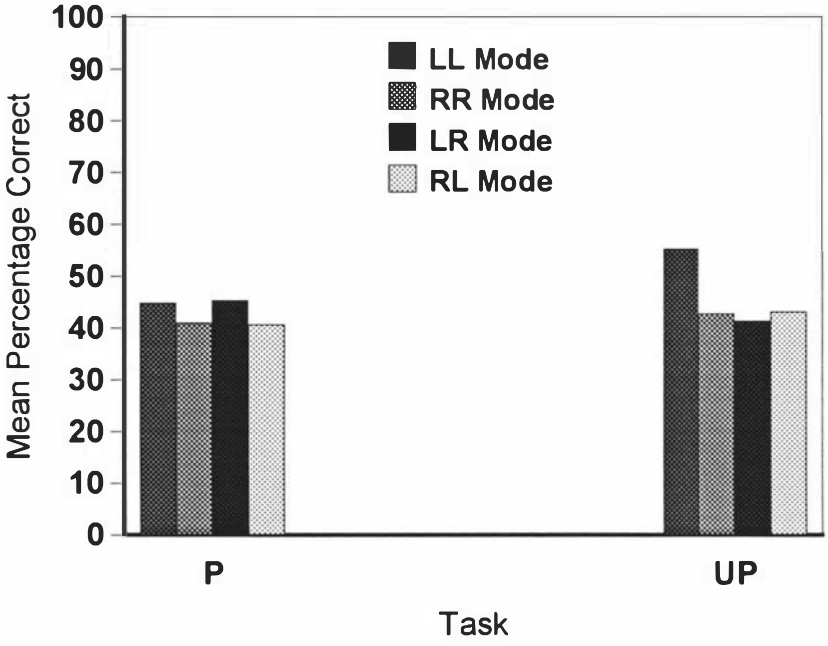

Figure 8. Performance of normal participants in Task P compared to Task UP at the 1.2 s rate combined across Experiments 1 and 2.

Discussion

To summarise the results from Experiment 2 : no REA was found at any of the rates, an LEA was replicated at the 1.2 s rate by the Task UP participants only, and the Task P participants demonstrated an apparent superiority of the LR mode over the RL mode at the 1.2 s rate. The fact that again no REA was found with normal participants on the lateralised PASAT, after careful modifications to eliminate artefacts that could have occurred in Norman's (1984) procedures, does suggest that the lateralised PASAT fails to be of use for examining hypotheses on temporal integration involving hemispheric differences.

Although in Experiment 2 the LEA was replicated in the Task UP condition, the Task P participants, unlike Experiment 1 normal participants, did not demonstrate a LEA. The Task P participants instead manifested a better performance with the LR mode compared to the RL mode. These inconsistent results for Task P were further investigated by combining the data for normal participants over Experiments 1 and 2. The inferiority of RL to LR was again found at the 1.2 s rate for Task P but not Task UP. The LEA again only occurred in the Task UP condition.

The replication of a LEA for normal participants at the 1.2 s rate strengthens the argument that attentional factors, rather than temporal integration processes, were evoked by the faster presentation of stimuli. This finding of a RH performance advantage concurs with the study by Pardo et al. (1991) in which they examined brain blood flow via PET while normal right-handed participants performed vigilance tests. The first test was a somatosensory vigilance test in which the temporal parameters used were on the scale of seconds, like the PASAT. Participants were required to focus their attention upon either their left or right great toe so as to detect brief pauses in a volley of suprathreshold touches. The toe was touched with a fine hair. The pauses lasted 1 to 3 s and were delivered about every 10 s during a 40 s trial. Pardo et al. found that there was no evidence of activation in the LH frontal cortex, but there was RH prefrontal and superior parietal activation regardless of which toe was stimulated. The same participants were also administered a visual vigilance test. On this test they were told to detect near-threshold luminance changes of a dim central fixation mark. No actual changes in luminance occurred during the PET scan. So the behaviour of interest was really the participant's maintenance of attention at centre of visual field. The PET showed evidence of activation again in the RH prefrontal and superior parietal cortices. The somatosensory test had also shown some activation in the RH temporal regions, whereas the visual test did not. The results from both of these tests indicated that similar lateralised (RH) cortical activation was evoked by different sensory modalities and was not related to the laterality of sensory input. Pardo et al. argued that these results defined a RH neural network involved in sustained attention, which supports other observations that damage to the RH, as opposed to the LH, has greater detrimental effect on attentional processes.

Other evidence supportive of the hypothesis of RH specialisation for attentional processes comes from the study by Simos and Molfese (1997). They report that adult participants show significant abrupt changes in peak amplitude of auditory evoked EEG responses, located at the right parietal region, in response to non-lateralised presentation of temporal lags between tonal stimuli. Infants and young children do not show this lateralised response, which is another indication of how lateralisation of certain brain functions is developed throughout childhood.

In the two vigilance tests administered by Pardo et al. (1991) each trial was 40 s. These trials were considered to be tasks of sustained attention. Hence, it seems reasonable to argue that the trial length of 37 s for the 31 summations at the 1.2 s rate on the PASAT also certainly involved sustained attention. It also seems fair to argue that the very fast 1.2 s rate of stimulus presentation on the PASAT would pose substantial attentional demands on participant performance and so could activate the RH specialised neural network hypothesised by Pardo et al. Their study did not include actual dependent measures of participant performance. Therefore, there was no information to indicate whether performance may have been better with stimuli directed to the RH, as opposed to the LH, under conditions requiring sustained attention. The replicated LEA at the 1.2 s rate for normal participants in the present research suggests that this is in fact the case. The LR mode inferiority demonstrated by the clinical participants in Experiment 1, further supports this argument; that is, performance with left field stimuli, under conditions of sustained attention, is compromised by dysfunction of the RH neural network normally specialised for attention.

Although the combined analyses of results from both Experiment 1 and 2 showed the LEA was found with the Task UP condition, the Task P participants did not demonstrate a LEA. The Task P participants instead manifested a LR mode superiority over the RL mode. However, these two apparently different results could be interpreted as still supportive of the hypothesis of a RH specialised function for attention.

The first interpretation is that the LR and RL modes in Task P require a participant to switch their orientation between left and right sensory field. Although switching is predictable, the fast stimulus presentation would more likely evoke attentional processes. In this circumstance, a stimulus directed to the RH could likely be processed more efficiently than if first directed to the LH. That is, with the first stimulus of the LR mode pairing being directed to the RH, the left ear stimulus would be undergoing efficient processing before processing of the right ear stimulus begins. The reverse would be the case for the RL mode pairing; that is, the less efficient LH processing of the right ear stimulus could interfere more with the processing of the following left ear stimulus. This interpretation infers a necessary synthesis of Pardo et al.'s (1991) hypothesis of the RH specialised function for sustained attention and Kinsbourne's (1975) selective activation theory.

The second interpretation involves the LEA found for Task UP but not Task P. This apparent contrast between the tasks, could be due to the greater complexity of the unpredictable / intermixed modes, at a fast presentation rate, evoking the more efficient RH for attentional processes. In this context, a lateralised effect with a same mode pairing (LL vs. RR) might be more easily demonstrable. On the other hand, the simpler attentional demands of the predictable / blocked LL and RR same mode pairings would be insufficient to show a lateralised effect. That is, a task condition that poses less attentional demand might allow more diffuse individual variation in attentional strategy (Bryden, 1986; Iaccino & Houran, 1991). This does appear to be the case for the inconsistent results for Task P between Experiment 1 and 2 normal participants. Despite overall performance at the 1.2 s rate by Experiment 1 Task P participants (M = 37.4) being less than Experiment 2 Task P participants (M = 47.7), 7 out of 9 Experiment 1 Task P participants showed the LL mode superiority over the RR mode. In Experiment 2 Task P only 4 participants manifested the LL superiority, while 4 other participants showed the reverse.

In summary, no REA was found for normal participants in Experiment 1 or Experiment 2. In light of the abundant evidence on LH specialisation for temporal processing, this lack of a demonstrable REA suggests that the PASAT failed to be of use for examining temporal integration theory. However, the finding of a LEA for normal participants in the present research is compatible with Pardo et al.'s (1991) hypothesis and other evidence for a RH specialisation for vigilance and sustained attention (Coslett et al., 1987; Dimond, 1979; Heilman & van den Abell, 1979, 1980; Howes & Boller, 1975; Ladavas et al., 1989, 1994; Loring et al., 1989; Simos & Molfese, 1997; Whitehead, 1991; Wilkins et al., 1987; Yokohama et al., 1987). The findings of a LL and LR superiority for normal participants supports the interpretation that the LR inferiority found for the clinical participants of Experiment 1 is due to dysfunction of the RH neural network normally specialised for vigilance and sustained attention. The evidence from the present research further suggests that it requires a fast stimulus presentation rate and a task with unpredictability of mode (i.e., ear of presentation) to clearly demonstrate a LEA in normal participants, whereas for participants with schizophrenia, a fast presentation rate is also required, but the problem of disengagement can also be shown in less complex task conditions (i.e., predictable blocked modes of ear of presentation).

The present research programme set out primarily to examine mode effects that might indicate evidence of hemispheric specialisation for the PASAT in both normals and people with schizophrenia. As previously outlined one could have expected a REA for normals but an absence of a REA, or a LEA instead, in schizophrenia; but no evidence was found for LH advantage or dysfunction with the PASAT. Thus, all of the preceding discussion has been about observations that occurred only at the fastest (1.2 s) rate, which suggest support for the RH specialisation for attention.

However, another interesting observation occurred with the clinical participants in Experiment 1. Performance with Task P, compared to Task UP, seemed to relatively worsen as presentation rate slowed (see Figure 3). There were no differences between the Task UP and

Task P clinical groups in terms of selection into the study and their random assignment to either task. The ANOVA of the data for the three slower rates did not indicate a significant interaction of Sample x Task x Rate to support this observation. However, a possible trend toward poorer performance by the clinical participants of Task P as presentation rate was slowed seemed to be worthy of further examination. This observation also reflects what Nestor et al. (1992) described as Shakow's (1962) notion that person's with schizophrenia have difficulty with maintaining a mental set, particularly under conditions of regular and predictable sequences. Hence, the following experiment (Experiment 3) looked at this potential issue of the effect of slow presentation rate on performance. The twofold problem of difficulty in recruiting sufficient numbers of new clinical participants, and some uncertainty whether the PASAT is sufficiently reliable as a lateralised research tool, meant that only non-clinical participants were recruited for Experiment 3. Because of the interest in whether slow presentation rate *per se* might have an effect on performance, and not just potential effects caused by lateralised presentation, a non-lateralised version of the PASAT was also included in Experiment Three. However, the evidence on the RH specialisation for attentional processing in normal participants also suggests that very extended ISIs (slow presentation rates) might tax sustainability of attention. Therefore, it is hypothesised that a LEA would again be demonstrable with the lateralised PASAT at very extended ISIs.

Experiment 3

Method

There were two major changes to the procedures described in the General Method section and to those used in the two previous experiments. The first change was to the presentation rates. In the present experiment (Experiment 3) four rates were used beginning at 2.0, then 3.6, 5.2, and 6.8 s. The 1.2 s rate was not included as it is already apparent that this rate differs from slower rates in terms of performance and interactions with Mode. The 2.0 and 3.6 s rates were retained for comparison with the additional rates. The previously used 2.8 s rate was not included so as to keep the number of different rates constant as four. The two slower rates (5.2 and 6.8 s) were simply derived from equal increments of 1.6 s based on the difference between the rates 2.0 and 3.6 s.

The second change was the inclusion of a third mode condition. Both the Task P (predictable blocked presentation) and Task UP (unpredictable randomised presentation) as previously used in Experiments 1 and 2 were again employed. In addition, a Task S condition was included in which the presentation of each auditory digit stimulus is to both ears simultaneously, like the standard PASAT. The purpose of including this third condition was to examine whether any decrement in performance might have been common to all three conditions and hence due to slowing of presentation rate, rather than potential effects caused by the lateralised presentation.

Design and Procedure

Experiment 3 examined three factors, Task (Task P, Task UP and Task S), Rate (2.0, 3.6, 5.2, and 6.8 s), and Mode (LL, RR, LR, and RL). However, the analysis was predetermined as follows: a two-way ANOVA to examine Task x Rate, and a three-way ANOVA to look at Task x Rate x Mode. The reason for breaking the analysis into two ANOVAs was that Task S did not involve Mode as a factor. The participants were 15 female and 12 male non-clinical volunteers, all right handed and recruited as described in the General Method section. They were randomly assigned to the three tasks, with 5 females and 4 males being placed in each of the tasks. Participants' ages ranged from 22 to 43 years (M = 33.9 years, SD = 8.3) in Task P, from 21 to 40 years (M = 31.1 years, SD = 6.3) in Task UP, and from 20 to 43 years (M = 31.8 years, SD = 8.9) in Task S. In other respects, the procedures employed were identical to those in Experiments 1 and 2.

Hypotheses

The principal interest of this present experiment was to find out if performance with the PASAT is affected as presentation rate is slowed. This interest was based on the observation of a possible trend in worsening of performance by Experiment 1 Task P, relative to Task UP, clinical participants as presentation rate was extended. It was presumed that non-clinical participants might also show worsening of performance if presentation rate was sufficiently slowed. That is, it is not difficult to imagine that at very slow rates (and hence extended ISIs) a participant might experience increased saliency of other normal everyday cognitions. The interference of other cognitions could lead to decreased attention to the PASAT. Therefore, the first hypothesis of Experiment 3 was that as presentation rate is slowed, decreased attention to the task will lead to a corresponding decrease in performance. The inclusion of Task S was to examine the above hypothesis in the absence of any potential interaction with any lateralised effects.

Experiment 3 also allowed for testing Sampson and MacNeilage's (1960) stimulus-dependent model of temporal integration theory. Their theory assumes that in order for temporally integrated response sequences to be sustained, a variable but consistent and related background of stimulation is required. That is, with insufficient stimulation, break down in temporal integration is indicated by poorer performance. By their definition, the very extended presentation rates in the present experiment would have meant insufficient stimulation. Another hypothesis, related to Sampson and MacNeilage's model, is that performance with Task UP would be less affected than with Task P as presentation rate slowed. In Task UP there is the requirement of participants to switch their orientation to either left or right sensory field. This additional feature of unpredictable stimulus presentation was expected to maintain a higher level of attention to the PASAT than in Task P. In other words, maintenance of some attention to the task would then lead to less decrement of performance at slow presentation rates.

A fourth hypothesis was that a LEA would again be found due to the above predicted effects of slowed presentation rate on participants' ability to maintain their attention to the PASAT. This hypothesis is based on the LEA already demonstrated for non-clinical participants in the present research and other evidence of RH specialisation for attentional processes (Pardo et al., 1990). The third hypothesis predicted greater difficulty in maintaining attention in Task P, as opposed to Task UP. Hence, the LEA is expected to be found with Task P and not only (or not at all) with Task UP at the slow rates of presentation.

Results

Table 6 shows mean PC as a function of Task and Rate (for all three tasks), and also in relation to Mode (for Tasks P & UP only). These data were entered into two different ANOVAs. The first was a two-way mixed ANOVA (Task as a between-subject factor, and Rate as a within-in subject factor) of the data on rate across all three tasks but excluding Mode

(because Task S did not include Mode).The second was a three-way mixed ANOVA (Task as a between-subject factor, and Rate and Mode as within-subject factors) conducted for the data from Task P and UP. The summary tables of these ANOVAs are presented in Appendices E 6 and E 7, respectively.

Table 6.

Mean Percentage Correct as a Function of Rate, Task, and Mode in Experiment 3.

		Rate							
		2.0 s		3.6 s		5.2 s		6.8 s	
Task	Mode	M	SD	M	SD	M	SD	M	SD
UP	LL	75.6	11.9	91.4	8.4	96.4	4.1	97.5	1.4
UP	RR	74.6	14.5	93.8	7.6	95.8	3.1	99.3	1.4
UP	LR	75.2	8.5	91.9	5.0	95.2	5.0	96.7	3.3
UP	RL	68.5	8.6	92.1	6.0	98.2	3.6	96.1	3.9
P	LL	87.5	15.8	94.9	8.4	96.1	7.2	98.6	4.3
P	RR	86.0	18.3	95.7	6.6	98.2	3.6	98.5	3.2
P	LR	84.9	17.7	95.0	7.4	99.6	1.1	98.2	2.3
P	RL	82.1	18.8	97.1	3.4	98.6	2.3	98.2	3.3
S	[none]	81.5	13.4	93.4	7.2	96.6	2.9	96.9	3.2

Note. S denotes the simultaneous task, which has no separate presentation of mode for each ear.

It can be seen in Table 6 that at the 2.0 s rate the SDs are larger for Task P (mean SD = 17.6) compared to Task UP (mean SD = 10.7). However, an examination of individual performances showed that there was general consistency in levels of performance with respect to each mode in both tasks.

Rate and Performance (Across Tasks P, UP, and S)

The two-way ANOVA indicated there was no main effect for Task, F (2, 24) = 1.39, p = 0.27, ES = .34, SP = .86. There was also no significant interaction of Task x Rate, F (6, 72) = 1.77, p = 0.12, ES = .38, SP = .81. Although there was no overall significant difference in mean PC between Task P (M = 94.3), Task UP (M = 89.9), and Task S (M = 92.1), (see Figure 9), it can be noted that there were moderate effect sizes of .34 and .38. There was a significant main effect for Rate, as expected, F (3, 72) = 52.96, p < .0001, ES = 1.46, SP 1.00. A Tukey test showed that PC at the 2.0 s rate (M = 80.0) was significantly different from the other three rates (Figure 9). However, PC was not different between these three slower rates: 3.6 s (M = 93.8), 5.2 s (M = 97.0), and 6.8 s (M = 97.5). However, the failure to reach significance here was probably due to a ceiling effect as PC approached a maximum. It is important to note that the mean PC values are consistent with the idea that Rate and PC are positively correlated, but with performance increments plateauing as the ISI increased to 6.8 s (or rate of change slowing). An ISI of 6.8 s is quite lengthy and so it is a little surprising that performance did not decline.

Effects of Mode (Across Tasks P and UP)

The three-way ANOVA (2 tasks x 4 rates x 4 modes) of the data from Tasks P and UP showed that there was no main effect for Mode, F (3, 48) = 1.15, p = 0.34, ES = .27, SP = .97. However, there was a significant Mode x Rate interaction, F (9, 144) = 2.06, p = 0.04, ES = .36, SP = .99. A LSM analysis indicated that this interaction was attributable to the RL condition producing fewer correct responses compared to LR (p = .004), to LL (p =.0002), and to RR (p = .002), but only at the fastest 2.0 s rate. There were no other effects of mode at the 2.0 s rate or the three slower rates. There was also a significant Task x Rate interaction, F (3, 48) = 3.05, p = .04, ES = .44, SP 1.00. A LSM analysis of this interaction showed that Task UP participants obtained lower PCs relative to the Task P participants, but only at the 2.0 s rate (p < .0001). There were no differences between tasks at the three slower rates. Figure10 shows that the effects identified by the ANOVA pertain to PC for Task UP participants being less than that for Task P participants for all 4 modes, but possibly more so for RL.

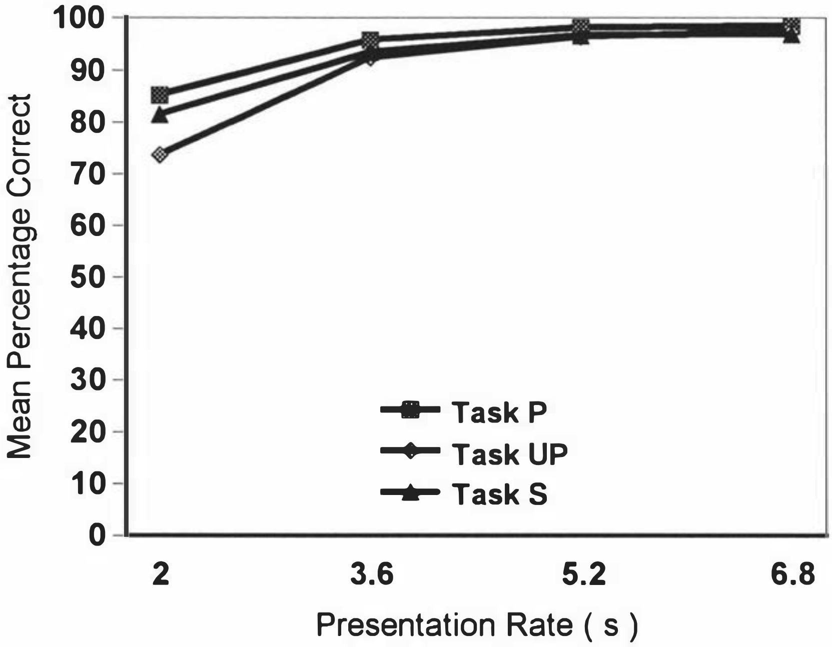

Figure 9. Mean percentage correct across all four rates for normal participants in Task P (predictable), Task UP (unpredictable), and Task S (simultaneous), in Experiment 3.

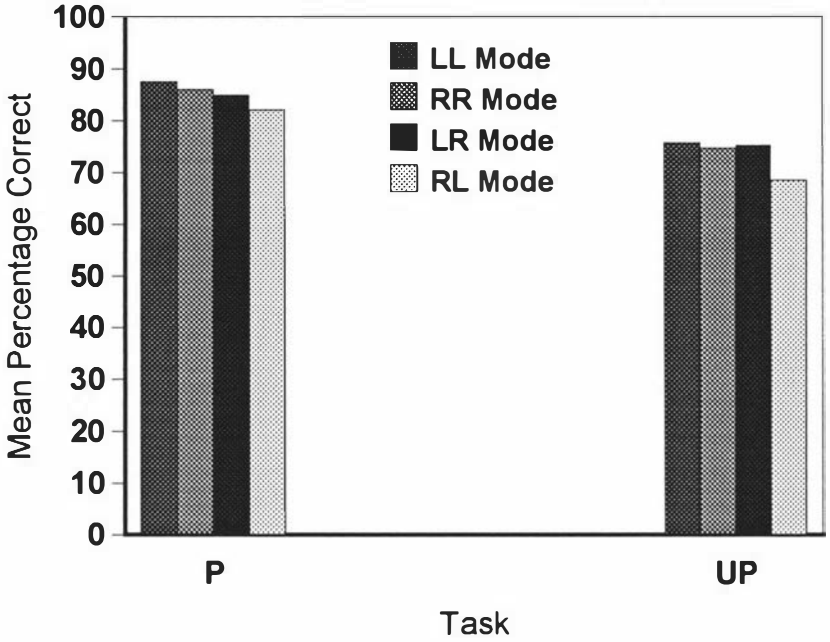

Figure 10. Mean percentage correct for each mode at the 2.0 s rate for normal participants in Task P and Task UP of Experiment 3.

However, the ANOVA indicated there was no interaction of Mode x Rate x Task, F (9, 144) = .52, p = .86, ES = .18, SP = .47. Hence, the findings with regard to the RL inferiority seemed to be attributable to both tasks. The 2.0 s rate, like the 3.6 s rate, had been previously used in the first two experiments. However, no effects of Mode were previously found at the 2.0 s rate. Hence, a reanalysis was conducted on data from both Task P and Task UP, at the 2.0 s and 3.6 s rates, combined across Experiments 1, 2, and 3.

Combined Analyses

Combining the data for normal participants across Experiments 1, 2, and 3 gave a sample size of 28 participants for each of the Task P and Task UP conditions. A three-way mixed ANOVA (2 tasks x 2 rates x 4 modes) indicated a significant Task x Mode x Rate interaction, F (3, 162) = 2.98, p = .03, ES = .23, SP = .99. A LSM analysis of this interaction showed significant effects at the 2.0 s rate but not at the 3.6 s rate. These findings are illustrated in Figure 11. In Task UP performance with the LL mode was again better than with RR(p = .05) and RL (p = .04). The LR mode was also found to be superior to RR (p = .02) and RL (p = .02). In Task P the LL mode was only superior to RL (p = .06), there were no differences between LL and RR, or LR and RL. In other words, the LL and LR mode advantages found with the fastest rate (2.0 s) of this present experiment, support the RH advantage found with the 1.2 s rate in Experiments 1 and 2.

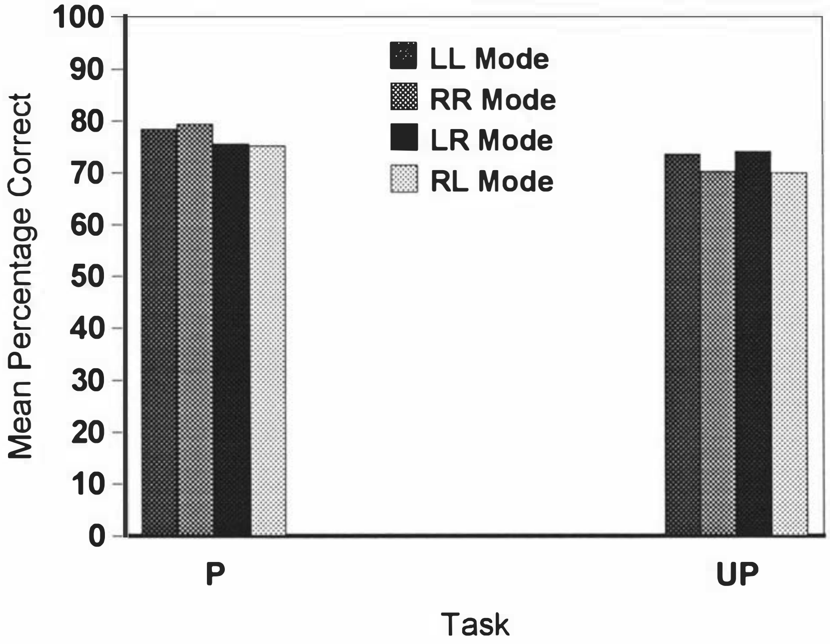

Figure 11. Mean percentage correct for each mode at the 2.0 s rate for normal participants in Task P and Task UP combined across Experiments 1, 2, and 3.

Discussion

The first hypothesis of the present experiment was that performance on the PASAT would decline as a result of slowed presentation rate and as a consequence of decreased attention to the task. The decrease in attention was presumed to occur because of interference by ordinary cognitions regaining saliency during the extended ISIs. However, no such decrement in performance was found at the three slowest rates for any of the task conditions. This was despite the fact that nearly all participants spontaneously remarked on how they had increased lapses in attention to the task and interference from thoughts about their own exigencies of the day.

The second hypothesis was also not supported. That is, on the basis of Sampson and MacNeilage's (1960) model of temporal integration, it was predicted that performance would have declined due to insufficient stimulation at the very slow rates of presentation. However, as noted above, performance did not decline despite the reduction of external stimuli and interference by covert lapses in attention. The third hypothesis, as a subsidiary to the second, predicted that the additional feature of unpredictable stimulus presentation in Task UP would have assisted the maintenance of attention at slow presentation rates. It was, therefore, expected that performance would decline less with Task UP as compared to Task P or Task S. Again, the lack of any decline in performance on any of the tasks did not confirm the third hypothesis. Therefore, Sampson and MacNeilage's stimulus-dependent model of temporal integration is again shown to be in need of modification.

The fourth hypothesis was that a LEA would be demonstrated as presentation was slowed. That is, on the basis of the above hypothesised involvement of attentional processes, it was proposed that performance would be better for stimuli directed to the RH. Also, it was expected that the unpredictability of stimulus presentation in Task UP would help preserve some attention to the PASAT; whereas in the absence of this factor of stimulus presentation, as in Task P, normal participants would experience difficulty in maintaining attention. Hence, it was predicted that RH processes for maintaining attention would be evoked as presentation rate became particularly slow, and would be demonstrable in at least the Task P condition. However, no effects of mode were found at all with the three slowest rates in either Task P or Task UP. There were effects of mode found at the 2.0 s rate, which will be discussed shortly.

To summarise the above, there was no decrement in performance and no effects of mode found for any of the three task conditions at the three slowest rates of stimulus presentation. These findings contradict what was predicted on the basis of Sampson and MacNeilage's (1960) stimulus-dependent model of temporal integration. The fact that performance on the PASAT at very slow rates did not decline indicates that normal participants could maintain, or quickly regain, their attention to the test, despite decreased external stimulation and interference by unrelated cognitions. The above findings further suggest that the PASAT alone, and the dependent measure of percentage correct, might be insufficient to demonstrate any hemispheric differences; that is, in terms of attention and the possibility that the RH might be evoked even at quite slow presentation rates. It may instead be that any test presented at slow presentation rates needs to be administered in conjunction with a psychophysiological measure of brain activity so as to demonstrate RH, as opposed to LH, activity for attention; such measures could include functional MRI as reported by St George et al. (1999), and rCBF with PET as reported by Pardo et al. (1991).

However, one intriguing observation was that Task P tended to show better performance than Task S over all four rates (refer to Table 6). There were no significant results involving Task but the moderate effect sizes do support a possible difference between Task P and Task S. Hellige's (1987, 1993) model of cross-hemispheric integration perhaps provides an interpretation. Task P could be categorised as a *within-hemisphere* condition (i.e., successive singular stimuli are presented to one hemisphere at a time) and Task S as a *between-hemisphere* condition (i.e., a digit stimulus is actually presented stereophonically and simultaneously to the LH and RH). According to Hellige, with long ISIs and a within-hemisphere condition there is less demand on the hemisphere's to sort out which one will take charge of the initial processing (such as allocation of attention). However, with simultaneous presentation of multiple stimuli there is greater requirement of the hemispheres to allocate resources. When task requirements are demanding (e.g., concurrent subtasks) performance can be enhanced by distributing processing across the two hemispheres. On the other hand, when task requirements are light (e.g., slow stimulus presentation) and the hemispheres are still required to distribute the processing of simultaneous stimuli there is a cost to performance. Hence, the poorer performance with Task S relative to Task P might have been due to the hemispheres having to allocate additional initial resource to processing more than one stimulus simultaneously. Thus, for normal participants it appears that performance on the PASAT is better at slow rates when a stimulus is presented to only one hemisphere, such as with Task P. The relative worsening of performance by Task P, compared to Task UP, clinical participants of Experiment 1 might then suggest a reversal of the above finding for the normal participants of Experiment 3, for whom longer ISIs may have been necessary to manifest their difference in performance. This contrast between normal and clinical participants with Task P at slow rates possibly again reflects the idea that persons with schizophrenia have difficulty maintaining a mental set or focusing attentional resources (Baribeau-Braun et al., 1983; Nestor et al., 1992; Shakow, 1962).

Returning to the effects found at the 2.0 s rate in the present experiment, the three-way ANOVA (involving Task P and Task UP, but not Task S) showed a significant Mode x Rate interaction, attributable to poorer performance of the RL mode relative to the three other modes. The ANOVA also indicated a significant Task x Rate interaction, which reflected the overall poorer performance by Task UP participants at the 2.0 s rate. There was, however, no significant Mode x Rate x Task interaction. Hence, the RL mode inferiority was apparently attributable to both Task P and Task UP participants. This RL inferiority is generally consistent with the prior evidence, in the present research and by Pardo et al. (1991), of a RH advantage over the LH for attentional processes. That is, the RL inferiority relative to the LR mode, suggests that the performance difference between these two modes is based on the first stimulus of the RL pairing being initially processed by the LH, which is less efficient for attentional processing. Furthermore, this finding of a RL inferiority at the 2.0 s rate for normal participants is in the opposite direction to the LR inferiority found at the 1.2 s rate for clinical participants in Experiment 1. The LR inferiority found for the clinical participants probably reflects dysfunctional RH attentional processing, whereas the RL inferiority found for the normal participants possibly represents the normal difference between the RH and LH for attentional proficiency.

There were no effects of mode found at the 2.0 s rate in Experiments 1 and 2. However, the combined analyses for normal participant data across Experiments 1, 2, and 3, yielded significant effects of mode at the 2.0 s rate but none at the 3.6 s rate. Again, these findings are all consistent with the hypothesis of RH specialisation for attentional processing. That is, in Task UP both the

LL and LR modes were found to be superior to the RR and RL modes. In Task P the LL mode was found to be superior to the RL mode. The finding of no difference in performance between the LL and RR modes in Task P is consistent with what was found at the 1.2 s rate with the combined analyses of Experiments 1 and 2. To reiterate, it was found in those earlier experiments that to clearly demonstrate a difference between the same mode stimulus pairings the task needed to be of greater attentional complexity; that is, unpredictability in addition to the fast rate of stimulus presentation (Task UP as opposed to Task P). Furthermore, it would appear that extra power, via larger sample size, was needed to clearly show the effects of mode at the 2.0 s rate. This suggests that such effects are more subtle as presentation rate is slowed. Overall, though, the evidence from the present research programme suggests that it required the fastest presentation rates and unpredictability of stimulus presentation to more fully demonstrate support for the hypothesis of the RH's specialisation for attention.

A final point of consideration was whether there were any differences between male and female normal participants with regard to the mode effects found in the present research. Prior research has indicated that the expected REA for auditory word recognition tests found with males has instead either been reversed (Lake & Bryden, 1976), diminished (Young & Ellis, 1980), or been non-existent (Iaccino & Sowa, 1989) for females. Gender effects have also been reported for visual studies. Bradshaw and Gates (1978) found that while both genders showed a right visual field advantage (RVFA) for naming of words, presented tachistoscopically, females demonstrated a reversal of the RVFA by males for a lexical decision task. In face recognition tasks, a left field reaction time advantage (LVFA) has been found for males but not for females (Rizzolatti & Buchtel, 1977), whereas for recognition of facial emotion, males show a RVFA but females either no asymmetry (Strauss & Moscovitch, 1981) or a LVFA (Ladavas, Umilta, & Ricci-Bitti, 1980). To explain reported interactions between gender and laterality, Geschwind and Galaburda (1987) proposed the theory that prenatal testosterone has a differential effect on the developing brain in males. In terms of morphology, the corpus collosum has been reported as being thicker anteriorly and posteriorly for males and so attributed as having a greater inhibitory effect on inter-hemisphere transmission (Raine et al., 1990), thus resulting in greater functional lateralisation for males.

In the present research, Experiment 1 had an unintentional disproportionate representation of males. This was due to mostly male clinical participants having been referred and to males being generally represented more among persons with schizophrenia. Hence, no analysis of interaction between gender and mode was possible. However, it should be noted that despite a majority of male participants a LEA was still demonstrated by the normal controls. With regard to gender and the mode effects reported in Experiment 2 (with 5 participants of each gender in both Tasks UP & P) and Experiment 3 (with 5 female and 4 male participants in each task) there is nothing to suggest gender had any effects. In Experiment 2, the superiority of the LL mode over the RR mode (i.e., LEA) in Task UP was demonstrated by 5 females and 4 males, and the inferior RL mode relative to the LR mode in Task P was found for 3 females and 3 males. For Experiment 3, a formal analysis also indicated no interaction of gender with mode, so the RL inferiority found with Task UP and Task P is apparently attributable to both female and male participants. Hence, there was no evidence from the present research to show that the mode effects were associated with one gender more than the other.

General Discussion

Temporal Integration

The first major outcome of the present research was that the lateralised PASAT, after considerable upgrading for hemispheric research, failed to be of use for examining temporal integration theory in relation to hemispheric specialisation (Miller, 1996 ; Norman, 1984). The REA found by Norman (1984), with the lateralised PASAT and normal participants, was not replicated over the three experiments in the present research. Hence, it appears that the careful modifications to the PASAT may have removed artefacts, such as arithmetic or practise effects, that gave the REA reported by Norman. The failure by the lateralised PASAT to show a REA stands in contrast to the abundant neuropsychological evidence which indicates LH specialisation for temporal processing (Bradshaw & Nettleton, 1981; Bryson et al., 1980; Elfgren & Risberg, 1998; Gordon, 1978; Leek & Brandt, 1983; Prior et al., 1990; Robinson & Solomon, 1974; Troyer et al., 1998). This neuropsychological evidence, in conjunction with Miller's (1996) argument for the LH being proficient for delayed axonal conduction, and other neuroanatomical evidence for interneuron temporal functioning (Freund, 1997), all support Lashley's original theory on there being innate brain mechanisms specialised for temporal integration. Furthermore, no evidence was found to support Sampson and MacNeilage's (1960) stimulus-dependent model of temporal integration, which was the original theoretical basis for the PASAT. Indeed, the present research also found evidence to show that their model is incorrect. In Experiment 3 it was found that performance, on both the lateralised and the non-lateralised PASAT, did not decline at very slow presentation rates (i.e., under conditions of decreased stimulation). Therefore, despite its apparent sequential nature the PASAT now appears to lack efficacy for research into temporal integration. Instead, other tests involving verbal fluency (e.g., Elfgren & Risberg, 1998; Troyer et al., 1998), in conjunction with psychophysiological measures (e.g., St George et al., 1999) may better serve to demonstrate the link between temporal integration and language. While it was disappointing that the present research programme did not find evidence to support temporal integration theory other interesting findings suggested hemispheric differences for attentional processing. These findings which differed between the normal and clinical participants are discussed next.

Attention

Although the PASAT failed to deliver useful evidence on temporal integration, some other findings of the present research show support for hypotheses on the normal RH's specialisation for vigilance and its impairment in schizophrenia being an alternative explanation for previously noted asymmetric difficulty in shifting attention from left to right field. The latter has previously been attributed to slowness of the LH instead. The findings of the present research only occurred at the fastest (1.2 & 2.0 s) presentation rates. They were supported by significant and replicated main effects and interactions involving Mode and Rate, by at least moderate effect sizes, and were associated with ample power. For the normal participants a LEA was replicated across two experiments and more clearly demonstrated with an unpredictable task condition. That is, it required the combination of fast (1.2 s) and unpredictable stimulus presentation to demonstrate a LEA with stimulus pairings of the same mode (i.e., LL vs. RR). Normal participants also showed a RL mode inferiority to the LL mode at the 2.0 s rate. This suggests that under conditions of fast stimulus presentation evoking vigilance, stimuli as mixed mode pairs are processed less efficiently if the first stimulus is presented to the LH (i.e., RL mode) than if presented to the RH (i.e., LR mode). It did not require the unpredictability of stimulus presentation to show this difference between the mixed mode pairs. This findings of a LEA for the normal participants provides further evidence of the RH's specialisation for vigilance (Coslett et al., 1987; Dimond, 1979; Heilman & van den Abell, 1979,1980; Howes & Boller, 1975; Ladavas et al., 1989, 1994; ; Loring et al., 1989; Pardo et al., 1991; Simos & Molfese, 1997; Whitehead, 1991; Wilkins et al., 1987; Yokohama et al., 1987;).

Schizophrenia and Lateralised Attention Deficits

The findings with regard to clinical participants, in the present research, also appear consistent with the hypothesis of a RH specialisation for vigilance at fast presentation rates, although in schizophrenia this appears to manifest as RH dysfunction. Firstly, the clinical participants did not show a LEA and compared to normal controls demonstrated no difference in performance with the right ear (RR). Furthermore, the controls manifested an inferior performance with the RL mode, whereas the clinical participants did so with the LR mode. Hence, the LR deficit in schizophrenia may instead be due to difficulty in disengaging from the left visual or auditory field rather than impaired performance of the right field (i.e., LH) as previously suggested (Bustillo et al., 1997; Posner et al., 1988; Posner & Raichle, 1994; Wigal et al., 1997).

Other researchers, using the same visual task as that developed by Posner et al. (1988), have found evidence to possibly contradict the above interpretation and instead suggest slowness by the LH (Bustillo et al., 1998), or over reaction by the LH (Nestor et al., 1992). However, the comparison of the present research with these other studies is complicated by diagnostic and medication factors. It appears that the samples in the studies by Bustillo et al. and Nestor et al. contained clinical participants primarily with positive symptoms of schizophrenia, whereas in the present research, and in the studies by Posner et al. and Wigal et al., participants had negative symptoms. Hence, it is possible that the problems in attention identified in a positive symptom group may be of a different origin to that for a negative symptom group. For example, Woodruff et al. (1997) reported that with using functional MRI they found that the positive symptom of auditory hallucinations was associated with reduced response to external speech in the LH temporal cortical regions. This reduced activity in the LH in response to external stimuli, in association with a positive symptom, is possibly the factor underlying the findings by Bustillo et al. (1998). In other words, the positive symptom of auditory hallucinations competes within the same brain mechanisms in which attention to and processing of external speech stimuli would otherwise be undertaken. The positive symptom has a direct effect on a person's ability to attend to external auditory stimuli.

The apparently contrasting finding of over activation in the LH by Nestor et al.(1992) may instead be due to another factor, such as the effect of medication. For example, Williams et al. (1998) measured auditory latent inhibition (the ability to filter out irrelevant stimuli) and found that this was absent in participants on medication but present in participants naive to antipsychotic medication. Hence, a reduced ability to filter out irrelevant external stimuli for participants on medication might partially explain the over reaction to invalid visual cues in the right visual field found by Nestor et al. (1992). Gruzelier and Hammond (1979) had previously noted the effects of medication on LH performance for auditory discriminations. In the absence of medication participants with schizophrenia showed a worsening of LH (right ear) discriminations. However, with increasing dosage LH performance improved accordingly. Also, Gur, Resnick, Gur, et al. (1987) noted normalisation of previously abnormal increased glucose metabolism in the LH of participants with schizophrenia after treatment with neuroleptic medication. Thus, medication can give different effects, such as reduced latent inhibition compared to improved auditory discriminations. Fortunately, Wigal et al. (1998) examined the issue of medication with Posner's cued visual reaction time task. They replicated the findings by Posner et al. (1988) with participants who were medication-free at the time of testing. To reiterate, the clinical participants in the present study predominantly had negative symptoms and were on their usual medications at the time of testing. Their performance indicated the particular difficulty with changing attention from the left to right auditory field, similar to that found by other researchers using Posner's visual cued reaction time task. While other researchers interpret this LR deficit in schizophrenia as being due to slowness of the LH, the overall results of the present research, for both control and clinical participants, instead suggest the basis of the deficit is a dysfunction of the usual RH specialisation for vigilance.

The foregoing discussion has been on the evidence for normal RH specialisation for vigilance and its dysfunction in schizophrenia. Other findings from the present research also arose to indicate differences between the normal and clinical participants in terms of cross-hemispheric allocation of attention.

Cross-Hemispheric Allocation of Attention

Another interesting finding in the present research was the different trends in performance by the clinical participants as compared to normal participants with the single stimulus blocked mode task (Task P) at the slower presentation rates on the lateralised PASAT. Clinical participants showed a relative worsening of performance with Task P, compared to Task UP, as presentation rate decreased from 1.2 s to 3.6 s. Normal participants showed better performance with Task P as compared to Task S (in which a left and right ear stimulus were presented simultaneously) from rate 2.0 s to the very slow rates of 5.2 s and 6.8 s. By applying Hellige's (1987, 1993) model of cross-hemispheric integration Task P could be categorised as a within-hemisphere condition and Task S as a between-hemisphere condition. The slow as opposed to fast presentation rates could be classified as a light task condition. For normals no advantage is gained by having both hemispheres involved in the initial stages of attentional processing during light tasks. However, when both hemispheres are engaged at initial stages of processing (between-hemisphere), as in the simultaneous presentation of two stimuli in Task S, the process of allocating attention by one or other hemisphere slightly impedes performance. Indeed, the trend of better performance with Task P compared to Task S for normal participants at slow presentation rates supports Hellige's model.

In contrast, it would appear that the difficulty clinical participants had with Task P compared to Task UP as presentation rate slowed represents a problem of being stuck with a between-hemisphere process regardless of whether stimuli are presented singularly or simultaneously. This possibly translates into meaning that the hemispheres are unable to work out the allocation of executive attention between themselves, or unable to focus attention (Nestor et al., 1992), or establish a mind set (Shakow, 1962), because of not having developed as lateralised processing systems (Crow et al., 1995). Hence, in schizophrenia and under conditions of slow and unilateral stimulus presentation the hemispheres waste resource on trying to focus executive attention that otherwise could be used for ongoing processing. Because participants with schizophrenia tend to perform better at fast as opposed to slow presentation rates (Baribeau-Braun et al., 1983) suggests that fast rates of stimulus presentation assist the separation of processing between the hemispheres and maintains some distribution of the various factors of processing. Of further interest is that some Task P and Task UP clinical participants spontaneously reported that they found it more difficult to concentrate as presentation slowed. Some Task P participants also reported that they found that having to switch attention from ear to ear (the LR or RL modes) as opposed to the repetitive ear presentations (LLLLL.... or RRRRR....) helped to maintain concentration. So this difficulty with performance at slow rates of presentation possibly represents a deficit in focusing executive attention, whereas the previously noted LR mode inferiority possibly represents a lateralised (RH) dysfunction of processes normally evoked for selective attention.

Most of the above discussion has been based on findings related to stimulus parameters (single, simultaneous, same mode or mixed mode, and fast or slow etc.). However, there is the possibility that participant processing strategies also an have an influence on lateralised effects.

Processing Strategies

Bryden (1986) and Iaccino and Houran (1991) have pointed out that the demonstration of laterality effects often can depend on the particular experimental task sufficiently directing the attention of participants to one ear or the other, rather than it being other characteristics of the task (e.g., monitoring consonant / vowel syllables) on their own. For example, by instructing participants to attend to one ear and ignore the other, or by presenting unilateral blocked trials to one ear and then the other, can strengthen findings of REAs. Otherwise, some participants might deploy a focused ear-side strategy and others might adopt a less favoured, attentional division between the two ears. The use of blocked trials in the present research (Task P) did therefore comply with some methodological recommendations by Bryden, and by Iaccinno and Houran.

Elfgren and Risberg (1998) have also argued that differences in participant cognitive strategies (internally driven responses) can affect observations of lateralised rCBF. In their study participants were asked to report the cognitive strategy they used when doing the phonemic verbal fluency test. Participants were divided into one subgroup with a "pure" verbal memory strategy and another with a mixed verbal and visual search strategy. The participants who reported using a verbal strategy with the test showed significant rCBF in the LH. However, participants who reported using the mixed strategy showed no significant rCBF increases. Furthermore, the mixed strategy group produced significantly fewer words than the pure verbal group, which indicated that the mixed strategy resulted in less efficient performance. Here again the evidence suggests that between-participant variability in cognitive processing can affect whether lateralised effects are demonstrable.

In the present research one assessment of participant response strategy was undertaken to examine for a possible association of strategy with the mode effects reported above. That is, during scoring of individual raw data it was clear how some participants at the fastest 1.2 s rate of the lateralised PASAT tended to respond only intermittently, or at the most in an alternating strategy, to exclusive pairs of digits rather than in a continuous manner, as instructed. The intermittent or alternating strategy (noncontinuous) was used by nearly all clinical participants with both the LR mode and RL mode. Only 2 clinical participants in Task UP used the continuous strategy. So the suspicion that the overt noncontinuous strategy had a bearing on the poorer performance with the LR mode compared to the RL mode by clinical participants was quashed. An inspection of the overt response strategies used by the non-clinical control participants in Experiment 1 gave a similar outcome. That is, among Task P and Task UP non-clinical controls 11 participants used the same continuous strategy and 7 others used the same noncontinuous strategy for both the LL and RR modes.

However, the above findings by Elfgren and Risberg (1998) do suggest the possibility of various covert processing strategies having different effects on performance with the PASAT. In reference to Figure 1 , and its description on page 85, it will be recalled that a single-paced serial addition response on the PASAT involves an underlying complex range of different forms and stages of perceptual, cognitive, and motor performance. With regard to perceptual processing, the conclusion of this present research is that the evidence of an LEA for normal participants concurs with other evidence of RH specialisation for vigilance. However, covert responding at the other cognitive and motor stages on the PASAT might have led to different predictions of lateralised effects. For instance, with regard to a possible working memory or temporal integration strategy, such as maintenance of a stimulus in memory and associating with it a new digit stimulus, and doing so as quickly as possible within the 1.2 s temporal span, better performance with the LH would have been predicted. With regard to a possible bias in the use of a mental arithmetic strategy a LH advantage would again have been predicted, based on prior evidence on LH proficiency for arithmetic processing (McCarthy & Warrington, 1991). Similarly, a strategy of greater proficiency in the generation and articulation of a response, in light of the known typical location of Wernicke's and Broca's areas, should have produced a LH advantage. Even if one were to predict a selective activational response bias (Kinsbourne, 1970, 1973), based on the above described and possible disproportionate activation of the LH, then a LH advantage would have still been expected. Alternatively, in terms of an attentional resource strategy (Hellige & Cox, 1976; Kinsbourne & Cook, 1971) one might have predicted that the disproportionate loading on the LH, particularly at the fastest presentation rates, would lead to the limit of attentional capacity being more easily reached. Hence, for normal participants LH capacity might reach threshold at the faster presentation rates and therefore no LH advantage would be demonstrable. However, one might then expect that participants with schizophrenia, and presumed LH dysfunction, would have demonstrated LH performance relatively inferior to normal participants. Yet, this was not the case.

Therefore , many of the possible covert response strategies with the PASAT, other than the perceptual stage evoking RH specialisation for vigilance, were likely to have involved LH processes. However, despite this purported disproportionate activation of LH processing a RH advantage was instead observed and replicated with normal participants in the present research. A possible explanation for the LH advantage found by Norman (1984) not being reproduced is the careful precision in randomising and counterbalancing arithmetic outcomes in the present research. In the 1984 study a greater percentage of digits leading to easier outcomes might have been presented to the right ear. However, in light of Baddedly's (1998, 1999) finding that longer words are harder to remember because they require longer rehearsal time, the LH advantage found by Norman might have been a consequence of the longer time taken for generation and articulation of larger arithmetic outcomes (i.e., two or more syllable outcomes; e.g., "thir-teen", "sev-en-teen" vs. "four" , "six" etc.). What remains of interest, then, for further research is whether manipulation of length of arithmetic outcome might produce changes in hemispheric advantage.

Improvements and Further Suggestions for Future Research

Some clinical participants reported that they found the switching of mode from ear to ear helpful to maintain concentration at slow rates. Normal participants in Experiment 3 reported that at slow presentation rates they experienced increased lapses in attention and interference from thoughts about their own exigencies of the day. These reports suggest that participants may have needed to call upon their own strategies when the experimental conditions were insufficient to assist them in maintaining attention. Consequently, the use of a self-report questionnaire to record these observations across all participants might have yielded specific information on how they maintained attention despite lengthy ISIs. For example, it might have been found that some participants silently repeated the digit last heard, or some may have reported that they needed to remain partially alert to expecting another auditory stimulus. Other participants might have reported that with any of the presentation rates they concentrated their attention more on the ear receiving the stimulus rather than on the arithmetic or sequential task. As Bryden (1986), Iaccino and Houran (1991), and Elfgren and Risberg (1998) all point out, variability between participants in their use of covert strategies can affect whether lateralised effects are demonstrable. Hence, any replication of the present research would perhaps need to formally collect self-reports from participants on their cognitive strategies and to analyse these for the potential relationship with mode effects, or lack thereof.

Another improvement could have been the use of questionnaires to record the self-report by participants of their type and level of mood and anxiety, particularly for clinical participants. All participants were well informed about what to expect from the test, and no participant indicated any adverse reaction during or upon completion of the test. However, it still might have been useful to demonstrate whether or not mood or anxiety had any influence on performance, and at some stages but not others during test sessions. The potential is that a participant's sense of not having done well with one set of trials (e.g., at the 1.2 s rate) might elicit anxiety or lower mood which could then impact on subsequent performance.

An additional recommendation for further research pertains to the observation that performance on the lateralised PASAT by clinical participants tended to worsen as presentation slowed. This notably occurred with Task P, in which stimuli were presented singularly to each hemisphere. It was earlier discussed how this trend may represent a problem in unnecessarily engaging both hemispheres, which wastes attentional resource. The trend noted for the normal participants, as discussed above, was the opposite to that found for the clinical participants. However, the observation for the normal participants was at presentation rates much slower than the clinical participants were tested with. Furthermore, the trend for the normal participants occurred with a comparison of Task P with another task (Task S); the clinical participants were not tested with Task S either. Hence, testing clinical participants at the much slower rates and with Task S (which presented a stimulus to both hemispheres simultaneously) could re-examine the interpretation that people with schizophrenia have difficulty disengaging from a between-hemisphere process. The prediction is that clinical participants would show even poorer performance at the slower rates and with Task S as compared with Task P and Task UP.

Conclusion

In conclusion though, the evidence from the present research indicates that the combined task conditions of fast presentation rate and unpredictability of mode (ear of presentation) sufficiently limited between-participant variability for normal participants, and hence showed the RH specialisation for vigilance. The deficit with disengaging attention from the left auditory field, as shown by clinical participants (i.e., persons with schizophrenia), appears to suggest dysfunction of the usual RH proficiency for vigilance. The evidence for clinical participants also suggests that the lateralised deficit for selective attention is pervasive and so did not require stimulus unpredictability to demonstrate its existence.

The possible trend of a within-hemisphere advantage shown by normal participants for processing at very slow rates, was reversed for clinical participants. The poorer performance by clinical participants at slow rates of presentation and with predictable single stimulus presentation instead possibly reflects a dysfunctional between-hemisphere process which affects executive attention. This evidence found with the clinical participants also supports the hypothesis that in schizophrenia there is a lack of the normal development of hemispheric lateralisation (Crow et al., 1995).

As a final note, the finding of the RH effects at the fastest presentation rates in the present research is possibly the first evidence to show specific attentional processes at one level of rate but not at slower rates on the PASAT. This suggests that impaired performance on the PASAT should not be attributed solely to the generalised effects of concussion. Instead, impaired performance may, for example, be more persistent following subtle RH insult as compared to LH insult. Hence, a differential assessment of the effects of lateralised brain insult on performance with the PASAT may require a lateralised version along the lines of the modifications used in this present research.

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Appendix A

1. Example scoring sheet for Task P.
2. Example scoring sheet for Task UP.

SUBJECT (NON-PATIENT) RESPONSE RECORD

NAME: D.O.B. DATE:

EXPERIMENT: RATE: 1·2 MODE: LL

TAPE: ONE

#	STIM.	RESP.	√ v X	INTER.	STIM-L	STIM-R	√ v X		
	4								
	4								
	8								
	9								
	8								
	6								
	2								
	3								
	8								
	2								
	6								
	1								
	5								
	1								
	4								
	5								
	3								
	8								
	3								
	3								
	6								
	9								
	1								
	2								
	1								
	2								
	9								
	6								
	4								
	9								
	5								
	5								

= Trial number

STIM. = Stimulus

RESP. = Response

√ v X = Correct vs Wrong solution

INTER. = Within interval (Yes or No)

STIM. R = Stimulus Right mode

STIM.L = Stimulus Left mode

SUBJECT (NON-PATIENT) RESPONSE RECORD

NAME: D.O.B. DATE:

EXPERIMENT: RATE: 1·2 MODE/ TAPE FOUR

#	STIM.	RESP.	✓ v X	INTER.	STIM-L	STIM-R	✓ v X		
L	1								
L	4								
R	9								
R	9								
L	1								
R	3								
R	1								
L	5								
R	2								
R	1								
L	6								
L	9								
L	2								
R	9								
R	8								
R	4								
L	8								
L	8								
R	3								
R	8								
L	4								
L	3								
L	3								
R	2								
R	4								
R	5								
L	5								
L	6								
R	2								
L	6								
R	6								
L	5								

# = Trial number
STIM. = Stimulus
RESP. = Response
✓ v X = Correct vs Wrong solution
INTER. = Within interval (Yes or No)
STIM. R = Stimulus Right mode
STIM.L = Stimulus Left mode

Appendix B

1. Participant Information Sheet.
2. Participant Consent Form.

Appendix B 1. Participant information sheet.

TEMPORAL INTEGRATION (COGNITIVE) RESEARCH STUDY

INFORMATION PAGE

Researchers / addresses: Bernard Norman (PhD student, School of Psychology, Massey Univer., PN; & Consultant Clinical Psychologist,PN)Ph# xxxxxxxxxx or xxxxxxxxxx. or altern. c/- Dr John Podd; Psych,Massey Univer. (as below).

Dr John Podd (Senior Lecturer, School of Psychology, Massey Univer.,PN) Ph# xxxxxxxxxxx.

The Study: The aim of this study is to develop a test to assist clinicians assess the difficulties clients may have with keeping thought production timely and well ordered (such as is observed in Schizophrenia).

Many of the participants in this study will be non-clinical controls. Please note that the research procedures used, and eventually the test, will alone not be able to diagnose mental illness or level of intelligence. In any case, all individual participant's data are confidential and are used in comparisons of group not individual data.

Test Procedures: The test procedures in this present research are based on the Paced Auditory Serial Addition Test (PASAT), which already has international recognition for the assessment of post-concussion recovery. If you agree to take part, you will be asked to listen through headphones to numbers spoken on a tape recorder. You will be asked to add the numbers in a way that the researcher will demonstrate, but is only a minor alteration to normal arithmetic. The numbers will all be smaller than 10. However, they will sometimes be spoken slowly or quickly throughout the test. You will have some practise first and the whole test will take about 1 to 1 ½ hours. Brief breaks can be taken as needed.

[see over for Consent Form]

Appendix B 2. Participant consent form.

TEMPORAL INTEGRATION (COGNITIVE) RESEARCH STUDY

CONSENT FORM

[Before reading and signing this consent form please read the Information Page over leaf]

Name (participant):...

Mr/Dr...has explained to me the reasons for this study (i.e. to develop a clinical test and as part of Mr Norman's research toward PhD qualification), and why I am being asked to take part and what I shall be asked to do. I have read the Information Page and my questions have been answered to my satisfaction.

I understand that I have the right to ask questions at any time, and that I have the right to withdraw from the study at any time if I wish. If I am unable to finish the test in one session (i.e. 1 to 1 ½ hours), and still wish to complete it, I can arrange a time to return that is convenient to me.

I understand that I am entitled to have time to think about this study, and to talk with other persons if I wish, before signing this consent form and before taking part.

I also understand that the results from the test will have no clinical meaning for me and may or may not be useful in helping others in the future. I have indicated whether I would like the results of my test discussed with me, and realise there may be some delay depending upon the completion of statistical analyses: **Yes** **No** (circle that which applies)

I agree / do not agree to take part in this study (strike out that which does not apply)

Signed:.. **(participant)**

Signed:.. **(witness, if required by participant)**

Signed:.. **(researcher)**

Date:..

If any problems arise from your involvement in this study please contact the researchers (Bernard Norman and John Podd; addresses overleaf).

Appendix C

Instructions for administration of experimental PASAT procedure.

Appendix C. Instructions for administration of PASAT procedure.

1) Check handedness, sex, DOB, absence of hearing problem history, and whether consent of participant still stands.

2) Read to participant: " You will hear a list of single numbers read one after the other. You will hear the numbers in either your left or right ear, or only one ear for some of the time. [*] However, you do not have worry about which ear you hear in. I just want you to listen to the number and add it to the previous number. You give your answer aloud. When you have given your answer you can forget it. Add each new number to the one just before it, not to your own answer. So add the second number to the first, the third to the second, and so on."

" The numbers only range from 1 to 9, there are no numbers bigger than these. So the largest sum you will to do is 9 + 9, which equals 18."

* [For Task S Experiment Four participants explain to them that they will hear each number in both ears at once].

3) Demonstration: a) for some participants the tester may have to demonstrate with written numbers, then or either
b) give a trial of 10 digits spoken by the tester at a consistent pace.

" For instance, if I said 2, 5. You would say?... 7. Then if I said 6, you would say?...11. Remember you add each new number to the one heard just before it and not to your own answer."

" Now let us try these". (practise until participant can do all of string correctly)

" 2, 5, 6, 3, 8, 6, 4, 5, 1, 4 "

(answers: 7, 11, 9, 11, 14, 10, 9, 6, 5)

4) " Right, now we will try the tape and headphones." (check which ear should receive first presentation; check headphones are situated to correct ear)."
" This time the list of numbers is much longer. You will notice that on some tapes the numbers will be faster than on other tapes. I will let you know when the very fast tapes come up. Do not worry about making mistakes or leaving some out. Try not to, but if you do try and pick up again as quick as you can. You can restart anywhere with a fresh pair of numbers."

5) For clinical participants, the tester may need to re-emphasise the latter instructions, especially not spending time worrying about mistakes or leaving some out. The tester should advise all participants that they can request a break at anytime between tapes (but avoid restarting on a very fast tape).

Appendix D

Handedness questionnaire (source: Briggs and Nebes, 1975).

Appendix D. Handedness questionnaire (source: Briggs & Nebes, 1975).

Name______________________ Sex________ DOB____________

Indicate hand preference	Always left	Usually left	No preference	Usually right	Always right
1. To write a letter legibly					
2. To throw a ball to hit a target					
3. To play a game requiring the use of a racket					
4. At the top of a broom to sweep dust from the floor					
5. At the top of a shovel to move sand					
6. To hold a match when striking it					
7. To hold scissors to cut paper					
8. To hold thread to guide through the eye of a needle					
9. To deal playing cards					
10. To hammer a nail into wood					
11. To hold a toothbrush while cleaning teeth					
12. To unscrew the lid of a jar					

Are either of your parents left-handed? If yes, Which?_______________
How many siblings of each sex do you have? Male____________ Female______________
How many of each sex are left-handed? Male_______________ Female_____________
Which eye do you use when using only one (e.g., telescope, keyhole) ? _____________
Have you ever suffered any severe head trauma? ________________

Appendix E

1. Four-way ANOVA for Experiment 1 : Comparison of mean PC for sample (clinical vs control) x task (P vs UP) x rate (1.2, 2.0, 2.8, & 3.6s) x mode (LL, RR, LR, & RL).
2. Four-way ANOVA for Experiment 1 : Comparison of mean PC for sample (clinical vs control) x task (P vs UP) x rate (2.0, 2.8, & 3.6s) x mode (LL, RR, LR, & RL). (ii)
3. Three-way ANOVA for Experiment 1 : Comparison of mean PC at rate 1.2 s for sample (clinical vs control) x task (P vs UP) x mode (LL, RR, LR, & RL).
4. Three-way ANOVA for Experiment 2 : Comparison of mean PC for normal participants with task (P vs UP) x rate (1.2, 2.0. 2.8, & 3.6 s) x mode (LL, RR, LR, & RL).
5. Three-way ANOVA of data combined over Experiments 1 and 2 for normal participants with task (P vs UP) x rate (1.2, 2.0, 2.8, & 3.6 s) x mode (LL, RR, LR, & RL).
6. Two-way ANOVA for Experiment 3 : Comparison of mean PC for normal participants with task (P vs UP vs S) x rate (2.0, 3.6, 5.2, & 6.8 s).
7. Three-way ANOVA for Experiment 3 : Comparison of mean PC for normal participants with task (P vs UP) x rate (2.0, 3.6, 5.2, & 6.8 s) x mode (LL, RR, LR, & RL).
8. Three-way ANOVA of data combined over Experiments 1, 2, and 3 for normal participants with task (P vs UP) x rate (2.0 & 3.6 s) x mode (LL, RR, LR, & RL).

Appendix E 1. Four-way ANOVA for Experiment 1 : Comparison of mean PC for sample (clinical vs control) x task (P vs UP) x rate (1.2, 2.0, 2.8, & 3.6 s) x mode (LL, RR, LR,& RL).

Source	df	SS	MS	F	p
Between-subjects					
Sample (S)	1	74643.70	74643.70	19.40	0.0001
Task (T)	1	2925.46	2925.46	0.76	0.3897
S x T	1	2999.20	2999.20	0.78	0.3838
Subject x S x T error	32	123106.10	3847.07		
Within-subject (Rate)					
Rate (R)	3	121119.14	40373.05	191.46	0.0001
Sample x R	3	8185.63	2728.54	12.94	0.0001
Task x R	3	686.49	228.83	1.09	0.3592
Sample x Task x R	3	1796.74	598.91	2.84	0.0419
Subject x R x Sample x Task error	96	20243.43	210.87		

continued/-

Appendix E 1. continued

Source	df	SS	MS	F	p
Within- subject (Mode)					
Mode (M)	3	592.78	197.60	2.45	0.0683
Sample x M	3	206.80	68.93	0.85	0.4677
Task x M	3	83.22	27.74	0.34	0.7937
Sample x Task x M	3	115.16	38.39	0.48	0.6999
Subject x M x Sample x Task error	96	7747.04	80.70		
Within-subject (Mode x Rate)					
Mode x Rate (R)	9	1669.52	185.50	2.69	0.0051
Sample x Mode x R	9	704.31	78.26	1.13	0.3379
Task x Mode x R	9	484.07	53.79	0.78	0.6352
Sample x Task x Mode x R	9	634.63	70.51	1.02	0.4219
Subject x Mode x R x Sample x Task error	288	19861.90	68.96		

Appendix E 2. Four-way ANOVA for Experiment 1: Comparison of mean PC for sample (clinical vs control) x task (P vs UP) x rate (2.0, 2.8, & 3.6 s) mode (LL, RR, LR,& RL).

Source	df	SS	MS	F	p
Between-subject					
Sample (S)	1	78048.23	78048.23	22.32	0.0001
Task (T)	1	1991.33	1991.33	0.57	0.4560
S x T	1	4581.09	4581.09	1.31	0.2609
Subject x (S x T) error	32	111890.73	3496.59		
Within-subject (Rate)					
Rate (R)	2	23656.46	11828.23	85.92	0.0001
Sample x R	2	870.47	435.24	3.16	0.0490
Task x R	2	666.84	333.42	2.42	0.0968
Sample x Task x R	2	155.55	77.77	0.56	0.5712
Subject x R x Sample x Task error	64	8810.54	137.66		

continued/-

Appendix E 2. continued

Source	df	SS	MS	F	p
		Within-subject (Mode)			
Mode (M)	3	281.28	93.76	1.37	0.2557
Sample x M	3	96.31	32.10	0.47	0.7038
Task x M	3	69.19	23.06	0.34	0.7981
Sample x Task x M	3	66.18	22.06	0.32	0.8087
Subject x M x Sample x Task error	96	6555.61	68.29		
		Within-subject (Mode x Rate)			
Mode x Rate (R)	6	471.80	78.63	1.29	0.2619
Sample x Mode x R	6	41.80	6.97	0.11	0.9946
Task x Mode x R	6	381.51	63.58	1.05	0.3969
Sample x Task x Mode x R	6	476.27	79.38	1.31	0.2563
Subject x Mode x R x Sample x Task error	192	11671.75	60.79		

Appendix E 3. Three-way ANOVA for Experiment 1: Comparison of mean PC at rate 1.2 s for sample (clinical vs control) x task (P vs UP) x mode (LL, RR, LR, & RL).

Source	df	SS	MS	F	p
Between-subject					
Sample (S)	1	3910.63	3910.63	5.53	0.0251
Task (T)	1	953.78	953.78	1.35	0.2543
S x T	1	59.31	59.31	0.08	0.7741
Subject x S x T error	32	22648.25	707.76		
Within-subject (Mode)					
Mode (M)	3	1509.22	503.07	5.15	0.0024
Sample x M	3	772.99	257.67	2.64	0.0541
Task x M	3	116.59	38.86	0.40	0.7550
Sample x Task x M	3	207.34	69.11	0.71	0.5500
Subject x M x Sample x Task error	96	9381.58	97.72		

Appendix E 4. Three-way ANOVA for Experiment 2 : Comparison of mean PC for normal participants with task (P & UP) x rate (1.2, 2.0, 2.8, & 3.6 s) x mode (LL, RR, LR, & RL).

Source	df	SS	MS	F	p
		Between-subject (Task)			
Task (T)	1	142.34	142.34	0.12	0.7364
Subject x T error	18	21919.47	1217.75		
		Within-subject (Rate)			
Rate (R)	3	101813.82	33937.94	174.18	0.0001
Task x R	3	115.96	38.65	0.20	0.8970
Subject x R x T error	54	10521.45	194.84		
		Within-subject (Mode)			
Mode (M)	3	466.10	155.37	3.41	0.0239
Task x M	3	264.72	88.24	1.93	0.1350
Subject x M x T error	54	2463.31	45.62		

continued/-

Appendix E 4. continued

Source	df	SS	MS	F	p
			Within-subject (Mode x Rate)		
Mode x Rate (M x R)	9	1062.28	118.03	2.55	0.0092
Task x M x R	9	1175.03	130.56	2.82	0.0042
Subject x M x R x T error	162	7509.17	46.35		

Appendix E 5. Three-way ANOVA of data combined over Experiments 1 and 2 for normal participants with task (P vs UP) x rate (1.2, 2.0, 2.8, & 3.6 s) x mode (LL, RR, LR, & RL).

Source	df	SS	MS	F	p
			Between-subject		
Task (T)	1	80.73	80.73	0.04	0.8390
Subject x T error	36	69354.68	1926.52		
			Within-subject (Rate)		
Rate (R)	3	196883.22	65627.74	340.69	0.0001
Task x Rate (T x R)	3	611.15	203.72	1.06	0.3704
Subject x T x R error	108	20804.54	192.63		
			Within-subject (Mode)		
Mode (M)	3	416.32	138.77	2.37	0.0745
Task x M (T x M)	3	172.46	57.48	0.98	0.4041
Subject x T x M error	108	6322.19	58.54		
			Within-subject (Mode x Rate)		
Mode x Rate (M x R)	9	1736.43	192.94	3.79	0.0001
Task x M x R	9	1551.68	172.41	3.38	0.0006
Subject x M x R x Task error	324	16509.52	50.95		

Appendix E 6. Two-way ANOVA for Experiment 3 : Comparison of mean PC for normal participants with task (P vs UP vs S) x rate (2.0, 3.6, 5.2, & 6.8 s).

Source	df	SS	MS	F	p
			Between-subjects (Task)		
Task (T)	2	355.80	177.90	1.39	0.2693
Subject x T error	24	3079.70	128.32		
			Within-subject (Rate)		
Rate (R)	3	5471.02	1823.67	52.96	0.0001
Task x R	6	365.52	60.92	1.77	0.1177
Subject x R x T error	72	2479.52	34.44		

Appendix E 7. Three-way ANOVA for Experiment 3: Comparison of mean PC for normal participants with task (P vs UP) x rate (2.0, 3.6, 5.2, & 6.8 s) x mode (LL, RR, LR, & RL).

Source	df	SS	MS	F	p
			Between-subjects (Task)		
Task (T)	1	1423.11	1423.11	3.10	0.0975
Subject x T error	16	7349.43	459.34		
			Within-subject (Rate)		
Rate (R)	3	16381.31	5460.44	38.29	0.0001
Task x R	3	1303.08	434.36	3.05	0.0376
Subject x R x T error	48	6844.37	142.59		
			Within-subject (Mode)		
Mode (M)	3	72.03	24.01	1.15	0.3404
Task x M	3	26.08	8.70	0.41	0.7432
Subject x M x T error	48	1006.27	20.96		
			Within-subject (Mode x Rate)		
Mode x Rate (M x MR)	9	450.64	50.07	2.06	0.0366
Task x M x R	9	113.01	12.56	0.52	0.8603
Subject x M x R x Task error	144	3495.64	24.27		

Appendix E 8. Three-way ANOVA of data combined over Experiments 1, 2, and 3 for normal participants with task (P vs UP) x rate (2.0 & 3.6 s) x mode (LL, RR, LR, & RL).

Source	df	SS	MS	F	p
			Between-subjects (Task)		
Task (T)	1	1658.27	1658.27	1.71	0.1965
Subject x T error	54	52353.76	969.51		
			Within-subject (Rate)		
Rate (R)	1	34496.28	34496.28	165.51	0.0001
Task x R	1	182.43	182.43	0.88	0.3537
Subject x R x T error	54	11254.88	208.42		
			Within-subject (Mode)		
Mode (M)	3	58.45	19.48	0.60	0.6130
Task x M	3	136.38	45.46	1.41	0.2417
Subject x M x T error	162	5221.24	32.23		
			Within-subject (Mode x Rate)		
Mode x Rate (M x R)	3	438.83	146.28	3.68	0.0133
Task x M x R	3	355.29	118.43	2.98	0.0331
Subject x M x R x Task error	162	6434.72	39.72		

Appendix F

Mean PC for normal participants as a function of mode (LL & RR) and presentation rate (1.2, 1.6, 2.0, & 2.4 s) with both the auditory and visual forms of the lateralised PASAT as used by Stewart (1995).

Appendix F. Mean PC for normal participants as a function of mode (LL & RR) and presentation rate (1.2, 1.6, 2.0, & 2.4 s) with both the auditory and visual forms of the lateralised PASAT as used by Stewart (1995).*

		Presentation Rate							
		1.2		1.6		2.0		2.4	
Form	Mode	M	SD	M	SD	M	SD	M	SD
AUD	LL	51.8	28.0	71.4	28.8	74.8	19.4	85.7	20.0
AUD	RR	53.6	27.5	69.8	22.1	76.8	22.6	89.8	17.0
VIS	LL	52.7	20.0	73.3	27.0	81.4	16.0	84.1	14.7
VIS	RR	48.2	27.0	63.3	19.5	85.7	20.6	85.9	12.8

Note 1. AUD denotes the auditory form and VIS the visual form of the lateralised PASAT.

Note 2. * The above table is an adapted reproduction of Stewart's (1995) Table 6, p 108.

Note 3. The trend of a mode advantage that Stewart refers to is indicated in the VIS form of the test at the 1.2 s rate (LL mean = 52.7 compared to RR mean = 48.2), and particularly at the 1.6 s rate (LL mean = 73.3 compared to RR mean = 63.3).

Appendix G

1. Mean PC for normal and clinical participants as a function of mode (LL, RR, LR, & RL) and presentation rate (1.2, 1.6, 2.0, & 2.4 s) for Experiments 1 and 2 in Norman (1984).

2. Two-way ANOVAs of data from Norman's (1984) Experiments 1 and 2 for normal participants with rate (1.2, 1.6, 2.0, & 2.4 s) x mode (RR & LL).

3. Three-way ANOVA of data from Norman's (1984) Experiment 2 for groups (normal controls and clinical participants) x rate (1.2, 1.6, 2.0, & 2.4 s) x mode (RR & LL).

4. Two-way ANOVA of data from Norman's (1984) Experiment 2 for clinical participants with rate (1.2, 1.6, 2.0, & 2.4 s) x mode (RR & LL).

Appendix G 1. Mean PC for normal and clinical participants as a function of mode (LL,RR, LR & RL) and presentation rate (1.2, 1.6, 2.0, & 2.4 s) for Experiments 1 and 2 in Norman (1984).

		Presentation Rate							
		1.2		1.6		2.0		2.4	
Expt.	Mode	M	SD	M	SD	M	SD	M	SD
1 N	LL	42.2	19.9	56.2	18.5	64.5	16.1	78.1	15.9
1 N	RR	48.4	15.7	60.4	15.6	73.4	19.7	78.1	20.5
1 N	LR	19.6	11.8	47.0	15.8	55.9	17.7	75.6	20.9
1 N	RL	23.7	14.5	41.6	22.1	58.3	25.6	71.4	22.9
2 NC	LL	44.5	19.3	40.6	21.4	47.6	25.9	69.5	24.2
2 NC	RR	44.5	15.1	53.9	13.7	69.5	14.7	75.8	25.7
2 NC	LR	19.6	13.1	33.9	21.8	51.8	17.8	63.4	27.4
2 NC	RL	20.5	10.4	34.8	20.0	49.1	15.5	62.5	22.8
2 CL	LL	39.8	19.5	36.7	10.8	52.3	17.3	59.4	16.7
2 CL	RR	25.0	12.0	46.9	16.7	46.1	16.0	49.2	17.8
2 CL	LR	16.1	33.1	19.6	10.9	31.2	15.2	43.7	15.4
2 CL	RL	13.4	8.7	28.6	17.5	32.1	13.2	42.8	16.6

Note 1. Expt. denotes Experiment 1 or 2 (Norman, 1984); N denotes normal participants (6 male & 6 female university students, mean age = 26.7); NC denotes normal controls and CL denotes clinical participants, with a history of schizophrenia (4 males & 4 females, both for NC & CL, all recruited from the same psychiatric hospital; mean age = 29.3). Both experiments used unpredictable presentation of mode.

Note 2. Refer to Appendix G 2 for summaries of ANOVAs for normal participants in Experiment 1 and 2, and to Appendix G 3 for summary of ANOVAs for normal controls with clinical participants, and Appendix G 4 for clinical participants alone.

Appendix G 2. Two-way ANOVAs of data from Norman's (1984) Experiments 1 and 2 for normal participants with rate (1.2, 1.6, 2.0, & 2.4 s) x mode (RR & LL).

Source	df	SS	MS	F	p
Experiment 1					
Rate (R)	3	368.11	122.70	25.47	0.0001
Subject x R error	33	159.01	4.82		
Mode (M)	1	14.26	14.26	4.53	0.05
Subject x M error	11	34.61	3.15		
Rate x Mode	3	6.45	2.15	.62	NS
Subj. x R x M error	33	115.12	3.49		
Experiment 2					
Rate (R)	3	201.42	67.14	18.69	0.001
Subject x R error	21	75.45	3.59		
Mode (M)	1	43.89	43.89	14.14	0.01
Subject x M error	7	21.73	3.10		
Rate x Mode	3	27.17	9.06	1.83	NS
Subj. x R x M error	21	103.70	4.94		

Appendix G 3. Three-way ANOVA of data from Norman's (1984) Experiment 2 for groups (normal controls and clinical participants) x rate (1.2, 1.6, 2.0, & 2.4 s) x mode (LL and RR).

Source	df	SS	MS	F	p
		Between-subjects			
Group (G)	1	105.12	105.12	2.80	
Subject x G error	14	526.10	37.57		
		Within-subject (Rate)			
Rate (R)	3	294.53	98.18	15.49	0.001
Group x R	3	18.07	6.02	0.95	
Subject x R error	42	266.15	6.34		
		Within-subject (Mode)			
Mode (M)	1	5.28	5.28	1.26	NS
Group x M	1	50.01	50.01	11.98	0.01
Subject x G x M error	14	58.46	4.17		
		Within-subject (Mode x Rate)			
Mode x Rate	3	47.41	15.80	4.65	0.01
Group x M x R	3	16.05	5.35	1.57	
Subject x G x M x R error	42	142.79	3.40		

Appendix G 4. Two-way ANOVA of data from Norman's (1984) Experiment 2 for clinical participants with rate (1.2, 1.6, 2.0, & 2.4 s) x mode (LL & RR).

Source	df	SS	MS	F	p
Rate (R)	3	111.17	37.06	4.08	0.05
Subject x R error	21	190.70	9.08		
Mode (M)	1	11.39	11.39	2.17	NS
Subject x M error	7	36.73	5.25		
Rate x Mode	3	36.30	12.10	6.50	0.01
Subject x R x M error	21	39.08	1.86		